# OPTICAL FIBER COMMUNICATIONS

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## KEYWORDS

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## ABSTRACT

*Optical fiber communication systems have moved rapidly from research laboratories into commercial applications. It represents a new era of communications which, in many ways, is a radical departure from the electronic communications we have been used to. Now instead of electrons moving back and forth over metallic wires to carry our signals lightwaves are being guided by tiny fibers of glass or plastic to accomplish the same purpose.*

*With a bandwidth or information capacity thousands of times greater than that of copper circuits, fiber optics will provide us with all the communication paths we could ever want, at a price we can afford.*

*This paper presents an overview of fiber optic development starting with historical perspective and proceeds to fiber construction and theory of operation. Various system components and applications will be discussed and at the end of the paper future directions in this field are presented.*

## Introduction

Fiber optics has evolved from a simple system to guide light into inaccessible places to a system of significant importance that will affect our lives as much as computers and electronics have done. The advantages of optical fibers are enormous such as low loss and small size but most important of all is the very high bandwidth offered which is in the multigigabits per second. All over the world optical glass fibers are superseding wires in a wide variety of applications including metropolitan telephone exchanges, long haul commercial trunking systems and under sea transmission links.

The evolution of fiber optics technology has advanced at a very rapid pace over the past decades.

Based on these developments we can distinguish few generations of fiber optics systems. The first generation was designed for bit rates from 2-140 Mb/s that used GaAs light sources and silicon photodetectors operating in the 810 to 900 nm wavelength range. In the second generation, development in light sources and photodetectors allowed the operation to shift to the 1300 nm wavelength region, where the losses of optical fibers is around 1 dB/km.

The use of single mode fibers in the third generation eliminated the dispersion effect in multimode fibers and provided higher bandwidth. The use of single mode fiber links operating at 1300 nm with attenuation of less than 1 dB/km permitted repeater spacings of 40 km for BER of $10^{9}$.

In the fourth generation systems the operation is shifted to the 1.55 $\mu m$ region where the attenuation is lower than at 1300 nm. Components developments such as sources and detectors have led to build systems that operate at a transmission rate of 10 Gb/s. Significant improvements in the receiver sensitively is achieved by heterodyne detection of signal, rather than direct detection, which offers efficient means for channel selection in a densely packed wavelength-multiplexed system. Development of erbium-doped glass fibers has been a major impetus in the fiber optic technology in the 1.55 $\mu m$ wavelength region. High gain erbium doped fiber amplifiers (EDFA's) have been developed and are finding their way in practical system. These doped fibers are also finding their ways in lasers, switches and variety of nonlinear devices.

Erbium doped fiber amplifiers have paved the way for new field of high speed communications to emerge that is called soliton communications which use optical solitons that can propagate over long distances without distortion.

These fast developments have led to deployment of fiber optics in all areas of communications from long haul to fiber in the loop to meet the various applications such as TV transmission, video conferencing and data communications.

## I. Historical Perspective

The use of light for communication has been common since the dawn of history. Simple systems such as signal fires, reflecting mirrors and signalling lamps have been used for a limited amount of data transfer. The first light signalling system was built in France in 1790 by Claude Chappe. He used a group of towers with moving light arms. It was used to transmit data over a distance of 200 km and it took 15 minutes to transmit one piece of information. In 1854 John Tyndall an English physicist performed a simple experiment in which he proved that light can be bent and guided if a proper medium is used. In 1880 Alexander Graham Bell reported the transmission of speech using light beam. Many trials were done during this century to use optical communications but were not quite successful due to lack of suitable light sources, restriction of atmospheric transmission to line of sight and due to atmospheric disturbances such as rain, snow, dust, fog and atmospheric turbulence.

The invention of the laser in 1960 renewed interests in optical communications but it was not until 1966 when Charles Kao and George Hockham proposed the use of optical fibers fabricated from glass. In 1970 the first low loss optical fiber was fabricated, the losses came down from 1000 dB/km to 20 dB/km and within a span of ten years fiber losses were reduced to 0.2 dB/km.

## II. Optical Fibers

Fig.1 shows a typical fiber optic system which consists of the following:

i. A transmitter that accepts an electrical signal and converts it to current to drive the light source.
ii. The light source launches the optical signal into the fiber.
iii. The optical fiber provides a path for the optical signal.
iv. A light detector that detects and converts the optical signal to electrical signal.
v. A receiver produces low noise and large voltage gain from the power detector signal.
vi. Various connectors and splices interface the system.

