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New Trends in Fiber Optic Communication

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Abstract *This paper deals with communication using optical fibers. The transmission using high bandwidth can handle vast amounts of information, which can be further improved by reduction in fiber losses, increase in data rates and distances, development of optical sources and detectors compatible with fibers. The recent development in the area of fiber optic communication as well as the advances in different fiber types and their properties, optical sources, detectors, system limitations and applications are also discussed in the paper.*

Keywords- *communication, fiber, cable, optical, DAS.*

I. Introduction

The need for economical and reliable transmission media with large information carrying capacity has been a motivating force in telecommunication research. The first fiber-optic communication systems developed in 1978 were able to transmit signals at 100 Mb/s using multimode fibers operating near 0.85 µm (repeater spacing of <10 km but sufficiently larger than the heritage coaxial system). This is followed by the introduction of the single-mode fiber which has propelled the system capacity to Gb/s with repeater spacing in excess of 50kms with increase in the wavelength of system operation to 1.55 µm. The increased propagation distance allowed by lower fiber loss and the larger fiber dispersion at 1.55 µm has identified fiber dispersion as the next obstacle to deal with. Several systems were developed with reduced dispersion which could operate in excess of 10 Gb/s with repeater spacing as large as 100 kms.

Now-a-days, the optical communications up to 100 Gb/s for several kilometers have been introduced and the research is now focused to develop fiber optic system up to terabits per second (Tb/s).The present paper reviews the research and development in fiber optic communication and the challenges thereof. The paper is organised as follows: Section II deals with literature review. Section III classifies the fibers. Section IV discusses the optical source. Section V deals with optical signal degradation. Section VI covers the optical detectors and section VII gives the benefits and applications of fiber optic communication and finally the conclusions are given in section VIII.

II. Classification Of Fibres

The fiber is a dielectric waveguide consisting of discrete number of propagating modes. Based on the modes, the fibers can be classified as single and multi-mode and are discussed as below:

A. Multimode Fiber (MMF)

It has larger core diameter and relative refractive index than single mode fiber and allows large number of modes for the light rays to travel through it. These fibers may be further categorized as:

1) *Multimode Step-Index Fiber:* The refractive index of the core is uniform throughout and undergoes an abrupt or step change at the core cladding boundary. Due to its larger core size (usually 100 µm), more light can be coupled into this type of fiber. However, there is typically more signal loss as well as more signal distortion due to the multiple paths of light signal that may proceed with this larger fiber [1].

2) Multimode Graded-Index Fiber: It is an improved multimode step index fiber in terms of signal loss and signal distortion.

The refractive index of its core is made to vary in the parabolic manner such that the maximum refractive index is at the center of the core. Its core size is usually 50 or 62.5 µm.

B. Single mode Fiber (SMF)

It has small core and only one pathway of light. The difference between the refractive index of the core and the cladding is very small. SMF has a higher capacity to transmit information as it can retain the fidelity of each light pulse over longer distances and exhibits no dispersion caused by the multiple modes. It has also lower fiber attenuation than multimode fiber. Its demerits are its smaller core diameter making the coupling light into the core more difficult, difficult fabrication and higher cost.SMF also called single mode step index fiber is discussed as below:

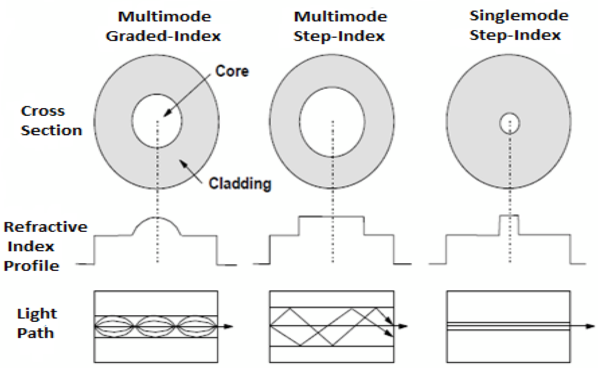

Fig.1- Different Types of Fibers

It has significantly smaller central core diameter (ranging from 8-12 μm) than any of the multimode fiber. Light rays, that enter the fiber, either propagate down the core or are reflected only few times. All rays approximately follow the same time to travel the length of the fiber. The cross section, refractive index profile and light path for different types of fibers are shown in Fig. 1.

