Brief History and Overview of Optical Fiber Technology in Telecommunications

Author: **Omar X. Avelar**

Abstract

This document will guide you through the historical development of fiber optics and the advances in recent years, from events in usage of optical technology to physical phenomena that permitted light to be used as an excellent communication service.

Focusing on telecommunications and networking, we will be talking about different types of connectors used in modern equipment and their characteristics and recent costs in the technology.

Table of Contents

1. History

Data suggests that light has been used in telecommunications since early ages, like candles between ships or huge torch towers to represent various meanings. But it was not until the late XVIII century that French inventor **Claude Chappe** demonstrated a practical and more complex light-based system which he called the semaphore system (Figure 1) which spanned across France.

The concept of this semaphore system was to have special towers built with pivots on their top that were used to encode messages according to the mechanical position of the pivot and the lights that were emitted.

The system was far more efficient than postal riders, the mainstream usage failed against the electrical telegraph as privacy and costs were a main disadvantage.

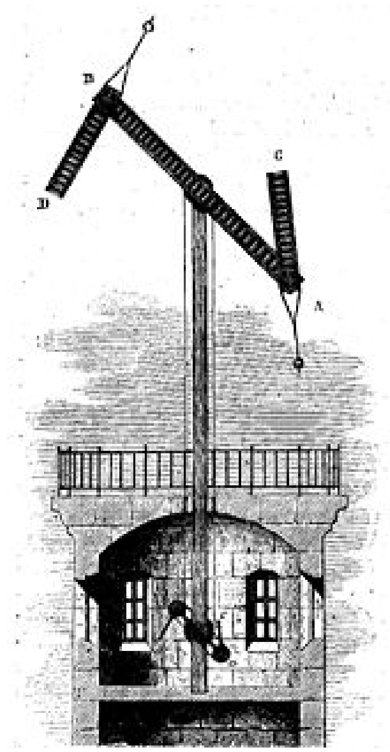

Figure 1: Semaphore System.

By the year of 1880, **Alexander Graham Bell** had patented an optical telephone device which he called the photo-phone, but his earlier invention, the electrical telephone was also cheaper and easier to implement. Bell believed the photo-phone to be his greatest invention, it allowed sound signals to be encoded and transmitted into a beam of light which varied intensity to represent different tones and finally the message was decoded back again as sound.

Since this optical devices required a visible line of sight between the emitter and receiver it failed miserably between their electrical counterparts. During the following years research on light subjects such as reflection and refraction phenomena, specifically the total internal reflection solved this problem.

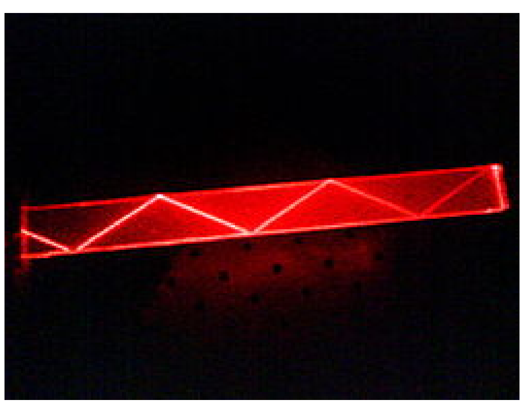

Figure 2: Total internal reflection in a block of Plexiglas surrounded by air using a laser as a source.

Total internal reflection allows to bounce-in and confine light in a material surrounded with lower refractive index (Figure 2). By the beginning of the XX century, inventors realized that bent quartz rods could carry light and were used for microscope illumination. During the first half of the XX century different kind of people were trying to exploit the use of the total internal reflection phenomenon. Some examples of this are:

1920: **John Logie Baird** in England and **Clarenee W. Hansell** in U.S.A patented the idea of using arrays of hollow pipes or transparent rods to transmit images for television or facsimile systems.

1930: **Heinrich Lamm**, a Jew medical student in Munich, reported transmitting the image of a light bulb filament through a short bundle. He is the first person known to have demonstrated image transmission through a bundle of optic fibers.

