NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

FIBER OPTIC CABLES
(Structure Measurement and Testing)

Graduation Project
EE-400

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ABSTRACT

In fiber optic communication system connectors are used to connect two fibers or a fiber to active devices. Splices are used to permanently connect two fibers. For both connectors and splices, loss is the primary performance parameter. With durability and repeatability next in importance. Optical return loss (back reflection) is only of importance in single mode fiber networks. Connectors and cable assemblies are tested for insertion loss with meters and sources. Mode power distribution has a large effect on the connector or splice loss measured in multimode fibers. Couplers and switches are tested for output consistency and total excess loss. Mode power distribution is critical for proper measurements in both switches and couplers.

Fiber comes in two major types: singlemode and multimode. Multimode may be either step index or graded index (GI), with GI more common. Fiber is generally tested for attenuation coefficient (dB/km), but manufacturers will also test for diameter and concentricity, numerical aperture (NA) and perhaps even bandwidth. Mode power distribution can greatly affect the measurement of attenuation and bandwidth in multimode fiber.OTDRs can be used to get indirect measurements of attenuation, but with higher measurement uncertainty than with insertion loss measurements.Bandwidthconsists of both modal and chromatic dispersion and is very difficult to test.

Standards are necessary for insuring compatibility and interoperability, but should not stifle the development oftechnology. Standards come from organized standards groups and market acceptance: Primary standards are needed to allow measurements to be made with agreement among groups of users. Networks standards insure product interoperability.

INTRODUCTION

In this project fiber optic communication system is studied with intensive care. Fiber optic communication system is a new technology, which will have a large impact on telecommunications as well as fast data transmission and computer interconnections.The project consists of four chapters.

Chapter 1 gives a short introduction to fiber optic communication system by considering the historical development, the general system and the major advantages & disadvantages provided by this technology.

Chapter 2 gives the basic idea of a communication system and a communication network. Important elements in the communication process are introduced, which consist of Connectors and Splices, Connectorized Cable Testing, Couplers and Switches.

Chapter 3 will cover important and advanced topics in fiber optic communication system.. On the fiber optic side, attenuation, optical fiber test, sources for loss measurement and modal effects on attenuation are discussed in detail. Finally, gives the detail idea of fiber optic standards, optical power and more other applications of fiber optic system.

Chapter 4 covers the. important networking aspects and installing FO cable plant. Specifically, testing networks and topologies in fiber optic communication are explained, and various innovative networking are described.

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1. INTRODUCTION TO FIBER OPTIC CABLES

1.1 Introduction

Jn recent years it has become apparent that fiber-optics are steadily replacing copper wire as an appropriate means of communication signal transmission. Fiber-optic systems are currently used most extensively as the transmission link between terrestrial hardwired systems. They span the long distances between local phone systems as well as providing the backbone architecture of a city phone system. Other system users include cable television services, university campuses, office buildings, industrial plants, and electric utility companies. This briefing will give an overview of the beginning of fiber optic, fiber basics, fiber optic structure, fiber-optic advantages and disadvantages.

1.2 The Beginning of Fiber Optic

The fiber-optic is defined as branch of optics that deals with the transmission of light through ultra pure glass, plastic or some other form of transparent media. One of first noted experiment that demonstrated the transmission of light through a dielectric medium has been created to John Tyndall. In 1854 John Tyndall demonstrated that light could be guided through stream of water based on the principle of total internal reflection.

In 1880 Alexander Graham Bell invented the photo phone, a device that transmits voice signals over a beam of light.

In 1951, some American researchers were able to demonstrate the transmission of an image through a bundle of glass fibers. With experiments with light propagation in glass fibers well under way, Narinder Singh Kapany in 1953 developed fibers with cladding. The cladode fibers greatly improved transmission characteristics. The cladding significantly reduced the amount of dispersion of the light. The laser came about in 1960 being developed by

Theodore Maiman. Two years later, Maiman invented the semiconductor laser. The laser was very important to advancing fiber optic technology because now it was possible to have a coherent light source. A coherent light source consists of a light beam of a single wavelength.

Great interest in communication at optical frequencies was created in 1958 with the invention of the laser by Charles H. Townes.

In 1966 Charles K. Kao and George Hockham of Standard Telecommunications Laboratories of England performed several experiments to prove that, if glass could be made more transparent by reducing its impurities, light loss could be minimized. Their research led to a publication in which they predicted that optical fiber could be made pure enough to transmit light several kilometres.In the next two decades researchers worked intensively to reduce the attenuation to 0.16 dB/km.

