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Fiber Optic Communication Systems: A Brief Overview

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Abstract

In recent times, optical fiber communication technology has progressed considerably with continuous exploration of emerging technologies to support more bandwidth, higher data rate and improved security along with reduction in losses. The optical fiber communication system has remarkably low loss and is reliably capable of meeting the demand of massively increased information traffic with minimum number of repeaters in its link. In this paper, we discuss broadly about optical fiber technology theory, types, working principle with its various merits and demerits in the application scenario. Single-mode graded index fiber has been mainly analysed in comparison to multimode fibers and it has emerged as the most efficient means of broad band signal transmission offering distinct advantages. The possible consequences of both linear and nonlinear effects of the optical fiber and other limiting factors that predominantly influence the performance of propagation attributes have been discussed which are reasonably relevant to the thrust areas of optical engineering ,photonics and fiber optic devices.

Keywords: Optical fiber, Single –mode graded index fiber, TIR, WDM, Bandwidth, Dispersion, Nonlinearity.

1. Introduction

Optical fiber technology supports signals in the form of data, video or voice and these signals are modulated using light pulses during transmission over long distances using glass or plastic tube. The attenuation loss is greatly minimised for such mode of communication technique. This modulated light pulses propagate through the glass tube using the principle of TIR (Total Internal Reflection). Generally, a basic fiber link comprises of data transmitter that consists of a laser diode or Light Emitting Diode (LED) which convert electric signal to light, a transmission fiber in which the modulated light propagates, and a receiver which consist of a photo detector that converts light to electric signal. A simple optical fiber consists of a thin cylindrical dielectric core surrounded by coaxial dielectric cladding and the value of cladding refractive index (n_2) being slightly less than that of the core (n_1). As the optical frequencies are much higher compared to radio waves and microwaves, a light beam acting as a carrier can be effectively employed to carry much more information as compared to radio waves and microwaves. In optical fiber communication systems, information is usually transmitted in the form of optical pulses. The propagation of optical pulses through a fiber involves propagation of various modes that can be obtained from possible solution of Maxwell's electromagnetic wave equations relating to guidance of optical pulses through the fiber. A mode is basically a transverse electromagnetic field distribution which propagates through the fiber with a definite propagation constant, group velocity and a definite state of polarization [1].

Further, the fiber carrying only the fundamental mode is called single-mode while the fiber carrying more than one mode is known as multimode fiber. Single-mode fibers can be step index or graded index, W fiber, trapezoidal fiber etc. depending on the nature of refractive index profile distribution within the core. It has been found out that higher bandwidth, increased data rate, electromagnetic immunity, reduced losses, long distance transmission with enhanced signal security are some of the striking features for wide acceptability of optical fibers in the vast emerging field of communication. Dispersion is another important phenomenon as it limits the bandwidth or information carrying capacity of the optical communication system. Generally, an optical pulse launched into an optical fiber tends to be broadened in time domain as it propagates through the fiber. Different light rays take different time to propagate through the fiber and this typical phenomenon of pulse broadening occurring due to transit time delay differences is called dispersion which is basically sum of waveguide dispersion, material dispersion and composite profile dispersion and they tend to affect the linear and nonlinear characteristics of the fiber and as such affect system performance. For high information carrying system, it is important to minimise pulse dispersion effects by use of appropriate graded index fibers or single-mode fibers or employing other appropriate dispersion management techniques [1-4].

This present paper mainly discusses about the types of fibers and their operating principles and the possible remedial measures so as to reduce the losses, dispersion and nonlinearity effects in the broad application area of optical engineering.

2. Working Principle of Fiber

Total Internal Reflection is the underlying operating principle for fiber optical communication. It is the reflection that takes place when light travelling in one medium having higher refractive index strikes another material medium having lower refractive index and reflects back to the original medium. With increase in angle of incidence, the angle of refraction increases and the particular angle of incidence value that yields refraction angle of 90^0 is known as critical angle. If the angle of incidence at core-cladding interface exceeds the critical angle, the light wave is totally reflected back to the original medium and no energy is lost due to refraction and these laws are governed by popular Snell's laws. These simple principles form the basis of propagation of light through optical fiber. The classification of optical fiber can be based on modes or refractive index profile distribution. It is important to mention here that refractive index profile distribution of core(n_1) and cladding(n_2) will determine categorisation of the fiber. For step index fibers, the value of n_1 is uniform throughout . On the contrary, for graded index profile fiber, the core refractive index is not uniform and the value of n_1 is maximum at centre and gradually decreases towards cladding. There is no sharp discontinuity at core-cladding interface for the case of graded index fibers [1-4].

The optical fiber can be either single-mode or multi mode. For single –mode or mono-mode ,the diameter of fiber shrinks and only the fundamental mode is allowed to propagate. On the other hand, for multi mode fibers, many modes propogate. Since 1983, long distance communication links have been dominated by the use of single-mode fiber. Essentially, a fiber is characterized by an important propagation parameter known as V number which is the normalised frequency value. Each mode has a definite normalised cut-off V number below which it cannot propagate. For single- mode fiber, V number is kept below the cut-off V number of first higher order mode so that only the fundamental mode propagates.

