Fiber Optics Research Paper

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Introduction

To start this paper, first we should know what fiber optics are. Verizon states that fiber optics are “the technology used to transmit information as pulses of light through strands of fiber made of glass or plastic over long distances” (Verizon, 2021). I chose to write a paper about fiber optics because I am a huge data nerd and I want to learn how data is transmitted; this topic is a great learning opportunity for me. This paper will explain what fiber optics are, their history, describe physics concepts and attenuation in fiber optics, their modern applications, and why they play a key role in future infrastructure.

The History of Fiber Optics

In 1966, while working at the Standard Telecommunication Laboratories (STL) in Harlow, UK, Charles K. Kao published his groundbreaking paper that discovered fiber optics.. Kao had spent the first 14 years of his life living in Shanghai before his family migrated to Hong Kong where he lived for 5 years. At age 19, he enrolled at Woolwich Polytechnic. Kao spent the first few years of his career working on microwaves, which when he was working at STL, combined with the invention of the laser, gave him the idea of fiber optics. Kao won a Nobel Prize in Physics in 2009 (Kao, 2009).

In 1970, after Kao’s discovery, scientists at Corning Glass Works managed to make glass with an attenuation of under 20dB/km. Then, in 1975, Bell Laboratories manufactured a low loss optical fiber. In 1975, the Dorset Police laid the first consumer fiber optic cable. In 1996, the first cable that was made entirely of fiber optics was laid on the Pacific Ocean (Timbercon, 2018).

What are Fiber Optics?

Fiber optic cables are thin, clear cables made of glass or plastic used to transmit information in the form of light across long distances (Freudenrich, 2006). Fiber optic cables have 3 main components to them; the core, the cladding, and the buffer (protective) coating.

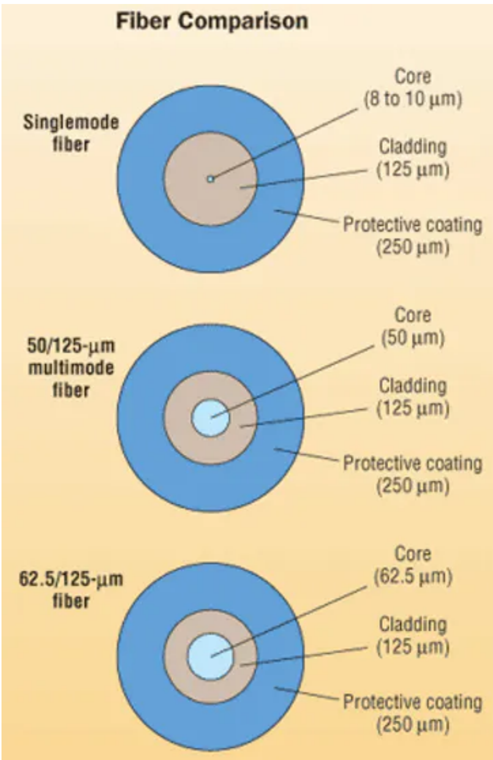

Figure 1: The Diameters of Fiber Optic Cables (Cliche, 2002).

Figure 1 shows the different types of fiber optic cables and the diameters of their respective cores, claddings, and protective coatings.

The core of a fiber optics cable is where light is transmitted. It is typically made of pure silica glass or clear plastic. Single mode fibers are fiber optic cores that can only carry 1 mode of light, and have a diameter so small that light only has 1 trajectory. That diameter is approximately 9 micrometers, which is approximately 11 times smaller than the size of a human hair (Cleerline, 2019).

In comparison, multimode fibers are fiber optic cores that can carry multiple modes of light. Multimode cores are considerably slower than single mode cores, due to effects that will be discussed later on in this paper. Multimode cores have diameters of approximately 50 micrometers (Cleerline, 2019).

There are 2 different types of multimode cores: step index cores and graded index cores. Step index cores are fiber optic cores that are made out of the same material throughout, which means that they also have the same refractive index throughout (The Fiber Optic Association, 1999). In comparison, graded index cables have materials with a higher refractive index in the middle of the core, and materials with lower refractive indexes towards the edge. This creates flatter angles for light as it approaches the edge of the core (The Fiber Optic Association, 1999). The advantages and disadvantages of each type of core will be explored later on in this paper.

The cladding of a fiber optic cable is a layer of glass that allows light to refract back into the core. To do this, it must have a lower refractive index than that of the core (Liu, 2018). They bring the diameter of the cable to 125 micrometers (Figure 1) (Cliche, 2002).

