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A Unit of Instruction in Fiber-Optic Communication

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Abstract

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2. Develop a laboratory exercise to demonstrate fiber-optic communication.

3. Construct equipment to demonstrate the use of fiber optics in communication. This equipment is used in the laboratory exercise.

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A UNIT OF INSTRUCTION IN
FIBER-OPTIC COMMUNICATION

Approved by:

May 5, 1986

Dr. Rex Pershing (Graduate Advisor)
Date

May 5, 1986

Dr. Roger Betts (Faculty Member)
Date

A Unit of Instruction in
Fiber-Optic Communication

A Research Project
Submitted to the
Department of
Industrial Technology
University of Northern Iowa

In Partial Fulfillment
of the Requirements for the
Non-Thesis Master of Arts Degree

By
Ronald Struble
April 1986

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CHAPTER I

INTRODUCTION

Ever since May 24, 1844, when Samuel F. B. Morse sent the historic message "What hath God wrought" from the Supreme Court chambers in Washington, D.C., and had the message echoed back from Baltimore, Maryland, men have sought to make the transfer of information between places faster, cheaper, and more convenient (Kuecken, 1980). Morse had solved the problem of conveying information over great distances in the form of electrical impulses at nearly the speed of light over wire.

Progress in communication technology has increased at a rapid pace in the past decade. One of the components of this new technology is fiber-optics, the use of glass or plastic fiber as a transmission medium instead of the use of radio waves or wire. In order to met the needs of this new industry, as well as utilize its employment opportunities, it is important our curriculum introduces the student to the application of fiber-optics in communication.

PURPOSES OF THE STUDY

The purposes of this research project were to:

1. Review the historical developments, components, and applications of optical fiber in communications.
2. Develop a laboratory exercise to demonstrate fiber-optic communication.
3. Construct equipment to demonstrate the use of fiber optics in communication. This equipment is used in the laboratory exercise.

IMPORTANCE OF THE STUDY

As mentioned in the introduction, fiber-optics has become an important component in communication. The question is not how fiber-optics can fit into the communication industry but the "rate at which this growth will progess" (Kuecken, 1980). Optical fibers can be used any place where metallic wires are used with the added advantages of being immune to static discharges, inductance, and crosstalk, all common problems of wire and radio communications.

LIMITATIONS OF THE STUDY

The study was conducted with the following limitations:

1. Whereas the subject of fiber-optics is quite involved and complex, only the principles of fiber-optic communications were covered.
2. The study is not concerned with the chemical structure or manufacture of optical fiber but rather is concerned with its use.
3. Material for the study was obtained from literature in the UNI library, local school library, manufacturers, and researchers in fiber-optics.

DEFINITIONS OF TERMS

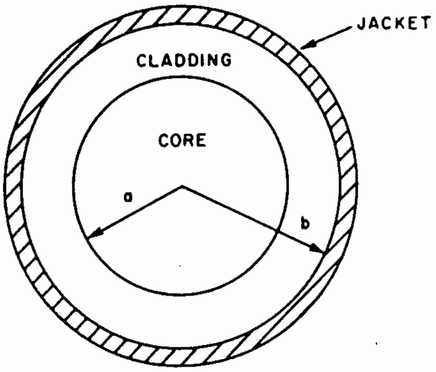
The following terms are defined to clarify their use in the context of this study:

1. Attenuation. Because of impurities in the fiber, dispersion at fiber ends, and other losses, the amount of light energy emerging from a fiber is less than that injected. The loss is normally measured in dB/Km (Elion, 1978).

2. Bandwidth. The upper and lower frequency limits that can be used for transmission of optical signals (Elion, 1978).
3. Cladding. The refractive material around the central core of the optical fiber. In some fiber it is a thin reflective layer while in others it is a thicker layer having a refractive index lower than the core (Elion, 1978).
4. Coherence. Emitted light waves having basically the same wavelength (Kuecken, 1980).
5. Collimate. To render parallel the light waves emitted from a light source (Kuecken, 1980).
6. Core. The central transmission material of an optical fiber having a higher index of refraction than the cladding (Elion, 1978).
7. Db/Km. The abbreviation for decibel(s) per kilometer. Used in fiber-optics to measure the amount of light energy lost in transmission of signals through optical fiber.
8. Laser. An acronym for **L**ight **A**mplification by **S**timulated Emission of **R**adiation. A device that produces coherent, collimated light (Mims, 1975).
9. Optical Fiber. An optical fiber consists of a core, cladding and jacket (see Figure 1). It has the abilities to conduct light waves with the direction of the core (Miller, 1979).
10. Optically resonant cavity. The part of a laser where light is amplified by bouncing between two mirrors (AT&T, 1985).
11. Photon. The fundamental unit of light and other forms of electromagnetic energy. Photons are to optical fibers what

electrons are to copper wires; like electrons, they have a wave motion (AT&T, 1985).

11. Stripe geometry. In the structure of a laser, the stripe is the narrow extension (stripe) of the positive electrode of the laser under which the lasing action occurs (Elion, 1978).
12. Refractive index. The ratio of the speed of light in a vacuum to its speed in a given material such as glass. The larger the ratio the more the light entering the material is bent (Elion, 1978).



Cross section of an Optical Fiber (Miller, 1979).

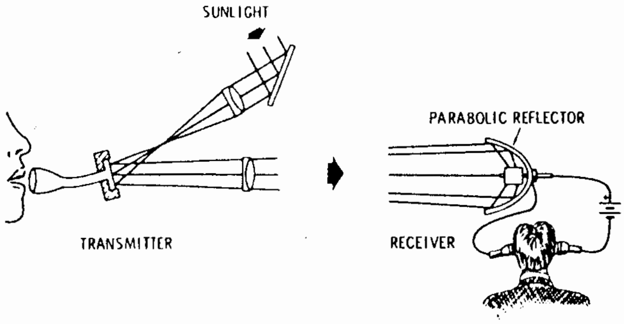
Figure 1

CHAPTER II

HISTORICAL BACKGROUND

THE PHOTOPHONE

In the 1880s, Alexander Graham Bell performed a number of experiments with a device called the photophone (see Figure 2). Bell considered the photophone a greater invention than the telephone because it did not require wires to connect the transmitter to the receiver. But, unfortunately, the photophone was ahead of its time in that the technology to support it would not be available for years to come.



Simplified diagram of Bell's Photophone (Mims, 1975)

Figure 2

Before the invention of the lightbulb, Bell had to use sunshine redirected by mirrors to illuminate the diaphragm. The diaphragm performed the modulation function of the photophone. For receiving, Bell used a selenium resistor. The selenium resistor had the ability to change resistance according to the light intensity. The resistor was mounted in a parabolic reflector concentrating the modulated light signals on the resistor. The resistor was connected in series with a battery and a telephone receiver. As one spoke into the speaking tube, the mirrored diaphragm vibrated from the sound waves striking it. The vibrations modulated the intensity of the light beam aimed at the resistor. This, in turn, varied the resistance of the selenium resistor and, therefore, the current in the series circuit. The varying current was then used to produce a fluctuating magnetic field in the receiver of the telephone. Bell's photophone worked, but it had some serious disadvantages. It would not work over long distances, and it had to be directed in line-of-sight with available sunlight (Mims 1975).

THE FIBERSCOPE

It was not until the 1950s when the first fiber-optic device was developed-called the fiberscope. The fiberscope consisted of a rope of parallel, glass-coated, flexible-glass fibers. A short, focal length lens was used to conduct the image formed on one polished end of the rope back to the eyepiece. At the eyepiece, the image was magnified for viewing. The remarkable part of the fiberscope was its flexibility. The device would permit viewing around corners. The image was not even disturbed when the fiberscope was tied in knots.

Early uses of the fiberscope included inspecting welds inside reactor vessels and combustion chambers of aircraft engines. Just as significant was the use of the fiberscope in the medical field. The small size and flexibility of the device made practical, without surgery, the inspection of the esophagus and the digestive tract.

Although useful, early fiberscopes suffered from broken fibers and the field of view had a few black spots; nevertheless, they represented a remarkable break through in fiber-optic communications. A flexible conductor was now available to transmit light modulated information (Kueken, 1980).

For communications work, however, a very significant piece was still lacking. There was no practical way of getting any significant power level of light into the tiny fibers. The light produced by an incandescent lamp is too incoherent and consists of many different wave-lengths. Also, because incandescent light and sunlight are all in the visible spectrum, there is much interference. This made the incandescent lamp unsuitable as a light source for fiber-optic communications.

THE LIGHT EMITTING DIODE (LED)

The invention of the transistor by three Bell Laboratories' scientists in 1949 sparked a major research program in semiconductor electronics. Howard Briggs, James Haynes, and William Schockley, discovered p-n junctions fabricated in silicon and germanium emitted infrared radiation when forward biased. The scientists, awarded U.S. Patent 2,683,794 for their invention, performed a series of tests. The tests of the infrared emitter revealed the p-n junction emitted a narrow, spectral bandwidth with a fast-radiation rise-time.

