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CHAPTER

Introduction to Optical Fiber Communications

1.1 INTRODUCTION

The communication usually means the transfer of signal from one point to other. This is achieved by using an electromagnetic wave as a carrier on which the information to be transferred is superimposed or modulated. At the receiving end carrier is removed by the process of demodulation and the original information retrieved. Carrier can be generated by using radio, microwave and millimeter wave frequencies. More recently, the communications have also been achieved by using optical range of frequencies as a carrier. The frequencies and wavelengths corresponding to radio, microwave and optical regions of the electromagnetic spectrum are given in Fig. 1.1.

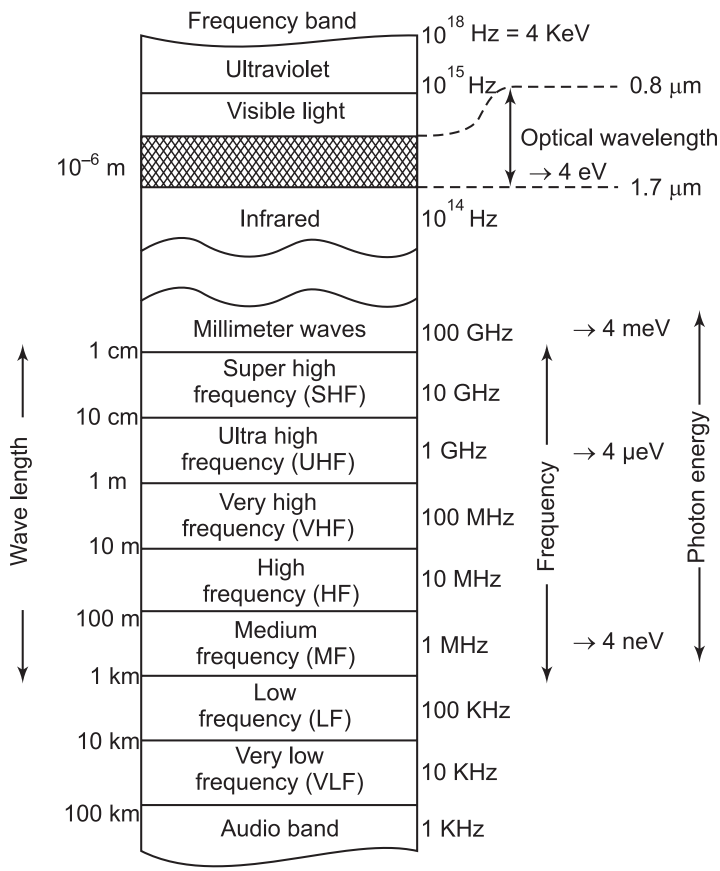


Fig. 1.1: Electromagnetic spectrum.

Fiber optics are being used extensively in place of copper wires as an effective means of communication. They are in use spanning long distances between local phone systems as well as providing viable set up for many network systems. They have found extensive use in cable Television services, university campuses, office buildings, industrial plants and electrical utility.

At one end of the system is a transmitter which accepts the coded electronic pulse information. These are then processed and translated into equivalently coded light pulses. These are then coupled into the fiber optic medium and transmitted down the line. Light pulses move down the fiber optic line by the process of total internal reflection, where the angle of incidence exceeds the critical value, thereby transmitting information down the fiber lines in the form of light pulses. Fiber optic cable functions as a light guide, guiding the light introduced at one end of the cable through to the other end. The light source is pulsed on and off, and a light sensitive receiver at the other end of the cable converts the pulse back into the digital ones and zeros of the original signal.

1.2. HISTORICAL BACKGROUND

The use of light for communication purposes dates back to antiquity if we interpret optical communications in a broad sense. Most civilizations have used mirrors, fire beacons, or smoke signals to convey a single piece of information (such as victory in a war).

Communication using light in not a new science. Greeks used smoke and reflected sunlight during the day and fire at night to convey message over long distances. Old Romans used polished metal plates as mirrors to reflect sunlight for long range signaling. The navies of the world have been using for centuries blinking lights to send messages from one ship to another. This process is practised even today. In 1880, Alexandra Graham Bell experimented with his photophone that used sunlight reflected off a vibrating mirror and a selenium photocell to send telephone like signals. Fig. 1.2 shows the photophone experiment, where sunlight is deflected by a mirror and directed onto another mirror. This mirror is mounted on the diaphragm of a microphone. The beam after reflection from the diaphragm falls on a selenium photocell. Diaphragm varies in accordance with the speech acoustic signal which results in the intensity modulation of the reflected beam.

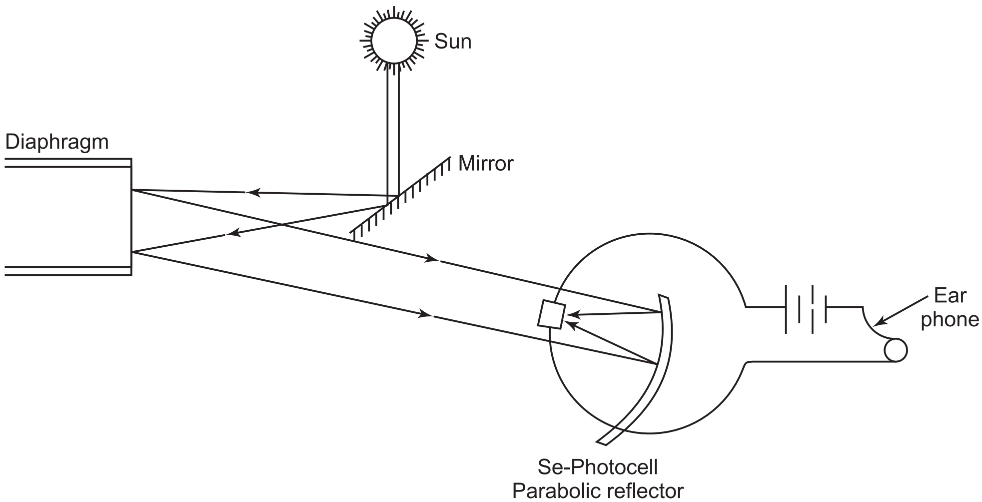


Fig. 1.2: Photophone experiment.