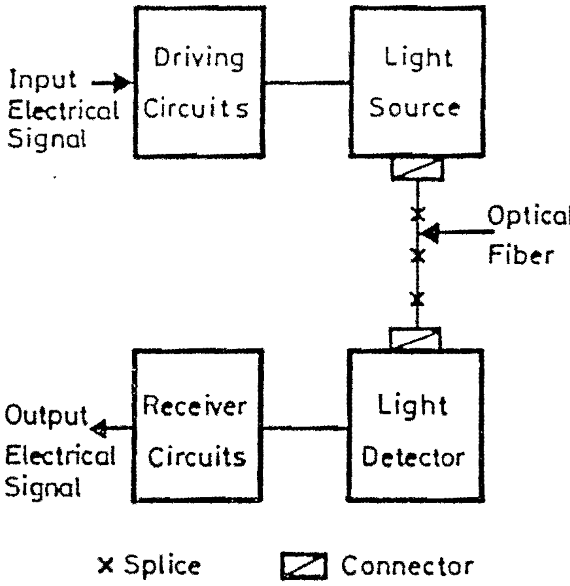


Fig.1 Block diagram of a fiber optic system.

### II.1 Fiber construction and theory of operation

Optical fibers are dielectric cylinders surrounded by a second transparent dielectric cylinder. The fibers are light waveguides used to transmit energy at optical wavelengths. The light is transported by a series of reflection from wall to wall at the interface between the inner cylinder called the core and the outer cylinder called the cladding. The reflections are obtained by making the index of refraction of the core to be higher than the index of refraction of the cladding. Fig.2 shows across sectional view of the optical fiber where light propagates through a series of reflections from one boundary to the other. This is explained by using ray theory and Snell's law. When light passes from a medium of higher refractive index into a medium of lower refractive index, the refracted ray is bent away from the normal.

At a certain angle of incidence, called the critical angle $\theta_c$, the refracted ray emerges at an angle of 90° with respect to the normal or parallel to the boundary between the core and cladding. When the angle of incidence exceeds $\theta_c$, the ray will be reflected inside the core and this is called total internal reflection.

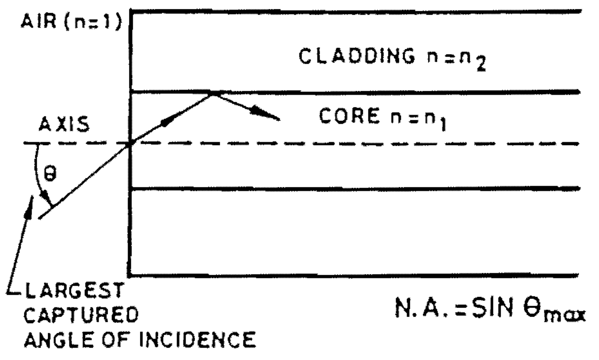


Fig.2 Basic optical fiber.

II.2 Advantages of fibers

There are several advantages that make fibers attractive for use in many communication systems over other alternatives. The advantages are as follows:

i. Vary high bandwidth.
ii. Smaller diameter and light weight.
iii. Lack of cross talk between parallel fibers.
iv. Immunity to electromagnetic or inductive interference.
v. Low installation and operating costs.
vi. Greater Safety and security.
vii. Longer life span.
viii. Environmental stability.
ix. Greater reliability and ease of maintenance.

II.3 Types of fibers

There are three types of optical fibers which are classified according to their modal and physical properties:

i. Single mode fibers
The index of refraction of single mode fibers is a step index. The core diameter is within 3-10 $\mu$m. They are made of pure silica and are used for higher data rate transmission and long haul communications.

ii. Multimode step index fibers
Step index fiber is characterized by an abrupt change in refractive index between core and cladding. These are made of pure silica or plastic. They are large in size compared to single mode fibers and more economical than graded index. They are used for moderate transmission rates and distance with distance-bandwidth product of 10-100 MHz-km. Their core diameter ranges from 80 $\mu$m-400 $\mu$m.

iii. Multimode graded index
The index of refraction of these fibers is graded, with its highest value at the center of the core and decreases gradually torward the cladding. They are more expensive than step index fibers but they offer higher data rates over longer distances. Typical core diameters ranges from 30 $\mu$m to 60 $\mu$m. Their bandwidth-distance product is between 150 MHz-km and 2 GHz-km.