In 1962,J. I. Pankove of RCA Laboratories reported the development of an infrared-emitting, semiconductor diode having much higher efficiency than those made from silicon and germanium. Pankove's diodes were made from gallium arsenide (GaAs), a semiconductor compound having superior optoelectronic properties. His diodes were more energy efficient and a more practical candidate for optical communications (Mims, 1975).

In 1962 scientists at Lincoln Laboratory, Massachusetts Institute of Technology, used a GaAs diode to send a 4-MHz television signal to a receiver 84 meters away. Then, in 1963, the same team of scientists sent both audio and television signals from the crest of Mt. Wachusett, Princeton, Massachusetts, to the roof of the Lincoln Laboratory, a distance of 55.6 kilometers. The infrared source was a GaAs diode (Mims, 1975).

THE LASER

In 1958, the final piece of the fiber-optic link fell into place with the development of the laser by two United States physicists, Arthur L. Schawlow and C. H. Townes. Their ideas were further refined by another American physicist, Theodore H. Maiman in 1960. He built and operated the first laser. The laser had the ability to produce an extremely intense source of coherent light with an extremely narrow bandwidth. This made it possible to load light powers, measured in watts, into a single, glass fiber (De Maria 1980).

A prerequisite for laser action is a material capable of being excited to a higher-than-normal energy level by an external energy source. If more molecules or ions in the substance are in an excited rather than an unexcited state, called population inversion, and if the active material is provided with an optically resonant cavity, laser action will occur.

Maiman's original laser utilized a ruby rod for the active material. Ruby consists of aluminum oxide (Al_2O_3) doped with a small quantity of chromium. The chromium ions occupy aluminum sites in the Al_2O_3 matrix and provide the optically active properties of ruby.

The ruby rod was provided with an optically resonant cavity by polishing both its ends until they were perfectly flat and parallel. The external energy was supplied by a coiled, xenon, flash-tube placed over the rod. The laser process was started by discharging a large capacitor through the flash tube. The ruby rod absorbed some of the radiation from the flash tube. This excited the chromium atoms to a higher than normal energy level. When a level of population inversion of the chromium atoms was reached, photons spontaneously emitted by some excited atoms begin to trigger the emission of large numbers of photons from other excited atoms. This stimulation process was further reinforced by two silver coatings on the ends of the ruby rod. The mirrored ends formed a resonant cavity and caused the photons to bounce back into the ruby where they stimulated more emission. The result was a standing wave of light which eventually emerged from one of the mirrors. The mirror through which the laser light emerged was partially transparent, the other was totally nontransparent. The emitted light was in a series of very narrow, powerful pulses of light lasting a total of several milliseconds.

The radiation emitted by Maiman's ruby laser was a brilliant red at a wave-length of 694.3 nanometers. Although ruby remains an important laser material, many combinations of active materials, resonant cavities, and excitation methods have been developed to produce laser action. Today, literally hundreds of solids, liquids and gases are being used to produce thousands of laser frequencies at wave-lengths from the ultraviolet to the far infrared (Mims, 1975).

CHAPTER III

THE FIBER-OPTIC LINK

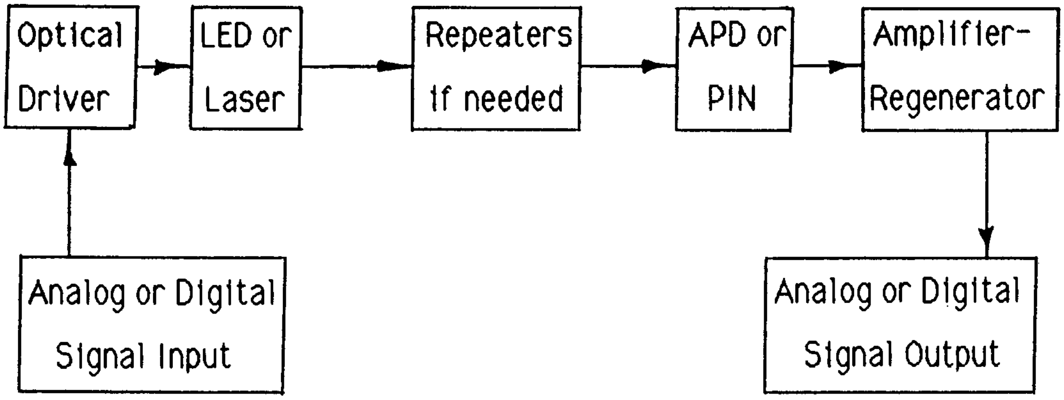
With the technological advances being made in light sources, detectors, fibers, cables and related-system design, the field of fiber-optic communication has steadily taken over many of the roles of the conventional hard-wire and radio-communication systems. Some of the advantages of fiber-optic transmission lines are:

1. One fiber-optic filament, several mils in diameter, can replace a copper wire cable several inches in diameter. This is a savings in both size and weight, especially in underwater applications and in areas of overcrowded transmission wires.
2. Optical transmission is immune to any outside electrical noise or electromagnetic interference, and it does not create any of its own electrical noise which eliminates any problems with crosstalk.
3. Optical cables are safe to use in explosive environments and eliminates the hazards of short-circuits in metal wires.
4. Properly designed, optical transmission lines and couplers are relatively immune to adverse temperature and moisture conditions making them ideal for underwater applications. Bare fibers of glass composition can withstand temperatures of over 1000^{0}C where metal coax cable is limited to 300^{0}C.
5. The number of repeaters required for low-loss, fiber-optic cable is less than with conventional systems, and for short distances of less than 30 km. no repeaters are necessary.

6. Fiber-optic cable costs about the same as premium-grade, coax cable. As production volumes increase, these costs should decrease to less than half their present cost.
7. Equipment now used for electronic cable that protects against grounding and voltage problems can be eliminated using fiber-optic cables. The exception to this is when repeaters are used; then it is necessary to provide power through metal conductors to each of the repeaters.
8. Upgrading a fiber-optic system can easily be done as new light sources, detectors, modulators and equipment become available. This can all be done without having to replace the original cable.
9. The installation costs of fiber-optic cable are less than metal cable because the shipping and handling costs are about one-fourth that of metal cables, and installation labor is about one-half (Mims, 1975).

These advantages, along with increased information bandwidth, make optical communication very attractive for various applications including telecommunication, computers, cable television, space vehicles, avionics, ships, security and alarm systems, medical systems, satellite-ground systems, and industrial automation and process controls. Of all these applications, the telecommunication industry is leading in both the research and application of fiber-optic communication (Elion, 1978).

Shown in figure 3 is a block diagram of a simplified fiber-optic communications link. The link consists of three or four main parts: the transmitting terminal; fiber cable; repeaters, if necessary, and the



Fiber-Optic Link

Figure 3

receiving terminal. The remainder of this chapter will take a closer look at each of these parts.

OPTICAL DRIVERS

Light sources for fiber-optic communications systems require certain characteristics including long life, high efficiency, reasonably low cost, sufficient power output, capability of various types of modulation and physical compatibility with fiber cables. The three light sources meeting these requirements are semiconductor light emitting diodes (LED's), solid state lasers and semiconductor injection lasers. There are a variety of LED's currently available for optical communication with an increasing number of lasers entering the market.

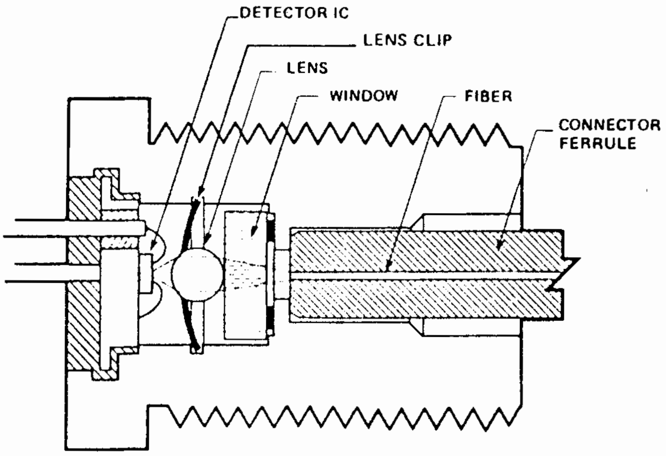
LED'S

Light emitting diodes generate light when carriers injected across a p-n junction recombine, emitting light wave radiation. The actual output-power of LED's, while relatively high, is scattered over a wide angle of emission. This results in high coupling losses to optical cable.

Therefore, most LED's designed for communication systems are engineered for high output radiance and short-range transmission.

LED's have a few advantages over lasers in that they are cheaper and have less temperature dependence on total emitted power. However, the bandwidth for communications is smaller. In many cases, the problem of the wide angle of emission is somewhat overcome by placing the LED in a well and using an array of microlenses to focus the emitted light-power into a fiber. With this arrangement it is possible to couple 300 to 400 microwatts into a fiber with a numerical aperture of 0.18 (Elion, 1978).