In 1970, Corning Glass Company produced the first set of low-loss fibers. This began to revolutionize the fiber optic industry. AT&T, in 1980, began the first major fiber optic communication link between Boston, Massachusetts, and Richmond, Virginia. The next year, Corning Glass Company modified their low loss fibers and came up with single-mode fibers with high bandwidth and low loss capabilities to increase data transmission rates. Starting in the mid-eighties, the major communication companies began installing long-distance fiber optic communication links using single-mode fibers. In 1988, the first transatlantic fiber optic cable was installed. Starting during the end of the eighties and working into the nineties, cable providers began implementing widespread usage of fiber optic networks. During the _past few years cable companies began replacing their coaxial cable lines with fiber optic cable.

1995 Multimedia applications foe business have become the major impetus for increased use. of optical fiber within the LAN, MAN, and WAN environment.

1.3 Fiber Optic Basics

Three kinds of optical fiber are distinguished by their material composition. Glass, the most common, has a maximum bandwidth limited only by the electronic equipment attached to it (gigabits per second are possible with glass fiber). Plastic-clad silica, a glass core with plastic cladding is capable of 200 Mbs. Plastic fiber has a bandwidth of only 50 Mbs but is cheap and its use of visible red light minimizes safety hazards associated with glass fiber and permits easier troubleshooting.

Table 1.1 summarizes common characteristics of glass fiber. For in-depth information.

Characteristic	Description	Result
Modal Dispersion	occurs in multimode fibers	can be limited by smaller core diameters, use of graded-index fibers, or by using singlemode fiber
Material Dispersion	dispersion caused by wavelength fluctuations	a greater problem in singlemode fibers
Waveguide Dispersion	dispersions caused by light traveling between the core and cladding	a greater problem in single mode fibers
Scattering	loss of light due to fiber flaws or inherent properties of the fiber	
Absorption	fiber absorbs a small amount of light due to impurities	the light dims when absorption occurs
Microbend Loss	small flaws in the core-cladding border	flaws cause light absorption
Dispersion	light spreading out as it travels down the fiber	dispersion limits bandwidth
Numerical Aperture (NA)	the light gathering potential of a fiber	the higher the NA, the higher the bandwidth
Fiber Strength	the ability of a fiber to be	fiber has greater strength

	stretched or pulled without breaking	than steel, size for size; cable is six times stronger than Category 5 cable
Bend Radius	fiber can be wrapped in circles, but the limit is called the maximum bend radius	bends increase attenuation and decrease the amount of light that travels down the fiber

1.4 Components of Fiber

Three components comprise an optical communications system:

- transmitter (either a Light Emitting Diode or Laser Diode) converts information to light,
- medium, such as single mode fiber optic cable, transmits the light signal,
- receiver converts the light signal into an information again.

These components are similar to modem technology, which converts information to a signal carried over the medium of a phone line, and converts it back to information at the other end.

Diodes transmit light at one of three wavelengths: 850, 1300 or 1550 nanometers. Laser diodes are generally used with single mode fiber, while Light Emitting Diodes (LEDs) are less expensive devices more commonly used with multimode fiber. Pin and avalanche _photodiodes are the most common detectors. In photodiodes or receivers, the light contacts an electrical circuit, converting the light into current for use by the system.

1.5 Fiber Structure

The physical structure of fiber optic cable consists of an inner core, cladding and a protective buffer coating. Light resides and information is conveyed in the ultra-pure quartz or silicon dioxide glass core. Glass cladding surrounding the core is a different refractive index than the core so that light in the core reflects off the cladding and remains contained in the core. The protective exterior buffer coating adds several layers of plastic to preserve the strength of the cable.

Fiber cables are available in two designs loose tube and tight tube. Loose tube fiber is used for long distances, where low attenuation is desired and. extreme temperature variations are expected. It allows several fibers to be incorporated into a tube. Kevlar is used to reinforce the tubes and reduce elongation and stress. Tight tube buffering is usually used for interior fiber runs where temperature variations are minimal.

Fiber run inside a building must meet local fire codes. The National Electrical Code requires that outdoor cable installed inside a building must be converted within 50 feet of entrance, or it must be run in a metal conduit to prevent toxic fumes from spreading in case of fire. Outdoor cable (aerial or underground) generally does not meet indoor code requirements.