II.4 Fiber properties

i. Numerical Aperture
Numerical Aperture (NA) which is defined as the sine of the incidence angle $\theta$ and also written as NA $= \sqrt{n_1^2 - n_2^2} = \sin\theta$, where $n_1$ is the index of refraction of the core and $n_2$ is the index of refraction of the cladding. NA determines how much power is coupled to the fiber.

ii. Attenuation
Attenuation is the loss or reduction of the amplitude of transmitted energy. There are two types of losses, intrinsic which is due to absorption of the fiber material and scattering which is mostly due to the molecular structure of the fiber material. Other less important intrinsic losses are due to imperfections or bubbles in the fiber material. The other types of losses are extrinsic which is due to microbending, or macrobending, or scratches on the fiber surface.

iii. Dispersion
Dispersion in the spreading or widening of transmitted signals. In fiber optic systems, dispersion is either intermodal or intramodal. The intermodal or multimode is the propagation of rays of the same wavelength along different paths through a fiber. Thus transmitted waves arrive at different times which causes pulse spreading or broadening and happens in multimode fibers. The other kind of dispersion in the intramodal which has two types material dispersion that is due to variation in velocities of different waves due to the difference in their wavelengths. Waveguide dispersion is due to the structure of the waveguide.

# III System components

In designing a fiber optic link there are three factors that should be considered (1) Attenuation (2) Dispersion (3) Numerical aperture. Considering the type of application, we have to strike a balance among the various components of the fiber optic system, careful insulation methods and proper components must be used. If we start from the transmitting end, the light source shall emit at the appropriate wavelength with the minimum spectral width and has enough optical power, light emitting diodes (LED's) and laser diodes are used in fiber optic systems. Coupling the optical power to the optical fiber requires good matching between the source and the fiber, couplers used to couple light from the source to the fiber should have the minimum possible loss. Connecting fiber to fiber is done by splicing. Losses at the splices are possible due to (1) Lateral displacement (2) Angular misalignment (3) End separation. At the receiving end light detectors must operate at the proper wavelength and should have the proper responsivity, response time, quantum efficiency and minimum detectable power. Usually PIN and avalanche photodiodes (APD's) are used in fiber optic links.

# IV. Fiber optics applications

The advantages of fiber optics have made it to be attractive and widely used in many fields. The following examines few of the applications.

### IV.1 Telephone systems

The world's first optical link providing regular telephone service to the public was placed in operation on April 22, 1977 by General Telephone Company of California with a data rate of 1.544 M b/s per pair of fibers and carried 24 voice channels. The fiber optic links installed this year operating at 5 G b/s can transmit 320000 voice channels per pair of fibers. Fibers are used in telephone networks, in interoffice trunking, in local distribution sections and down to the home. Fiber is very popular for long-distance trunking because of its high capacity, high performance and low cost compared to other mediums. They are installed in land and under the sea.

### IV.2 Video

Applications for video transmission on fiber include:

i. High-quality video trunked from studio to transmitter
ii. Broadcast CATV video
iii. Baseband video for closed circuit, security etc.
iv. High definition television transmission.

### IV.3 Power lines

Since fiber is a dielectric it is not sensitive to interference. They are used by power utilities to provide telephone calls and data transmissions between stations.

### IV.4 Computers and data transmission

Wideband fiber technology is having a major impact on the way data are transmitted and although transmission is slowed by conventional standards which were based on the low bandwidth copper wire systems, totally new standards such as Fiber Distributed Data Interface (FDDI), Synchronous Optical Networks (SONET), and Asynchronous Transfer Mode (ATM) are emerging, tailored to the broadband capability of the fiber.

FDDI is a 100 Mb/s local area network that permits up to 1000 connections in a LAN upto 100 km long. SONET is a synchronous time division multiplexing standard that permits many channels of different formats to be multiplexed together at rates of 2.48 Gb/s or more. ATM is a cell relay transmission method that utilizes the high transmission capacity of the fiber for integrated transmission of data, voice and picture, and consequently achieving BISDN (Broadband Integrated Services Digital Networks).

# V. Future Directions

The fast developments in the field of fiber optics have made it. difficult to predict what to expect in the future. Based on the current research and the demand on communication systems, the following areas will see a lot of development:

i. Coherent transmission
ii. Photonic switching
iii. Erbium doped fiber amplifiers (EDFA)
iv. Single wavelength and tunable lasers
v. Photonic integrated circuits
vi. Soliton propagation in fibers
vii. Halide fibers
viii. Optical frequency division multiplexing (OFDM)
ix. Chips with very high component density

# VI. Conclusion

Optical fiber has revolutionized telecommunications in the past few years. Its large scale deployment has been accompanied by proven technical and operational success. The development, during the past few years were not forecasted even by those who are specialists in the area of fiber optics. With the latest developments for example in erbium doped fiber amplifiers, it will be possible to use repeaterless links for thousands of kilometers a thing that was never envisioned; and as a matter of fact there are systems under construction that utilizes such technology. Systems operating at 2.48 Gb/s are in operation in many parts of the world. Other systems operating at 5 Gb/s and 10 Gb/s are under construction and will be commissioned shortly. It is like a dream come true. Fiber optics will be the communication media of the twenty first century.

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