Optical Fiber Communication System – Theory & Analysis

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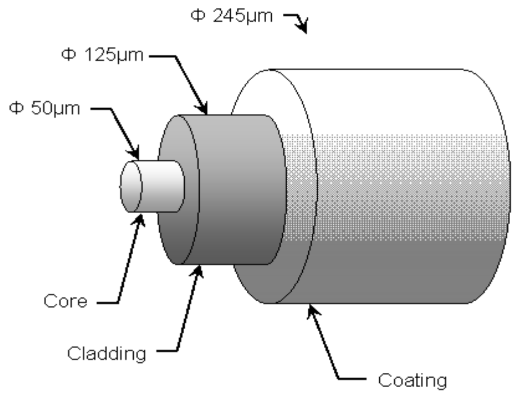
Abstract –
The visible optical carrier waves or lightweight has been usually used for communication purpose for several years. Alexander Graham Bell transmitted a speech data employing a light for the primary time in 1880. Simply once four years of the invention of the phone Bell projected his photo phone that was capable of providing a speech transmission over a distance of 200m. Within the year 1910 Hondros and Debye administered a theoretical study and in 1920 Schriever reported an experimental work. Though within the early a part of twentieth century optical communication was researching some analysis work however it had been getting used solely within the low capability communication links because of severe have an effect on of disturbances within the atmosphere and lack of appropriate optical sources. However, low frequency (longer wavelength)magnetism waves like radio and microwaves well-tried to be rather more helpful for data transfer in atmosphere, being way less tormented by the region disturbances. The relative frequencies and their corresponding wavelengths may be best-known from the spectrum and it's graspable that optical frequencies supply a rise within the potential usable information measure by an element of around ten thousand over high frequency microwave transmission. With the optical maser returning into the image the analysis interest of optical communication got stimulation. A robust coherent light along side the likelihood of modulation at high frequencies was the key feature of optical maser. Kao and Hockham projected the transmission of data via stuff waveguides or fiber cables fictitious from glass nearly at the same time in 1966. Within the earlier stage optical fibers exhibited terribly high attenuation (almost one thousand dB/km) which was unrivalled with homocentric cables having attenuation of around five to 10dB/km. yet, at intervals 10 years fiber losses were reduced to below 5dB/km and appropriate low loss jointing techniques were formed furthermore. Parallel with the invent of the optical

fibers alternative essential optical elements like semiconductor optical sources (i.e. injection LASERs and LEDs) and detectors (i.e. photodiodes and phototransistors) were conjointly researching rigorous analysis method. Primarily the semiconductor Lasers exhibited terribly short life of at the most many hours however by 1973 and 1977 lifetimes larger than one thousand 60 minutes and 7000 60 minutes severally were obtained through advanced device structure.

I. **Introduction –**

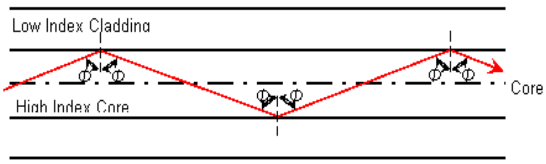
Optical fiber may be a material conductor or medium during which data (voice, information or video) is transmitted through a glass or plastic fiber, within the variety of light-weight. The fundamental structure of AN optical fiber is shown in figure one. It consists of a clear core with a index of refraction n1 enclosed by a clear protective cover of a rather less index of refraction n2. The index of refraction of protective cover is a smaller amount than a hundred and twenty fifth, not up to that of core. Typical values as an example area unit a core index of refraction of one.47 and a protective cover index of one.46. The protective cover supports the conductor structure, protects the core from interesting surface contaminants and once adequately thick, well reduces the radiation loss to the encompassing air. Glass core fibers tend to possess low loss compared with plastic core fibers. To boot, most of the fibers area unit encapsulated in AN elastic, abrasion-resistant plastic material that automatically isolates the fibers from little geometrical irregularities and distortions. a collection of radio-controlled magnetism waves, additionally referred to as the modes of the conductor, will describe the propagation of sunshine on the conductor. Solely an exact variety of modes area unit capable of propagating through the conductor.