See Figure 4 for an example of a high-efficiency, fiber-optic transmitter manufactured by Hewlett-Packard. Note how the emitted light from the wide angle of emission is focused by a lens. This will allow more of the emitted light to be injected into the fiber and, therefore, increase the efficiency of the transmitter.



Cross Sectional View of a

High-Efficiency LED Transmitter (Hewlett-Packard, 1985)

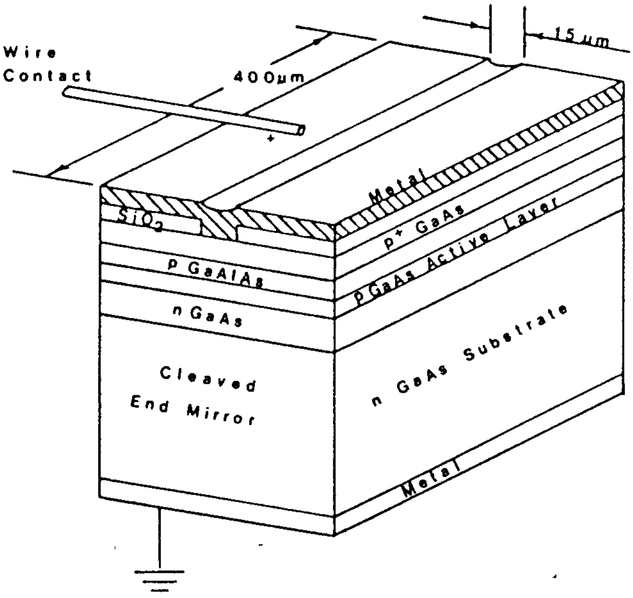
Figure 4

The noise introduced by LED's into fiber-optic cable, in most cases, is rather small and is proportional to the information bandwidth, spectral width, and number of transmission modes propogated into the fiber. LED's have been the first light sources used in optical communications systems since they have been readily available in large quantities at low cost and have long expected life-time in use values of up to 500,000 hours (Elion, 1978).

LASERS

Laser light sources for communications are designed to have long life-time-in-use ratios at room temperatures because of their physical structure. Double-heterojunction (DH) laser structures can be made with relatively long life-times when the lattice structure of the elements in the various layers and boundaries are carefully matched. The DH layers are made by careful growth of materials above and below the active laser region where light is generated by the radiative recombination of carriers injected across the p-n junction. In the DH laser with the stripe geometry, the lasing region occurs only in the transverse direction under the width of the contact stripe. Figure 5 shows the typical layer structure of a DH laser.

The development of injection lasers has involved the examination of many elements. The basic semiconductor for both LED's and lasers is the GaAs combination with a characteristic wave-length of 905 nm. Shifting of this wave-length can be accomplished by doping the basic GaAs material with other elements. The elements tested for this purpose must meet numerous physical and electrical criteria as well as simple limitation criteria such as having sufficiently high vapor pressures at



Sectional View of a
Double Heterojunction Injection Laser (Elion, 1978)
Figure 5

room temperatures to maintain its physical integrity. The elements commonly used in doping of the GaAs material are aluminum, arsenic, indium, phosphorus, and antimony, which must be available in ultra-purified form to eliminate other materials from generating lattice imperfections in the crystal growth stages. The range of wave-lengths achieved by the various doping techniques and elemental combinations range from 800 to 1150 nm.

The life-time-in-use of lasers compares with that of LED's. In most cases, life-times of 500,000 hours can be expected. The actual life-time will depend on current density, duty cycles, overload surges and temperature feedback control (Elion, 1978).

MODULATION

Light sources can be modulated by externally modifying the emitted light after it leaves the light source or by directly affecting the source by current variations. The typical type of modulation of LED's and semiconductor lasers is by directly modulating the current. This can be accomplished in one of three ways.

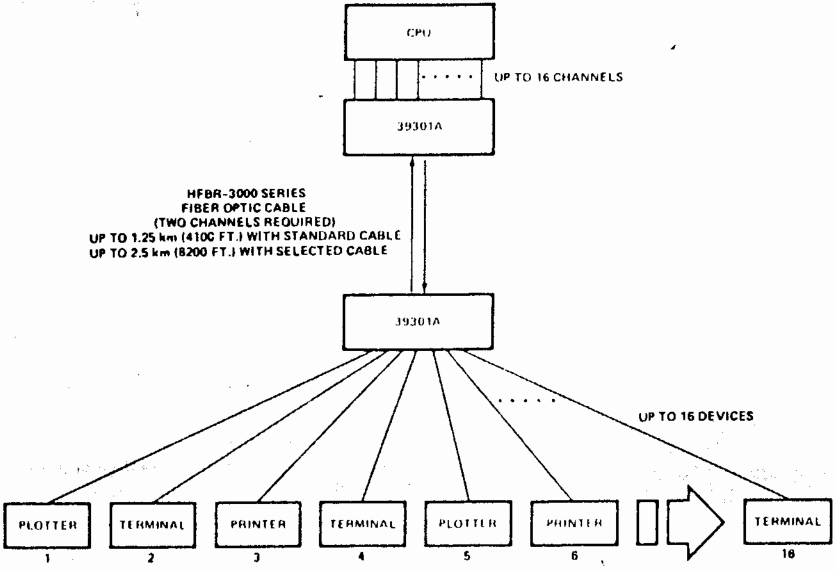
The first is to use direct modulation which has a time delay associated with the rise time to get above the threshold current. The second way is to bias the transmitter just below the threshold current and modulate the desired signal to levels above the threshold. This eliminates time delay but adds constant threshold noise to the outgoing signal. The third method is to bias the transmitter above the threshold. This method eliminates time delay and threshold noise but adds continual background noise to the photodetector and decreases life-time because of higher current levels.

Modulation of LED's is accomplished by varying the current to the LED. The limitations of the speed of modulation is dependent upon the device response time. The response time is determined by the free carrier generation and recombination time across the p-n junction and the driving circuit capacitance

As in LED's, lasers can be modulated by varying the injection current with modulation bandwidths of several hundred megahertz, or data rates of several hundred megabits per second. Compared to LED's. injection lasers have a higher efficiency in comparing optical output-power to driving current. In lasers this is from 10 to 50% as compared to 3% for LED's (Mims, 1975).

MULTIPLEXING

Through the use of multiplexing and the use of duplex, fiber-optic cable, it is possible to increase the information-carrying capabilities of a fiber-optic link. Multiplexing of an optical link is similar to multiplexing in digital and other hard-wire applications. Multiplexing can be accomplished on either frequency, time, or space division of the modulated optical transmission.



Multiplexed Optical Link (Hewlett-Packard, 1985)

Figure 6

Shown in Figure 6 is a typical multiplex configuration that makes it possible for a digital data link of 16 channels over 1 pair of optical fibers. The advantages of this link include immunity to electromagnetic interference of all types, from lighting strikes to noisy motors, and freedom from static discharge and crosstalk. The system can be used in hazardous and volatile environments because no sparks or static discharge are generated by the dielectric medium (Hewlett-Packard, 1985).

OPTICAL DETECTORS

Since Bell's photophone, many devices have been developed to detect light-wave signals. The photophone used a photoresistor as a detector. While the photoresistor has been refined and is still an important electrical component, other devices such as the vacuum phototube, solar cell, phototransistor, avalanche photodiode (APD), and PIN photodiode have been developed. Of the available light detectors, the APD and PIN photodiodes prove to be the most acceptable for fiber-optic communication (Mims, 1975).

Photodetectors used in fiber-optic systems must meet several physical and electrical requirements including: adding a minimal amount of noise, having sufficient speed of response to track light variations, peak sensitivity to the light source wave-length, stability over temperature extremes, and long life-times at a reasonable cost (Mims, 1975).

Semiconductor photodiodes all have a depletion region where electron-hole pairs are generated by the absorbed photons, with a high electric field between the two semiconducting regions. Fiber-optic systems usually involve low light levels, so the detectors are operated in reverse bias so output current varies linearly with the intensity of the optical signal. The probability of light absorption in the depletion region depends on the wave-length of the optical signal, the type of semiconductor material used and the thickness of the depletion region.

Photodiodes are usually described by four basic factors:

1. Response time is the transit time for electrons in the

photodiode to transverse from the cathode to anode, typically from 0.2 to 0.5 nanoseconds.

2. Responsivity is the average emitted current divided by the average incident power.
3. Quantum efficiency is the percentage of incident photons that liberate photodetector electrons.
4. Total noise equivalent power is a measure of the undesirable electrical noise the photodetector adds to the signal.

Many of the APD devices are silicon based with anti-reflection coatings to provide quantum efficiencies near 90% (Elion, 1978).