1.6 Advantages and Disadvantages of the FOS

1.6.1 Advantages

The major advantages are:

a) Bandwidth

One of the most significant advantages that fiber has over copper or other transmission media is a bandwidth. Bandwidth is directly related to the amount of information that can be transmitted per unit time. Today's advanced fiber optic systems are capable of transmitting several gigabits per second over hundreds of kilometers. Ten thousands of voice channels can now be multiplexed together and sent over a single fiber strand.

b) Less Lose

Currently, fiber is being manufactured to exhibit less than a few tenths of a decibel of loss per kilometer.

c) Less Weight and Volume

Fiber optic cables are substantially lighter in weight and occupy much less volume than copper cables with the same information capacity. For example, a 3-in.diameter telephone cable consisting of 900 twisted-pair wires can be replaced with a sinqle fiber stand 0.005 inch in diameter (approximately the diameter of a hair strand) and retain the same information-carrying capacity. Even with a rugged protective jacket surrounding the fiber, it occupies enormously less space and weights considerably less.

d) Security

Since light does not radiate from a fiber optic cable, it is nearly impossible to secretly tap into it without detection. For this reason, several applications requiring communications security employ fiber-optic systems. Military information, for example, can be transmitted over fiber to prevent eavesdropping. In addition, metal detectors cannot detect fiber-optic cables unless they are manufactured with steel reinforcement for strength.

e) Flexibility

The surface of glass fiber is much more refined than ordinary glass. This, coupled with its small diameter, allows it to be flexible enough to wrap around a pencil. In terms of strength, a 0.005-in. strand of fiber is strong enough to cut one's finger before it breaks, if enough pressure is applied against it.

f) Economics

Presently, the cost of fiber is comparable to copper at approximately $0.20 to $0.50 per yard and is expected to drop as it becomes more widely used. Since transmission losses are considerably less than for coaxial cable, expensive repeaters can be spaced farther apart. Fewer repeaters mean a reduction in overall system cost and enhanced reliability.

g) Reliability

Once installed, a longer life span is expected with fiber over its metallic counterparts since it is more resistant to corrosion caused by environmental extremes such as temperature, corrosive gases, and liquids.

1.6.2 Disadvantages

In spite of the numerous advantages that fiber optic systems have over conventional methods of transmission, there are some disadvantages, particularly because of its newness. Many of these disadvantages are being overcome with new and competitive technology.

a) Interfacing costs

Electronic facilities must be converted to optics in order to interface to fiber. Often these costs are initially overlooked. Fiber-optic transmitter, receiver, couplers, and connectors, for example, must be employed as part of the communication system. Test and repair equipment is costly. If the fiber optic cable breaks, splicing can be a costly and tedious task.

b) Strength

Fiber, by itself, has a tensile strength of approximately 1 lb, as compared the coaxial cable at 180 lb (RG59U) surrounding the fiber with stranded Kevlar and a protective PCV jacket can increase the pulling strength up to 500 db. Installations requiring greater tensile strengths can be achieved with steel reinforcement.

c) Remote Powering of Devices

Occasionally it is necessary to provide electrical power to a remote device. Since this cannot be achieved through the fiber, metallic conductors are often included in the cable assembly. Several manufacturers now offer a complete line of cable types, including cables manufactured with both copper wire and fiber.

2. FIBER OPTIC DEVICES

2.1 Connectors and Splices

Connectors-are used to couple two fibers together or to connect fibers to transmitters or receivers, and connectors are designed to be demountable. Splices, however, are used to connect two fibers in a permanent joint. While they share some common requirements, like low loss, high optical return loss and repeatability, connectors have the additional requirements of durability under repeated matings white splices are expected to last for many years through sometimes difficult environmental conditions.

2.1.1 Connectors

Today, there are approximately 70 different connectors in use. The figure above shows the most widely used connector types. A new series of "small form factor" connectors appeared in 1998-2000.Most work by simply aligning the two fiber ends as accurately as possible and securing them in a fashion that is least affected by environmental factors. Many techniques like expanded beam, using lenses, have been tried and abandoned for all but some very specialized applications.