This idea however took around 80 years to have better glasses and low cost electronics for use in practical applications. Table 1.1 indicates the chronology of the Research and Development to achieve the fiber optical transmission as it exists today. In any communication system, signal from end is transmitted via a transmitter and received at other end by a matched receivers through a low loss medium. The transmitter and the receiver operates at low frequency of 10^3 Hz, medium frequency of 10^6 Hz and higher frequency of 10^{14} Hz depending upon the requirement of communication at narrow band, medium band or broad band frequencies and according, transmitters and receivers are used at different frequencies. Similarly, different media are used for communication of audio, video, data, and text messages, which are sent over short and long distances.

Telephone signals are transmitted through copper wire at frequencises upto 10 kHz. Higher frequency signals are transmitted over coaxible cables upto 100 MHz. The radio and microwave frequencies are transmitted through atmosphere from ground to satellite and then back to ground. Broadband communication at super high frequencies (10^{14} Hz) is done over optical fiber cables which are satisfactorily working at 1300 nm, 1550 nm and in future it will go to higher wavelengths around 2550 nm.

Table 1.1

Year	Light Sources	Transmission Medium
1879		Theoretical study of waveguide (Rayleigh)
1910		Theoretical study of dielectric waveguide (Hondros and Debye)
1920		Experimental study of dielectric waveguide (Schriever)
1951		Development of glass fiber for medical use
1960	Invention of ruby laser	
1961	He-Ne laser oscillation (Bell laborateries)	Mode Theory of dielectric wave guide (Snitzer)
1962	GaAs Semiconductor laser (General Electric, IBM, MIT)	Study of lens array waveguide (Goubou et al.)
1964		Experiment of the above (Bell labs). Suggestion of graded index fiber (Nishi zawa and Sasaki, Tohoku University)
1965	CO_2 laser oscillation (Bell labs)	Study of thin film optical waveguide (Karbowiak)
1966		Dielectric fiber surface waveguides for optical frequencies (Kao and Hockharm)
1969		Trially made graded index fiber (Uchida and Kitano) Graded index rod (Bell labs)
1970	GaAl As laser continuous oscillation (Bell labs, USSR, NEC)	Development of low loss silica fiber (20 dB/km) (Corning glass works) concept of weakly guiding fiber (Gloge)

1972	GaAl As Sb laser oscillation (NTT)	Development of 4 dB/km fiber (corning glass works)
1973		Development of MCVD process (Bell labs)
1974		Installation and splicing of optical fiber cable on site (Furukawa)
1976	Ga In ASP laser continuous oscillations (MIT, KDD, NTT, Tokyo institute of Technology)	Development of 0.5 dB/km fiber (1.2 μm) (NTT, Fujikura)
1977	Estimated life of GaAl AS (1,000, 000 hr)	Invention of VAD process (NTT)
1978		Development of ultra-low loss fiber (0.2 dB/km 1.55 μm) (NTT)
1980		Invention of the optical fiber amplifier

Out of these inventions and developments, the four inventions have basically contributed to the progress of the optical communication system. These are ;

(*a*) The inventions of laser during 1960's

(*b*) Fabrication of low loss optical fiber in 1970's

(*c*) Optical fiber amplifier development in 1980's

(*d*) In-fiber Bragg grating invention in 1990's.

During the last thirty years great strides have been made in electro-optics. Light beam communication devices are now extensively used in many common appliances, like telephone equipment and computer systems. The invention of laser in 1960 as a coherent, monochromatic and very intense source of optical frequency, helped in the rapid development of optical communication technology. Initially these lasers had a poor lifetime, but today we have lasers which have a lifetime of around 10 years at room temperature and above. This optical frequency was used as a carrier for telecommunication. This gave an enormous increase in bandwidth. Infact at optical frequencies there is an increase in the usable bandwidth by a factor of 10^4 over high frequency microwave transmission. A semi-conductor laser that emits a narrow wavelength of light if modulated at a modest 10 GHz rate, could transmit in one second : 900 high density floppy discs, 6,50,000 pages of text, 1000 novels, two 30-volume encyclopedias, 200 minute of high quality music or 10,000 T.V. Pictures. The use of high carrier frequencies allows the communication systems to concentrate available power within the transmitted electromagnetic wave, thus improving the system performance. Another unique feature of the optical communication is that it is usually guided through a fiber and the signalling rates are very high. It was felt during this period that the type of glass fiber used in endoscopes might be used for telecommunications. Thus the concept of the use of fiber for communications was evolved.

The fiber is made of a central glass core surrounded by a cladding of slightly lower refractive index. The fiber is thus like a dielectric waveguide. Originally the fiber with the best glass then available gave a minimum attenuation of 1000. db/km at visible wavelength which initially discouraged its use. But, by eliminating the absorbing impurities from the fiber glass at a convenient wavelength in visible or near infrared, it was possible to develop a practical communication system.

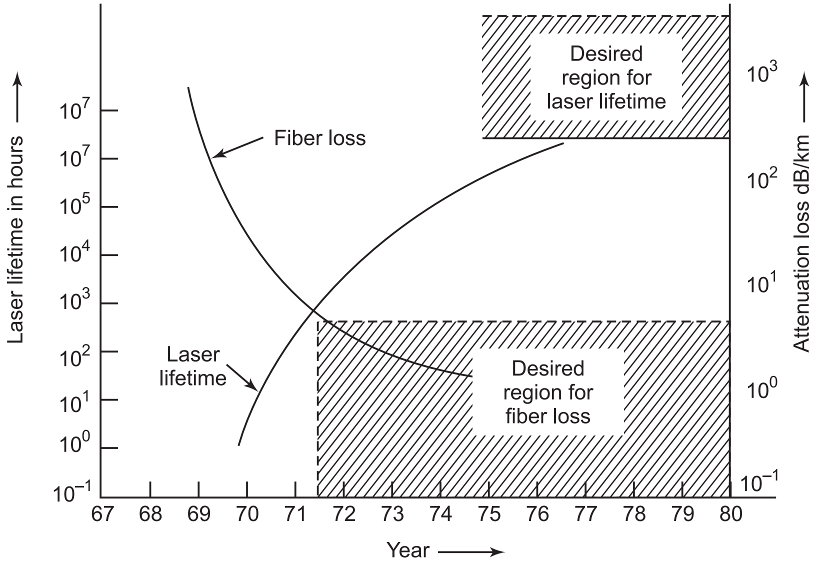


Fig. 1.3: Shows the progress that has been made in optical loss in the fibers and semi-conductor laser lifetime.