FIBERS AND CABLES

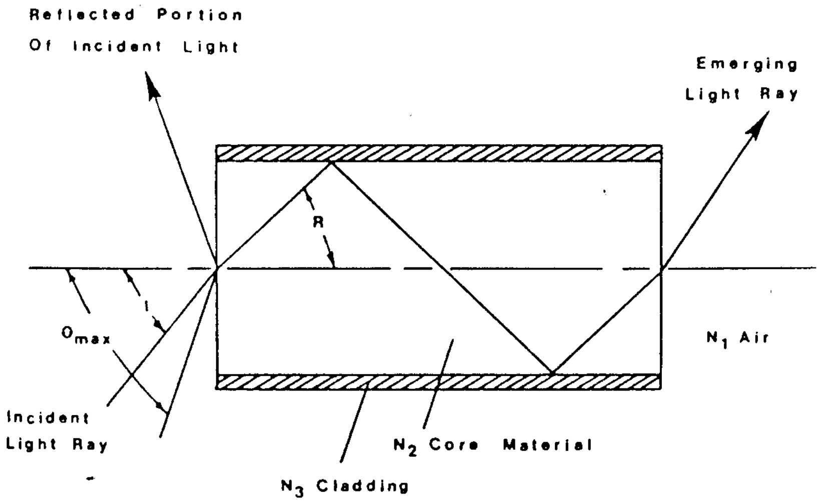
Optical fibers for communication consist of a central glass or plastic core and a reflective cladding. Of the two, plastic fibers have higher attenuations than glass fibers. Therefore, plastic fibers are commonly used for short-distance, digital applications.The information capabilities of plastic fiber range up to 6 megabits per second over distances of 50 - 200 meters. One distinct mechanical advantage of plastic fiber is simpler, more reliable couplings since the plastic cladding can be gripped directly without cracking or splitting. Plastic fiber couplings have minimal attenuation losses when compared to total fiber loss (Hewlett-Packard, 1985).

For long distance communications where attenuation losses are critical, glass fiber is the better choice. Glass fibers exhibit not only smaller fiber losses, but less end-fiber coupling losses as well. This is due to the ability to polish the end of the glass fiber to provide for less distortion and reflection of the injected or emerging signal.

There are many properties of optical fiber which determine the optical transmission of light. Some of these are manufactured into the fiber while other properties are a result of its installation.

NUMERICAL APERTURE

The numerical aperture (NA) of an optical fiber is defined as: $NA = \text{Sin } 0 = (N_{core}^2 - N_{clad}^2)^{1/2}$ where N_{core} is the refractive index of the core and N_{clad} is the refractive index of the cladding. Figure 7 shows the light emitted from an open ended fiber and the relationships of the indices of refraction. This is a very significant feature of the fiber because it shows a ray striking the fiber end at an angle wider than the acceptance-cone half-angle will either be bound in the cladding or will be lost on the first reflection.



Numerical Aperture (Elion 1978)

Figure 7

The numerical aperture determines the efficiency of coupling between the light source and the fiber. For light sources such as LED's a wide NA is desired because the light energy from an LED is widely dispersed. On the other hand, for laser sources, a smaller NA is acceptable because of the well collimated beam.

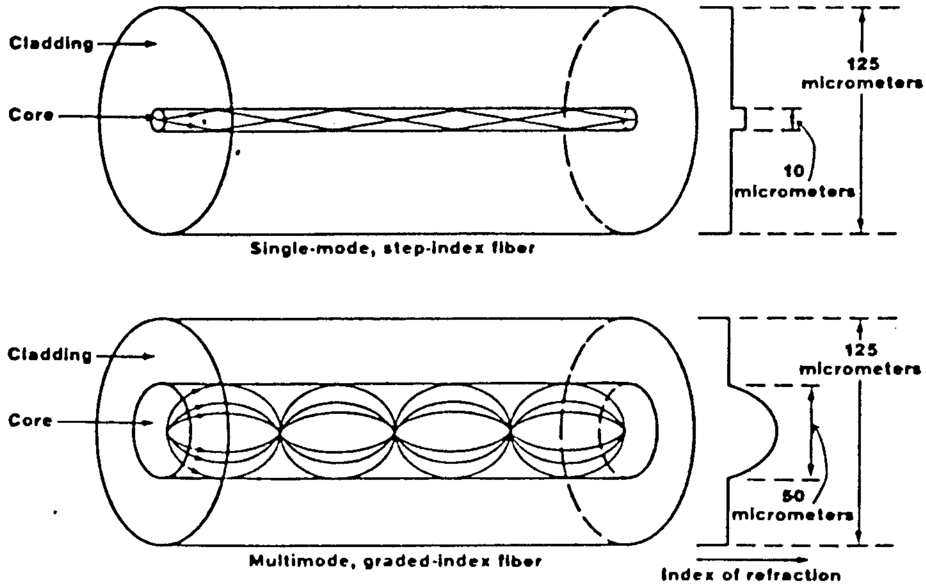
Numerical aperture is determined by the type and amount of dopants added to the base material during manufacturing. The oxides of germanium, boron, phosphorous, titanium and aluminum are commonly used as dopants. In general, fibers with large NA values have high attenuation loses but are easier and cheaper to manufacture. This is due to a simpler fiber-drawing process and lesser chemical purity (Elion, 1978).

REFRACTIVE INDEX

The central transmission core of the fiber can be manufactured to have a variety of indices of refraction. The two most common are the stepped-index and the graded-index (see Figure 8). The stepped-index fiber will have a smaller, relative core diameter than the graded-index fiber. In the stepped-index fiber there is a sharp jump or step in the index of refraction between the core and cladding. The graded-index fiber has a higher index of refraction at the core and gradually decreases outward toward the cladding. This is because light travels faster where the refractive index is lower. Therefore, light is speeded along the longer, outer path of the core and slowed on the inner path to equalize the time needed for light to travel the length of the fiber. This is a way to reduce dispersion of the light wave.

ATTENUATION

Attenuation is the loss of light energy as it passes through the optical fiber. This loss is undersirable and is a result of material absorption and scattering, waveguide scattering, and radiation losses.



Modes of Optical Fiber (AT&T, 1985)

Figure 8

Material absorption and scattering is a result of impurities in the core and can be controlled only through higher refinement processes during manufacturing. Waveguide scattering is caused by irregularities at the interface between the core and cladding and is another result of fiber manufacturing. Radiation losses are caused by the bending of fibers and are most extreme at small, radius bends. These loses can be minimized by using a larger bend radius and fibers with a higher NA value.

Being able to manufacture optical fiber with small attenuation losses is desirable. This will allow for longer transmissions without the need of repeaters. These low losses, measured in dB/km, have made it possible to design optical communication systems of over 30 kilometers without the need of repeaters. Attenuation losses range from as low as 5 dB/km to over 1200 dB/km (Elion, 1978).

MODE

Mode is the path a light ray follows through an optical fiber as in Figure 8. That mode is divided into two types. The single-mode fiber will have a smaller core of about 10 micrometers. This small core will confine the light to one path. It offers low dispersion and enormous information-carrying capacity. The single-mode fiber is manufactured from step-index fiber. This is the type of fiber which is more ideally suited for laser light sources because of the laser's collimated light beam (AT&T, 1985).

The multi-mode fiber has a relatively large core of 50 to 100 micrometers. This large core allows light to zig-zag along many different paths. To eliminate dispersion, mult-mode fiber is normally manufactured from graded-index material. This type of fiber is better suited for light sources with large dispersion angles such as LED's.

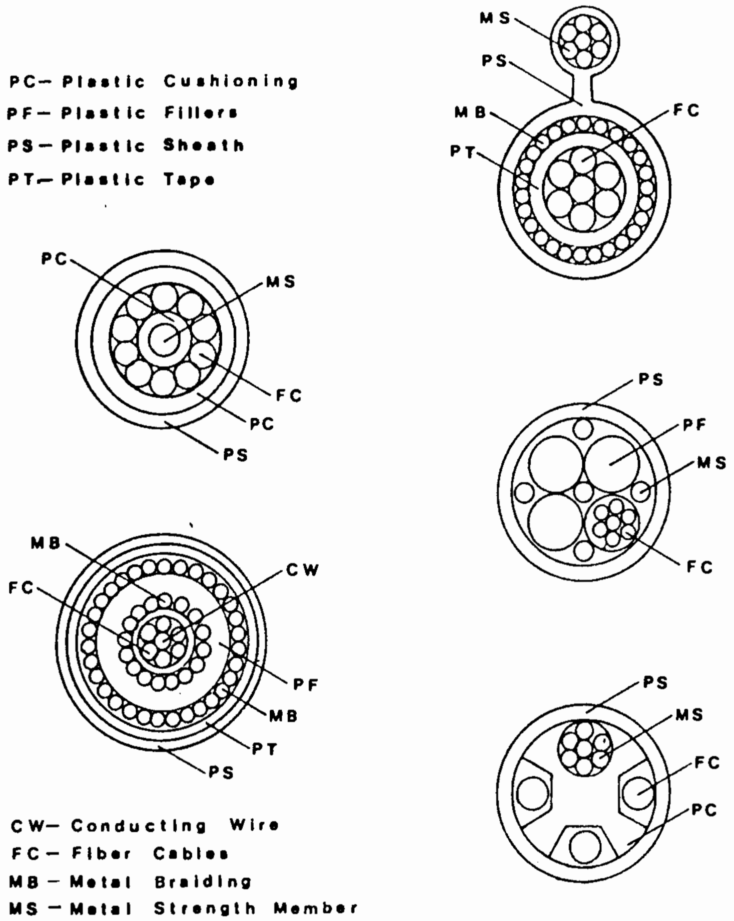
CABLES

Optical fiber cable can generally be divided into two types. One type will have a large number (100 - 1000) of high-loss fibers with a large numerical aperture. Several of the fibers in one bundle will be exposed to the same light source. This method is employed to avoid the breakage problem of single-strand links.

