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Comparative Study of Step Index and Graded Index Fiber

Sarita Rani[1], Smridhi Malhotra[2], Vinesh Sangwan[3]
Department of ECE, Dronacharya College of engineering,
Khentawas, Farrukhnagar, Gurgaon-123506, India

Abstract: Optical fibers are widely used in optical fiber communications. Optical fibers permit transmission over longer distances and at higher bandwidth (data rates) than the wire cables. Fibers are used instead of metal wires for communications because signals travel along them with less loss and also they are immune to electromagnetic interference. These fibers are also used for illumination, and are wrapped in bundles so that they can be used to carry images, allowing viewing in confined spaces. Various specially designed fibers are there, used for a variety of other applications, including fiber lasers and sensors. Optical fibers consist of a transparent core surrounded by a transparent cladding material with a lower refractive index. The process of total internal reflection is used to keep the light in the core and this causes the fiber to act like a waveguide. Fibers supporting more than one propagation paths or transverse mode are called multimode fiber (MMF), while those supporting a single mode are called single mode fiber (SMF).

Keywords: SMF, MMF, Nondestructive Measurement, Refractive Index Profile Measurement

I. INTRODUCTION

Optical fibers are used as a medium for telecommunication and computer networking because it is flexible and can be bundled like cables. It is very advantageous especially for long-distance communications, as light propagates through the fiber with little attenuation as compared to electrical cables. This allows long distances to be covered with few repeaters. The per-channel light signals propagating in the fiber have been modulated at rates as high as 111 gigabits per second (Gbit/s) by NTT, although 10 or 40 Gbit/s is typical in deployed systems. Researchers demonstrated transmission of 400 Gbit/s over a single channel using 4-mode orbital angular momentum multiplexing in June 2013. Each fiber can carry many independent channels, each of them using a different wavelength of light by Wavelength Division Multiplexing (WDM)). The net data rate (data rate without overhead bytes) per fiber is the per-channel data rate reduced by the FEC overhead, multiplied by the number of channels (usually up to eighty in commercial dense WDM systems as in 2008). As in 2011 the record for bandwidth on a single core was 101 Tbit/s (370 channels at 273 Gbit/s each). The record for a multi-core fiber as of January 2013 was 1.05 petabits per second. In 2009, Bell Labs broke the 100 (petabit per second)×kilometer barrier (15.5 Tbit/s over a single 7000 km fiber). For short distance application, if we consider a network in an office building, fiber-optic cabling save space in cable ducts. This is because a single fiber can carry much more data than electrical cables such as standard category 5 Ethernet cabling, which typically runs at 100 Mbit/s or 1 Gbit/s.

II. MEASUREMENT OF REFRACTIVE INDEX

An experimental system for nondestructive measurement of the refractive-index profile of an optical fiber pre form is reported. The result shows that the profile does not change significantly from the pre form stage to fiber stage. Total internal reflection is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. If the refractive index on the other side of the boundary is lower and the incident angle is greater than the critical angle, the wave cannot pass through it and is entirely reflected by the surface. The critical angle is the angle of incidence above which the total internal reflection occurs. This is particularly common in an optical phenomenon where light waves are involved but it occurs with many types of waves such as electromagnetic waves in general or sound waves. When a wave crosses a boundary between different materials with different kinds of refractive indices, the wave gets partially refracted at the boundary surface, and partially reflected. Consider a light ray passing from glass into air. The light that emanate from the interface is bent towards the glass. When the incident angle is sufficiently increased, the transmitted angle (in air) reaches 90 degrees and it is the point when no light is transmitted into air. The critical angle θ_c is given by Snell's law,

$$n_1 \sin\theta_i = n_2 \sin\theta_t.$$

Rearranging Snell's Law, we get incidence

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$$\sin\theta_i = \frac{n_2}{n_1}\sin\theta_t .$$

To find the critical angle, we find the value for θ_i when $\theta_t =$90° and thus $\sin\theta_t = 1$. The resulting value of θ_i is equal to the critical angle θ_c.

Now, we can solve for θ_i, and we get the equation for the critical angle:

$$\theta_c = \theta_i = \arcsin\left(\frac{n_2}{n_1}\right),$$

If the incident ray is precisely at the critical angle, refracted ray is the tangent to the boundary at the point of incidence. For example, if visible light were traveling through acrylic glass (with an index of refraction of approx. 1.50) into air (with an index of refraction of 1.00), this calculation would give the critical angle for light from acrylic glass into air, which is given by

$$\theta_c = \arcsin\left(\frac{1.00}{1.50}\right) = 41.8^\circ .$$

Light incident on the border with an angle less than 41.8° would be partially transmitted, while incident on the border at larger angles with respect to normal would be totally internally reflected.