III. OPTICAL SOURCES

High optical output power as well as a small electrical input power is the most important requirements for optical sources. The spectral width of light as well as the beam divergence and the geometrical size should also be small for a sufficient coupling efficiency. Semiconductor Light Emitting Diodes (LEDs) or lasers are the primary light sources used in fiber-optic transmission systems.

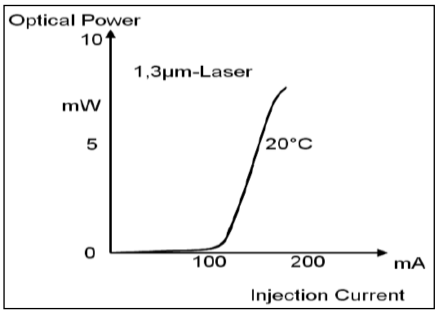

Fig.2 Optical Power versus Injection Current

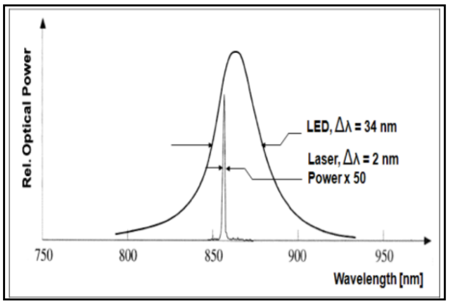

Fig.3 Spectral Width of LED and LASER

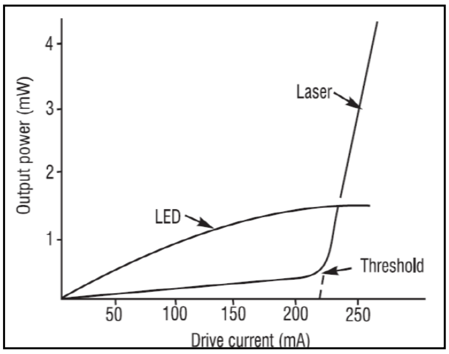

Fig.4 Drive current versus output power for LED and laser

The principal parameters are the power coupled into the fiber, the modulation bandwidth and the spectral width Strobe and Lubkoll have explained the difference between LED and LASER. Below the threshold current, the laser operates as an LED. When the injection current exceeds the threshold current, stimulated emissions occur as shown in Fig. 3

Since, the threshold current is strongly dependent on temperature and therefore, the additional measures like temperature control or control by a monitor diode is required to stabilize the optical output power.

A comparison between laser and LED based on coherence properties is given in Fig.4 which shows that the spectral width of a laser diode is much smaller than that of an LED, i.e. the laser produces significantly less chromatic dispersion compared to LED. A plot of typical power output versus current for LEDs and laser diodes given in Fig. 5 shows that the LED has a more linear output power making it more suitable for analog modulation.

IV. OPTICAL SIGNAL DEGRADATION

The design of fiber-optic communication system is limited by the loss, dispersion and nonlinearity of the fiber. Since the fiber properties are wavelength dependent, the choice of operating wavelength becomes a major design issue.

As the optical signal pulse travels through a fiber, several factors can degrade the data transmission. Longer the distance an optical pulse travels, less the chance that the data is received at the receiver end, the faster a pulse is transmitted and more successfully the data is recognized at the receiver side. This is due to the attenuation and dispersion of a propagating light wave. The attenuation effect reduces the signal power and the dispersion effect distorts the shape of the pulse when the light wave travels down the fiber. The mechanisms causing these effects are mentioned below:

A. *Optical Signal Attenuation*

Signal attenuation is a very important property in the design of an optical fiber communication system, as it largely determines the maximum transmission distance between a transmitter and receiver. The three basic mechanisms causing signal attenuation in a fiber i.e. absorption, scattering and imperfection losses of the optical energy are briefly discussed as follows:

1) Absorption Loss:

Any impurity, like hydroxyl ions and traces of metals remaining in the fiber after manufacturing process can block some of the light energy.