The other cable type consists of a small number (1-50) of low-loss fibers with a smaller numerical aperture. This type of cable is being used more as manufacturing and installation methods make the optical strands more reliable and less likely to fail.

To meet requirements for optical communications, the cable must be designed as follows:

1. The cable can be handled and installed similar to conventional



Cable Configurations (Elion 1978)

Figure 9

hard wire systems.

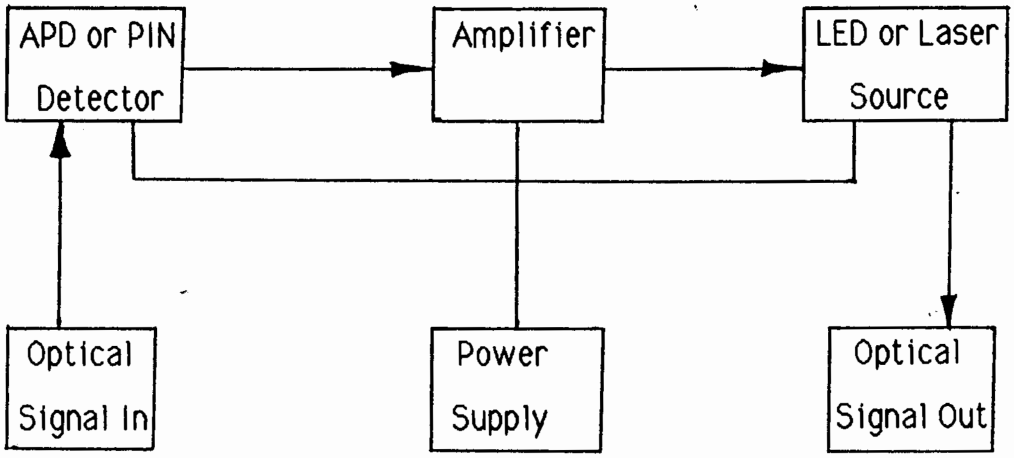
2. The cable must have mechanical and electrical configurations so it can be adapted to its specific use, such as metal support wires for aerial installations and conducting wires to power repeaters in underwater systems.
3. The cable can be spliced or terminated in the field with reasonable ease and time.
4. The cable must be economically competitive with existing hard wire communication systems.
5. The individual fibers must be distinguishable from each other.

Figure 9 shows some of the typical configurations of fiber cable. Depending on the application requirements, the cable may include not only the optical fiber, but metal conducting wires, support wire, and insulation.

REPEATERS

Because of the optical attenuation of both glass and plastic fibers, it is necessary to use repeaters for long-distance communications. The purpose of the repeater is to detect a weak optical signal, amplify it, and then inject it back into the optical fiber, thus allowing communication over extended distances.

The repeater may be simplified as in Figure 10. Its basic components are a PIN or APD detector, an amplifier similar to conventional wire systems, an LED or laser light source, and a power supply. It should be noted this is a simpified diagram for illustration only. Actual repeaters are complex and contain circuits for bias voltages, automatic gain control, noise filters, and signal comparators.



Block Diagram of a Repeater

Figure 10

Power to run the repeater is obtained from a hard-wire connection to an external source of electrical power. In the case of underwater communications, the hard-wire feed is manufactured as part of the cable. The conducting wires, along with the optical fiber, insulation, and metal strength members are formed into a cable at the time of manufacture. At each repeater location, power to run the repeater is then taken from the conducting wire. For land communications, power for the repeaters may come from the internal conducting wire or it may come from an external source at each repeater location. This eliminates the need to have conducting wires in the cable which cuts down on installation and cable costs (Elion, 1978).

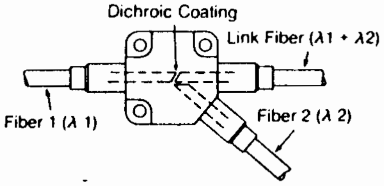
COMPONENT DESIGN

Presently there are no industry-wide standards for interfacing of fiber-optic equipment and cable. However, most manufacturers of fiber-optic devices are using couplers and connections that will interface with equipment of other manufacturers. In some cases, there are industries whose sole business is designing and manufacturing connectors, couplers, and end polishing kits for fiber-optics.

An example of this is Optical Fiber Industries, Inc. (OFTI), who are specialists in connectors. They not only offer pre-terminated cable but connectors that can be field installed on a variety of cable sizes that will couple to most optical devices. They also supply a termination kit to polish fiber ends square and flat. This polishing procedure reduces end-diffusion and increases transmitter and detector efficiency (OFTI, 1984).

Another manufacturer who specializes in couplers includes a wave-length multiplexer/demultiplexer in their product line as shown in

Figure 11. As illustrated, the coupler can be used either to combine two distinct wavelengths onto a single fiber or split two signals on the same fiber into two separate ones. This allows for duplex communications over single fiber to double the capacity of an existing single wave-length system (ADC, 1985).



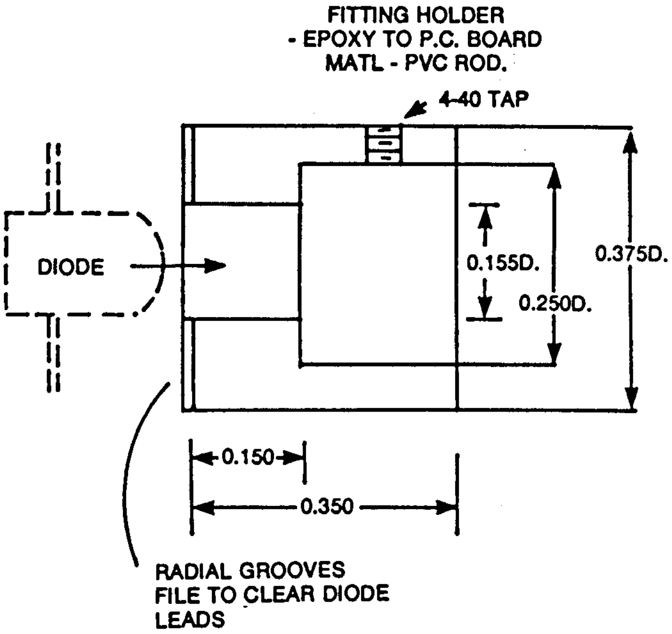
Wave-Length Division Multiplexer/Demultiplexer (ADC, 1985)

Figure 11

Early LED's for fiber-optic communication, such as the Motorola MLED 900, came in a package (T - 1 3/4) similar to the common LED's used for signal lights in electronic equipment. While there is no problem with the LED itself, there is considerable difficulty with the physical linkage of the optical fiber to the LED. As can be seen in Figure 12, it is necessary to mount the LED in an appropriate position so a metal or plastic collar can be placed around the LED. The optical fiber is then cemented into the collar.

This arrangement has several disadvantages:

1. A variety of parts need to be fabricated to accomplish the coupling.
2. The cement used has to have the same optical properties as the



Custom Holder for MLED 900 Transmitter (Kuecken, 1980)

Figure 12

optical fiber.

3. There are alignment problems, both angular and offset.
4. If a metal collar is being used, care must be taken the collar does not short out any leads or printed circuits.

While LED's of this mounting type are still available, other methods of coupling the fiber-optic cable to the LED have been developed. Several manufacturers have incorporated the LED into a holder that can be soldered or mechanically fastened to the circuit board or mounted to the bulkhead of a transmitting device. The holder also includes provisions to align the fiber with the LED as well as provide a locking mechanism to retain the cable in the holder.