The buffer (protective) coating is a layer of hard plastic that protects the cables from physical damage (Liu, 2018). It makes the cable's diameter a total of 250 micrometers (Figure 1) (Cliche, 2002).

Physics Concepts in Fiber Optics

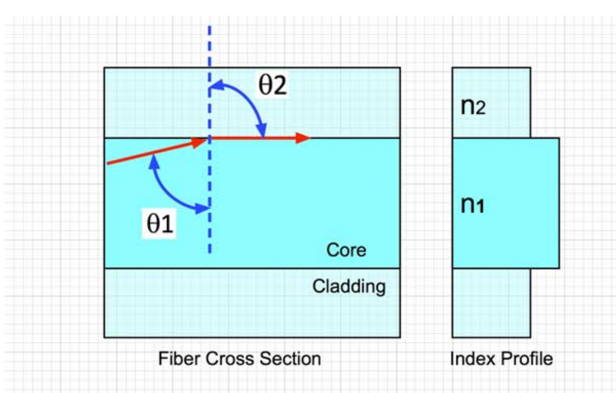

Figure 2: The Relationship Between the Index of Refraction and the Angle Of Incidence between the Core and Cladding (The Fiber Optic Association, 1999).

One of the main concepts that fiber optics deals with is total internal reflection. Total internal reflection is the property of light where, at a certain angle, all light is totally reflected inside the object (Gregersen, 2021). The relationship that creates the total internal reflection can be defined as Snell's law, $n = c/v$ where n equals the refractive index of the glass, c is the speed of light in a vacuum, and v is the light's speed in the material. This equation can be manipulated to $n_1 sin_1 = n_2 sin_2$, which can be visualized in figure 2.

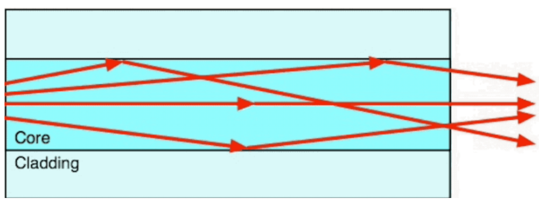

Figure 3: Modal Dispersion In Step Index Cores
(The Fiber Optic Association, 1999).

Figure 3 shows that in Step Index Cores, light has many different paths and different angles of incidence.

Another physics concept that is found in multimode fiber optic cores is modal dispersion. Modal dispersion is the light that is lost from light taking different trajectories (The Computer Language Company, 1981). Modal dispersion affects step index cores more than graded index cores, because step index cores have an infinite number of angles of incidence trajectories; this results in an infinite number of trajectories, making it easier for light to disperse (Figure 3) (The Fiber Optic Association, 1999).

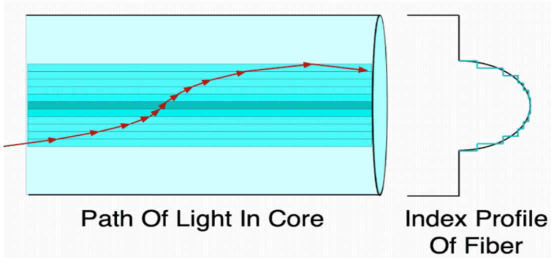

Figure 4: The Path of Light in a Graded Index Core (The Fiber Optic Association, 1999).

On the other hand, graded index fiber optic cores don't tend to lose as much light from modal dispersion due to their refractive index profile, which can be seen in Figure 4. Having the refractive index of the materials as they approach the edge of the core allows the trajectory of light to be more parabolic. Using Snell's law, we know that $n = c/v$, $v = c/n$ and that $n_1 sin_1 = n_2 sin_2$. Using those manipulations of Snell's law, we can see that as the index of refraction of the material decreases, so does the angle of incidence, and the velocity of light in the core. These manipulations of the refractive index allow light to be more controlled, thus losing less of it from modal dispersion (The Fiber Optic Association, 1999).

Attenuation in Fiber Optics

Attenuation is the loss of optical power. It is primarily caused by absorption of the light, which heats the glass, and the scattering of light due to collisions with other atoms. In order to calculate the attenuation, you divide the loss of the fiber by the wavelength. This curve can be seen below in Figure 5, which shows that as wavelength increases, scattering decreases in normal fibers (The Fiber Optic Association, 1999).