III. TYPES OF OPTICAL FIBRE

A. GRADED INDEX FIBER: In fiber optics, a graded-index fiber is an optical fiber whose core has a refractive index that decreases with increasing radial distance from the optical axis of the fiber.Because parts of the core closer to the fiber axis have a higher refractive index than the parts near the cladding, a sinusoidal path is followed by the light rays down the fiber. The commonly existing refractive index profile for a graded-index fiber is very nearly parabolic. The parabolic refractive index profile results in continual refocusing of the rays in the core, and so it minimizes the modal dispersion. Multimode fiber can be built either with graded index or step index. The advantage of the graded index as compared with step index is the considerable decrease in modal dispersion.This type of fiber is normalized by the International Telecommunications Union ITU-T at recommendation G.651.1.

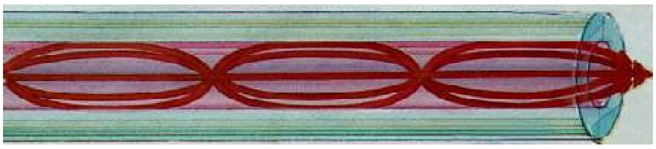

Figure 1: Graded Index Multimode Fiber

1. Attenuation: Attenuation is a general term that refers to any reduction in the strength of a signal to be transmitted. Attenuation can occur in any digital or analog signal. Attenuation also sometimes known as is a natural consequence of signal transmission over long distances. Attenuation is mainly due to absorption & dispersion. Extent of attenuation is usually expressed in units called decibels (dBs). If P_s is the signal power at the transmitting end (source) of a communications circuit and $P_d$is the signal power at the receiving end (destination), then $P_s > P_d$. The power attenuation (A_p) in decibels is given by the formula: $A_p = 10 \log_{10}(P_s/P_d)$. Attenuation can be also expressed in terms of voltage. If A_v is the voltage attenuation in decibels, V_s is the source signal voltage, and V_d is the destination signal voltage, then: $A_v = 20 \log_{10} (V_s/V_d)$. Attenuation of light rays is less in graded index fiber so there is less reduction in the strength of a signal to be transmitted.

B. STEP-INDEX FIBER: Step-index profile is a refractive index profile which is characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface so that the cladding is of a lower refractive index. The step-index profile corresponds to a power-low index profile with the profile parameter approaching to infinity. The step-index profile is used in most single mode fibers and some multimode fibers.

A step-index fiber is characterized by the core and cladding refractive indices n_1 and n_2 and the core and cladding radii a & b. Some examples of standard core and cladding diameters 2a/2b are 8/125, 50/125, 62.5/125, 85/125, or 100/140 (of µm). The fractional refractive-index

$$\triangle = \frac{n_1 - n_2}{n_1} \ll 1$$

The value of n_1 lies between 1.44 and 1.46, and of $\triangle$ lies between 0.001 and 0.02. Step-index optical fiber is generally made by doping high-purity fused silica glass (SiO_2) with different concentrations of materials like titanium, boron or germanium. Step Index Fiber are of two types:- Single Mode & Multimode fibers.

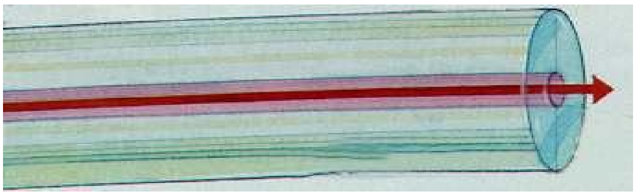

Figure: 2 Step Index Single Mode Fiber

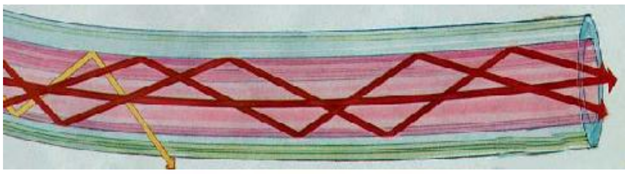

Figure: 3 Step Index Multimode Fiber

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C. DIFFERENCE BETWEEN STEP INDEX & GRADED INDEX FIBER

Step indexfiber	**Graded index fiber**
Step index fiber is of two types: single mode fiber and multimode fiber.	Graded index fiber is of one type i.e. multimode.
The refractive index of the core of step index fiber is constant throughout.	The refractive index of the graded index fiber is maximum at the center of the core and then it decreases towards core-clad interface.
The light rayspropagate in the zig-zag manner in the core. The rays then travel in the fiber as the meridional rays.	The light rays propagate in the form of skew rays or helical rays.
Signal distortion is more in multimode step index fiber whereas there is no distortion in single mode step index fiber.	Signal distortion is very low in case of graded index fiber.
NA of multimode step index fiber is more as compared to single mode step index fiber.	NA of graded index fiber is less.

