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Design and Study of a Fiber Optic Digital Link

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Abstract – Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution. Progressing from the copper wire of a century ago to today's fiber optic cable, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas. This paper deals with the historical development of optical communication systems an their failures initially. Then the different generations in optical fiber communication along with their features are discussed. Some aspects of total internal reflection, different types of fibers along with their size and refractive index profile, dispersion and loss mechanisms are also mentioned. Finally the general system of optical fiber communication is briefly mentioned along with its advantages and limitations. Future soliton based optical fiber communication is also highlighted.

Keywords:- Optical Fiber; Group Index; Group Velocity; Soliton V-Number; Dispersion.

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1. INTRODUCTION

Fiber optics technology is rapidly becoming a familiar and indispensable part of human life. You have undoubtedly heard of fiber optics. All giant telephone companies like AT & T, sprints have saturated the airways & print media with advertisements heralding this bright and new technology. Futurists, science writers & entrepreneurs forecast fantastic growth for Fiber Optics applications. And their enthusiasm is valid. Today medical fiber optic systems allow physicians to peer inside the human body without surgery. Military commanders demand portable battlefield communication systems, which use superior fiber optic transmissions. The massive bundles of copper wiring which once carried telephone conversations between continents now are being replaced with the optical fibers from coast to coast. Very few technologists ever come close to the fantastic growth rate that market analyst love for them to predict. Fiber optics has exceeded those rates. The next decade promises even more wonders. The influence of fiber optics will pervade our homes, workplaces & recreational facilities. Your television will take on starting clarity. Newsprint may largely become a thing of the past as environmentally to “attend college” in the comfort of your home. Anyone who takes an interest in fiber optics & pursues a career in the field today is on the ground floor of opportunity. The technology is sufficiently new that few “experts” exist. Many science colleges, universities & engineering colleges have included fiber optics in their syllabus. The future beckons exciting with the prospect of making new discoveries, finding new applications for the technology. This is an introduction to fiber optics communication technology for instructors, students & hobbyists. Welcome to the fascinating & expanding world of fiber optics. We hope that you find the kit challenging, stimulation & -yes-even fun. Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution. Progressing from the copper wire of a century ago to today's fiber optic cable, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas. Today's low-loss glass fiber optic cable offers almost unlimited bandwidth and unique advantages over all previously developed transmission media. The basic point-to-point fiber optic transmission system consists of three basic elements: the optical transmitter, the fiber optic cable and the optical receiver. Now we are in the twenty first century, the era of ‘Information technology’ (Daugas et. al., 2000. Bock et. al., 1977. Lefort and Ch. Ngˆo, 1978. Olmi et. al., 1978. Gelbke et. al., 1973. Takai et. al. 1988). There is no doubt that information technology has had an exponential growth through the modern telecommunication systems. Particularly, optical fiber communication plays a vital role in the development of high quality and high-speed telecommunication systems. Today, optical fibers are not only used in telecommunication links but also used in the Internet and local area networks (LAN) to achieve high signaling rates.

