



# Fiber Optics (Volume 1) - Theory

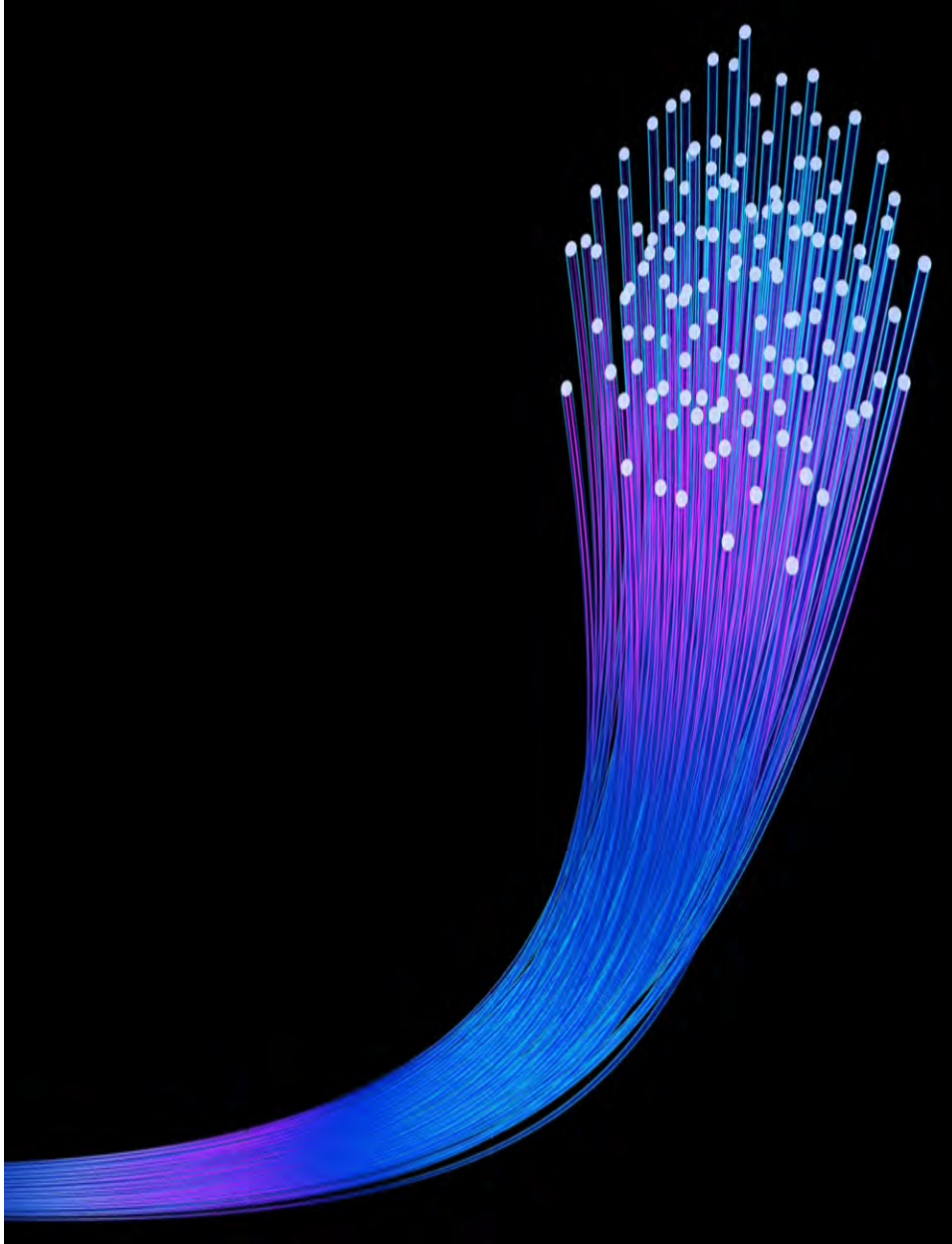
An Online Continuing Education Course for Engineers

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# Fiber Optics (Volume 1) - Theory

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## Preface

This is the first in a series of five courses about fiber optic cable systems. The series covers fiber optics from basic light theory transmission to cables, connectors, testing, and signal transmission.

The complete series includes these five courses:

1. Fiber Optics I – Theory
2. Fiber Optics II – Cable Design
3. Fiber Optics III – Connectors
4. Fiber Optics IV – Testing
5. Fiber Optics V – Equipment

The first course, *Fiber Optics I – Theory*, is an overview of the technology of fiber optic cables including a description of the components, history, and advantages of fiber optic cables. This course also discusses the electromagnetic theory of light and describes the properties of light reflection, refraction, diffusion, and absorption.