IV. CONCLUSION

In the end we conclude that the optical fiber cables are suitable for long distance communication as there is less distortion of the signal. Though there are some negatives of optical fiber communication system in terms of fragility, splicing, coupling, set up expense etc. but it is also an un avoidable fact that optical fiber has revolutionized the field of communication. Single Mode fiber optic cable has a small diameter core that allows propagation of only one mode of light. Because of this, the number of light reflections created as the light passes through the core decreases, lowering the attenuation and further creating the ability for the signal to travel faster. In multimode we have various modes. In particular few-mode fibers (FMFs) are demonstrated as a good compromise since they are sufficiently resistant to mode coupling compared to standard multimode fibers but they still can have large core diameters compared to the single-mode fibers. As a result, these fibers can have significantly less nonlinearity and at the same time they can have the same performance as single-mode fibers in terms of dispersion and loss. It is possible to use these fibers in the single-mode operation in the absence of mode coupling where all the data is carried in only one of the spatial modes throughout the fiber. As soon as computers will be capable of processing optical signals, the total arena of communication will be opticalized immediately producing a totally different scenario.

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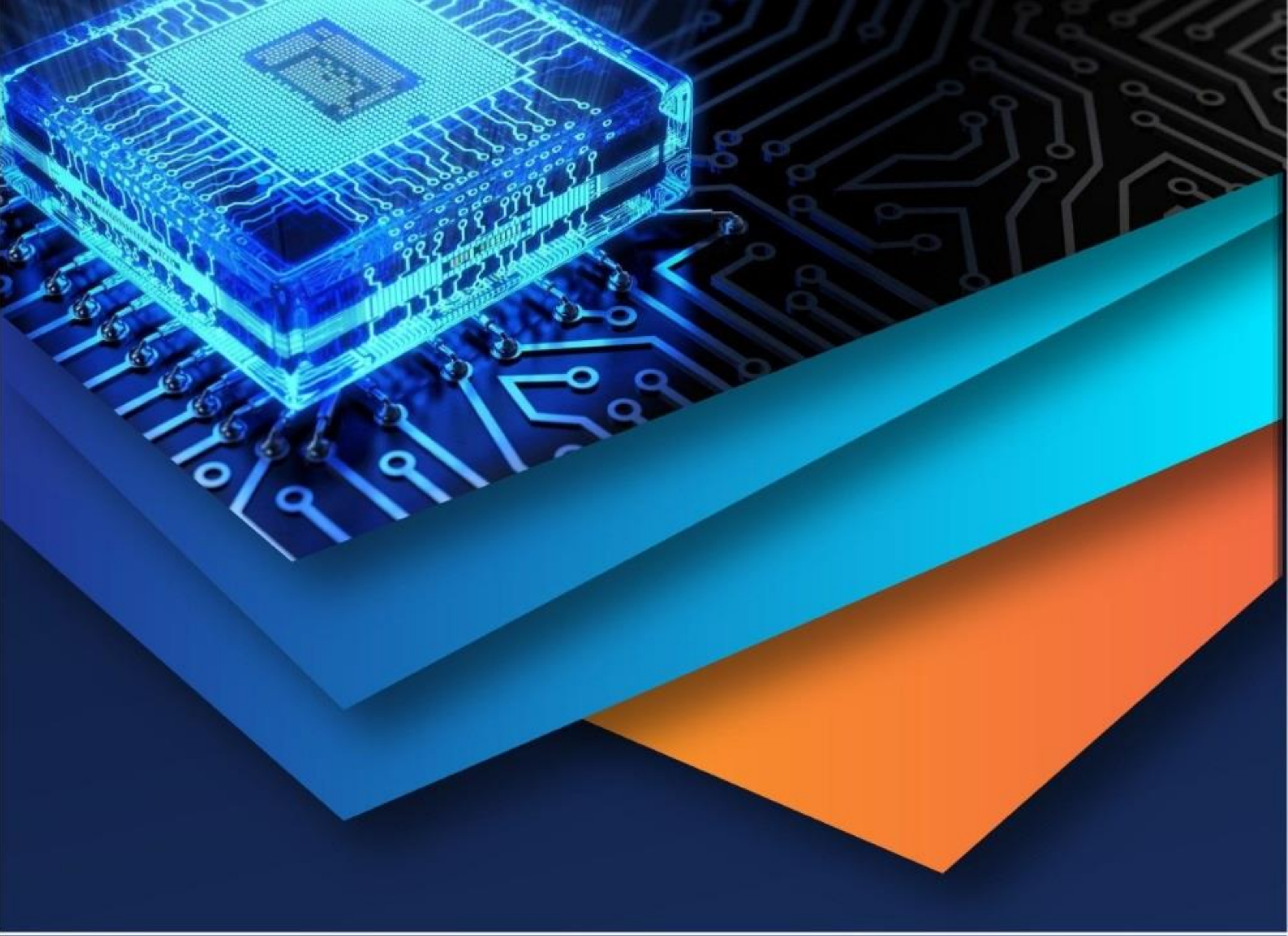

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