Different Types of Dispersions in an Optical Fiber

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Abstract- The intended application of our Different Types of Dispersions in an optical fiber. In this report we discuss about the Optical Fiber and its advantages, Theory and principles of the fiber optics, Fiber geometry, Types of optical fiber, Different parameters and characteristics of fiber are also explained. Fiber has linear and non-linear characteristics. Linear characteristics are wavelength window, bandwidth, attenuation and dispersion. Non-linear characteristics depend on the fiber manufacturing, geometry etc.Dispersion is the spreading of light pulse as its travels down the length of an optical fiber. Dispersion limits the bandwidth or information carrying capacity of a fiber.

Index Terms- Optical Fibers, Dispersions, Modal Dispersions, Material Dispersion, Wave Guide Dispersions, Polarization Dispersions, Chromatic Dispersions.

I. INTRODUCTION

Copper wires have been used in data transmission since the invention of the telephone in 1876. But as the demand increased, the use of copper wires consistently got reduced due to many reasons such as low bandwidth, short transmission length and inefficiency.

Optical Fiber is new medium, in which information (voice, Data or Video) is transmitted through a glass or plastic fiber, in the form of light. The field of applied science and engineering concerned with the design and application of optical fibers is known as fiber optics. Optical fibers are widely used in fiber optics, which permits transmission over longer distances and at higher bandwidth (data rates) than other forms of communication. Optical fibers may be connected to each other or can be terminated at the end by means of connectors or splicing techniques.

This was the reason for the introduction of optical fiber. Optical fiber played a very important role due to its wide properties like high bandwidth, long distance transmission, and high level of security.

II. FIBER OPTICS

Optical Fiber is new medium, in which information (voice, Data or Video) is transmitted through a glass or plastic fiber, in the form of light, following the transmission sequence.Information is encoded intoelectrical signals. Electrical signals are converted into light signals.Light travels down the fiber. A detector changes the light signals into electrical signals.Electrical signals are decoded into information.

III. ADVANTAGES OF FIBER OPTICS

Fiber Optics has the following advantages:
- (I)   Optical Fibers are non-conductive (Dielectrics).
- (II) Electromagnetic Immunity:
- (III) Large Bandwidth (> 5.0 GHz for 1 km length)
- (IV) Small, Lightweight cables.
- (V)   Security.

Principle of Operation - Theory

Total Internal Reflection - The Reflection that Occurs when a Light Ray Travelling in One Material Hits a Different Material and Reflects Back into the Original Material without any Loss of Light
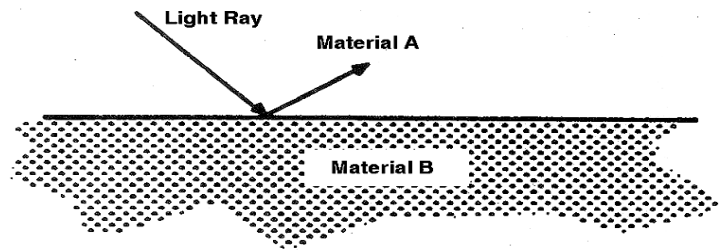
IV. THEORY AND PRINCIPLE OF FIBER OPTICS

Speed of light is actually the velocity of electromagnetic energy in vacuum such as space. Light travels at slower velocities in other materials such as glass. Light travelling from one material to another changes speed, which results in light changing its direction of travel. This deflection of light is called Refraction.

The amount that a ray of light passing from a lower refractive index to a higher one is bent towards the normal. But light going from a higher index to a lower one refracting away from the normal, as shown in the figures.

As the angle of incidence increases, the angle of refraction approaches 90° to the normal. The angle of incidence that yields an angle of refraction of 90° is the critical angle. If the angle of incidence increases amore than the critical angle, the light is totally reflected back into the first material so that it does not enter the second material. The angle of incidence and reflection are equal and it is called Total Internal Reflection.