3. Attenuation and Dispersion

Attenuation and dispersion are two important limiting factors related to optical communication system and its transmission attributes. Absorption, scattering and fiber bends are the key reasons for signal attenuation in fibers. Fiber impurities, structural imperfections, wavelength of light, non-uniformities at core-cladding boundary are the factors accountable for attenuation in fiber. Attenuation invariably plays a primary role in the determination of maximum transmission distance between transmitter and receiver in a communication system. Pulse dispersion is due to intermodal dispersion as well as intramodal dispersion. In a multimode fiber, both intermodal and intramodal dispersions are present resulting in dispersion on a large scale and therefore multimode fiber is not suitable for long distance communication. Single- mode graded index fibers have gained tremendous importance in high bandwidth optical fiber communication systems and wavelength division multiplexing (WDM) optical networks. Use of single-mode graded index fiber eliminates intermodal dispersion and are also very less sensitive to micro and macro bending losses. Once single-mode fiber system has been installed , it becomes convenient to upgrade the system capacity and this optimises the installation costs effectively [1,3-5].

Dispersion certainly affects the information carrying capacity of any optical fiber. It is the pulse broadening effect in fibers.The operating wavelength of optical communication system ranges from 1.3 µm to 1.6 µm to reduce attenuation loss as well as material dispersion. With advancement in technology, optical fiber made of pure silica has extremely low attenuation loss (~0.2dB/km) at the wavelength 1.55µm while its material dispersion is almost absent around the wavelength 1.3µm.Modal dispersion, material dispersion and waveguide dispersion mainly account for the dispersion effects in fibers. Use of single-mode fiber eliminates intermodal dispersion. Shifting of zero dispersion wavelength to 1.55 µm provides mimimum attenuation loss of about 0.2dB/km and negligible dispersion at the same time. Such fibers are termed as dispersion shifted fibers that eventually results in bandwidth enhancement and the fiber parameters are judiciously monitored for such condition [5,6]. Additionally, the composite profile dispersion is primarily proportional to the derivative of relative core-cladding refractive index difference with respect to wavelength and it is negligible owing to its small value which is less than 0.5ps/ (km nm). It is noteworthy that owing to the presence of narrow spectral width of the light source used in optical communication system, the material as well as waveguide dispersions result in pulse broadening. In dispersion flattened fiber, the waveguide dispersion effect is cancelled out by material dispersion over a range of wavelength and it improves the information carrying capacity by employing wavelength division multiplexing (WDM.) Such dispersion management techniques have been encouraged by the optical engineers for linear and nonlinear applications [5-7].

4. Nonlinear Effects in Fiber

Nonlinearity is a severe constraint for any fiber communication system and its impact has to be minimised for satisfactory performance of any optical communication system. Nonlinear electro-optic effects are observed essentially due to the dependence of refractive index profile of fibers on the electric field associated with intense light beam. The nonlinear optical fibers subjected to highly intense optical beam possess propagation characteristics significantly different from those belonging to the same fibers operating in the linear region. Accordingly, these nonlinearities largely affect the information capacity by limiting launched power, channel spacing, channel bit rate and bandwidth of the optical communication system [8,9]. Light beam self focussing or defocusing occurs due to nonlinear dependence of refractive index on beam intensity. The presence of nonlinearity causes pulse compression while dispersion broadens the pulse. Accordingly, simultaneous action of dispersion and nonlinearity causes propagation of the optical beam as such in fiber and this is popularly known as soliton propagation. Consequently, optical soliton in nonlinear graded index fiber facilitates more data transfer in communication by the process of multiplexing. The formation of different types of nonlinearity effects primarily depends on the light beam intensity and the nature of the doped material of the fiber [8-12].

The nonlinear effects can be scattering phenomena like stimulated Brillouin scattering(SBS) and stimulated Raman scattering (SRS) and they they can give rise to optical amplication.The high power incident beam termed as pump.SBS and SRS can have serious implications for WDM systems. Fiber doped cores with erbium also can act as suitable optical amplifiers operating at 1.55 μm with large gain. Signal is in the wavelength of 1500-1600 nm with pump operating around 980 nm wavelength and such amplifiers do generate interest in the study of launching power and other fiber parameters taking into consideration the nonlinearity effect. Different types of nonlinearity effects, namely third order, fifth order, saturable etc., solely depends on the light beam intensity and the nature of the fiber doped material. Soliton propagation facilitates higher rate of data transfer and can propagate larger distances without appreciable change in shape. Kerr nonlinearity that is produced due to anisotropic polarization of the medium by highly intense light source is of utmost importance owing to its impact over various fiber parameters and their propagation constants.

Judicious selection of V number ensures satisfactory communication inspite of predominance of nonlinearity in fibers. Kerr nonlinearity produces other dominant effects like self phase modulation, cross phase modulation and four wave mixing and affect the performance of optical fibers and fiber related devices [8-14].The field of nonlinear photonics with its challenges is the major area of interest for researchers and experimentalists in contemporary times.

5. Conclusion

The popularity of optical fibers and fiber optic devices relating to use in communications, broadcasting, networking, military, command and control links, signalling purposes, cables, security systems, spectroscopy, sensors and many other industrial, medical and commercial applications is increasing day by day. Despite the fact that such fibers involve higher installation costs, the superior performance owing to their inherent merits surpasses these drawbacks. Linear and nonlinear effects on the performance of optical fibers and devices with other limitations have been discussed in this paper and the emphasis focuses on the analysis of propagation characteristics under the influence of linear and nonlinearity effects. Undoubtedly, the fiber optic communication technology explores immense opportunities to engineers and researchers so as to cater to future demands efficiently.

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