1.1 Historical perspective of optical communication

The use of light for transmitting information from one place to another place is a very old techniq -ue. In 800 BC., the Greeks used fire and smoke signals for sending information Like victory in a war, alerting against enemy, call for help, etc. Mostly only one type of signal was conveyed. During the second century B.C. optical signals were encoded using signaling lamps so that any message could be sent. There was no development in optical communication till the end of the 18th century. The speed of the optical communication link was limited due to the requirement of line of sight transmission paths, the human eye as the receiver and unreliable nature of transmission paths affected by atmospheric effects such as fog and rain. In 1791, Chappe from France developed the semaphore for telecommunication on land. But that was also with limited information transfer. In 1835, Samuel Morse invented the telegraph and the era of electrical communications started throughout the world. The use of wire cables for the transmission of Morse coded signals was imple -mented in 1844. In 1872, Alexander Graham Bell proposed the photo phone with a diaphragm giving speech transmission over a distance of 200 m. But within four years, Graham Bell had changed the photophone into telephone using electrical current for transmission of speech signals. In 1878, the first telephone exchange was installed at New Haven. Meanwhile, Hertz discovered radio waves in 1887. Marconi demonstrated radio communication without using wires in 1895. Using modulation techniques, the signals were transmitted over a long distance using radio waves and microwaves as the carrier. During the middle of the twentieth century, it was realized that an increase of several orders of magnitude of bit rate distance product would be possible if optical waves were used as the carrier Table 1 shows the different communication systems and their bit rate distance product. Here the repeater spacing is mentioned as distance. In the old optical communication system,the bit rate distance product is only about 1 (bit/s)-km due to enormous transmissionloss (105 to 107 dB/km). The information carrying capacity of telegraphy is about hundred times lesser than a telephony. Even though the high-speed coaxial systems were evaluated during 1975, they had smaller repeater spacing. Microwaves are used in modern communication systems with the increased bit rate distance product. However, a coherent optical carrier like laser will have more information carrying capacity. So the communication engineers were interested in optical communication using lasers in an effective manner from 1960 onwards. A new era in optical communication started after the invention of laser in 1960 by Maiman. The light waves from the laser, a coherent source of light waves having high intensity, high monochromaticity and high directionality with less divergence, are used as carrier waves capable of carrying large amount of information compared with radio waves and microwaves. Subsequently H M Patel, an Indian electrical engineer designed and fabricated a CO2 laser.

1.2 Unguided Optical Communication

The optical communication systems are different from microwave communication systems in many aspects. In the case of optical systems, the carrier frequency is about 100 THz and the bit rate is about 1T bit/s. Further the spreading of optical beams is always in the forward direction due to the short wavelengths. Even though it is not suitable for broadcasting applications, it may be suitable for free space communications above the earth's atmosphere like intersatellite communications. For the terrestrial applications, unguided optical communications are not suitable because of the scattering within the atmosphere, atmospheric turbulence, fog and rain. The unguided optical communication systems played an important role in the research between 1960 and 1970.

Table 1. Bit rate distance product.

System	Bit rate distance product (bit/s) - km
Old optical communication	1
Telegraph	10
Telephone	103
Coaxial cables	105
Microwaves	106
Laser light in open air	109

For longer range unguided optical communication systems the neodymium laser (1.06 mm) and the carbon dioxide laser (10.6 mm) were the most favorable sources. Using narrow bandgap compound semiconductors like indium sulphide (for neodymium laser) and cadmium mercury telluride (for CO2 laser) one can have better detection using heterodyne detection techniques.

2. THE BIRTH OF FIBER OPTIC SYSTEMS

To guide light in a waveguide, initially metallic and non-metallic wave guides were fabricated. But they have enormous losses. So they were not suitable for telecommunication. Tyndall discovered that through optical fibers, light could be transmitted by the phenomenon of total internal reflection. During 1950s, the optical fibers with large diameters of about 1 or 2 millimetre were used in endoscopes to see the inner parts of the human body. Optical fibers can provide a much more reliable and versatile optical channel than the atmosphere, Kao and Hockham published a paper about the optical fiber communication system in 1966. But the fibers produced an enormous loss of 1000 dB/km. But in the atmosphere, there is a loss of few dB/km. Immediately Kao and his fellow workers realized that these high losses were a result of impurities in the fiber material. Using a pure silica fiber these losses were reduced to 20 dB/km in 1970 by Kapron, Keck and Maurer. At this attenuation loss, repeater spacing for optical fiber links become comparable to those of copper cable systems. Thus the optical fiber communication systembecame an engineering reality.

2.1 Different types of fibers

We know that the light or the optical signals are guided through the silica glass fibers by total internal reflection. A typical glass fiber consists of a central core glass (_50 mm) surrounded by a cladding made of a glass of slightly lower refractive index than the core's refractive index. The overall diameter of the fiber is about 125 to 200 mm. Cladding is necessary to provide proper light guidance i.e. to retain the light energy within the core as well as to provide high mechanical strength and safety to the core from scratches. Based on the refractive index profile we have two types of fibers (a) Step index fiber (b) Graded index fiber.