2) Scattering Loss:

Four kinds of scattering losses in optical fiber are: Rayleigh, Mie, Brillouin and Raman scattering. Rayleigh is the most important scattering loss due to small localized changes in the refractive index of the core and the cladding material. These changes are due to two problems of manufacturing process: the fluctuations in the _mix‘ of the ingredients are impossible to completely eliminate and the slight change in the density as the silica cools and solidifies.

The Rayleigh scattering loss in dB/km can be approximated by the expression:

$$L = 1.7\left(\frac{0.85}{\lambda}\right)^4$$

Where, is the wavelength in µm

The scattering loss is inversely proportional to fourth power of wavelength. Therefore, the use of short wavelength in fiber optic communication is severely restricted by Rayleigh scattering.

3) Imperfection Loss: It includes bending, coupling and splicing losses.

C. *Dispersion*

It is the velocity of propagation of an electromagnetic wave dependent on the wavelength. The dispersion effect can be explained by considering the situation shown in Fig.6. A finite line width optical source emits a pulse into a dispersive glass fiber. The input pulse is assumed to be composed of three different single wavelengths: λ1, λ2, and λ3 which travel at different velocities (due to wavelength dependent refractive index) in the fiber. After propagating a distance, these arrive at different intervals of time at the receiver end result in the spreading of output pulse. In a very long fiber cable, the dispersion can be sufficiently large making the adjacent pulses overlap eventually, which, in turn, result in Inter-Symbol Interference (ISI) and high bit-error rate in communications.

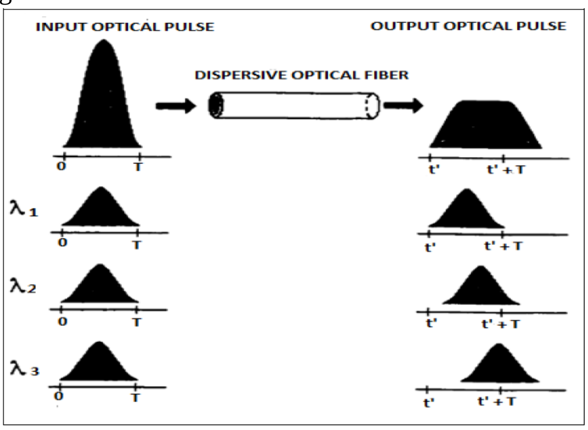

Fig.5 Pulse spreading caused by propagation through a dispersive optical waveguide.

A number of methods have been developed to solve all limitations, to some extent, to provide better communication system for future generations.

V. OPTCAL DETECTORS

The parameters for optical detectors are high sensitivity, low noise, linearity (for analog systems only) and small geometrical size. In fiber optic communication, PIN and APD photodiodes are generally used. All photodiodes are used in reverse voltage operation for transmission systems.

A positive-intrinsic-negative (p-i-n) photodiode consists of *p* and *n* regions separated by a very lightly *n* doped intrinsic region. Silicon p-i-n photodiodes are used at 0.8 nm wavelength and InGaAs p-i-n photodiodes at 1.3 and1.55 nm wavelengths. In normal operation, the p-i-n photodiode is under high reverse bias voltage. So the intrinsic region of the diode is fully depleted of the carriers. When an incident photon has energy greater than or equal to the band gap energy of the photodiode material, the electron-hole pair is created due to the absorption of photon. Such photons generate carriers in the depleted intrinsic region, where most of the incident light photons absorbed are separated by the high electric field present in the depletion region and are collected across the reverse biased junction. This produces a photocurrent flow in the external circuit to get high quantum efficiency and hence the maximum sensitivity and the thickness of the depletion layer should be increased so that the absorption of photons will be maximum. InGaAs p-i-n photodiodes have high quantum efficiency and high responsivity in the 1.33 and 1.55nmwavelengths.

