

A

Seminar report

On

Optical Fiber Communication

Submitted in partial fulfillment of the requirement for the award of degree
Of Mechanical

SUBMITTED TO:

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Preface

I have made this report file on the topic **Optical Fiber Communication**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude towho assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

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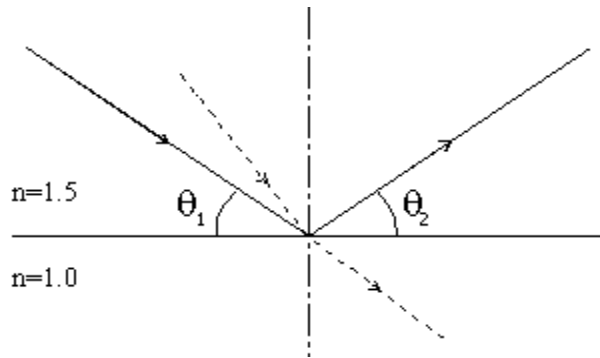
Introduction

Optical fibers are arguably one of the world's most influential scientific developments from the latter half of the 20th century. Why has the development of fibers been given so much attention by the scientific community when we have alternatives? The main reason is bandwidth – fibers can carry an extremely large amount of information. More indirectly, many of the systems that we either rely on or enjoy in everyday life such as banks, television and newspapers as (to name only a very limited selection) are themselves dependent on communication systems that are dependent on optical fibers.

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Fundamentals of Fibers

The fundamental principle that makes optical fibers possible is *total internal reflection*. This is described using the ray model of light as shown in following figure.



Total Internal Reflection

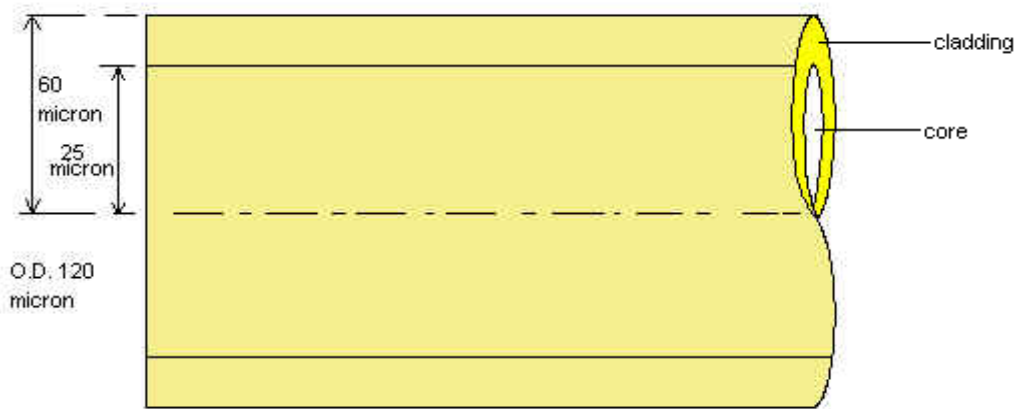
From Snell's Law we find that refraction (as shown by the dashed line) can only occur when the angle θ_1 is large enough. This implies that as the angle is reduced, there must be a point when the light ray is reflected, where $\theta_1 = \theta_2$.

The angle where this happens is known as the critical angle and is:

$$\theta_c = (90^\circ - \theta_1)$$

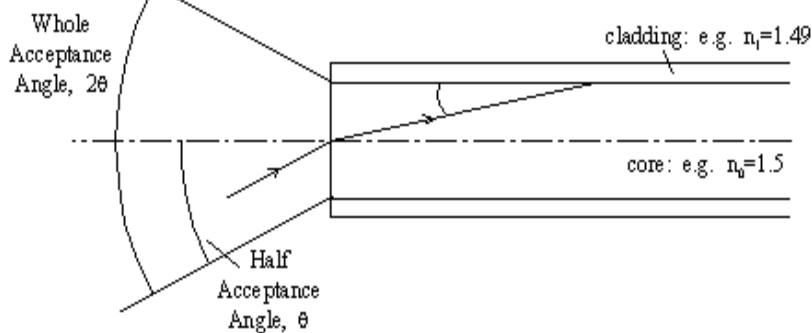
CONSTRUCTION OF FIBERS

In fibers, there are two significant sections – the core and the cladding. The core is part where the light rays travel and the cladding is a similar material of slightly lower refractive index to cause total internal reflection. Usually both sections are fabricated from silica (glass). The light within the fiber is then continuously totally internally reflected along the waveguide.