The second course, *Fiber Optics II - Cable Design*, explains the basic construction of fiber optic cables including the types of cables, cable properties, and performance characteristics. The course reviews multimode, single mode step-index and graded index fibers, and fabrication procedures.

The third course, *Fiber Optics III - Connectors*, describes fiber optic splices, connectors, couplers and the types of connections they form in systems. It includes a discussion on the types of extrinsic and intrinsic coupling losses, fiber alignment and fiber mismatch problems, and fiber optic mechanical and fusion splices.

The fourth course, *Fiber Optics IV - Testing*, describes the optical fiber and optical connection laboratory measurements used to evaluate fiber optic components and system performance, including the near-field and far-field optical power distribution of an optical fiber. This course also reviews optical time-domain reflectometry (OTDR).

The fifth course, *Fiber Optics V - Equipment*, explains the principal properties of an optical source and fiber optic transmitters, the optical emission properties of semiconductor light-emitting diodes (LEDs) and laser diodes (LDs), and explains the operational differences between surface-emitting LEDs (SLEDs), edge-emitting LEDs (ELEDs), superluminescent diodes (SLDs), and laser diodes.

It is not necessary to take the courses in sequence. However, for best comprehension it is suggested that the courses be taken in the order presented.

## Introduction

Electrical systems include telephone, radio, cable television (CATV), radar, and satellite links. In the past 30 years, researchers have developed a new technology that offers greater data rates over longer distances at costs lower than copper wire systems. This technology is fiber optics.

Fiber optics uses light to send information (data). More formally, *fiber optics* is the branch of optical technology concerned with the transmission of radiant power (light energy) through fibers.

### Overview

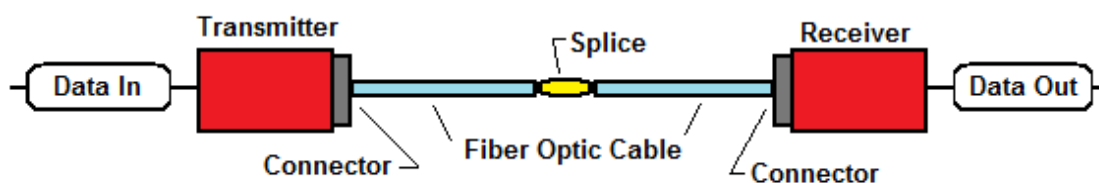
A fiber optic data link sends input data through fiber optic components and provides this data as output information. It has the following three basic functions:

- To convert an electrical input signal to an optical signal
- To send the optical signal over an optical fiber
- To convert the optical signal back to an electrical signal

A fiber optic data link consists of three parts - transmitter, optical fiber, and receiver. Figure 1 is an illustration of a fiber optic data-link connection. The transmitter, optical fiber, and receiver perform the basic functions of the fiber optic data link. Each part of the data link is responsible for the successful transfer of the data signal.

A fiber optic data link needs a transmitter that can effectively convert an electrical input signal to an optical signal and launch the data-containing light down the optical fiber. A fiber optic data link also needs a receiver that can effectively transform this optical signal back into its original form. This means that the electrical signal provided as data output should exactly match the electrical signal provided as data input.

*Figure 1. - Parts of a fiber optic data link.*



The transmitter converts the input signal to an optical signal suitable for transmission. The transmitter consists of two parts, an interface circuit and a source drive circuit. The transmitter's drive circuit converts the electrical signals to an optical signal. It does this by varying the current flow through the light source. The two types of optical sources are light-emitting diodes (LEDs) and laser diodes.

The optical source launches the optical signal into the fiber. The optical signal will become progressively weakened and distorted because of scattering, absorption, and dispersion mechanisms in the fiber waveguides.

The receiver converts the optical signal exiting the fiber back into an electrical signal. The receiver consists of two parts, the optical detector and the signal-conditioning circuits. An optical detector detects the optical signal. The signal-conditioning circuit conditions the detector output so that the receiver output matches the original input to the transmitter. The receiver should amplify and process the optical signal without introducing noise or signal distortion. Noise is any disturbance that obscures or reduces the quality of the signal. Noise effects and limitations of the signal-conditioning circuits cause the distortion of the receiver's electrical output signal.

An optical detector can be either a semiconductor positive-intrinsic-negative (*PIN*) diode or an avalanche photodiode (APD).

A *PIN* diode changes its electrical conductivity according to the intensity and wavelength of light. The *PIN* diode consists of an intrinsic region between p-type and n-type semiconductor material.

