CHAPTER 1

BACKGROUND ON FIBER OPTICS

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions are based on the objectives. By successfully completing the NRTC, you indicate that you have met the objectives and have learned the information. The learning objectives are listed below.

Upon completing this chapter, you should be able to do the following:

1. Describe the term *fiber optics*.
2. List the parts of a fiber optic data link.
3. Understand the function of each fiber optic data link part.
4. Outline the progress made in the history of fiber optic technology.
5. Describe the trade-offs in fiber properties and component selection in the design of fiber optic systems.
6. List the advantages and the disadvantages of fiber optic systems compared to electrical communications systems.

DEFINITION OF FIBER OPTICS

In the other Navy Electricity and Electronics Training Series (*NEETS*) modules, you learn the basic concepts used in electrical systems. 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 new 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.

Q1. Define fiber optics.

FIBER OPTIC DATA LINKS

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 1-1 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.

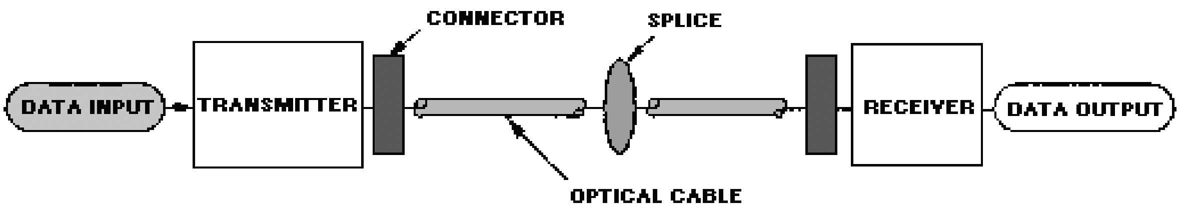

Figure 1-1.—Parts of a fiber optic data link.

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. Chapter 2 discusses the fiber mechanisms of scattering, absorption, and dispersion. Chapter 3 discusses the types of optical fibers and cables.

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. Chapter 6 provides further explanation of optical sources. Chapter 7 provides further explanation of optical detectors.

A fiber optic data link also includes passive components other than an optical fiber. Figure 1-1 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. Chapter 4 outlines the types of optical splices, connectors, and couplers and their connection properties that affect system performance.

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. Chapter 5 discusses the laboratory and field measurements used to measure link performance.

Q2. Describe the basic functions of a fiber optic data link.

Q3. List the three parts of a fiber optic data link.

Q4. What mechanisms in the fiber waveguides weaken and distort the optical signal?

Q5. What effect does noise have on the fiber optic signal?

HISTORY OF FIBER OPTIC TECHNOLOGY

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. Chapter 2 discusses the differences between the fiber types. 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.

Q6. Define loss.

Q7. In 1969, what did several scientists conclude about optical fiber loss?

Q8. How can loss be reduced during construction (or fabrication) of optical fibers?

Q9. What are the two basic types of optical fibers?

FIBER OPTIC SYSTEMS

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 to the nearest switching center. Cable television is an example. Limited work has also been done on short-distance applications and some military systems. 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 and military systems tend to use only multimode technology. Examples of short-distance systems include process control and local area networks (LANs). Short-distance and military systems have many connections. The larger fiber core and higher fiber numerical aperture (NA) of multimode fibers reduce losses at these connections. Chapter 4 explains fiber connection properties in more detail. Chapter 2 provides more detail on multimode and single mode fibers.

In military and 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. This module identifies the types of components chosen by the Navy for shipboard applications.

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.

Q10. Which type of optical fiber (multimode or single mode) tends to have lower loss and produces less signal distortion?

Q11. What optical fiber properties reduce connection loss in short-distance systems?

Q12. In fiber optic systems, designers consider what trade-offs?

ADVANTAGES AND DISADVANTAGES OF FIBER OPTICS

Fiber optic systems have many attractive features that are superior to electrical systems. These include improved system performance, immunity to electrical noise, signal security, and improved safety and electrical isolation. Other advantages include reduced size and weight, environmental protection, and overall system economy. Table 1-1 details the main advantages of fiber optic systems.

Table 1-1.— Advantages of Fiber Optics

System Performance	• Greatly increased bandwidth and capacity • Lower signal attenuation (loss)
Immunity to Electrical Noise	• Immune to noise (electromagnetic interference [EMI] and radio-frequency interference [RFI] • No crosstalk • Lower bit error rates
Signal Security	• Difficult to tap • Nonconductive (does not radiate signals)
Electrical Isolation	• No common ground required • Freedom from short circuit and sparks
Size and Weight	• Reduced size and weight cables
Environmental Protection	• Resistant to radiation and corrosion • Resistant to temperature variations • Improved ruggedness and flexibility • Less restrictive in harsh environments
Overall System Economy	• Low per-channel cost • Lower installation cost • Silica is the principle, abundant, and inexpensive material (source is sand)

Despite the many advantages of fiber optic systems, there are some disadvantages. Because of the relative newness of the technology, fiber optic components are expensive. Fiber optic transmitters and receivers are still relatively expensive compared to electrical interfaces. The lack of standardization in the industry has also limited the acceptance of fiber optics. Many industries are more comfortable with the use of electrical systems and are reluctant to switch to fiber optics. However, industry researchers are eliminating these disadvantages.