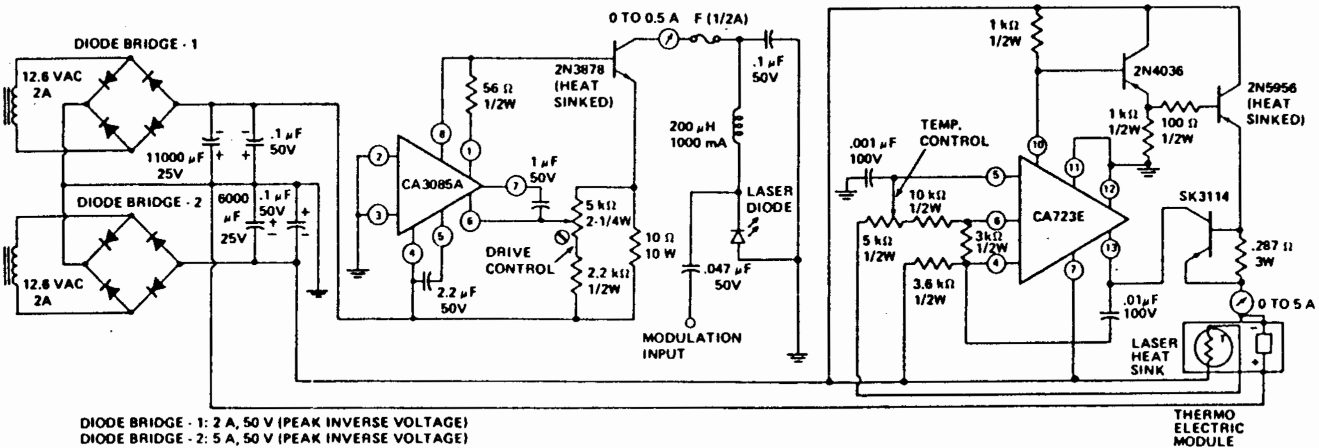
An example of these new types of devices is currently being produced by Hewlett-Packard. They have designed both their LED transmitters and detector receivers into three basic configurations. All three of these configurations eliminate the need for special adapters and fittings.

Hewlett-Packard's HFBR-0500 series of transmitter and receiver connections incorporate snap together fittings for use with plastic cable. The components are designed for distances of up to 60 meters at transmission rates up to 5 megabaud. This series features low cost (transmitter-$9.05; receiver-$9.50; and 5-meter, connectored cable assembly-$13.95) and ease of use. It is well suited for applications connecting computers to terminals, printers, plotters, or industrial control equipment.

For systems up to 1600 meters at 5 megabaud, Hewlett-Packard supplies the HFBR-0200 series of miniature fiber-optic link. This series employs screw-together fittings and glass fiber. Component costs for the extended distance are higher. The transmitter and receiver costs are $37.00 and $60.00 respectively, and a 10-meter length of connectored cable retails for $120.00.

Hewlett-Packard features a high performance transmitter and receiver series for applications that require higher data rates. The system uses the same optical fiber and connections as the HFBR-0200 series but is capable of data rates of over 10 megabaud. Costs of this system are $175.00 for each the receiver and transmitter (Hewlett-Packard, 1985).

With the increased use of lasers in communications, the cost of discrete laser devices compare with LED's. RCA has developed a line of single and double heterojunction injection lasers with spectral emission

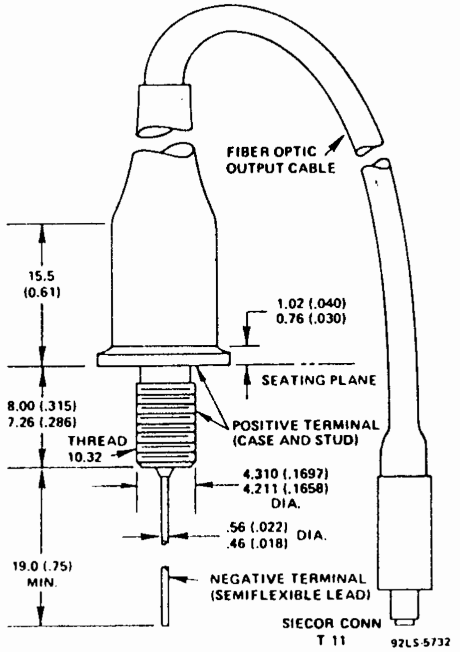


DIODE BRIDGE - 1: 2 A, 50 V (PEAK INVERSE VOLTAGE)
DIODE BRIDGE - 2: 5 A, 50 V (PEAK INVERSE VOLTAGE)
T: THERMISTOR FENWALL PART GB41P2 (10 kΩ AT 25° C), OR EQUIVALENT.
THERMO-ELECTRIC MODULE: MELCOR PART CP1.4-17-10TL, OR EQUIVALENT.

Laser Drive Circuit With

With Temperature Stabilization (RCA, 1984)

Figure 13



Dimensions in millimeters. Dimensions in parentheses are in inches.

RCA C86022E Laser (RCA, 1984)

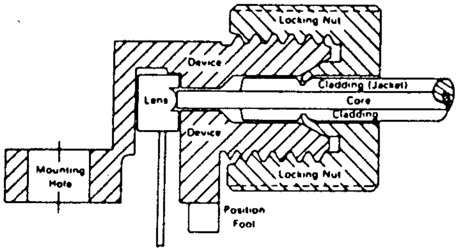
Figure 14

from 820 to 1300 nanometers. They are available with common configured headers and with or without headers. Figure 13 shows a typical drive circuit for one of these lasers, and Figure 14 shows the size and shape of one of these lasers.

Complete laser systems are considerably more expensive than LED devices. The cost for a complete laser module can range from $5300 to over $19,500 depending on wave-length and other power requirements. Photodetector receiver costs for these systems range from $130 to $6100 (Opto-Electronics, 1985).

As in most manufacturers' systems, the fiber-optic cable is available in bulk. Connectors may be installed either by the user or custom built by the manufacturer. Rolls of cable are available in lengths up to 1000 meters.

Plastic optical fiber is ideal for not only short distances but for experimentation and small projects. Plastic fiber is readily available from most component suppliers such as Radio Shack (Part no. 276-228) at a minimal cost, $5.99 for a 3 meter length. It can be easily terminated and stripped with a sharp knife or razor blade. It is coupled to either the transmitter or detector by a compression fitting that grips the outer plastic jacket as in Figure 15.



Internal view of Motorola MFOE71 and MFOD72 Infrared Emitting Diode and Detector coupled to 1000 micron plastic fiber cable (Radio Shack, 1985)

Figure 15

CHAPTER IV
FIBER-OPTIC APPLICATIONS

Less than a decade ago, fiber-optics was an emerging technology. Today, light wave communications is the system of choice worldwide. The advantages of fiber-optics are not only being used for voice communications, but other purposes are being researched as well.

TAT-8

A good example of the application and capabilities of fiber-optic communication is the construction of the eighth transatlantic cable (TAT-8). AT&T and 28 other telecommunications administrations from Europe and North America have combined forces to construct the $335 million project. "With the completion of TAT-8, scheduled for service on June 30, 1988, the system will be able to transmit 37,800 simultaneous telephone conversations" (AT&T, 1985). TAT-8 also will be able to transmit an equivalent combination of voice, data and video signals. This will be accomplished by laying 3,161 nautical miles of cable from Tuckerton, New Jersey, to a branching repeater site in the Atlantic. From the repeater a 280 nautical-mile branch will extend to Widemouth, United Kingdom while the second branch of 166 nautical miles will terminate at Penmarch, France.

The system will use 125 repeaters, an average of one repeater every 31 nautical miles. The system design will consist of two working pairs of single-mode light wave fibers, each driven by a laser operating at 296 megabits per second. One working pair will go from the United States to the United Kingdom and the other from the United States to France

(AT&T, 1985).

THE LOOP

In telecommunications, the term "loop" refers to the portion of the network closest to the customer. It is all the wires, cables, poles, and other devices used to connect a customer to a central office. The central office is a building that houses the equipment for switching, transmitting and otherwise manipulating signals.

New loop systems are being installed with fiber-optic components to take advantage of the new technology. New systems handle an enormous amount of information at high speeds over long distances at less cost than conventional systems.

Bell Labs has designed a new system called the Fiber-SLC™ carrier system especially for the loop. The Fiber-SLC system is designed to withstand the variable and extreme conditions for the loop environment, yet it is easy and economical to install. The system is a set of components configured, installed, and maintained similar to conventional electronic components. It is comprised of:

1. A lightguide cable that links a central office terminal and a remote terminal to which customers' lines are connected.
2. Optical interface units that plug into the central office terminal and remote terminal.
3. Protection line switch units that also plug into the two terminals.

All of these components are being manufactured by Western Electric for Bells' new system.

The lightguide cable for the system is only 12 millimeters in diameter and is easy to install in any loop right of way. It can be buried in the ground, strung next to aerial cables, or placed in underground duct. The outer sheath can withstand extreme temperatures from minus 40 degrees to plus 65 degrees Centigrade (AT&T, 1985).

The brains of the system are the Optical Line Interface Units (OLIU). These compact devices are used to generate, receive, and manipulate light signals. Each OLIU incorporates an LED as the transmitter and a PIN diode as the receiver. They can reliably generate and receive signals at a rate of six million bits per second.

The final component of the Fiber-SLC system is the protection line switch units. These switches, when necessary, automatically switch signals to free lines when one line becomes overloaded. They serve the same purpose as line switches in conventional systems but are used to manipulate optical signals instead of electrical signals.

Following an 18-month test of the Fiber-SLC system in a simulated loop environment, the first commercial application of the system was installed in Chester Heights, Pennsylvania, in November of 1982. Before the end of that year nearly 600 of the systems were installed throughout the country.