1931: **Owens-Illinois** devises method to mass-produce glass fibers for Fiberglas.

1939: **Curvlite** Sales offers illuminated tongue depressor and dental illuminators made of Lucite, a transparent plastic invented by DuPont.

1949: **Holger Moller Hansen** in Denmark and **Abraham C. S. Van Heel** at the Technical University of Delft begin investigating image transmission through bundles of parallel glass fibers.

After the first half of the XX century, in 1954 **- Neither van Heel nor Hopkins** and **Kapany** made fiber bundles that could carry light further. The innovation consisted on including a cladding layer (Figure 3) surrounding the material with lower than air refractive index which protected the light-beam from noise and reduced crosstalk between fibers.

By 1960, glass-clad fibers had a typical attenuation of about 1dB/m, fine for medical imaging, but much too high for long distance communications.

Another breakthrough in optical communications came as the laser was invented in 1960 which permitted to emit light in a narrow wavelength spectrum and thus allowing to work at different frequencies by utilizing the wave properties of light.

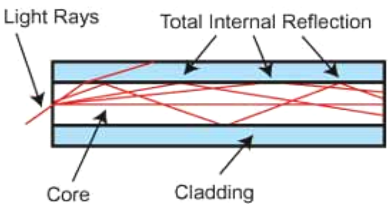

Figure 3: Basic fiber diagram.

During 1964, a Shanghai engineer named **Charles K. Kao** had done research on different materials and was convinced by his research that the attenuation was caused by impurities and that it should be theoretically possible to reduce the attenuation to at least 20dB/km, Kao and other members of his group presented a paper at a London meeting of the IEEE in 1966 and the same year the British post office funded a research to study fiber loss and attenuation.

With Kao's papers promoting the principle and the huge companies inverting on studies it took four years to reach the goal of 20dB/km. In September 1970 laboratories announced single-mode fibers with attenuation at the 633 nm (Helium-Neon [HeNe] laser) below 20dB/km, in the same year Bell labs and a team at the Ioffe Physical institute built the first semiconductor laser diodes (Figure 4) which allowed continuous-wave beams to be emitted at room temperature allowing lasers to be used as light sources more easily.

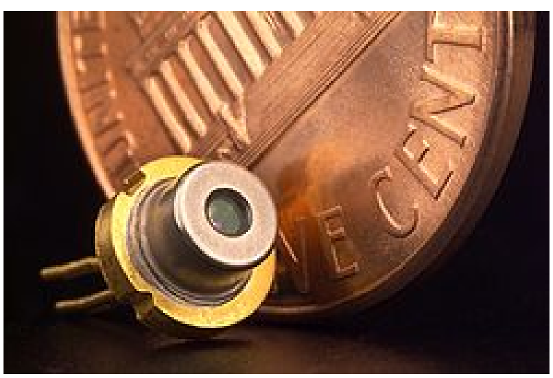

Figure 4: A modern laser diode.

Those first generation systems could transmit light for several kilometers, but it was inevitable for the technology to continue improving looking for higher bandwidth and even less attenuation.

It is important to mention that optical fiber technology can be used at various wavelengths and some factors affecting the performance of fiber include material composition, geometry, light-source technology and physical environment.

2. Types

There are different types of fibers used in telecommunications depending on the use and application, mainly single-mode and multi-mode (Figure 5).