Standards committees are addressing fiber optic part and test standardization. The cost to install fiber optic systems is falling because of an increase in the use of fiber optic technology. Published articles, conferences, and lectures on fiber optics have begun to educate managers and technicians. As the technology matures, the use of fiber optics will increase because of its many advantages over electrical systems.

Q13. List seven advantages of fiber optics over electrical systems.

SUMMARY

Now that you have completed this chapter, let's review some of the new terms, concepts, and ideas you have learned. You should have a thorough understanding of these principles before advancing to chapter 2.

FIBER OPTICS is the branch of optical technology concerned with the transmission of radiant power (light energy) through fibers.

A **FIBER OPTIC DATA LINK** has three basic functions: to convert an electrical input signal to an optical signal, to send the optical signal over an optical fiber, and to convert the optical signal back to an electrical signal. It consists of three parts: transmitter, optical fiber, and receiver.

The **TRANSMITTER** consists of two parts, an interface circuit and a source drive circuit. The transmitter converts the electrical input signal to an optical signal by varying the current flow through the light source.

The **RECEIVER** consists of two parts, the optical detector and signal conditioning circuits. The receiver converts the optical signal exiting the fiber back into the original form of the electrical input signal.

SCATTERING, ABSORPTION, and **DISPERSION MECHANISMS** in the fiber waveguides cause the optical signal launched into the fiber to become weakened and distorted.

NOISE is any disturbance that obscures or reduces the quality of the signal.

SIGNAL LOSS is the decrease in the amount of light reaching the end of the fiber. Impurities in the fiber material cause the signal loss in optical fibers. By removing these impurities, construction of low-loss optical fibers was possible.

The **TWO BASIC TYPES OF OPTICAL FIBERS** are multimode fibers and single mode fibers.

A **LOW-LOSS MULTIMODE OPTICAL FIBER** was developed in 1970.

A **SMALL AREA LIGHT-EMITTING DIODE (LED)** was developed in 1971. This light source was suitable for low-loss coupling to optical fibers.

FIBER OPTIC SYSTEM DESIGN has centered on long-haul communications and the subscriber-loop plant. Limited work has also been done on short-distance applications and some military systems.

FIBER PERFORMANCE depends on the amount of loss and signal distortion introduced by the fiber when it is operating at a specific wavelength. Single mode fibers tend to have lower loss and produce less distortion than multimode fibers.

The **LARGER FIBER CORE** and the **HIGHER NUMERICAL APERTURE (NA)** of multimode fibers reduce the amount of loss at fiber connections.

In **MILITARY** and **SUBSCRIBER-LOOP APPLICATIONS**, system designers consider trade-offs in the following areas: fiber properties, types of connections, optical sources, and detector types.

The **ADVANTAGES** of fiber optic systems include improved system performance, immunity to electrical noise, signal security, and electrical isolation. Advantages also include reduced size and weight, environmental protection, and overall system economy.

The **DISADVANTAGES** of fiber optic systems include problems with the relative newness of the technology, the relatively expensive cost, and the lack of component and system standardization. However, these disadvantages are already being eliminated because of increased use and acceptance of fiber optic technology.

ANSWERS TO QUESTIONS Q1. THROUGH Q13.

A1. Fiber optics is the branch of optical technology concerned with the transmission of radiant power (light energy) through fibers.

A2. The basic functions of a fiber optic data link are to convert an electrical input signal to an optical signal, send the optical signal over an optical fiber, and convert the optical signal back to an electrical signal.

A3. Transmitter, optical fiber, and receiver.

A4. Scattering, absorption, and dispersion.

A5. Noise obscures or reduces the quality of the signal.

A6. Loss is the decrease in the amount of light reaching the end of the fiber.

A7. 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.

A8. By removing the impurities from optical fiber.

A9. Multimode and single mode fibers.

A10. Single mode fiber.

A11. Larger fiber core and higher fiber numerical aperture (NA).

A12. Trade-offs in fiber properties, types of connections, optical sources, and detector types in military and subscriber-loop applications.

A13. Advantages of fiber optics are improved system performance, immunity to electrical noise, signal security, electrical isolation, reduced size and weight, environmental protection, and overall system economy.