By Snell's law, $n1 \sin \varnothing_1 = n2 \sin \varnothing_2$
The critical angle of incidence $\varnothing_c$ where $\varnothing_2 = 90^\circ$
Is $\varnothing_c = \arc \sin (n_2 / n_1)$

At angle greater than $\varnothing_c$ the light is reflected, Because reflected light means that n_1 and n_2 are equal (since they are in the same material), $\varnothing_1$ and $\varnothing_2$ are also equal. The angle of incidence and reflection are equal. These simple principles of refraction and reflection form the basis of light propagation through an optical fiber.
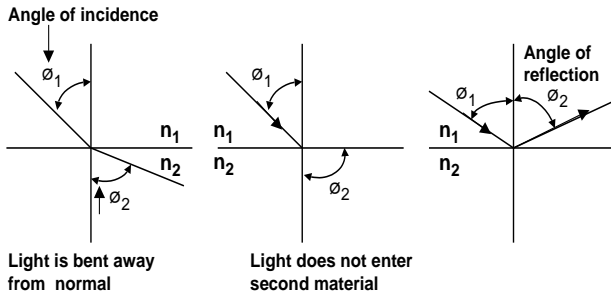
V.   FIBER TYPES

The refractive Index profile describes the relation between the indices of the core and cladding. Two main relationships exist:

- Step Index
- Graded Index

The step index fiber has a core with uniform index throughout. The profile shows a sharp step at the junction of the core and cladding. In contrast, the graded index has a non-uniform core. The Index is highest at the center and gradually decreases until it matches with that of the cladding. There is no sharp break in indices between the core and the cladding.

By this classification there are three types of fiber:

- Multimode Step Index fiber (Step Index fiber)
- Multimode graded Index fiber (Graded Index fiber)
- Single- Mode Step Index fiber (Single Mode Fiber).

VI.   STEP INDEX MULTIMODE FIBER

This fiber is called "Step Index" because the refractive index changes abruptly from cladding to core. The cladding has a refractive index somewhat lower than the refractive index of the core glass. As a result, all rays within a certain angle will be totally reflected at the core-cladding boundary. Rays striking the boundary at angles greater than the critical angle will be partially reflected and partially transmitted out through the boundary. After many such bounces the energy in these rays will be lost from the fiber. The paths along which the rays (modes) of this step index fiber travel differ, depending on their angles relative to the axis. As a result, the different modes in a pulse will arrive at the far end of the fiber at different times, resulting in pulse spreading which limits the bit-rate of a digital signal which can be transmitted.
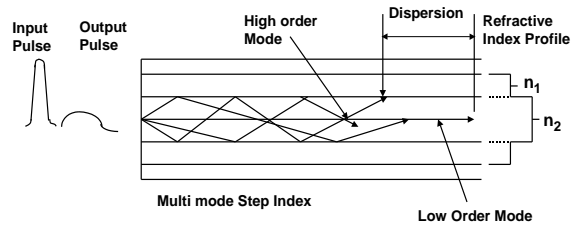
VII.   GRADED INDEX MULTI-MODE FIBER

This fiber is called graded index because there are many changes in the refractive index with larger values towards the center. As light travels faster in a lower index of refraction. So, the farther the light is from the center axis, the grater is its speed. Each layer of the core refracts the light. Instead of being sharply reflected as it is in a step index fiber, the light is now bent or continuously refracted in an almost sinusoidal pattern. Those rays that follow the longest path by travelling near the outside of the core, have a faster average velocity. The light travelling near the center of the core, has the slowest average velocity.

As a result all rays tend to reach the end of the fiber at the same time. That causes the end travel time of different rays to be nearly equal, even though they travel different paths.
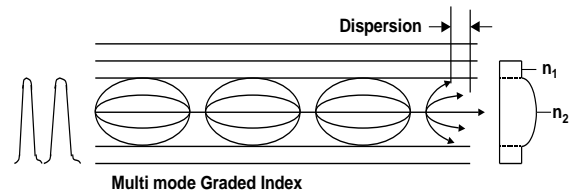
The graded index reduces modal dispersing to 1ns/km or less.

Graded index fibers have core diameter of 50, 62.5 or 85 μm and a cladding diameter of 125 μm. The fiber is used in applications requiring a wide bandwidth and low model dispersion. The number of modes in the fiber is about half that of step index fiber having the same diameter.

Single mode step index fiber:

Another way to reduce modal dispersion is to reduce the core's diameter, until the fiber only propagates one mode efficiently. The single mode fiber has an exceedingly small core diameter of only 5 to 10 μ m. Standard cladding diameter is 125 μm. Since this fiber carries only one mode, model dispersion does not exists. Single mode fibers easily have a potential bandwidth of 50to 100GHz-km.

The core diameter is so small that the splicing technique and measuring technique are more difficult. High sources must have very narrow spectral width and they must be very small and bright in order to permit efficient coupling into the very small core diameter of these fibers.