(a) **Step index fiber:** In the step index fiber, the refractive index of the core is uniform throughout and undergoes an abrupt or step change at the core cladding boundary. The light rays propagating through the fiber are in the form of meridional rays which will cross the fiber axis during every reflection at the core cladding boundary and are propagating in a zig-zag manner as shown in figure 1a.

(b) **Graded index fiber:** In the graded index fiber, the refractive index of the core is made to vary in the parabolic manner such that the maximum value of refractive index is at the centre of the core. The light rays propagating through it are in the form of skew rays or helical rays which will not cross the fiber axis at any time and are propagating around the fiber axis in a helical (or) spiral manner as shown in figure 1b.

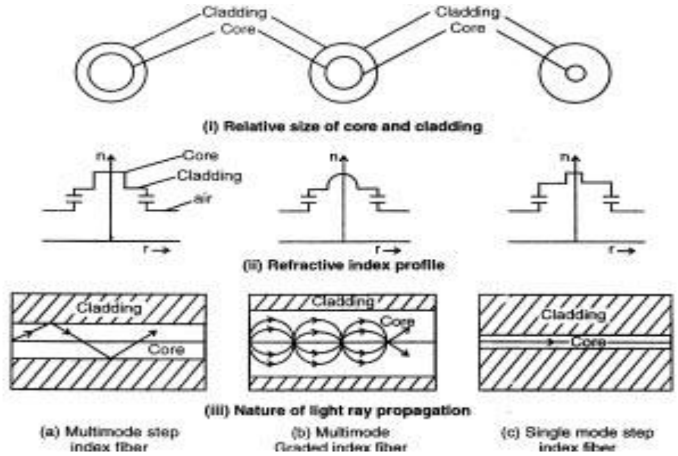


Figure 1. Different types of fibers.

Based on the number of modes propagating through the fiber, there are multimode fibers and single mode fibers. Mode is the mathematical concept of describing the nature of propagation of electromagnetic waves in a waveguide. Mode means the nature of the electromagnetic field pattern (or) configuration along the light path inside the fiber. In metallic wave-guides there are transverse electric (TE) modes for which Ez = 0 butHz 6= 0 and transverse magnetic (TM) modes for whichHz =0 butEz 6=0 when the propagation of microwaves is along the z-axis. In optical fibers, along with TE and TM modes, there are also hybrid modes which have both axial electric and magnetic fieldsEz and Hz. The hybrid modes are further classified into EH and HE modes. In EH modes, the axial magnetic field Hz is relatively strong whereas in HE modes, the axial electric field Ez is relatively strong. Based on the linearly polarized nature of light, today these modes are designated as linearly polarized (LP) modes. For example LP01 mode corresponds to HE11 mode. LP11 mode is the combination of HE21, TE01 and TM01 modes.

2.2 Basic Optical Fiber Communication System

Figure 2 shows the basic components in the optical fiber communication system. The input electrical signal modulates the intensity of light from the optical source. The optical carrier can be modulated internally or externally using an electro-optic modulator (or) acoustooptic modulator. Nowadays electro-optic modulators (KDP, LiNbO3 or beta barium borate) are widely used as external modulators which modulate the light by changing its refractive index through the given input electrical signal. In the digital optical fiber communication system, the input electrical signal is in the form of coded digital pulses from the encoder and these electric pulses modulate the intensity of the light from the laser diode or LED and convert them into optical pulses. In the receiver stage, the photo detector like avalanche photodiode (APD) or positive-intrinsicnegative (PIN) diode converts the optical pulses into electrical pulses. A decoder converts the electrical pulses into the original electric signal.