Structure of Fiber

When light enters the fiber we must also consider refraction at the interface of the air and the fiber core. The difference in refractive index causes refraction of the ray as it enters the fiber, allowing rays to enter the fiber at an angle greater than the angle allowed within the fiber as shown in the figure 3.



Acceptance Angle

This acceptance angle, θ , is a crucial parameter for fiber and system designers. More widely recognized is the parameter NA (*Numerical Aperture*) that is given by the following equation:

$$NA = \sin \theta = n_0 \sin \theta_c = \sqrt{n_0^2 - n_1^2}$$

CLASSIFICATION OF OPTICAL FIBERS

Optical fibers are classified into three types based on the material used, number of modes and refractive index.

1. Based on the materials used:-

a. Glass fibers:

They have a glass core and glass cladding. The glass used in the fiber is ultra pure, ultra transparent silicon dioxide (SiO₂) or fused quartz. Impurities are purposely added to pure glass to achieve the desired refractive index.

b. Plastic clad silica:

This fiber has a glass core and plastic cladding. This performance though not as good as all glass fibers, is quite respectable.

c. Plastic fibers:

They have a plastic core and plastic cladding. These fibers are attractive in applications where high bandwidth and low loss are not a concern.

2. Based on the number of modes:-

a. Single Mode fiber:

When a fiber wave-guide can support only the HE₁₁ mode, it is referred to as a single mode wave-guide. In a step index structure this occurs when the wave-guide is operating at $v < 2.4$ where v is dimensionless number which relates the propagating in the cladding. These single mode fibers have small size and low dopant level (typically 0.3% to 0.4% index elevation over the cladding index.)

In high silica fibers the wave-guide and the material dispersion are often of opposite signs. This fact can be used conveniently to achieve a single mode fiber of extremely large bandwidth.

Reduced dopant level results in lower attenuation than in multimode fibres. A single mode wave guide with its large and fully definable bandwidth characteristics is an obvious candidate for long distance, high capacity transmission applications.

b. Multimode fiber:

It is a fiber in which more than one mode is propagating at the system operating wavelength.

Multimode fiber system does not have the information carrying capacity of single mode fibers.

However they offer several advantages for specific systems. The larger core diameters result in easier splicing of fibers. Given the larger cores, higher numerical apertures, and typically shorter link distances, multimode systems can use less expensive light sources such as LEDs.

Multimode fibers have numerical apertures that typically range from 0.2 to 0.29 and have core size that range from 35 to 100 micro-meters.

3. Based on refractive index:-

a. Step index fiber:

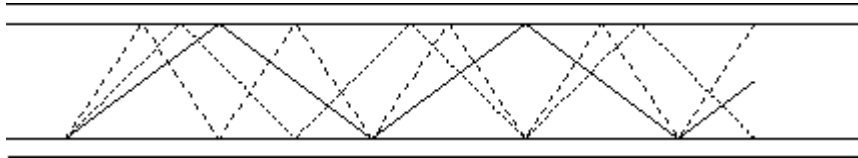
The step index (SI) fiber consists of a central core whose refractive index is n_1 , surrounded by a cladding whose refractive index is n_2 , lower than that of core. Because of an abrupt index change at the core-cladding interface such fibers are called step index fibers.

b. Graded index fibers:

The refractive index of the core in graded index fiber is not constant, but decreases gradually from its maximum value n_1 to its minimum value n_2 at the core-cladding interface. The ray velocity changes along the path because of variations in the refractive index. The ray propagating along the fiber axis takes the shortest path but travels most slowly, as the index is largest along this path in medium of lower refractive index where they travel faster. It is therefore possible for all rays to arrive together at the fiber output by a suitable choice of refractive index profile.