One advantage of single mode fiber is that once they are installed, the system's capacity can be increased as newer, higher capacity transmission system becomes available. This capability saves the high cost of installing a new transmission medium to obtain increased performance and allows cost effective increases from low capacity system to higher capacity system.

As the wavelength is increased the fiber carries fewer and fewer modes until only one remains. Single mode operation begins when the wavelength approaches the core diameter. At 1300 nm, the fiber permits only one mode, it becomes a single mode fiber.

As optical energy in a single mode fiber travels in the cladding as well as in the core, therefore the cladding must be a more efficient carrier of energy. In a multimode fiber cladding modes are not desirable; a cladding with in efficient transmission characteristic can be tolerated. The diameter of the light appearing at the end of the single mode fiber is larger than the core diameter, because some of the optical energy of the mode travels in the cladding. Mode field diameter is the term used to define this diameter of optical energy.

VIII. DISPERSION

Dispersion is the spreading of light pulse as its travels down the length of an optical fiber. Dispersion limits the bandwidth or information carrying capacity of a fiber. The bit-rates must be low enough to ensure that pulses are farther apart and therefore the greater dispersion can be tolerated.

There are three main types of dispersion in a fiber:
➢ Modal Dispersion.
➢ Material dispersion.
➢ Waveguide dispersion.

Linear Characteristics

IX. MODAL DISPERSION

Modal dispersion occurs only in Multimode fibers. It arises because rays follow different paths through the fiber and consequently arrive at the other end of the fiber at different times. Mode is a mathematical and physical concept describing the propagationof electromagnetic waves through media. In case of fiber, a mode is simply a path that a light ray can follow in travelling down a fiber. The number of modes supported by a fiber ranges from 1 to over 100,000. Thus a fiber provides a path of travels for one or thousands of light rays depending on its size and properties. Since light reflects at different angles for different paths (or modes), the path lengths of different modes are different.

Thus different rays take a shorter or longer time to travel the length of the fiber. The ray that goes straight down the center of the core without reflecting, arrives at the other end first, other rays arrive later. Thus light entering the fiber at the same time exit the other end at different times. The light has spread out in time.

The spreading of light is called modal dispersion. Modal dispersion is that type of dispersion that results from the varying modal path lengths in the fiber. Typical modal dispersion figures for the step index fiber are 15 to 30 ns/ km. This means that for light entering a fiber at the same time, the ray following the longest path will arrive at the other end of 1 km long fiber 15 to 30 ns after the ray, following the shortest path.

Fifteen to 30 billionths of a second may not seem like much, but dispersion is the main limiting factor on a fiber's bandwidth. Pulse spreading results in a pulse overlapping adjacent pulses as shown in figure. Eventually, the pulses will merge so that one pulse cannot be distinguished from another. The information contained in the pulse is lost Reducing dispersion increases fiber bandwidth.
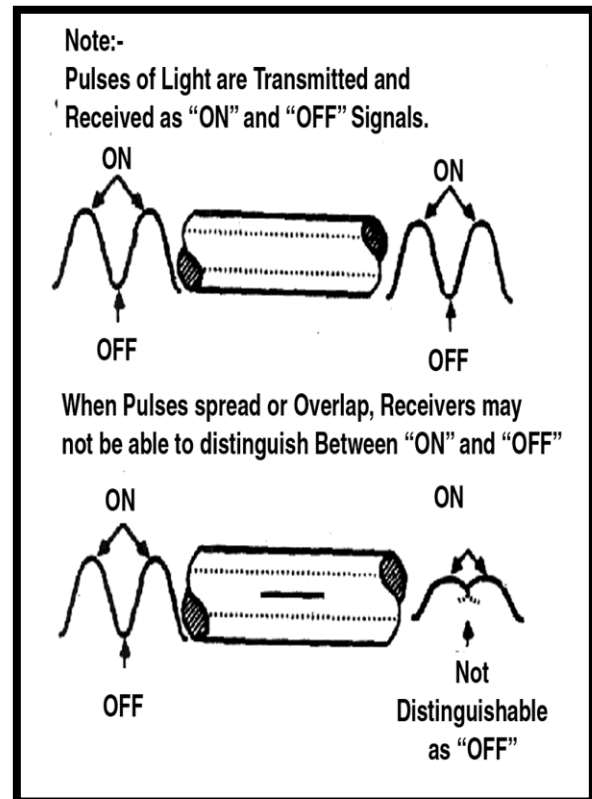
Modal dispersion can be reduced in three ways:
➢ Use a smaller core diameter, which allows fewer modes.
➢ Use a graded -index fiber so that light rays that allow longer paths also travel at a faster velocity and thereby arrive at the other end of the fiber at nearly the same time as rays that follow shorter paths.
➢ Use a single-mode fiber, which permits no modal dispersion.