In the meantime, Bell Labs have developed ways to improve the new systems to increase both the speed and capacity of previously installed systems. By adding a component called a DS2-to-DS3 multiplexer to the system, the transmission rate can be increased from six million bits per second to 45 million bits per second. The new multiplexer will increase the number of customers a fiber can serve from 96 to 672 (AT&T, 1985).

INTEGRATED OPTICAL DEVICES

Integrated optical devices are the components that will manipulate light for telecommunications just as integrated microelectronic circuits control electrons. Although they are still in the experimental stage, integrated optical devices have proved they can switch calls and multiplex messages in the laboratory. They can modulate an optical signal at high transmission and capacity rates.

These devices, being researched and fabicated by Bell Labs may well lead to the introduction of the crystal computer. Although still a theory, the crystal computer could carry out its functions with light at rates of a trillion bits per second (AT&T, 1985).

CHAPTER V

INSTRUCTIONAL INFORMATION

One of the goals of Industrial Arts is to develop a knowledge of industrial materials, processes, and products. Classroom exercises offer the student a hands-on experience that helps to reinforce and broaden the student's awareness and knowledge of new information.

The study unit on fiber-optic communications should begin with an introduction by the instructor.. Material from this research project could be used to provide information to the students. Students could also be instructed to use the library to find more information on fiber-optic communication. Following this, the students can follow the laboratory exercise using the fabricated equipment. To complete the study, unit a test is provided to see if the unit goals have been met.

The following experiment on fiber-optics could be incorporated into an Electricity/Electronics course. Although the laboratory exercise has been designed for high school, the lab equipment could easily be used in both middle and elementary schools to introduce students to fiber-optic communications.

____

(Name)

LABORATORY EXERCISE

FIBER-OPTIC COMMUNICATION

INTRODUCTION

This laboratory exercise will demonstrate light can be transmitted through an optical fiber. It will also determine optical fiber can be used in communications and optical communication is immune to some of the hazards of radio communications.

OBJECTIVES

1. To verify light can be transmitted the length of a plastic fiber cable.
2. To verify voice communications can be performed over optical fiber cable.
3. To verify twists or knots in an optical cable will not interfere with its use.
4. To verify optical communication is immune to electrostatic discharges.
5. To verify communications can be transmitted over air as well as optical cable.

EQUIPMENT REQUIRED

1. Lab-built optical transmitter and receiver
2. 15' fiber-optic cable
3. Radio and cassette player
4. A source of static such as a Jacob's Ladder or buzzer
5. A source of light both incandescent and fluorescent

PROCEDURE

1. a) Expose one end of the optical fiber to a source of light.
   b) Use your finger to alternately cover and uncover the exposed end of the fiber.
   c) Observe what is happening at the other end of the fiber.
   d) Try tying a loose knot in the cable and observe the unexposed end.
   e) In both cases did you notice a silver or white color appear on the unexposed end when the exposed end was uncovered and exposed to the light?__________
   f) What is the explanation for this? ____________________

      ____

      ____

      ____

   g) Which objective(s) does this meet? No(s).______________
2. a) Insert one end of the optical cable into the transmitter by carefully pushing the cable into the knurled clamping nut on the right side of the transmitter. The nut should be just tight enough to hold the fiber cable into the emitter diode.
   b) In a similar manner, connect the other end of the cable to -the receiver.
   c) Turn the radio on and set for a clear station. Music will work the best.
   d) Turn on the transmitter and set it in front of the radio.
   e) Place the receiver a convenient distance away. Turnon the receiver and adjust the volume.

f) What is happening at the receiver? ____________________

____

____

g) Turn off the transmitter. What happens to the music at the receiver? ____

____

h) Turn on the transmitter and carefully remove the fiber cable from the side of the transmitter. What happens to the music at the receiver? ____________________________

____

____

i) In both cases the music should have stopped at the receiver. How do you explain this? ______________________________

____

____

j) Which objective(s) do(es) this meet? ___________________

3. a) Repeat Procedure 2 after tying a loose knot in the fiber cable. Does the knot affect the function of the cable?

____

b) Which objective(s) do(es) this meet? ___________________

4. a) - Turn on the radio. The optical receiver and transmitter should be turned off for the first part of this procedure.

b) Turn on the source of static discharge.

c) What happens to the reception of the radio? ____________

____

____

d) What is the explanation for the poor reception of the radio when the static is turned on?________________________

____

____

e) Turn off the source of static.

f) Now replace the radio with the cassette player. Turn on both the optical transmitter and receiver. Adjust the volume of the cassette player and receiver for the best reception.

g) Turn on the source of static. Switch it on and off several times. Does the static affect the reception of the receiver? ________

h) Explain why the static does not affect the transmission through the optical fiber. __________________________

____

____

i) Which objective(s) do(es) this meet? _________________

5. a) Remove the optical cable from the receiver and transmitter.

b) Place them side by side so the emitter and detector line up.

c) Turn on both the transmitter and receiver.

d) Place either the radio or the cassette player in front of the transmitter and adjust it to a low volume.

e) Now carefully listen to the receiver. Can the sound be heard coming from the receiver? ___________________

f) Slowly separate the receiver and transmitter. What happens to the sound? ________________________________

g) Does this procedure determine that communications can take place through the air?________________________________

h) Which objective(s) do(es) this meet? ____________________

i) Does this procedure and Procedure 2 determine that the distance can be extended by the use of the optical fiber?

____

____

(Name)

UNIT TEST

FIBER-OPTIC COMMUNICATION

DIRECTIONS

The following test consists of twenty questions. The first ten questions are true-false and should be marked by circling either T or F. The last ten are multiple choice. Respond by placing the correct letter in the blank at the beginning of the question.

TRUE-FALSE

T F 1. The central core of an optical fiber is made from either glass or plastic.

T F 2. Light can be transmitted the length of an optical fiber even if the fiber is bent or twisted.

T F 3. Static discharges affect optical communication and is one of the disadvantages of fiber-optic communication.

T F 4. LED's emit more power than lasers and, therefore, are used in long-distance communications.

T F 5. Optical transmission works by transmitting electrons the length of the fiber.

T F 6. Optical fiber cannot carry as much information as the same size wire can.

T F 7. Single-mode fiber is manufactured from graded-index fiber.

T F 8. Fiber-optic communication is not suitable for long distance, underwater applications.

T F 9. The use of optical fibers is limited and can be used only in voice communications.

T F 10. The invention of the transistor in 1949 lead to the development of the LED and laser.

MULTIPLE CHOICE

_____ 11. The device used to boost the optical signal over long lengths of optical fiber is called a _____.

a. booster c. repeater

b. modulator d. multiplexer

_____ 12. Light energy lost in an optical fiber because of impurities in the fiber and dispersion in the fiber ends is called _____.

a. absorption c. refraction

b. attenuation d. coherence

_____ 13. Light waves that have basically the same wave length are known as being _____.

a. coherent c. collimated

b. reflected d. refracted

_____ 14. Light waves that are parallel are known as being _____.

a. collimated c. coherent

b. sectioned d. modulated

_____ 15. Light waves that have been bent as they enter a new transmission medium are said to be _____.

a. multiplexed c. reflected

b. guided d. refracted

_____ 16. A device used as a source of parallel light and producing the same wave-length of light is called a(n) _____.

a. LED c. photon

b. laser d. detector

_____ 17. The thin reflective layer around the core of an optical fiber is called the _____.

a. cladding c. jacket

b. index d. reflection zone

_____ 18. The path light follows through an optical fiber is called _____.

a. parallel c. multiplexed

b. graded d. mode

_____ 19. A device used by Alexander Graham Bell to communicate by using light waves is called a _____.

a. photophone c. laser

b. multiplexer d. fiberscope

_____ 20. Optical transmission is immune to _____.

a. electromagnetic noise c. crosstalk

b. short-circuits d. all the above

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

This chapter deals with two areas. The first area is a summary of the research project. This area deals with the concerns of the writer and the conclusions drawn from this project. The second area is the writer's recommendations for others desiring to do additional work in this area of study.

SUMMARY

The purpose of this study was to develop a laboratory exercise suitable for use in a high school industrial arts program. It was believed because of the increased use of optical fiber in communications this would be a worthwhile unit to include in the program. From the research it seems fiber-optic communications has an almost unlimited future and students should be exposed to what is happening in this area of industry.

From the research it can be concluded using optical fiber for communications has many advantages. The lightguide fiber is immune to electromagnetic and electrostatic noise. The small fiber filament can replace a copper wire many times its size and, as new devices are built, the filament will be able to handle even more information. The property of isolation from electrical short circuits and sparks makes it a prime candidate for use in explosive and other hazardous areas.

One of the merits in studying this area is the optical fiber can be manufactured from inexpensive, readily-available materials. The raw material for the glass fiber is silica sand. For plastic fiber the raw material is derived from a coal or petroleum by-product. This is an important point to bring up to students of today's technology. Optical fibers not only have many transmission benefits over copper wires but the raw material is cheaper and easier to obtain.