Connectors have used metal, glass, plastic and ceramic ferrules to align the fibers accurately, but ceramics seem to be.the best choice currently. It is the most environmentally stable material, closely matching the expansion coefficient of glass fibers. It is easy to bond to glass fiber with epoxy glues1and its hardness. is perfect for a quick polish of the fiber. As volume has increased, ceramic costs have been reduced to be competitive to metal connectors.

A new type of plastic, liquid crystal polymers (LCP), offers promise for molded ferrules at lower costs, if performance and durability can be proven.

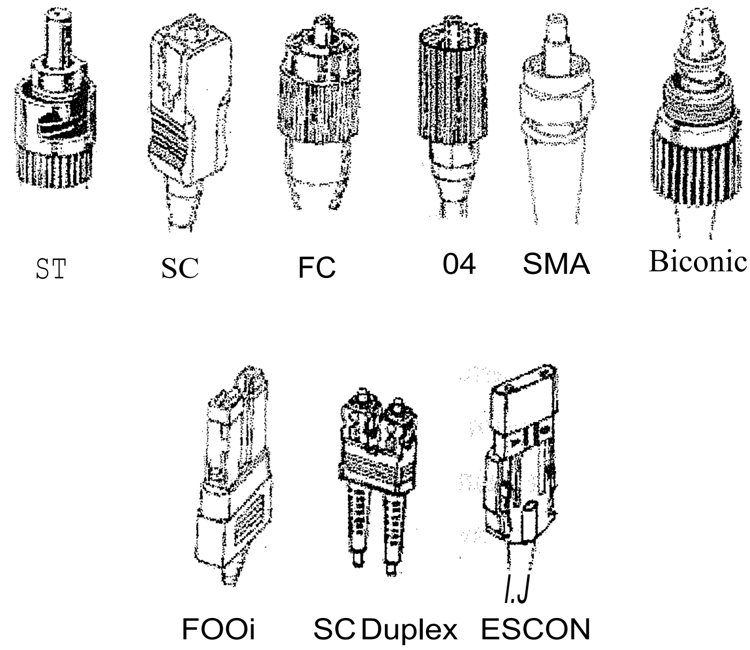


Figure2.1 Connectors

Splice bushings have been made from metal, plastic and ceramic also. The plastic types work well over environmental conditions, but may suffer problems with repeated matings, especially under conditions encountered in testing numerous connectors or cable assemblies. The plastic bushings "shave" small amounts of plasticateach insertion. Some of this material may accumulate on the end of the connector and causes loss. Sorrıemay also build up and form a ridge in the bushing to cause an end gap ih the rrıatiriğöf two connectors. Check splices bushings for these problems by viewing the end of the connector in a microscope looking for dust.

2.1.2 Splices

There are two types of splices, fusion and mechanical. Fusion splicing (top) is done by welding the two fibers together, usually with an electrical arc. It has the advantages of low loss, high strength, low backreflection (optical return loss) and long term reliability. Mechanical splices (bottom) use an alignment fixture to mate the fibers and either a matching gel or epoxy to minimize back reflection. Some mechanical splices use bare fibers in an alignment bushing, while others closely resemble connector ferrules without all the mounting hardware. While fusion splicing normally uses active alignment to minimize splice loss, mechanical splicing relies on tight dimensional tolerances in the fibers to minimize loss.

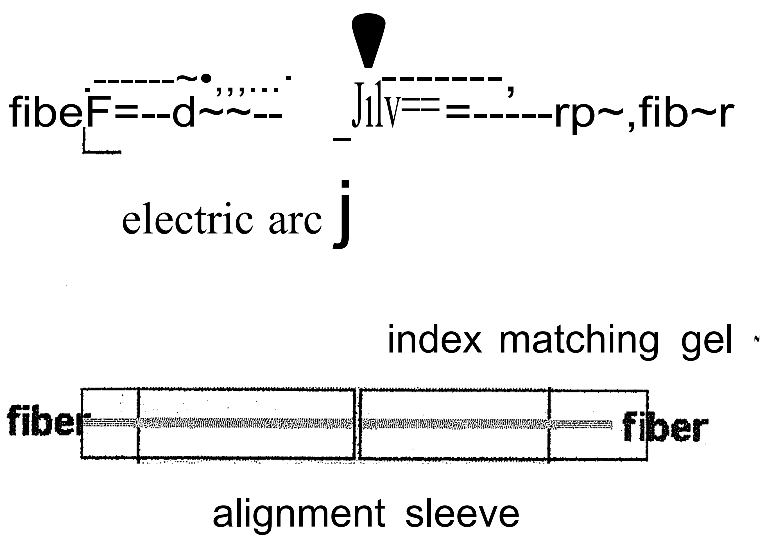


Figure 2.2 Splices

Low splice toss and high return loss is very dependent on the quality of the cleave on both fibers being spliced. Cleaving is done by using a sharp blade to put a surface defect on the fiber, then pulling carefully to allow a crack to propagate across the fiber. In order to get good fusion splices, both fiber ends need to be close to perpendicufar to the fiber axis. Then, when the fibers are fused, they will weld together properly.