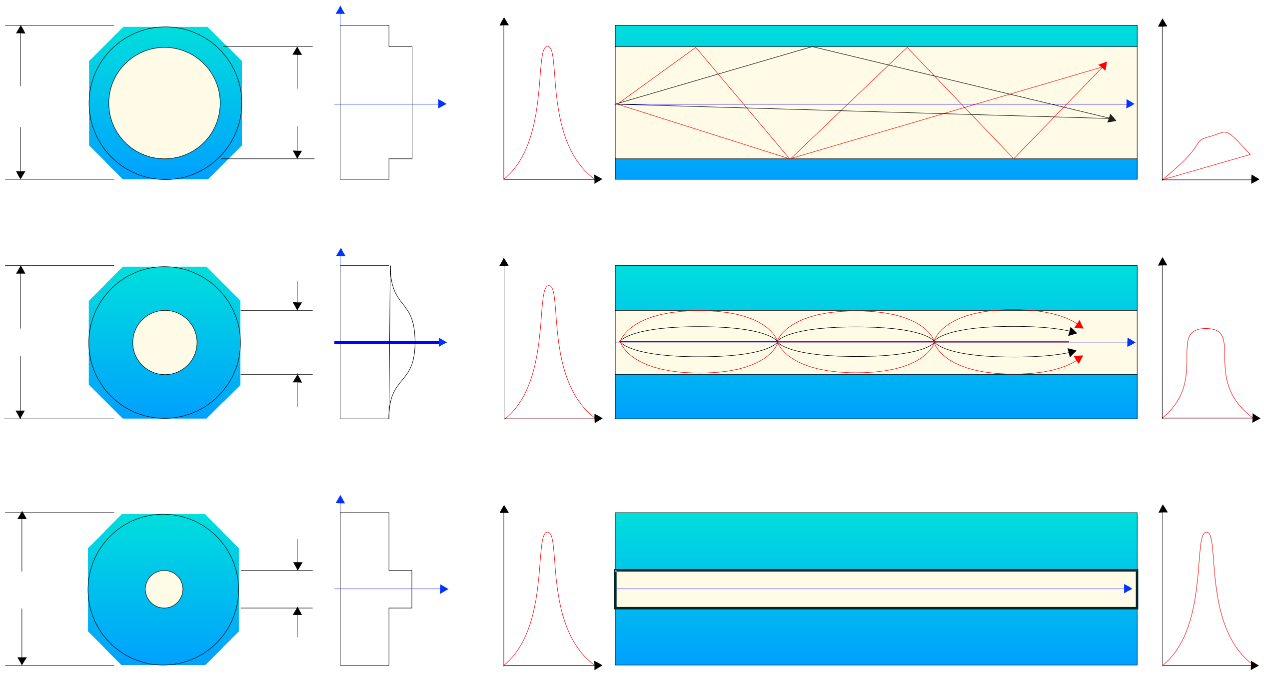

Figure 5:
Top: Step-index multi-mode fiber (2).
Middle: Graded-index multi-mode fiber (2).
Bottom: Single-mode fiber (1).

(1) **Single-mode** also known as mono-mode fiber. is in theory a single strand with a diameter of 8 to 10 µm and has one mode of transmission.

This fiber has a relatively narrow diameter, through which only one mode (or signal) will propagate, it possesses higher bandwidth than multi-mode fiber, but requires a light source with a narrow spectral width. Single-Mode fiber is used mainly in applications where data is sent at multi-frequency (WDM Wave-Division-Multiplexing) so only one cable is needed. This type of fiber gives you a high transmission rate and up to 50 times more distance than multi-mode, but it also costs more. Single-mode fiber has a much smaller core than multi-mode. The small core and single light-wave virtually eliminate any distortion that could result from interfering light pulses, providing the least signal attenuation and the highest transmission speeds of any fiber cable type.

(2) **Multi-mode** cabling has a typical diameters in the 50-100 µm range. WDM is not normally used on multi-mode fiber.

Multi-mode fiber gives you high bandwidth at high speeds. Light waves are dispersed into numerous paths, or mode. With long cable runs, multiple paths of light can cause signal distortion at the receiving end resulting in retransmission which yields typical usage on shorter runs.

Since multi-mode fiber uses a larger core than single-mode, it allows the use of lower cost electronics and light sources such as LEDs (light-emitting diode) or VCSELs (vertical cavity surface emitting lasers) operating near the 850 nm wavelength, where as single-mode utilizes sources in the range of 1310-1550 nm.

Below, a table summarizing the main differences in telecommunications between single-mode and multi-mode.