Fig. 1.3 shows the reduction in the optical loss of fibers and in the increase of the mean time of failure of the semiconductor lasers. The levels that should be obtained for viable optical communication system are also indicated. Fiber losses of less than few decibels per kilometer are necessary to obtain repeaterless communication for a few kilometers or more. At the same time the mean time failure for lasers should be of the order of atleast 10^6 hours.

Glass manufacturers led by corning in USA and Japanese workers succeeded in eliminating impurities in fiber and attained the attenuation levels as low as 0.2 db/km involving wavelengths (1.3 and 1.55 μm) and 0.15 dB/km at 1.6 μm using silica glass. This was made possible by eliminating transition elements and Hydroxyl ions (OH^-) from the fiber. Low attenuation is not the only requirement that the fiber must have, it should also have low dispersion so that the light pulse is not broadened where it becomes unrecognisable in a short transmission distance. Such broadening, which limits the bandwidth of the transmission medium has been controlled by careful radial distribution of the refractive index, which was achieved by corning and Japenese workers. The optical fibers that we use are generally robust and can be manufactured into multifiber cables. A single optical fiber could carry the equivalent information that would require tens of thousands of copper wires. The fiber can also carry information over much longer distances than the copper cables.

There are two types of fibers, multimode and the monomode. The multimode fiber has a core diameter in the range of 50-200 μm whereas for monomode fiber, core diameter is less than 10 μm. The cladding diameter has a value fixed at 125 μm except those with core diameter of 100 μm or more. The three optical wavelengths usually are at 0.85, 1.3 and 1.55 μm.

The first generation system made use of multimode fiber with a core diameter of 50 μm and a laser source radiating at 850 μm. However as the time passed, they became obsolete for long haul applications. Therefore we had to take recourse to the second-generation system where monomode fibers with longer wavelength sources of 1300 nm or 1550 nm were used, thereby giving higher capacity and the longer repeater spacings. The monomode optical fiber systems are thus used extensively for both the overland and the undersea telecommunications. One such example is the establishment of optical fiber transatlantic submarine cable TAT-8 in 1988. During 1998, the major area that emerged in optical communication was the Wavelength Division Multiplexing. This, helped to send as many as 1000 independent optical channels on a single fiber. In 1996, the first commercial WDM system appeared in the market. This was a major step towards fully optical networking.

1.3. ADVANTAGES OF OPTICAL COMMUNICATION SYSTEMS

The growth and application of optical fiber system resulted from the development of semiconductor technology, that provided necessary light sources, photodiodes and optical waveguide technology. The optical fiber transmission lines have certain advantages over conventional copper system and these are :

1. Low Transmission Loss and Wide Bandwidth: Optical fibers have low transmission losses and wider bandwidths as compared with the copper wires. Typical losses on fiber line are 0.2 dB/km whereas on a copper based facility one can usually expect a loss of atleast 5 dB/km. This means that more data can be sent over long distance in optical fiber system. The number of wire and repeaters needed for transmission are also reduced. The system cost is thus reduced because of reduction in the equipment and the components involved. It is possible to have low attenuation and low dispersion over the fiber links and one can have the repeater spacing as high as > 100 km, with the highest bit rates > 1 Gb/s.

2. Small Size and Weight: Fibers have a small size (Hair sized dimension) and low weight. This is an advantage over the heavy, bulky copper wire cables. A 7.6 cm bundle of 900 twisted copper pairs, can carry about 21,000 channels of traffic and weigh about 11250 kg/km whereas a 1.2 cm fiber with 12 fiber strands can carry about 3,00,000 channels and weigh about 90 kg/km. In addition less duct space is required to make the cable within the building. The small light weight cables are found to be advantages in aircraft, satellites, ships and in tactical military applications.

3. Immunity to Interference: We know that optical fibers form a dielectric waveguide. Because of this dielectric nature, it provides immunity to electromagnetic interference (EMI). This is so because the connection is not electrical with the result there can neither be a pick up nor creation of electrical interference. It also shows immunity to lightening. It also has immunity from electromagnetic pulse effect (BMP). This shows that optical fiber communication system is unaffected when transmission takes place through an electrically noisy environment. The fiber cable thus requires no shielding from EMI. This means that fiber cables can be placed almost anywhere in comparison to the electrical cables which create problems if placed near a lift, motor or in a cable duct with heavy power cables. Fiber cables also show great flexibility in route selection in wide area networks. Fiber cables can be layed near water or power lines without any risk to the people or equipment. This is of particular interest in military applications.

4. Electric Isolation: Ground loops in an electrical system cause serious problems particularly in the LAN or computer channel systems. This is so because connections are to be made with the ground which results in the voltage difference between the ground at various locations. A voltage difference of 1 to 2 volts is usual over a distance of around 1 km. Even if cables are shielded, they have to be connected to the earth at both ends of the connection. There is thus no electric isolation in the copper system. We know that optical fibers are constructed of glass and glass being an insulator, there won't be any ground loops and interface problems. The fiber-to-fiber cross talk is also low. The use of fibers is also attractive in electrically hazardous environment, because there is no arcing or sparking.

5. Signal Security: Optical fibers provide a high degree of data security because the optical signal is well contained within the wave-guide and signal cannot be obtained from the fiber without drawing the optical power. To draw optical power, a tap has to be inserted and once an intruder does that, there is an interruption of the service and the operational staff is alerted. Further there are very few access points where an intruder can insert a tap. In case the intruder uses an active tap, it is very difficult to actually insert a signal. In addition there is an opaque jacket surrounding the fiber which can absorb any emanations. Thus fiber finds use in applications where security is of prime concern like banking, computer network and military applications.