II. Principle of ray propagation –

This is the foremost fascinating factor regarding glass fiber cables. Such an essential a part of modern-day communication system works on an especially straightforward property of sunshine ray i.e. Total Internal Reflection. As we have a tendency to all grasp that once lightweight ray is passing from denser (refractive index is higher) stuff medium to a rarer (refractive index is lower) stuff medium then from the purpose of incidence at the interface it bends removed from the traditional. Once the angle is sufficiently high such the angle of refraction is 90º then it's referred to as incidence angle. Currently if lightweight ray falls at the interface of the 2 mediums at associate degree angle bigger than the incidence angle then the sunshine ray gets mirrored back to the originating medium with high potency (around ninety nine.9%) i.e. total internal reflection happens. With the assistance of numberless total internal reflections lightweight waves are propagated on the fiber with low loss as shown in figure2. during this context, 2 parameters are terribly crucial specifically Acceptance Angle and Numerical Aperture.

Figure 2.



Acceptance angle is that the most angles at that lightweight might enter the fiber so as to be propagated and is denoted by θa in figure3. the link between the acceptance angle and therefore the refractive indices of the 3 media involved-core, protection and air, ends up in the definition of Numerical Aperture that is given by – sodium = $(n1^2-n2^2)^{1/2}$ = n0 sin θa wherever n0 is that the ratio of air. The sunshine ray shown in figure3 is thought as a meridional ray because it passes through the axis of the fiber. However, another class of ray exists that is transmitted while not passing through the fiber axis and follows a spiraling path through the fiber.

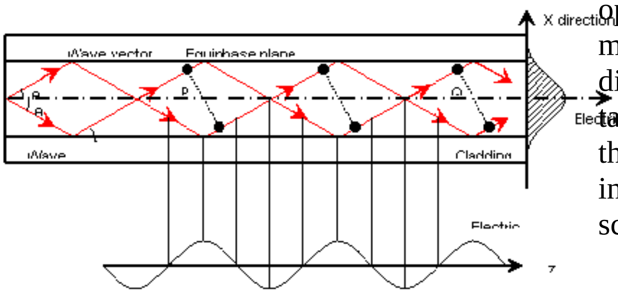
III. Modes in optical fibers-

The radiation theory should be taken into consideration for obtaining AN improved model for propagation of sunshine through optical fibers. The optical wave guides are often thought-about to be either a plane guide or a cylindrical guide. Electromagnetic field contains of a sporadically variable force field E and flux M that are familiarized at right angle to every alternative. Once the electrical field is perpendicular to the direction of propagation and thus Ez=0, however a corresponding flux parties within the direction of propagation, that mode is understood as cross electrical (TE) mode. However once the reverse issue happens then it's termed as cross Magnetic (TM) mode. Currently once total field lies within the cross plane, cross magnetic attraction (TEM) waves exist wherever each Ez and cycles/second ar zero. The formation of modes in a very plane insulator guide and therefore the interference of plane waves are shown in figure4. Here the stable field distribution within the x direction with solely periodic z dependence owing to sinusoidal variable force field in z direction is understood as a mode. In a very cylindrical fiber cross electrical (TE) and cross magnetic (TM) modes are obtained that is delimited in 2 dimensions. So 2 integers (l & m) are necessary to specify the modes. Hybrid modes may additionally occur within the cylindrical fibers. These modes result from skew ray propagation and are selected by HElm once H makes a bigger contribution to the cross field and EHlm once E makes larger contribution to the cross field.

IV. Transmission Characteristics of Optical Fiber Cables –

The transmission characteristics of fiber cables play a serious role in determinative the performance of the whole communication system. Attenuation and information measure square measure the 2most vital transmission characteristics once the suitableness of fi ber for communication is analyzed. The assorted attenuation mechanisms square measure linear scattering, non linear scattering, material absorption and fiber bends etc. The information measure determines the quantity of bits of data transmitted in an exceedingly given fundamental quantity and is essentially restricted by signal dispersion among the fiber.

Figure 4.