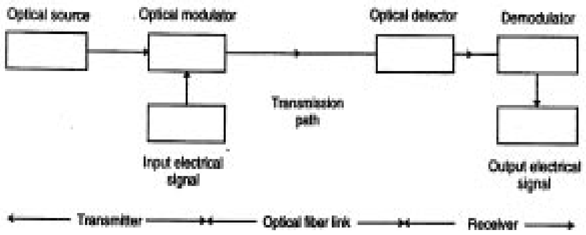


Figure 2. Basic analog optical fiber communication system.

2.3 Advantages of Optical Fiber Communication

The information carrying capacity of a transmission system is directly Proportional to the carrier frequency of the transmitted signals. The optical carrier frequency is in the range 1013 to 1015 Hz while the radio wave frequency is about 106 Hz and the microwave frequency is about 1010 Hz. Thus the optical fiber yields greater transmission bandwidth than the conventional communication systems and the data rate or number of bits per second is increased to a greater extent in the optical fiber communication system. Further the wavelength divisionmultiplexing operation by the data rate or information carrying capacity of optical fibers is enhanced to many orders of magnitude.

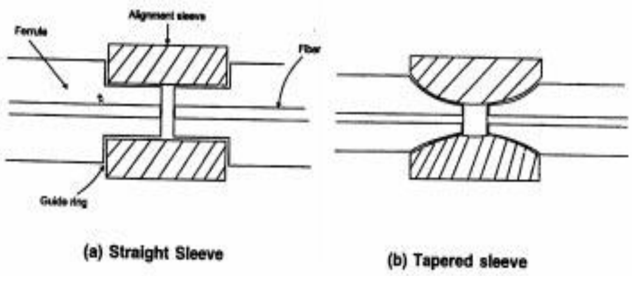
3. DIFFERENT COMPONENTS USED IN THE OPTIC FIBER COMMUNICATION SYSTEMS

Optical sources

Heterojunction LEDs and lasers are mostly used as the optical sources in optical fiber communicati -on. Heterojunction means that a *p-n* junction is formed by a single crystal such that the material on one side of the junction differs from that on the other side of the junction. In the modern GaAs diode lasers, a hetero junction is formed between GaAs and GaAlAs. This type of *p-n* junction diode laser or LED is used at 0.8 mm wavelength. At longer wavelengths, InP-InGaAsP heterojunction laser diodes are used. Heterojunction lasers or LEDs are superior to conventional homojunction lasers or LEDs. Generally heterojunction lasers and LEDs have minimum threshold current density (10 A/mm2), high output power (10 mW) even with low operating current (<500 mA), high coherence and high monochromaticity, high stability and longer life. For example in the case of a double hetero structure stripe laser, the active junction region is few microns. So the threshold current density is drastically reduced. The stripe geometry provides stability with longer lifetime for the diode. Thus it gives high power output, continuous wave operation, high efficiency, high coherence and high directionality .By means of the heterojunction formed by two different materials, both the carriers and the optical field are confined in the central active layer. The bandgap differences of adjacent layers confine the charge carriers while the step change in the indices of refraction of adjoining layers confines the optical field to the central active layer and provides an efficient waveguide structure. This dual confinement leads to both high efficiency and high power output.

4. MULTIPLEXERS

The transmission of multiple optical signals (channels) over the same fiber is a simple way to increase the transmission capacity of the fiber against the fiber dispersion, fiber nonlinearity and speed of electronic components which limit the bit rate. So multiplexing techniques are followed. *Multiplexing* means many signals at a given time . Suppose for each channel the bit rate is 100 Gb/s and by accommodating 100 channels through multiplexing technique the total bit rate through a single fiber can be increased to 10 Tb/s (1 Tera = 1012): Thus the information carrying capacity of a fiber is increased by the multiplexing technique. There are three types of multiplexing techniques:



(a) Straight Sleeve (b) Tapered sleeve

Connectors using butt-joint alignment designs

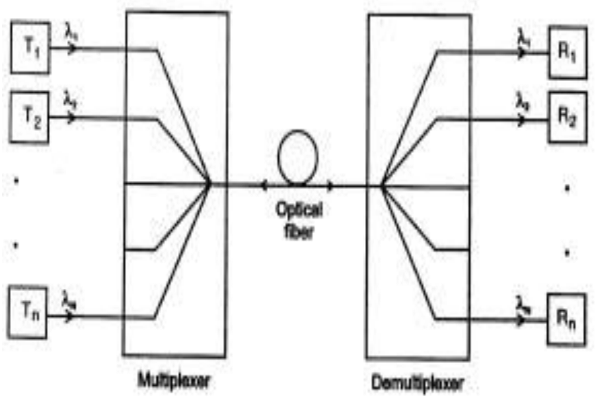
(i) TDM – time division multiplexing

(ii) FDM – frequency division multiplexing

(iii) WDM – wavelength division multiplexing

TDM and FDM techniques are operated in the electrical domain and are widely used in the conventional radio wave communication. WDM technique is very useful in the optical domain and by WDM, the bit rate can be increased beyond 10 Tb/s in the optical fiber communication.

Figure shows the basic principle of WDM technique. Here different wavelengths carrying separate signals are multiplexed by the multiplexer and then they are transmitted through a single fiber. At the receiver end, the separate signals at different wavelengths are demultiplexed by the demultiplexer and are given to separate receivers. From the receiver side also the signals can be transmitted in the same manner through the same fiber. Thus instead of handling a single channel with single wavelength and limited bit rate (10 Gb/s), the bit rate is raised to about 10 Tb/s, hence the information capacity of the fiber is increased byWDM technique. In principle any optical wavelength demultiplexer can be also used as a multiplexer. Thus for simplicity the word ‘multiplexer’ is often used as a general term to refer to both multiplexers and demultiplexers, except when it is necessary to distinguish the two devices or functions.



Multichannel point-to-point fiber link. T - transmitter; R - receiver

There are two types of wavelength division multiplexers:

1. Angularly dispensive devices such as prisms or gratings.

2. Interference filter based devices such as multilayer thin film interference filters or single mode integrated optical devices.

5. SOLITON BASED OPTICAL FIBER COMMUNICATION

Solitons are very narrow laser pulses of pulse width 10□14 second with high peak powers more than 100 mW. Solitons are mainly used to increase the bit rate or transmission capacity of the fiber by reducing the losses and dispersion effects. Soliton propagation means the propagation of laser pulses through the optical fiber without undergoing any loss or dispersion. That is the pulses are transmitted without change in their shape as they travel down the fiber. Today soliton fiber lasers are available. Soliton type propagation is achieved by the nonlinear property of the silica fiber when the intensity of the light pulses is more than 15 mW. In the case of single mode silica fiber, when the power level of optical pulses is more than 15 mW, then its refractive index is dependent on intensity such that *n* = *n*0+*n*2*I*: If the effective area of the fiber mode is about 50 mm2 and the power of the optical pulse is about 100 milliwatt, then *n*2 = 6:4_1011 for silica fiber. So inside the optical fiber, the high intensity portion of the pulse will propagate in a high refractive region of the fiber compared with the lower intensity portion of the pulse. This intensity dependent refractive index leads to a phenomenon called self phase modulation (SPM). Due to this phenomenon the distance traveled by the optical pulse inside the fiber is continuously increased due to lower speed of the high intensity portion of the pulse. Thus there is a generation ofadditional frequencies and hence the broadening of the spectrum of the pulse while keeping the temporal shape unaltered. Further SPM leads to a chirping of the pulse with lower frequencies in the leading edge and high frequencies in the trailing edge of the pulse. So one can conclude that even though the distance traveled by the high intensity optical pulse is greater than the distance traveled by the low intensity optical pulse inside the fiber having negative nonlinearity, the optical pulse travels down the fiber without any dispersion. When the operating wavelength is about 1.3 mm there is zero dispersion. But when the operating wavelength is greater than 1.3 mm, then the fiber has positive group velocity dispersion. So the low frequency components of the pulse will travel at a lower speed than the high frequency components of the pulse. But in the case of self phase modulation, we get the opposite effect. That is due to SPM the low frequency components of the pulse will travel faster than the high frequency components. Thus the broadening of the spectrum by SPM is properly compensated by the compressions of the spectrum by group velocity spectrum, then the pulse will propagate without change in the temperate shape and without broadening of the spectrum of the pulse. Even though there is no dispersion effect, still there is some loss in the fiber due to scattering and absorptions. To compensate this small loss in the transmissions link, for every 100 km or 150 km length, an optical fiber laser amplifier of length 10 m is connected. Due to sufficient amplification at the receiver end one can get the signal without loss of power. Thus during the propagation of the optical pulse through the fiber, there is no change in pulse shape and height and width. Such a propagation is called soliton propagation.