6. Resistance to High Temperature: The melting point of silica is about 1900°C, far above that of copper or plastics. Therefore cables made with silica are resistant to high temperatures.

7. Abundant Raw Material: Since the silica is the principal material for making the optical fibers, it is available in abundance and is inexpensive, as it is found in the ordinary sand. However, the cost of making actual fiber will depend on the process involving making of ultrapure glass from the raw material.

8. Open Ended Capacity: The capacity of the installed fiber is very great and theoretically is infinite. This means that with the availability of new technology, additional capacity can be added to the existing fibers. This can be done by changing the equipment at either end or upgrade the regeneration.

1.3.1. Limitation of Optical Fibers

1. Branching of Optical Fibers: Optical fibers cannot be branched easily. Optical fibers are thin, and it is difficult to branch them directly, where branching is required, it is done after converting that particular section into an electric system.

2. Joining Fibers: Fibers are usually joined by the use of fusion splicing which in itself is a difficult task as it requires precision equipment. The task is still more difficult if the splicing is done under extremely low temperature climates.

3. Effect of Gamma Radiation: Gamma radiation coming from space is always present. It can be considered as a high energy X-ray. Gamma radiation cause glass to emit light causing interference and also cause glass to discolour thereby attenuating the signal. Therefore fibers are not used as transmission medium inside a nuclear reactor or on a long distance space probe.

4. Effect of Electric Fields: It has been observed that very high electric fields also affect some glasses like the gamma rays. Although fiber communication cables are wrapped around high-voltage electric cables on transmission towers, the system works very well where voltage is around 30,000 volts or below.

Above that voltage, the glass tends to emit light and discolour producing losses. Nevertheless recent research effort have helped to produce glasses that will be unaffected by such high fields.

5. Effect of Sharks and Termites: During 1980's a new undersea fiber cable was found to be broken on the ocean floor and it was thought that the cable was attacked and eaten by sharks. It was suggested that the chemical composition of the cable sheathing was attractive to sharks. Another explanation indicated that the radiated electromagnetic field caused the sharks to be attracted. Although some people thought that the cable was badly laid and rubbed against rocks, others generally believe that sharks eat optical fiber cables.

Termites have also been known to attack and eat the plastic sheathing of an optical cable.

1.4. THE BASIC OPTICAL COMMUNICATION SYSTEM AND ITS ARCHITECTURE

The block diagram of a generalised optical communication system is given in Fig. 1.4. The system consists of an optical source, which is modulated with the signal to be transmitted. The transmission medium is usually made of optical fiber. This is followed by a photo detector, which converts the received optical power back into electric waveforms. Finally we use electronic amplification and signal processing to retrieve the signal and present it in a suitable form. The system can be used for both the analog and digital communication systems. Since optical fibers are used as transmission medium, sources used are only semiconductor light emitting diodes and lasers. At the receiver end semiconductor junction photodiode detectors are used. The advantage of semiconductor sources is that their output power can be modulated directly and with ease by controlling the flow of electric current. The optical signal is usually intensity modulated. The intensity modulation is also referred to as amplitude shift keying (ASK) and on-off keying (OOK). This is the simplest method for modulating the carrier generated by an optical source. The resulting modulated optical carrier is given by :

$$E_s(t) = E_0 m(t) \cos(2\pi f_s t)$$

where $m(t)$ is the modulating signal and the information assumes only the values of '0' and '1'. f_s is the optical carrier frequency.

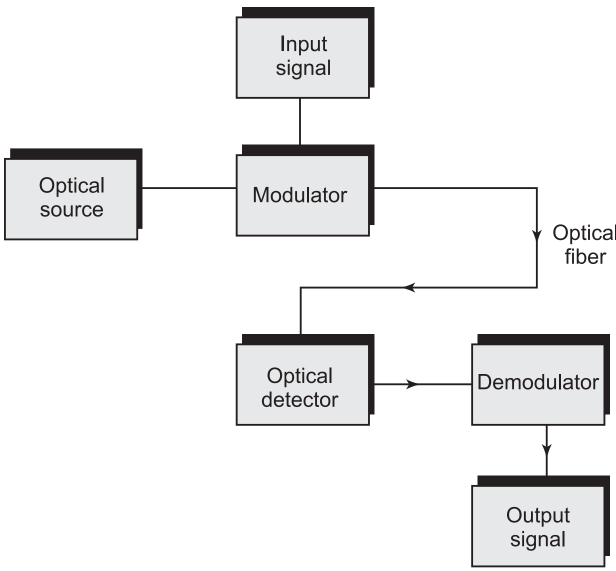


Fig. 1.4: Basic optical communication system.

The demodulation function in the receiver will be just to observe the presence or absence of energy during a bit time interval.

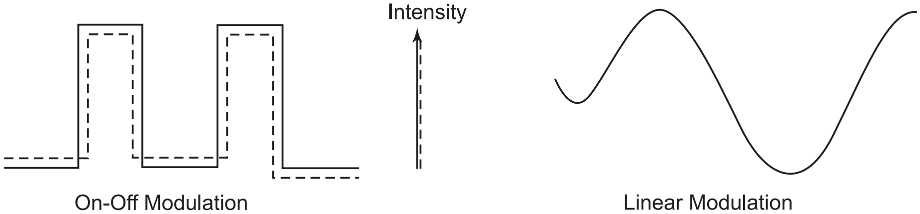


Fig. 1.5: Basic optical modulation methods.

The basic optical transmitter usually converts electric input signals into modulated light for transmission over an optical fiber. The modulated light may be turned on and off or may be linearly varied in intensity between two predetermined levels Fig. 1.5 shows a graphic representation of these two basic schemes.

Light emitting diodes (LEDs) and laser diodes (LDs) operate in the infrared portion of the electromagnetic spectrum. Their ligit output is therefore usually invisible to the human eye The wavelengths are so chosen that they have the lowest transmission loss wavelengths of glass fibers and highest sensitivity ranges of the photodiodes. The common wavelengths in use today are 850 nm : 1300 nm and 1550 nm. Both LED's and LDs are available in all three wavelengths. They can be modulated in one of the two ways either on and off or linearly. .