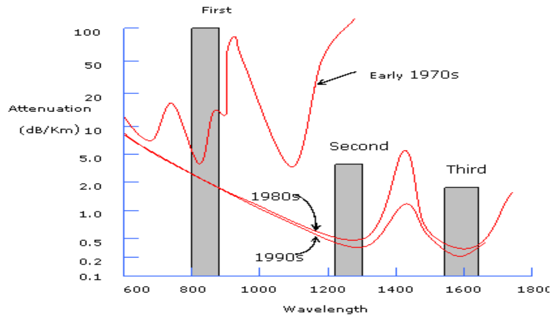
V. Attenuation in optical fibers –

Attenuation is outlined because the loss of optical power over a collection distance, a fiber with a lower attenuation, can permit a lot of power to succeed in to the receiver than a fiber with higher attenuation. Signal attenuation at intervals glass fiber is sometimes expressed in sound unit per unit length (i.e. dB/km).

Loss in decibel (dB) = $10 \log_{10}(Pi/Po)$

Where Pi and Po are the transmitted and output optical power respectively. Figure5 shows optical fiber attenuation as a function of wavelength.

Figure 5.



VI. Linear scattering losses –

Through this mechanism a portion/total optical power among one propagating mode is transferred to a different. Currently once the transfer takes place to a leaky or radiation mode then the result's attenuation. It is divided into 2 major classes particularly Mie scattering and Rayleigh scattering.

A. Mie scattering –

Non excellent cylindrical structure of the fiber and imperfections like irregularities within the core-cladding interface, diameter fluctuations, strains and bubbles could produce linear scattering that is termed as Mie scattering.

B. Rayleigh scattering –

The dominant reason behind Third Baron Rayleigh scattering is ratio fluctuations as a result of density and integrative variation within the core. It's the key intrinsic loss mechanism within the low ohmic resistance window. Third Baron Rayleigh scattering may be reduced to an oversized extent by victimization longest attainable w avelength.

C. Non linear scattering losses –

Especially at high optical power levels scattering causes disproportionate attenuation, attributable ton on linear behavior. Attributable to this non linear scattering the optical power from one mode is transferred in either the forward or backward direction to constant or different modes, at completely different frequencies. The 2 dominant kinds of non linear scattering are:

1) Stimulated Brillouin Scattering and
2) Stimulated Raman Scattering.

D. Material absorption losses –

When there happens to be some defect within the material composition and therefore the fabrication method of glass fiber, there's dissipation of optical power within the kind of heat within the conductor. Here conjointly there square measure 2 kinds of absorption losses within the fiber like intrinsic absorption and unessential absorption. once the absorption is caused by interaction with one or additional elements of glass it's termed as intrinsic absorption whereas if it's thanks to impurities among the glass like transition metal or water then it's referred to as the unessential one.

E. Dispersion –

It is defined as the spreading of the sunshine pulses as they travel down the fiber. Owing to the spreading result, pulse tends to overlap, creating them illegible by the receiver that may be essential drawback to alter. It creates distortion for each digital and analog transmission. Dispersion limits the most attainable information measure possible at intervals a selected fiber. Pulse broadening may be a quite common drawback created by dispersion in digital transmission. To avoid it, the digital bit rate should be but the reciprocal of the broadened pulse length.

1) Intermodal Dispersion –

The propagation delay distinction between completely different modes at intervals multimode fibers is to blame for intermodal dispersion and therefore pulse broadening. In fact, the various cluster velocities with that the modes travel through the fiber creates the most drawback. Multimode step index fibers exhibit an outsized quantity of intermodal dispersion whereas in a very pure single mode fiber there's no intermodal dispersion. By adopting associate degree optimum ratio profile (parabolic profile in most stratified index fibers), we will drastically cut back intermodal dispersion.

2) Intramodal Dispersion –

This type of dispersion takes place attributable to the very fact that optical sources don't emit one frequency however a band of frequencies and there happens to be propagation delay variations between these spectral parts. This type of pulse broadening happens in virtually each style of optical fibers. Once the dispersive characteristics of the conductor material area unit to blame for the delay variations then it’s called material dispersion. On the opposite hand if imperfect steering result is behind the heartbeat broadening then it’s termed as conductor dispersion. There's virtually zero conductor dispersion in multimode fibers.