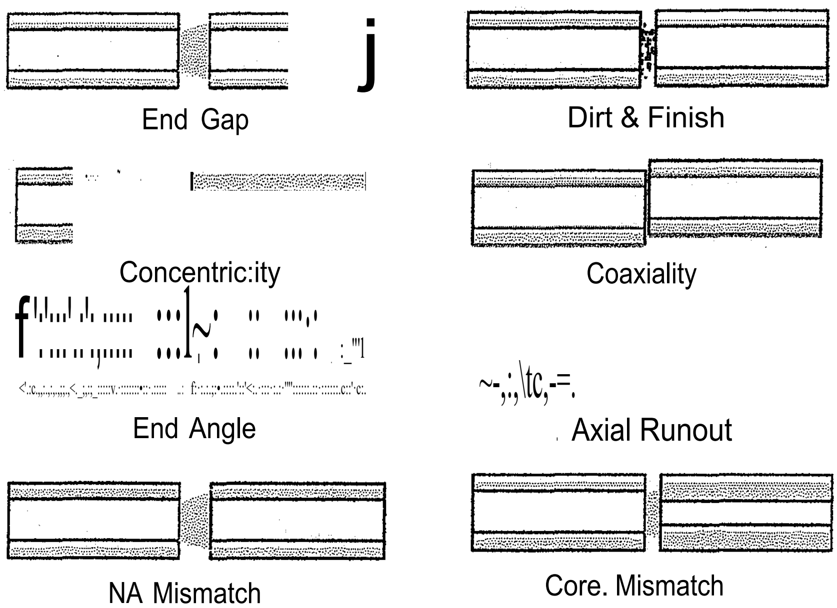


Figure 2.3 Connector Loss Factors

With a mechanical splice, the fibers are pushed together with an index-matching gel or epoxy between them. Since the index matching is not perfect, some reflection may·occur. If the fibers are cleaved at an angle, about 8 being best, the reflected light will be absorbed in· the ctaddiııg, reducing the back reflections. Special cleavers have been designed to provide angle cleaves·and should be available commercially in the near future.

2.1.3 Connector and Splice Loss Mechanisms

Connector and splice loss is caused by a number of factors, shown above. Loss is minimized when the two fiber cores are perfectly aligned. Only the light that is coupled into the receiving fiber's core will propagate, so all the rest of the light becomes the connector or splice loss.

Although it is common to compare the typical connectors quoted by manufacturers, it may not be a fair comparison. The manufacturer has a design that they. have qualified by expertly assembling and testing many samples of their connectors. But the actual loss obtained by any end user will be primarily determined by. their skill at the termination process. The manufacturer only has controt. over the basic design of the connector, the mechanical precision in manufacturing, and the clearness of the termination instructions.

End.gaps cause two problems, insertion loss and return loss. The emerging cone of.lightfrortrthe connector will spill over the core of the receiving fiber and be lost. iri addition,,the air gap between the fibers causes a reflection when the light encounters the change n refractive index from the glass fiber to the air in the gap. T~is reflection··(called fresnel reflection) amounts to about 5% in typical flat polished connectors, and means that no connector.with an air gap can have less than 0.3 dB loss. This reflection is also referred to as back reflection or optical return loss, which can be a problem in laser based systems. Connectors use a number of polishing techniques to insure physical contact of the fiber ends to minimize .back reflection. On mechanical splices, it is. possible to reduce back reflection by using non-perpendicular cleaves, which cause back reflections to be absorbed in the cladding of the fiber.