Fig. 1.6 shows the simplified circuitry for modulating LED's or laser diodes. Fig. 1.6(a) shows a transistor being used to switch the LED or LD on and off in step with an input digital signal.

Any digital format can be converted by appropriate circuitry to drive the base of the transistor. Fig. 1.6(*b*) shows an operational amplifier circuit for linear modulation of an LED or LD. The inverting input supplies the modulating drive to the LED or LD, whereas the non-inverting pulse is used to supply a D.C. bias reference. Digital on/off modulation of an LED or LD can take a number of forms. The simplest will be the light on for logic " 1" and light off for logic "0". The two other common forms are pulse width modulation and pulse rate modulation. In the pulse width modulation, a constant stream of pulses is produced with one width signifying a logic "1" and another width, a logic "0". In the pulse rate modulation, pulses are all of the same width but the pulse rate changes to differentiate between logic "1" and logic "0". Analog modulation can also take number of forms. The simplest is intensity modulation where the brightness of an LED is varied in direct step with the variations of the transmitted signal.

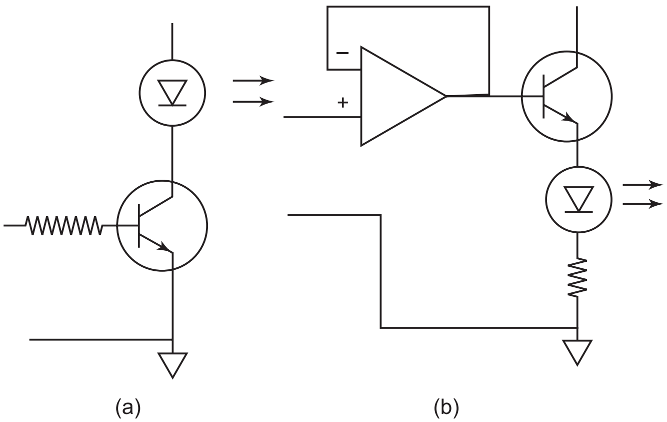


Fig. 1.6: Methods of modulating LED's or laser diodes.

There are other methods of modulation where an RF carrier is first frequency modulated with other signal or, in some eases, several RF carries are separately modulated with separate signals and these are then all combined and transmitted as one complex waveform. Fig. 1.7 shows various modulation methods as a function of light output.

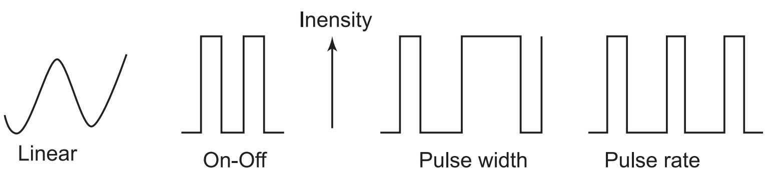


Fig. 1.7: Various methods to optically transmit analog information.

It is possible to have many combinations of the source and the detector. However, the source must be of high intensity and this can be provided by a laser. We also need an external means of modulating the light source. It has been observed that the transmission path is often variable leading to attenuation, which results in the fluctuating level of received power. At the receiver either a photodector or a photomultiplier can be used but the choice of detectors will depend upon the wavelengths to be used and the physical size of the systems involved.

1.5. CAPACITY OF A TELECOMMUNICATION CHANNEL FOR MEASUREMENT OF INFORMATION

The combination of transmitter, transmission medium and a receiver constitutes a communication link. How effectively this link can operate will depend on various factors.

The link performance will depend on the choice of the transmissions medium. Every transmission medium has constraints on its operation. As the signal propagates down a transmission medium to the receiver its amplitude decreases and gets weaker and weaker. The input data is said to suffer attenuation. Fig. 1.8 shows the signal attenuation as it propagates down the transmission medium.

Thus we find that the attenuation increases with distance through the transmission medium and is measured in dB/km. As the propagation continues, signal is attenuated until it can just be sensed by the receiver in the presence of whatever interference is expected. The distance at which the signal reaches this minimal level is quite significant, because the transmission medium must be able to deliver this minimum detectable signal to the receiver, otherwise the communication cannot take place. In such a situation, even if the minimal signal does not reach the receiver after attenuation, it can be regenerated by the use of a repeater and the signal will propagate on its way to the receiver. This is shown in Fig. 1.9.

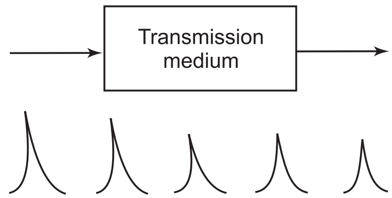


Fig. 1.8: Input data signal attenuating as it propagates down a transmission medium.

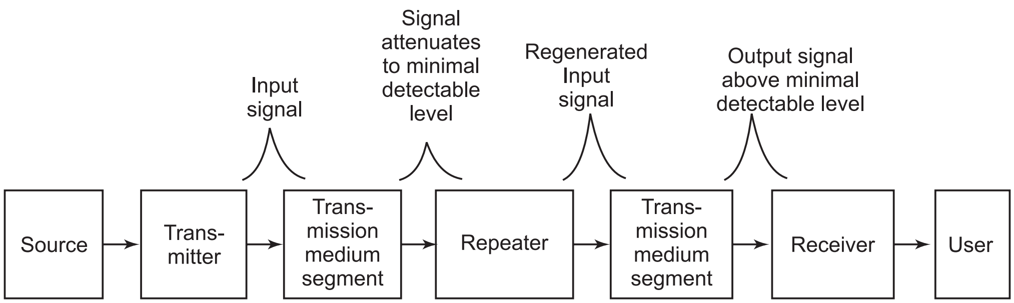


Fig. 1.9: Regenerating and repeating an attenuated signal in order to reach the user.

It has been observed that as the signal propagates down the transmission medium, it will encounter noise or interference. The noise is nothing but some extraneous signal that is usually generated outside the transmission medium and somehow gets into the medium and usually adds itself to the propagation signal. The effect of noise interference can be best known through bit error rate. Therefore, for any transmission medium to be effective, it must be capable of delivering the required BER in the presence of noise/interference.