Avalanche photodiode (APD) consists of four regions *p+ - i– p-n+* to develop very high electric field in the intrinsic region and to impart more energy to photoelectrons to generate new electron-hole pairs by impact ionization leading to avalanche breakdown in the reverse biased diode. The APDs have therefore, high sensitivity and high responsivity over p-i-n diodes due to the avalanche multiplication. APDs are made from silicon or germanium having operating wavelength of 0.8 nm and InGaAs with operating wavelength of 1.55 nm. Fig. 8 shows various types of detectors and their spectral responses.

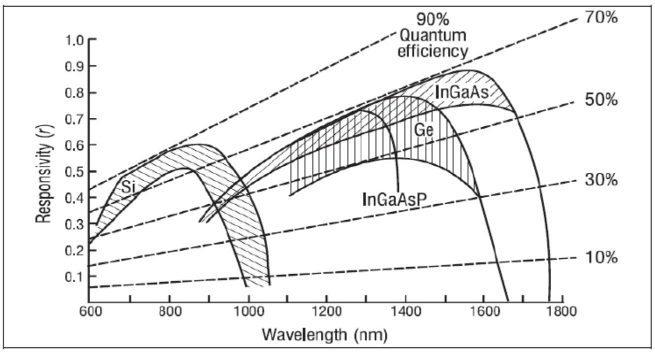

Fig.8 Detector spectral response

VI. BENEFITS AND APPLICATIONS

Advantages of developing and implementing fiber-optic communication cable systems are:

A. *Long transmission distance*

Optical fibers can be used to transmit or send the data over longer distances. These have lower transmission losses compared to copper wires, thereby, reducing the number of intermediate repeaters needed for these spans. This reduction in equipment and components reduces the system cost and complexity.

B. *Large information capacity*

Optical fibers have wider bandwidths than copper wires and can be used to send more information simultaneously over a single line. It results in the reduction in the number of physical lines needed for sending a certain amount of information.

C. *Small size and low weight*

The low weight and the small dimensions of fibers offer distinct advantage over heavy and bulky wire cables in crowded underground city ducts or in ceiling-mounted cable trays. It is also useful for aircraft, satellites and ships, where small and lightweight cables are beneficial. In military applications, large amounts of cable must be unreeled and retrieved rapidly.

D. Immunity to electrical interference

Optical fibers are made up of dielectric materials and make them immune to the electromagnetic interference effects like inductive pickup from other adjacent signal-carrying wires or coupling of electrical noise into the line from nearby equipment when compared to copper wires.

E. Enhanced safety

Optical fibers do not have the problems of ground loops, sparks and potentially high voltages unlike copper lines. However, precautions should be taken to prevent possible eye damage from laser light emissions.

F. Increased signal security

Optical fiber has the optical signal confined within the fiber and any signal emissions absorbed by an opaque coating around the fiber. This feature offers a high degree of data security compared to copper wires, in which the electric signals can be tapped off easily.

VII. Conclusion

The paper gives an overview of the developments in area of fiber optic communication. Optical fibers may be used as versatile transmission medium for variety of applications related to transmission of information. Single mode fiber enjoys lower signal attenuation than multimode and hence, it can be used for longer distances up to 100kms while multimode fiber can be used for smaller distances up to 6 km. LED and LASER have been discussed as optical sources. The later is preferred as it can be used with both SMF and MMF. Advantages of fiber optic communication over copper wire based communication are also given in terms of bandwidth, signal security, electrical interference, size, and weight. The fiber optic communication has huge scope for DAS for electricity distribution, communication, satellite, military applications in India.

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