The end finish of the fiber must be properly polished to minimize loss. A rough surface will scatter light and dirt can scatter and absorb light. Since the optical fiber is so small, typical airborne dirt can be a major source of loss. Whenever connectors are not terminated, they should be covered to protect the end ofthe ferrule from.dirt One should never touch the end of the ferrule, since the oils on one's skin causes the fiber to attract dirt. Before connection and testing, it is advisable to clean connectors with lint-free wipes moistened with isopropyl alcohol.

Two sources of loss are directional; numerical aperture (NA) and core diameter. Differences in· these two will create connections that have different losses depending on the direction of light propagation. Light from a fiber with a larger NA will be more sensitive to angularity and end gap, so transmission from a fiber of larger NA to one of smaller NA wili be higher loss than the reverse. Likewise, light from a larger fiber will have high loss coupled to a fiber of smaller diameter, while one can couple a small diameter fiber to a large diameter fiber with minimal loss, since it is much less sensitive to end gap or lateral offset.

These fiber mismatches occur for two reasons. The occasional need to interconnect two dissimilar fibers and production variances in fibers of the same nominal dimensions. VVith two mu!timode fibers in usage today and two others which have been used occasionally in the past, it is possible to sometimes have to connect dissimilar fibers or use systems designed for one fiber on another. Some system manufacturers provide guidelines on using various fibers, some don't. If you connect a smaller fiber to a larger one, the coupling losses will be minimal, 6ften only the Fresnel loss (about 0.3 dB). But connecting larger fibers to smaller ones results in substantial losses, not oniy due to the smaller cores size, but also the smaller NA of most small core fibers.

In the chart below, we show the losses incurred *in* connecting mismatched fibers. The range of values results from the variability of rnodat conditions. If the transmitting fiber is overfilled or nearer the source, the. loss will be higher. If the fiber is near steady state conditions, the loss will be nearer the lower value.

If you are connecting fiber directly to a source, the variation in power wili be approximately the same as for fiber mismatch, except replacing the smaller fiber with a !arger fiber will result in a gain in power roughly equai to the loss in power in coupling from the larger fiber to the smaller one.

Whenever using a different (and often unspecified) fiber with a system, be aware of differences in fiber bandwidths also. A system may work on paper, with enough power available, but the fiber could have insufficient bandwidth.

Table 2.1 Mismatched Fiber Connection Losses (excess loss in dB)

	Transmitting Fiber		
	62.5/125	85/125	100/140
Receiving Fiber			
50/125	1.6-1.9	3.0-4.6	4.7-9
62.5/125		0.9	2.1-4.1
85/125			0.9-1.4

2.1.4 Connector and Splice Loss Testing

In order to establish a typical loss for connectors, it is necessary to test ati connectors in a standardized fashion, to allow for comparisons among various connectors. Measurements of connector or splice losses are performed by measuring the transmitted power of a short length.of cable and then inserting a connector pair or splice into the fiber. This test (designated FOTP~34by the EIA) can be used for both multimode and singlemode fiber, but the results for multimode fiber are very dependent on mode power distribution.

FOTP-34 has three options in modal distribution: 1)EMO (equilibrium modal distribution or steady state) , 2)fully filled, and 3)any other conditions as long as they_ are specified. Besides mode power djstribution factors, the uncertainty of the measured loss is a combination of , inherent fiber geometry variations, installed connector characteristics, and the effects of the splice bushing used to align the two connectors.

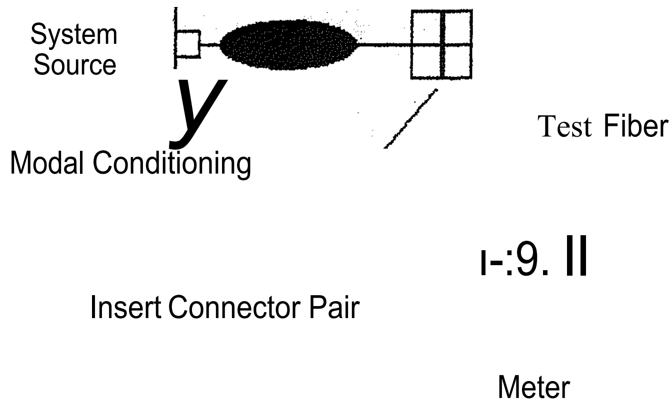


Figure 2.4 Connector and Splice Loss Testing

This test is repeated hundreds or thousands of times by each connector manufacturer, to produce data that shows the repeatability of their connector design, a critical factor in figuring margins for installations using many connectors. Thus loss is not the only criteria for a good connector, it must be repeatable, so its average loss can be used for these margin calculations with some degree of confidence.