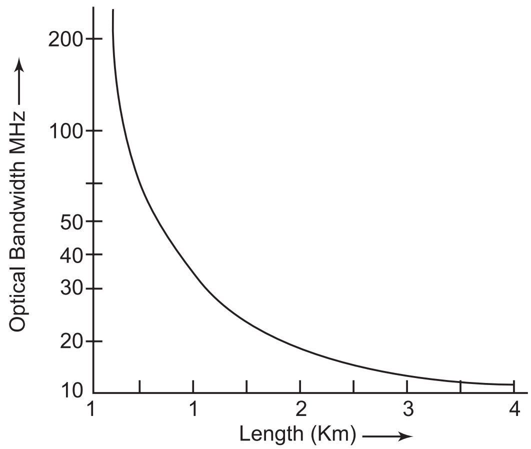


Fig. 1.10: Bandwidth of fiber optic cable vs length.

Another factor that must be considered is that the transmission medium have sufficient bandwidth to take care of intersymbol interference at the receiver. This means that the transmission medium must have a bandwidth that is some multiple of bit rate R. It has been observed that with the growing demand for video services and graphics in computer applications, there is a demand for a transmission medium to have a bandwidth matched to the source bit rates well upwards 1 MBPS possibly 1 GBPs. Fig. 1.10 shows the variation of the bandwidth of the fiber optic cable with its length. As seen bandwidth goes down with the increasing length. Note that upto 4 km the bandwidth is always above 10 MHz.

This implies that a fiber optic link can support data rates of many 10's of MBPS over these distances. Fiber optic cables are able to support Giga bits per second (1 Billion bits per second-GBPS), but this will depend upon the distance and may often require multiple repeaters.

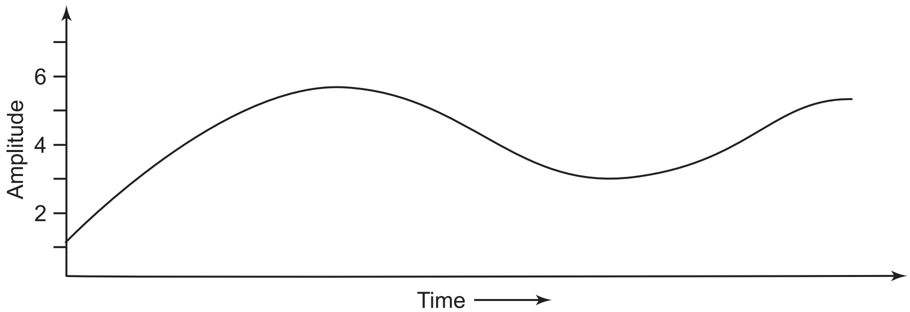
The effectiveness of an optical communication will depend on the information carrying capacity of a communication channel and the maximum distance over which a signal can be sent without intermediate repeaters. The channel capacity is given by the signal bandwidth and the signal-to-noise ratio at the receiver. However, the signal bandwidth is limited by the rate at which the source is modulated, the transmission medium, the detector and the electronic circuitry at the receiver. It has been observed that LED sources can be modulated upto a frequency of nearly 100 MHz and the laser sources upto about 1 GHz. These values can be increased by a factor often by evolving suitable device and the circuit design, p-i-n and avalanche photodiodes can be used to enhance the optical power modulation frequency above 10 GHz. This would mean the use of an advanced and sophisticated receiver amplifier design. Actually fiber acts as a low pass filter in which the upper cut-off frequency is inversely proportional to the propagation distance. Thus a given fiber type can be characterised by a bandwidth X distance. This may be lower than 10 MHz . km or higher than 100 GHz . km, which depends upon the type of fiber used and the characteristics of the source.

Signal to noise ratio is another parameter that needs to be considered. The effective noise level available at the input to receiver amplifier and the optical power reaching the detector determines the signal to noise ratio. It has been observed that in optical communications where the optical power is modulated, the noise level is signal dependent. It is thus essential that the receiver noise is minimized but in reality it increases in proportion to signal bandwidth.

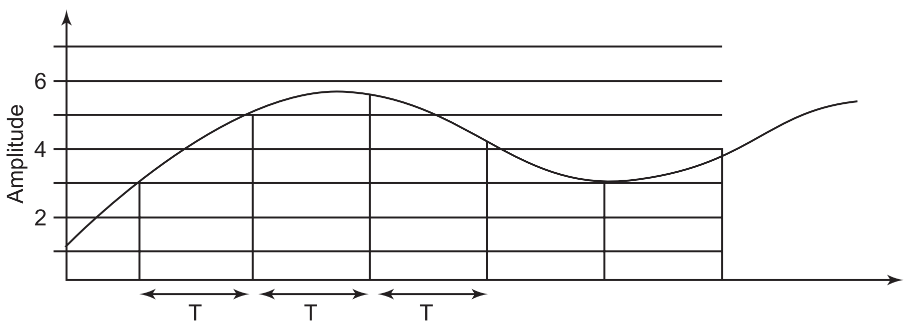
The quality of channel in the analog system is determined directly by the signal-to-noise ratio, whereas in the case of the digital system, the probability of error decides whether or not a pulse has been transmitted.

The amount of information that can be sent on a communication channel without the use of intermediate repeates can be found if we are able to quantify the nature of information to be sent. This quantified information can give a measure of information carrying capacity for communication system. It will also at the same time be able to identity parameters that would limit the capacity of a channel. Information can be in the form that varies continuously with time and may have continuous range of possible values. This could be an analog signal. Some information can be sent in a discrete form or the information can assume any continuous range but at discrete times. The form of information can be represented fully if we quantify by considering sequence of discrete binary digits (bits). The number of bits is then a measure of information carrying capacity of a channel. This can be realised by considering the basic ideas of communication theory. If we now consider an analog waveform shown in Fig. 1.1 l(*a*), then to convert this into binary levels, the waveform needs to be sampled at regular discrete intervals of time. With a sampling period of T, the sampled pattern is shown in Fig. 1.11(*b*). By sampling theorem we know that the sampling frequency $f_s = 1/T$ should be more than twice the highest frequency contained in the original waveform f_m. This is represented fully by the sampled waveform in Fig. 1.12(a). If we pass this sampled waveform through a low pass filter, it will allow the frequencies to pass below f_m, thereby retrieving the original waveform. The frequency range $0 - f_m$ will thus give the requisite bandwidth, which can be represented by Δf. Here $\Delta f = f_m$

Thus $$f_s > 2\Delta f = 2\,f_m$$



(a) Analog waveform.