A fiber optic data link also includes passive components other than an optical fiber. Figure 1 does not show the optical connections used to complete the construction of the fiber optic data link. Passive components used to make fiber connections affect the performance of the data link. These components can also prevent the link from operating. Fiber optic components used to make the optical connections include optical splices, connectors, and couplers.

Proof of link performance is an integral part of the design, fabrication, and installation of any fiber optic system. Various measurement techniques are used to test individual parts of a data link. Each data link part is tested to be sure the link is operating properly.

## **History**

People have used light to transmit information for hundreds of years. However, it was not until the 1960s, with the invention of the laser that widespread interest in optical (light) systems for data communications began. The invention of the laser prompted researchers to study the potential of fiber optics for data communications, sensing, and other applications. Laser systems

could send a much larger amount of data than telephone, microwave, and other electrical systems. The first experiment with the laser involved letting the laser beam transmit freely through the air. Researchers also conducted experiments letting the laser beam transmit through different types of waveguides. Glass fibers, gas-filled pipes, and tubes with focusing lenses are examples of optical waveguides. Glass fibers soon became the preferred medium for fiber optic research.

Initially, the very large losses in the optical fibers prevented coaxial cables from being replaced. Loss is the decrease in the amount of light reaching the end of the fiber. Early fibers had losses around 1,000 dB/km making them impractical for communications use. In 1969, several scientists concluded that impurities in the fiber material caused the signal loss in optical fibers. The basic fiber material did not prevent the light signal from reaching the end of the fiber. These researchers believed it was possible to reduce the losses in optical fibers by removing the impurities. By removing the impurities, construction of low-loss optical fibers was possible.

There are two basic types of optical fibers, multimode fibers and single mode fibers. The types of fiber designs are covered in Volume II – Cable Design.

In 1970, Corning Glass Works made a multimode fiber with losses under 20 dB/km.

This same company, in 1972, made a high silica-core multimode optical fiber with 4dB/km minimum attenuation (loss). Currently, multimode fibers can have losses as low as 0.5 dB/km at wavelengths around 1300 nm. Single mode fibers are available with losses lower than 0.25 dB/km at wavelengths around 1500 nm.

Developments in semiconductor technology, which provided the necessary light sources and detectors, furthered the development of fiber optics. Conventional light sources, such as lamps or lasers, were not easily used in fiber optic systems. These light sources tended to be too large and required lens systems to launch light into the fiber. In 1971, Bell Laboratories developed a small area light-emitting diode (LED). This light source was suitable for low-loss coupling to optical fibers. Researchers could then perform source-to-fiber jointing easily and repeatedly. Early semiconductor sources had operating lifetimes of only a few hours. However, by 1973, projected lifetimes of lasers advanced from a few hours to greater than 1,000 hours. By 1977, projected lifetimes of lasers advanced to greater than 7,000 hours. By 1979, these devices were available with projected lifetimes of more than 100,000 hours.

In addition, researchers also continued to develop new fiber optic parts. The types of new parts developed included low-loss fibers and fiber cables, splices, and connectors. These parts permitted demonstration and research on complete fiber optic systems.

Advances in fiber optics have permitted the introduction of fiber optics into present applications. These applications are mostly in the telephone long-haul systems, but are growing to include cable television, computer networks, video systems, and data links. Research should increase system performance and provide solutions to existing problems in conventional applications. The impressive results from early research show there are many advantages offered by fiber optic systems.

## **Fiber Optic Applications**

System design has centered on long-haul communications and the subscriber-loop plant. The subscriber-loop plant is the part of a system that connects a subscriber – or customer - to the nearest switching center. Cable television is an example. Limited work has also been done on short-distance applications.

Initially, central office trunking required multimode optical fibers with moderate to good performance. Fiber performance depends on the amount of loss and signal distortion introduced by the fiber when it is operating at a specific wavelength. Long-haul systems require single mode optical fibers with very high performance. Single mode fibers tend to have lower loss and produce less signal distortion.

In contrast, short-distance systems tend to use only multimode technology. Examples of short-distance systems include process control and local area networks (LANs). Short-distance systems have many connections. The larger fiber core and higher fiber numerical aperture (NA) of multimode fibers reduce losses at these connections.

In subscriber-loop applications, system design and parts selection are related. Designers consider trade-offs in the following areas:

- Fiber properties
- Types of connections
- Optical sources
- Detector types

Designers develop systems to meet stringent working requirements, while trying to maintain economic performance. It is quite difficult to identify a standard system design approach.

Future system design improvements depend on continued research. Researchers expect fiber optic product improvements to upgrade performance and lower costs for short-distance applications. Future systems center on broadband services that will allow transmission of voice, video, and data. Services will include television, data retrieval, video word processing, electronic mail, banking, and shopping.