6. LIMITATION OF OPTICAL FIBER OBJECTIVE

Measure propagation loss in plastic fiber provided with the kit at wavelengths of 660nm and to measure the bending loss.

Theory

Optical fibers are available in different variety of materials. These materials are usually selected by taking into account their absorption characteristics for different wavelengths of light. In case of optical fiber, since the signal is transmitted in the consider the interaction of matter with the radiation to study the losses in fiber. Losses are introduced in fiber due to various reasons. As light propagates form one end of fiber to another end, part of it is absorbed in the material exhibiting absorption loss. Also part of the light is reflected back or in some other direction from the impurity particles present in the material contributing to the loss of the signal at the other end of the fiber. In general terms it is known as propagation loss. Plastic fibers have higher loss of the order of 180 dB/Km. Whenever the condition for angle of incidence of the incident light is violated the losses are introduce due to refraction of light. This occurs when fiber is subjected to bending. Lower the radius of curvature more is the loss. Another losses are due to the coupling of fiber at LED & photo detector ends.

Equipments

Fiber Linker

1 MHz Function Generator

20 MHz Dual Trace Oscilloscope Fiber cable

Procedure

1. Make connection shown in Fig. Connect the power supply with proper polarity to Linker kit.

2. All other setting are same.

3. One end to Tx module & other is Rx module.

4. Input of Tx module & output of Rx module seen on oscilloscope.

5. Now bending the fiber or change length of fiber, we see the different output on all different condition.

6. By repeat all stop we can observe different losses in fiber.

7. CONCLUSION

At present there are many optical fiber communication links throughout the world without using optical solitons. When we introduce optical solitons as light pulses through the fibers, we can achieve high quality telecommunication at a lower cost. We can expect agreat revolution in optical fiber communication within a few years by means of solitons.

REFERENCES

A. Olmi et. al. (1978). Phys. Rev. Lett. 41, p. 688.

C.K. Gelbke et. al. (1973). Phys. Lett. B 43, p. 284.

D.A. Bromley (1984). Treatise on Heavy-Ion Science, Plenum Press, New York.

H. Takai et. al. (1988). Phys. Rev. C 38, p. 1247.

J.F. Sharpey-Schafer and J. Simpson (1988). Prog. Part. Nucl. Phys., 21, p. 293.

J.M. Daugas et. al. (2000). Phys. Lett. B 476, p. 213.

K. Debertin and R.G. Helmer (1988). Gamma and X-ray Spectrometry with Semiconductors Detectors, North-Holland, Amsterdam.

M. Koenen et. al. (1995). IEEE Tr. Nucl. Sci. 42, p. 653.

M. Lefort and Ch. Ngˆo (1978). Ann. Phys. 3, p. 5.

R. Bass (1980). Nuclear Reactions with Heavy Ions, Springer-Verlag, New York.

R. Bock et. al. (1977). Nukleonica, 22, p. 1.

R. Wichner et. al. (1974). IEEE Tr. Nucl. Sci. 21, p. 273.

R.N. Hall et. al. (1974). IEEE Tr. Nucl. Sci. 21, p. 260.

T. Mukoyama et. al. (1976). Nucl. Instr. and Meth. A134, p. 125.

web page: www.crystalsland.com/bgo.html.

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