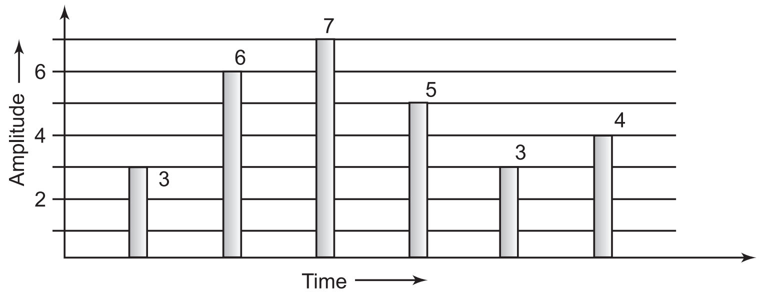
(b) Analog waveform sampled at time intervals of T.

Fig. 1.11

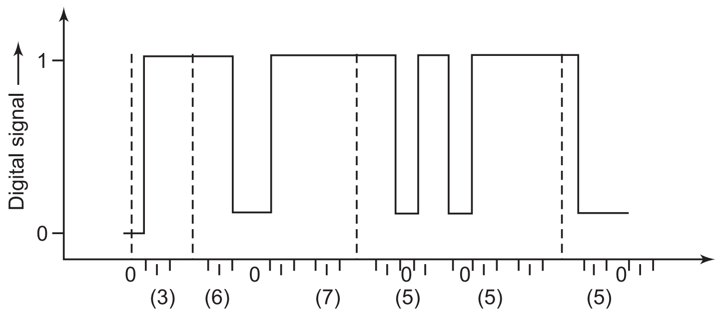
Now each of these sampled levels must have finite number of amplitude levels. These amplitude levels can be obtained if we consider the random fluctuations associated with the signal waveform. This is nothing but the system noise. Now if A is the amplitude, S is the maximum signal and N the system noise, then the ratio of the maximum signal amplitude, AS to the rms value of the system noise amplitude AN will give the number of levels that will give the true representation of the original signal. If m is the number of levels, then each sampled value will be given by

$$N = \log_2 m \qquad \text{...(1)}$$

This gives the number of binary digits to encode the signal. Fig. 1.12(*b*) shows sampled waveform of Fig. 1.12(*a*) converted into binary digital form with 3 bits/sample. When this binary signal is decoded to obtain the original waveform, an additional noise is introduced which is known as the quantisation noise. It has been shown that the quantisation noise is equal to or less than the original noise involving the waveform provided.



(a) Sampled waveform of Analog signal showing allocation of amplitude.



(b) Sampled information converted to binary digital form with 3 bits/sample.

Fig. 1.12.

$$m \text{ is greater than } \left[1+\left(\frac{AS}{AN}\right)^2\right]^{1/2}$$

Therefore if we have a waveform having a bandwidth of Δf (Hz) and a dynamic range represented by $\frac{AS}{AN}$, we require a minimum of binary digits per second (b/s); this can be represented by B where:

$$B = 2\Delta f \log_2\left[1+\left(\frac{AS}{AN}\right)^2\right]^{1/2} = \Delta f \log_2\left[1+\left(\frac{AS}{AN}\right)^2\right] \text{ [Shannon Formula]} \qquad ....(2)$$

It has been observed that in most practical systems $\frac{AS}{AN}$ is much greater than unity and is usually expressed in dB. Thus equation (2) can be written in the simplified form as :

$$X(\text{dB}) = 20\log_{10}\left[\frac{AS}{AN}\right] \qquad ...(3)$$

Then,
$$B\left[\frac{b}{s}\right] = 0.332 \times X\,[\text{dB}]\,\Delta f\,(\text{Hz}) \qquad ...(4)$$

$$\left(\text{since } \log_2 10 = 3.32 \text{ and we may neglect 1 in comparison with} \left[\frac{AS}{AN}\right]^2\right)$$

1.5.1 Sharing the Transmission Medium

The tremendous bandwidth of the fiber optic cable cannot be wasted for a single particular source user communication requirements. Instead it should be possible to share multiplicity of source user requirements. The simultaneous transmission of a number of independent signals along one communication channel of high capacity constitutes the sharing of the transmission medium. The technique used to bring about this sharing of the optical fiber is called multiplexing. It is not particular to fiber optic cable only, but occurs with any transmission medium like wire, microwave etc.; where the available bandwidth is more as compared to any individual source-user requirements. However, multiplexing is particularly attractive in fiber optic cable because of the tremendous bandwidth available. Concept of multiplexing is shown in Fig. 1.13. Here we have a number of sources indexed as 1. 2,... N. A multiplexer is provided at each end of the fiber optic cable. The multiplexer takes the data provided by each source and combines these data streams and sends the resultant stream out on the fiber optic cable. The multiplexer on the left is called multiplexer or combination function. The multiplexer on the right is called receiver that combines the stream and separates them into individual source streams.