F. Fiber bending losses –

Light energy gets radiated at the bends on their path through the fiber and eventually is lost. This can be the mechanism referred to as fiber bend losses. There area unit 2 varieties bending inflicting this loss particularly small bending and macro bending. If the fiber is sharply bent so the sunshine traveling down the fiber can't build the flip and gets lost then its macro bending as shown in figure 6(a). Once tiny bends within the fiber created by crushing, contraction etc causes the loss then it's known as small bending as shown in figure 6(b). These bends aren't sometimes visible with eye.

Figure 6a

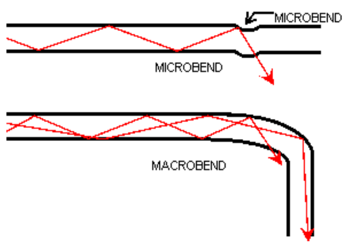


Figure 6b

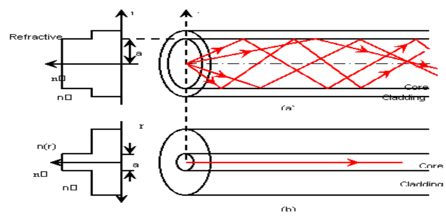
VII. Types of optical fibers –

According to the index of refraction profile optical fibers is divided into 2 classes specifically Step index fibers and hierarchic index fibers that area unit delineate below –

1) Step Index Fiber –

If the index of refraction profile of a fiber makes a step amendment at the core protective covering interface then it's referred to as step index fiber. A multimode step index fiber is shown in figure7(a), the core diameter of that is around 50µm. Some physical parameters like relative index of refraction, index distinction, core radius etc determines the most variety of target-hunting modes potential in a very multimode fiber. one mode fiber incorporates a core diameter of the order of two to 10µm and also the propagation of sunshine wave is shown in figure7(b). it's the distinct advantage of low intermodal dispersion over multimode step index fiber. On the opposite hand multimode step index fibers enable the employment of spatially incoherent optical sources and low tolerance necessities on fiber connectors.

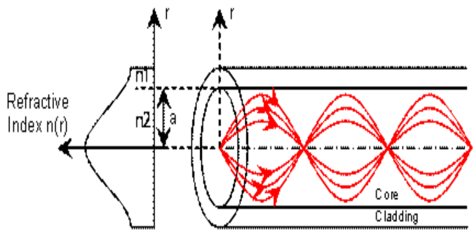
Figure7.



2) Graded Index Fiber –

The hierarchal index fibers have decreasing core index n(r) with radial distance from a most worth of n1 at the axis to a continuing worth n2 on the far side the core radius a within the facing as shown in figure8. The hierarchal index fiber offers best results for multimode optical propagation for parabolicratio profile. Owing to this special reasonably ratio profile multimode hierarchal index fibers exhibit less intermodal dispersion than its counterpart i.e. multimode step index fibers.

Figure 8.



VIII. Benefits of optical fiber communication –

Some of the innumerable benefits of optical fiber communication system are:

- Immense bandwidth to utilize
- Total electrical isolation in the transmission medium
  - Very low transmission loss,
  - Small size and light weight,
  - High signal security,
  - Immunity to interference and crosstalk,
  - Very low power consumption and wide scope of system expansion etc.

These are the main advantages that have made optical fiber communication system such an indispensable part of modern life.

XI. Field of application –

Due to its variety of advantages optical fiber communication system has a wide range of application in different fields namely :

a. Public network field which includes trunk networks, junction networks, local access networks, submerged systems, synchronous systems etc.

b. Field of military applications ,

c. Civil, consumer and industrial applications,

d. Field of computers which is the center of research right now.

X. Conclusion -

Though there are some negatives of optical fiber communication system in terms of fragility, splicing, coupling, set up expense etc. but it is an un avoidable fact that optical fiber has revolutionized the field of communication. As soon as computers will be capable of processing optical signals, the total arena of communication will be opticalized immediately.

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