X. MATERIAL DISPERSION

Different wavelengths also travel at different velocities through a fiber, in the same mode, as

n = c/v.

where n is index of refraction, c is the speed of light in vacuum and v is the speed of the same wavelength in the material. The value of v in the equation changes for each wavelength, Thus Index of refraction changes according to the wavelength. Dispersion from this phenomenon is called material dispersion, since it arises from material properties of the fiber.

Each wave changes speed differently, each is refracted differently. White light entering the prism contains all colors.

The prism refracts the light and its changes speed as it enters the prism. Red light deviates the leastand travels the fastest. The violet light deviates the most and travels the slowest.

XI. WAVEGUIDE DISPERSION

Waveguide dispersion, most significant in a single- mode fiber, occurs because optical energy travels in both the core and cladding, which have slightly different refractive indices. The energy travels at slightly different velocities in the core and cladding because of the slightly different refractive indices of the materials. Altering the internal structures of the fiber, allows waveguide dispersion to be substantially changed, thus changing the specified overall dispersion of the fiber.

Non Linear Characteristics
Polarization mode dispersion:

Polarization mode dispersion (PMD) is related to the differential group delay (DGD), the time difference in the group delays between two orthogonal polarized modes, which causes pulse spreading in digital systems and distortions in analogue systems.

In ideal circular symmetric fibers, the two polarization modes propagate with the same velocity. However, real fibers cannot be perfectly circular and can undergo local stresses consequently; the propagating light is split into two polarization modes.
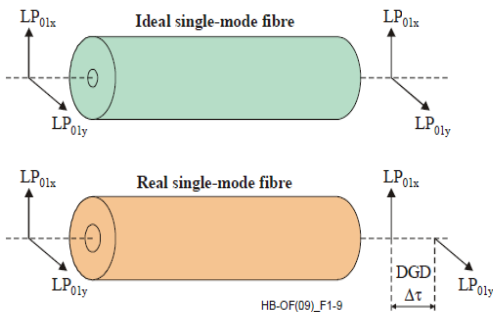
These two local polarization modes travel at different velocities causing a pulse spreading in digital systems. The so induced DGDs vary randomly along the fiber and in time, leading to a statistical behavior of PMD, both in time and wavelength. At a given time, the DGD values vary randomly with wavelength. The PMD value is the average of the DGD values. While the individual values can shift from one time to another the overall distribution, hence the average is assumed to be fixed.

Chromatic dispersion

Chromatic dispersion is caused by delay differences among the group velocities of the different wavelengths composing the source spectrum. The consequence of the chromatic dispersion is a broadening of the transmitted impulses.

Pulse stream without chromatic dispersion   HB-OF(09)_F1-5   Pulse stream with chromatic dispersion
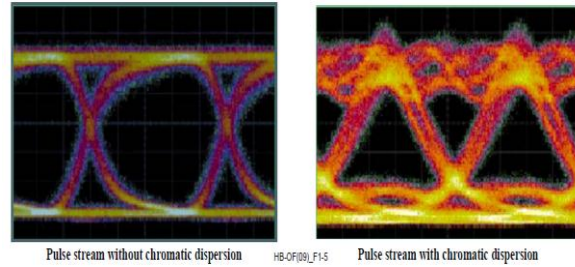
The chromatic dispersion is essentially due to two contributions: material dispersion and waveguide dispersion. The material dispersionoccurs because the refractive index changes with the optical frequency. It is generally the dominant contribution, except in the wavelength region in which it vanishes (for silica based material this happens around 1 300 nm). The waveguide dispersion depends on the dispersive properties of the waveguide itself. From a practical point of view, a significant property is that the waveguide dispersion has opposite signs with respect to the material dispersion in the wavelength range above 1300 nm.

XII. CONCLUSION

Fiber optic technology is the new trend in communications industry and is steadily and effectively replacing the copper wire system for transmission of signals. Dispersion can be avoided by using smaller core diameters which allows fewer modes. And also usage of single mode fiber permits no modal dispersion. By using a graded index fiber so that light rays that allow longer paths to travel at a faster velocity and there by arrive at the other end of the fiber nearly at the same time.

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