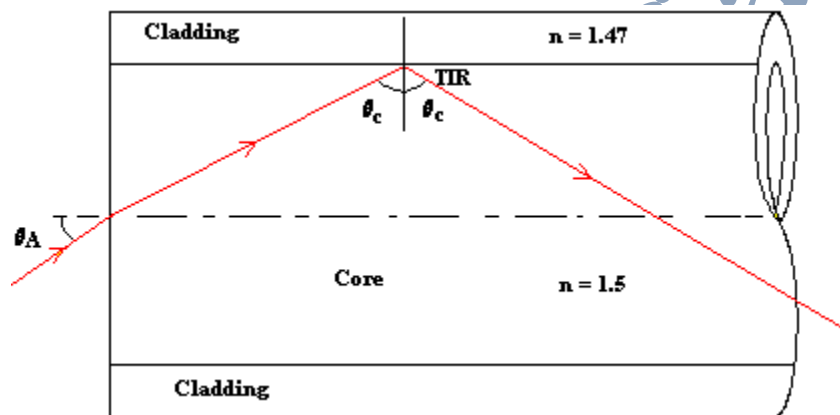
MODES AND PROPAGATION OF LIGHT IN FIBERS

Also crucial to understanding fibers is the principle of modes. A more in-depth analysis of the propagation of light along an optical fiber requires the light to be treated as an electromagnetic wave (rather than as a ray).



Modes

The solid line is the lowest order mode shown on figure 4. It is clear that according to the ray model the lowest order mode will travel down a given length of fiber quicker than the others. The electromagnetic field model predicts the opposite – that the highest order mode will travel quicker. However, the overall effect is still the same – if a signal is sent down the fiber as several modes then as it travels along the fibre the pulse will spread out, this can lead to the pulses merging and becoming indistinguishable.



Propagation of light in fibers

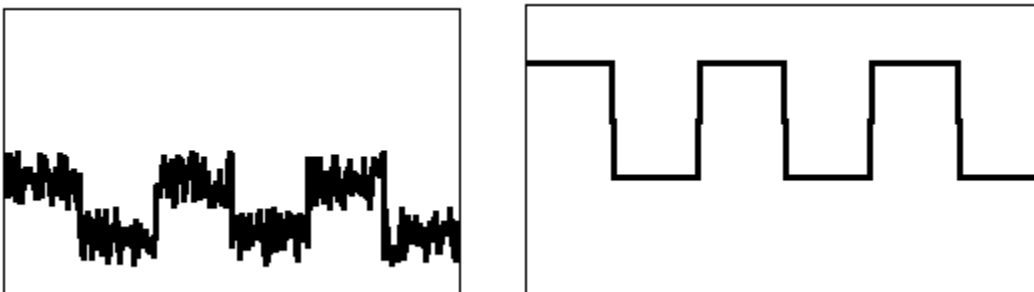
The propagation of light is as shown in figure 5. When light ray enters the core with an angle θ_A strikes the surface of cladding whose refractive index is less than that of core. As the incidence angle on surface of the cladding is greater than or equal to critical angle θ_c total internal reflection takes place. Hence the ray is reflected back into the core in the forward direction. This process continues until it reaches other end of the cable.

The method of signal transmission has benefits in terms of security – for the signal to be ‘tapped’ the fiber must be broken (since effectively no energy escapes from the fiber) and this can easily be detected (when no signal reaches the other end of the fiber!). This is one of the many

advantages of the medium. But mainly two factors, attenuation and dispersion of light, have to be considered while transmitting the light over large distances. We use repeaters and regenerators to reduce the attenuation and dispersion.

REPEATERS AND REGENERATORS:-

Optical repeaters are purely optical devices that are used simply to combat attenuation in the fiber; typically spans of 80km upwards are now possible. The recent introduction of soliton transmission methods has increased the allowed distance between repeaters and systems spanning 130km without a repeater are now possible. Regenerators are devices consisting of both electronic and optical components to provide '3R' regeneration – Retiming, Reshaping, Regeneration. Retiming and reshaping detect the digital signal that will be distorted and noisy (partly due to the optical repeaters), and recreate it as a clean signal as shown in figure 6 This clean signal is then regenerated (optically amplified) to be sent on. It should be noted that repeaters are purely optical devices whereas regenerators require optical-to-electrical (O/E) conversion and electrical-to-optical (E/O) conversion. The ultimate aim of many fiber system researchers is to create a purely optical network without electronics, which would maximize efficiency and performance. Many aspects of such a system are in place, but some still require the O/E and E/O conversion.



A digital signal before (noisy and attenuated) and after regeneration

The most common optical amplifier currently in use is the EDFA (Erbium Doped Fiber Amplifier). These consist of a coil of fiber doped with the rare earth metal erbium. A laser diode pumps the erbium atoms to a high-energy state; when the signal reaches the doped fiber the energy of the erbium atoms is transferred to the signal, thus amplifying it.