	Single-mode	Multi-mode
Typical Wavelength	1310-1550 nm	850 nm
Cheaper Electronics		•
Theoretical Bandwidth (Typical)	~200 MHz•km	»100 GHz•km
Longer Runs	•	
Fiber costs	Low	High
Cost of Connectors	High	Low
Cost of installation and equipment	High	Low

3. Connectors

Termination is the process in which the cable (in this case fiber) is coupled with the electronic devices or network gear. Terminations must be of the right style, installed in a manner that makes them have little light loss , less back reflection and protect the fiber against dirt or damage. Multiple styles of connectors have been developed to improve this properties.

ST (AT&T): This type of connector is used in multi-mode and it has a bayonet to hold in position and a ceramic, metal or plastic sleeve (Figure 6).

Figure 6: ST connector.

FC/PC: Used for single-mode fiber, it utilizes a screw mechanism to hold firmly (Figure 7).

Figure 7: FC/PC connector.

SC: Is a snap-in style connector mainly used with single-mode fiber, it also comes in full-duplex configurations (Figure 8).

Figure 8: SC connectors.

LC: This connector is categorized as small-form, highly used for single-mode and uses a standard ceramic sleeve (Figure 9).

Figure 9: LC connector.

MT-RJ: Is a strictly duplex connector with both fibers in a single package. Used only for multi-mode (Figure 10).

Figure 10: MT-RJ with a polymer sleeve.

Opti-Jack (Panduit): Another small form factor connector the size of a RJ-45, it is rugged and full-duplex (Figure 11).

Figure 11: Small sized Opti-Jack.

Volition (3M): An inexpensive duplex connector that accommodates the fiber in a V shape (Figure 12).

Figure 12: Volition connector.

E2000/LX-5: Very similar to the LC connector but with a shutter or slider to protect from dust over the end of the fiber (Figure 13).

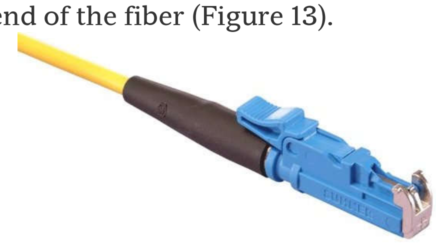

Figure 13: E2000 or LX-5 connector and coupler.

MU: Similar to the SC but in a smaller form, this connector is very popular in japan (Fig 14), arrays of this type of cables can be seen for easier organization.

Figure 14: MU connector.

4. Costs

As technology advances, and the manufacturing processes to produce the required equipment become more advanced and efficient the prices of what once was laboratory-only equipment becomes accessible to the mainstream consumer.

4.A. Couplers

LC Duplex Coupler	8.80 USD
SC Simplex Coupler	1.80 USD
SC Duplex Coupler	3.60 USD
SC Quad Coupler	16.20 USD
MT-RJ Coupler	1.50 USD
ST Simplex Coupler	1.80 USD
FC Simplex Coupler	3.00 USD
SC-ST Simplex Coupler	2.10 USD
SC-ST Duplex Coupler	3.60 USD

4.B. Connectors

ST Single-mode	2.04 USD
LC Single-mode	3.98 USD
MT-RJ Multi-mode	5.10 USD
SC Multi-mode	1.41 USD

4.C. Cables

Simplex multi-mode	62.5 μm	0.45 USD*
Simplex multi-mode	50 μm	0.45 USD*
Simplex single-mode	9 μm	0.45 USD*

* On orders of 25 meters and more.

Bibliography

[1] Lyne D. Green, Fiber Optic Communications, CRC Press, Boca Raton, 1992.

[2] Andreas Othonos & Kyriacos Kalli, Fiber Bragg Gratings, Artech House, Norwood, MA, 1999.

[3] Jim Hayes, Fiber Optics Technician's Handbook, Delmar Publishers, Albany, New York, 1996.

[4] Hecht, Jeff. 2002. Understanding Fiber Optics. 4th ed. Upper Saddle River, NJ: Prentice-Hall.