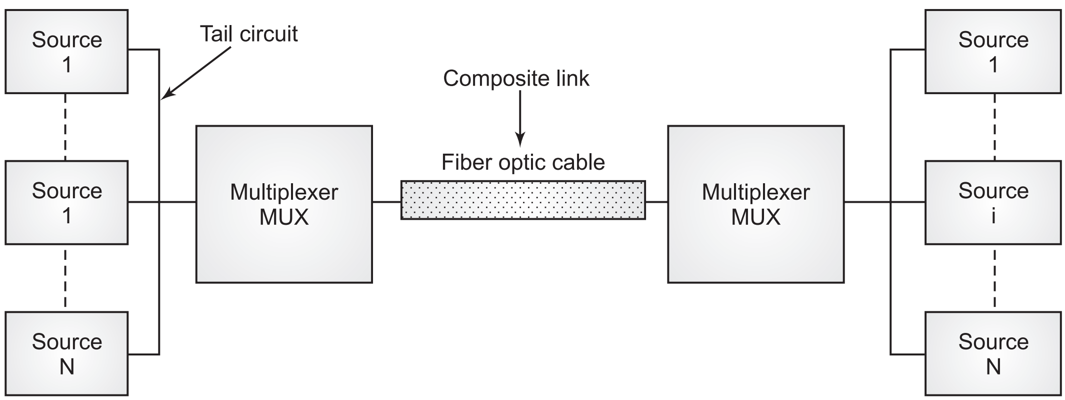


Fig. 1.13: Conceptual view of multiplexing. A single fiber optic cable is "carved" into a multiplicity of fiber optic data links.

The multiplexer on the right performs what is called a demultiplexing function. Here the transmitter is considered part of the multiplexer on the left and the receiver as part of the multiplexer on the right. The connection from source-to-multiplexer and multiplexer-to-user is called a tail circuit. If the tail circuit is too long a separate data link may be needed just to bring data from the source to the multiplexer or from multiplexer to the user.

1.6. FIBER TRANSMISSION WINDOWS OR BANDS

This can be best understood by considering the attenuation that would be expected for a particular wavelength. Fig. 1.14 shows the transmission windows with respect to the wavelengths.

It is observed that there are three windows or bands in the spectrum of the optical fiber. These are: (*a*) short wavelength band (first window), (*b*) medium wavelength band (second window) and (*c*) long wavelength band (third window).

(*a*) Short Wavelength Band (First window): This was the first band used for optical fiber communication in the 1970's and early 1980's. The wavelength of operation was around 800-900 nm. It showed promise because of a dip in the attenuation profile and also the use of low cost optical sources and detectors in this band.

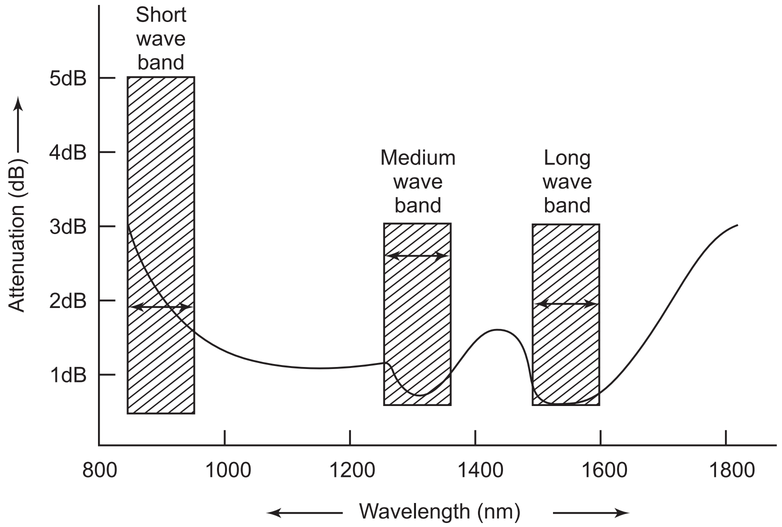


Fig. 1.14.

(*b*) The Medium Wavelength Band (Second Window): This came into use in mid 1980's and worked around a wavelength of 1310 nm. This band is attractive today because we get a zero fiber dispersion on a single mode fiber. Although the sources and the detectors are costly in this band, it had an enormous advantage in terms of attenuation being just 0.4 dB/km. This band is extensively used today in the long distance communication systems.

(*c*) Long Wavelength Band (Third Window): Long wavelength band operates between 1510 nm and 1600 nm. Although the attenuation as low as 0.26 dB/km can be obtained, it is expensive to make optical sources and detectors that operate in this band. There is also dispersion of the signal in this band. In late 1990's this band was used for almost all new communication systems.

1.7. OPTICAL NETWORKING

Major usage of optical fibers have been the optical networking which provides means of information interchange over transmission links. The main function of the network involves exchange of information between the end users. There are many types of networks which depend on the type of communication required. The simplest is the fixed communication path between end users. Another type is the one in which there is only one connection provided per user. The user can however have multiple connections and access to other users. Telephone network is one such example. A more complex network is the packet switching network, where information is carried between the end users in the form of packets. Here, a single user is able to communicate with large number of other end users at the same time. Packet switched networks also come in many types. In the connection oriented type of network, paths needed for the network are defined before transferring the information. However, if we have a connectionless network, data through the network is routed by means of network frames to the required destination, where the destination address is carried within the data itself. The distinction between various networks is dependent on the way switching is performed. Most networks, especially wide area ones have nodal points which can switch the information from link to link. The nodes are usually computer like devices. In some networks, information is switched by placing frames on a shared medium like a bus. Many end users are connected to this bus and each end user collects information only addressed to it.

This type is typical local area networks or LAN.

Networks are further characterised by their geographic extent, such as :

(*a*) Local Area Network (LAN)

(*b*) Metropolitan Area Network (MAN)

(*c*) Wide Area Network (WAN).

These networks indicate that many types of networks are required to meet different environment conditions.

Single link constitute a simple type of network, where this single link can be shared between different end users. One way to achieve is the use of Wavelength Division Multiplexing system (WDM). This system allows channels to be tapped to serve individual end users along the communication links. Network using this principle called add/drop multiplexing is finding increased acceptance in optical networking.

Over the time it is expected to have a fully optical networking, where we need not have to convert the signal from optical to electronic form for each routed or switched path. This could be made possible by making use of the properties and characteristics of special type of optical components.

REVIEW QUESTIONS

1. Discuss the evolution of optical communication system.
2. Give advantages of optical fiber over metallic cables.
3. What is the structure of an optical fiber ?
4. With the help of a block diagram discuss various components of an optical communication system, both in analog and digital link.
5. Describe the developments of various generations of optical fiber communication system.
6. How are optical fibers advantageous in communication application ?

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