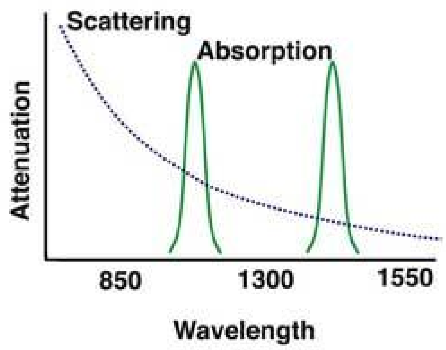

Figure 5: Graph that shows the relationship between attenuation from scattering and absorption in relation to the wavelength (The Fiber Optic Association, 1999).

Modern Uses for Fiber Optics And Their Significance in the 21st Century

Being in the 21st century, in the digital era, fiber optics have useful applications in many different fields. One of the most widely known uses of fiber optics is the internet because of its ability to provide extremely high speeds and long range data transmission with single mode cores. They are also preferred over copper wires due to their data capacity (Nexus-net, 2017). Nowadays, most internet service providers offer fiber optics, and the areas that fiber optics are offered has drastically increased in the past few years.

Other applications include cable TVs and automotive safety due to their speed of transmission. With TVs, like the internet, fiber optics help transmit the images faster. With automotive safety, the speed at which data is transmitted can help out with safety devices, such as Antilock-Brake Systems (ABS), airbags, lane keep assist, automatic braking, and many other safety devices, ultimately helping save lives (Nexus-net, 2017).

Conclusion

Since their discovery by Charles K. Kao in 1966, fiber optics have become a key part of modern infrastructure. Fiber optics work by shooting pulses of light down clear glass fibers. Light bounces off the cladding using the concept of total internal reflection. Fiber optic cables can have different types of cores: single mode cores, which only carry one mode of light pulses and multimode cores, which can carry multiple modes of light pulses. Most multimode cores use graded index cores instead of step index cores due to the lack of modal loss.

In my opinion, fiber optics will continue to remain one of most important physics innovations in modern times for the average person due to how widespread they have become and how many safety devices that people use.

References

The FOA Reference to Fiiber Optics. (1999). Retrieved from https://www.thefoa.org/tech/ref/basic/fiber.html

Total Internal Reflection - The Basic Principal of Optical Fiber - And Fiber Numerical Aperture. (1999). Retrieved from https://www.thefoa.org/tech/ref/basic/total_internal_reflection.html

Admin, C. (2021, September 07). Single Mode vs. Multimode Fiber Optic Cables. Retrieved from https://cleerlinefiber.com/2019/03/19/singlemode-vs-multimode-fiber-optic-cables/

Liu, Amelia (2018, October 18). The Core And Cladding Of Fiber Optic Cable. Retrieved from https://www.cables-solutions.com/the-core-and-cladding-of-fiber-optic-cable.html

Bass, Michael & Van Stryland, Eric. (2002). Fiber Optics Handbook. Retrieved from http://debracollege.dspaces.org/bitstream/123456789/566/1/Fiber%20optics%20handbook%20fiber%2C%20devices%2C%20and%20systems%20for%20optical%20communications%20by%20Michael%20Bass%2C%20Eric%20W.%20Van%20Stryland%2C%20Optical%20Society%20of%20America%20.pdf.

Craig Freudenrich, P. (2001, March 06). How Fiber Optics Work. Retrieved from https://computer.howstuffworks.com/fiber-optic1.htm

Definition: Dispersion. (n.d.). Retrieved from https://www.computerlanguage.com/results.php?definition=modal+dispersion

History of Fiber Optics. (n.d.). Retrieved from https://www.timbercon.com/resources/blog/history-of-fiber-optics/

Kao, Charles K & Hockham, George A (1966) Dielectric-Fibre Surface Waveguides For Optical Frequencies

The Most Popular Uses of Fiber Optic Cables. (2017, March 16). Retrieved from https://nexus-net.info/the-most-popular-uses-of-fiber-optic-cables/

The Nobel Prize in Physics 2009. (n.d.). Retrieved from https://www.nobelprize.org/prizes/physics/2009/kao/biographical/

Optical Fibers. (n.d.). Retrieved from https://pslc.ws/macrog/fiberopt/of.htm

Singlemode Will Go the Distance. Retrieved from https://www.cablinginstall.com/cable/fiber/article/16465017/singlemode-will-go-the-distance

Single Mode vs. Multi-Mode Fiber Optic Cable. (n.d.). Retrieved from https://www.multicominc.com/training/technical-resources/single-mode-vs-multi-mode-fiber-optic-cable/

What is Fiber Optics - Definition, Meaning & Explanation. (n.d.). Retrieved from https://www.verizon.com/info/definitions/fiber-optics/

Total internal reflection. (n.d.). Retrieved from https://www.britannica.com/science/total-internal-reflection.