Light Sources

Two types of light source are used with fibers, LEDs and Laser Diodes. LEDs can operate in the near infrared (the main wavelengths used in fibers are 1300nm and 1550nm, along with 850nm for some applications); they can emit light at 850nm and 1300nm. They also have the advantages of long lifetimes and being cheap. Unfortunately they are large compared to the cross-section of a fiber and so a large amount of light is lost in the coupling of an LED with a fiber. This also reduces the amount of modal control designers have over incident light. Laser diodes can be made to emit light at either 1300nm or 1550 nm, and also over a small spectral width (unlike LEDs), which reduces chromatic dispersion. Their emitting areas are extremely small and so the angle of incidence of light on a fiber can be accurately controlled such that <5% of the possible modes within a multimode fiber will be initially used. They are more efficient than LEDs in terms of coupling of light into the fiber, although they have shorter lifetimes than and are more expensive than LEDs. One crucial advantage of lasers over LEDs in today's world of digital communications is their high switching speed and small rise times, leading to increased bandwidth.

Detecting the Signal

The most efficient detectors are reverse-bias photo detectors. They essentially cause a current to flow when light is incident on them. The choice of semiconductor that is used to fabricate the detector is dependent on the wavelength sensitivity and the responsivity that are required. Bandwidth considerations are also important (determined by the rise time and fall time of a detector); in detectors the fall time is often appreciably greater than the rise time and so this must be used to calculate the bandwidth of a detector. There are many further complications in detectors, including noise equivalent power that indicates how 'clean' a signal from a detector is.

ADVANTAGES OVER CONVENTIONAL CABLES

Wide Bandwidth: Optical fibers offer greater bandwidth due to the use of light as carrier. The frequency range used for glass fiber communication extends from 2×10^{14} Hz to 4×10^{14} Hz. Hence optical fibers are suitable for high speed, large capacity telecommunication lines.

Low Loss: In a coaxial cable attenuation increases with frequency. The higher the frequency of information signals the greater the loss, whereas in an optical fiber the attenuation is independent of frequency. They offer a loss of 0.2 dB/km, allowing repeater separation up to 50 km or more.

Freedom from electromagnetic interference: Optical fibers are not affected by interference originating from power cables, railways and radio waves. They do not limit unwanted radiation and no cross talk between fibers exists. These fibers make an ideal transmission medium when EMI (Electro Magnetic Immunity) is increased.

Non conductivity: Optical fibers are non-conductive and are not affected by strong electromagnetic interference such as lightning. These are usable in explosive environment.

Small diameters and less weight: Even multi fiber optical cables have a small diameter and are light weight, and flexible optical fiber cables permit effective utilization of space and can also be applicable to long distance use are easier to handle and install than conventional cables.

Security: Fiber optic is a highly secure transmission medium. It does not radiate energy that can be received by a nearby antenna, and it is extremely difficult to tap a fiber and virtually impossible to make the tap undetected.

Safety: Fibre is a dielectric and does not carry electricity. It presents no sparks or fire hazards. It does not cause explosions, which occur due to faulty copper cable.

Areas of Application

Telecommunications: Optical fibers are now the standard point to point cable link between telephone substations.

Local Area Networks (LAN's): Multimode fiber is commonly used as the "backbone" to carry signals between the hubs of LAN's from where copper coaxial cable takes the data to the desktop. Fiber links to the desktop, however, are also common.

Cable TV: As mentioned before domestic cable TV networks use optical fiber because of its very low power consumption.

CCTV: Closed circuit television security systems use optical fiber because of its inherent security, as well as the other advantages mentioned above

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Conclusions

We are currently in the middle of a rapid increase in the demand for data bandwidth across the Earth. For most applications optical fibers are the primary solution to this problem. They have potentially a very high bandwidth, with many of the bandwidth limitations now being at the transceivers rather than being an intrinsic property of the fiber allowing easy upgrading of systems without relaying cable.

This is creating a surge in the deployment of fiber both in backbones of networks and in topologically horizontal cabling, which in turn is supporting and propelling the industry into further research. With the adoption of new techniques such as DWDM, soliton transmission, and ultimately the purely optical network, we have a medium that will satisfy our communication needs for the foreseeable future.

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