It can be concluded from the study the use of optical fibers will continue to increase in communications. Because of its many advantages, it is quickly replacing the use of bundles of wires for long-distance communications. The tremendous information-carrying capability of optical fibers compared to their size will bring a surge of applications. The new applications of this new technology are limited only by the imagination of the engineers and researchers involved.

RECOMMENDATIONS

After completing this project, it is evident there are many applications for fiber-optics that could be researched. This project dealt mainly with voice transmission. It should also be noted the same fiber can also be used as a digital link and could be used to interface computers and peripherals. Another lab exercise could be developed using a digital generator and a dual trace oscilliscope to compare the digital input to the digital output of the fiber.

With the increase in the use of lasers, some manufacturers of educational hardware have developed lasers that are safe to use in the classroom. The possibility of interfacing the laser to a receiver with an optical fiber could be explored. A laboratory exercise could then be developed that would closely resemble how communications are performed by the telephone industry.

Another area that could be researched is the manufacture of optical fiber. It would be interesting to know how it is possible to manufacture glass so clear a repeater is needed only every 30 miles. This area of study might also show the impact of using optical fiber instead of copper wire in communications on the industry and economy.

During the research, information was also received on line-of-sight infrared communications. This appears to be a spin-off technology of fiber-optic communications. A receiver and transmitter have been developed and installed that will transmit both an audio and video signal at up to a mile apart. This could also be an area of study that would enhance this research project.

In conclusion, after working with this project, the researcher believes this can be an interesting and meaningful unit in an industrial arts class. The challenge is to know fiber-optics is a very versatile technology and its use is practically unlimited.

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APPENDIX A

West Delaware Schools

Manchester, Iowa 52057

September 25, 1985

Dear Sir:

I am a graduate student at the University of Northern Iowa majoring in industrial arts-education. I am also a full-time teacher at West Delaware Schools. I am currently working on a research project to develop a unit of instruction on the use of fiber optics in communications.

I am seeking material on the following:

1. Fiber-optic cable
    a. fabrication
    b. applications
    c. splices
    d. terminations
    e. installation
2. Equipment used to interface from electrical to optical
3. Use of fiber optics in communications
4. Research being done on fiber optics

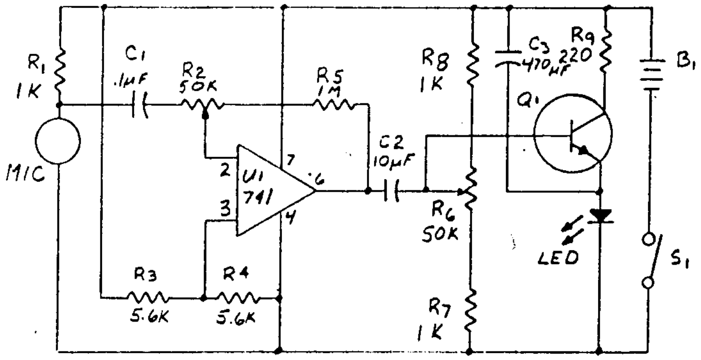
Thank you for any information you might be able to send me related to this subject.

Sincerely,

Ronald Struble

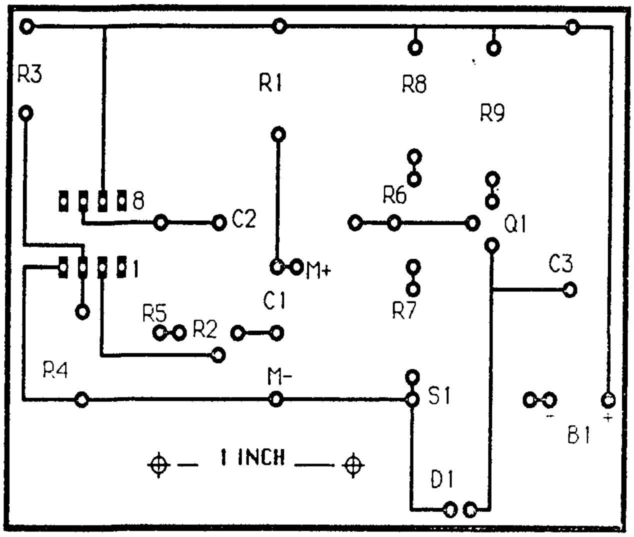
APPENDIX B

FIBER-OPTIC TRANSMITTER



Schematic Diagram for the Fiber-Optic Transmitter used in the Laboratory Exercise

Figure 16

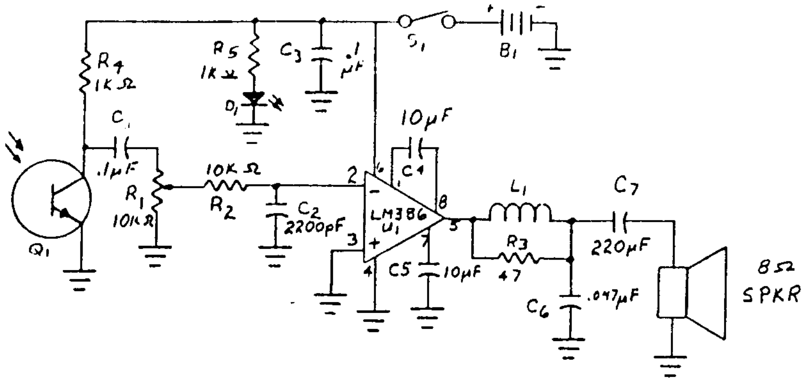


Printed Circuit Board Layout for the Fiber-Optic Transmitter

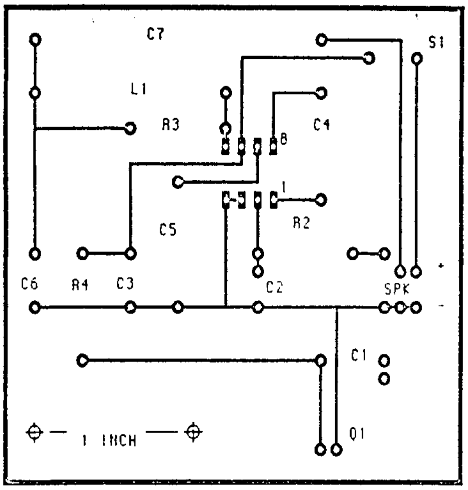
Figure 17

APPENDIX C

FIBER-OPTIC RECEIVER



Schematic Diagram for the Fiber-Optic Receiver
used in the Laboratory Exercise
Figure 18



Printed Circuit Board Layout for the Fiber-Optic Receiver
Figure 19

APPENDIX D

COMPONENTS AND COST FOR THE TRANSMITTER

COMPONENTS		
B1	9 volt battery	$1.79
C1	.1 mfd disc capacitor	.15
C2	10 mfd, 30 volt electrolytic capacitor	.50
C3	470 mfd, 30 volt electrolytic capacitor	1.00
LED	Infrared emitter (Radio Shack #276-225)	2.50
MIC	Electret mike element (Radio Shack #270-090)	.99
Q1	NPN transistor, 2N2222	.15
R1, 7, 8	1K ohm, 1/2 watt resistor	.15
R2, 6	50 K ohm, 1/2 watt potentiometer	1.50
R3, 4	5.6 K ohm, 1/2 watt resistor	.10
R5	1M ohm, 1/2 watt resistor	.05
R9	220 ohm, 1/2 watt resistor	.05
S1	SPST toggle switch	.89
U1	741 op amp integrated circuit	.69
MISC.		
PARTS		
	Printed circuit board	2.00
	Project case (Radio Shack #270-232)	2.99
	9 volt battery snap	.20
	9 volt battery holder (Radio Shack #270-326)	.30
	6-32 x 1/2 machine bolts	.30
	Total	$16.30

APPENDIX E

COMPONENTS AND COST FOR THE RECEIVER

COMPONENTS		
B1	9 volt battery	1.79
C1, 3	.1 mfd disc capacitor	.30
C2	2200 pfd disc capacitor	.15
C4, 5	10 mfd, 30 volt electrolytic capacitor	1.00
C6	.047 mfd disc capacitor	.15
D1	LED T-1	.15
L1	Coil	.10
Q1	Infrared detector (Radio Shack #276-225)	2.50
R1	10K ohm, 1/2 watt potentiometer	1.09
R2	10K ohm, 1/2 watt resistor	.05
R3	47 ohm, 1/2 watt resistor	.05
R4, 5	1K ohm, 1/2 watt resistor	.10
S1	SPST potentiometer switch	.69
SPKR	8 ohm, 2 inch speaker	.99
U1	LM386 integrated circuit	1.09
MISC. PARTS		
	Printed circuit board	2.00
	Project case (Radio Shack #270-232)	2.99
	9 volt battery snap	.20
	9 volt battery holder (Radio Shack #270-326)	.30
	6-32 x 1/2 machine bolts	.30
	Total	$15.99

APPENDIX F

TOTAL COST FOR THE LABORATORY EQUIPMENT

Fiber-optic transmitter		$16.30
Fiber-optic receiver		15.99
Optical fiber (Radio Shack #276-228)		5.99
	Total	$38.28