2.1.5 Inspecting Connectors with a Microscope

Visual inspection of the end surface of a connector is one of the best ways to determine the quality of the termination procedure and diagnose problems. A well made connector will have a smooth, polished, scratch free finish, and the fiber will not show any signs of cracks or pistoning (where the fiber is either protruding from the end of the ferrule or pulling back into it):

The proper rrı~gnification for viewing connectors is generally accepted to be 30-100 power. Lower magnification, typical with a jeweler's loupe or pocket magnifier, wiıt not provide adequate resolution for judging the finish on the connector. Too high a magnification tend to make small, ignorable faults look worse than they really are. A better solution is to use medium magnification, but inspect the connector three ways: viewing directly at the end of the polished surface with side lighting, viewing directly with side lighting and light transmitted through the core, and viewing at an angle with lighting from the opposite angle.

Viewing directly with side lighting allows determining if the ferrule hole is of the proper size, the fiber is centered in the hole and a proper amount of adhesive has been applied. Only the largest scratches will be visible this way, however. Adding light transmitted through the core will make cracks in the end of the fiber, caused by pressure or heat during the polish process, visible.

Viewing the end .of the connector at an angle,. while lighting it from the opposite side at approximately the same angle will allow the best inspection for the quality of polish and possible scratches.· The shadowing effect of angular viewing enhances the contrastof scratches against the mirror smooth polished surface of the glass.

One needs to be careful in inspecting connectors, however. The tendency is to be overly critical, especially at high magnification. Only defects over the fiber core are a problem. Chipping of the glass around the outside of the cladding is not unusual.andwill have no effect on the ability of the connector to couple light in the core. Likewise, scratches only on the cladding will notcause any loss problems.

2.1.6 Connector and Splice Durability

Another factor important to a connector is the dürability öf the design, shown;by its ability to withstand many matings withotıtdegradatidri irrlôss. Testing connector' durability is simply a matter ·~f repeated mating and demating of a connector pair while measuring loss. Since the loss is a function of both connectors and alignment sleeve, it is helpful to determine which are the contributors to degradation. Plastic alignment sleeves, when used with ceramic connectors, for example,will usually wear out much faster, shaving plastic off onto the connector ferrules and causing increased loss and return loss. When testing durabjlity, periodic inspection of the connector end faces and ferrules with a microscope to determine wear or contamlnaüon is very important.

Splice-durabilityis· one of withstanding many cycles of environmental stress, since splices are often used in splice enclosures in pedestals or mounted on poles where they are exposed to the extremes of climatic changes. Manufacturers usually test a number of. splices through many environmental cycles and accelerated aging to determine their durability. Süch tests may take years.

2.1.7 Optical Return Loss in Connectors

If you have ever looked at a fiber optic connector on an OTDR, you are familiar with the characteristic spike that shows where the connector is. That spike is a measure of the back reflection or optical return loss of the connector, or the amount of light that is reflected back up the fiber by light reflecting off the interface of the polished end surface of the connector and air. It is called fresnel reflection and is caused by the light going through the change in index of refraction at the interface between the fiber (n=1 :5) and air (n=t).

For most systems, that return spike is just one component of the connector's loss, representing about 0.3 dB loss (two air/glass interfaces at 4% reflection each), the minimum Joss for non-contacting connectors without index-matching fluid. But in high-bit rate single mode systems, that reflection can be a major source of bit-error rate prôblems. The reflected light interferes with the laser diode chip, causes mode-hopping and can be a source of noise. Minimizing the light reflected back into the laser is necessary to get maximum performance out of high bit rate laser systems, especially the AM n;ıodulated CATY systems.

Since this is only a problem with single mode systems, manufacturers have concentrated on solving the problem for their single mode components. Several schemes have been used to reduce back-reflections, including reducing the gap between connectors to a few wavelengths of light, which stops the fresnel reflection. The usual technique involves polishing the end surface of the fiber to a convex surface or at a slight angle to prevent direct back reflections.

Measuring this back reflection per standard test procedure EIA FOTP-107 is straightforward, but requires a·special test setup. This test setup can be used with· a bare fiber output into which a connector pair is installed (analogous to a FOTP-34 connector insertion loss test) or with a connector zed output for testing preconnectorized jumpers (like FOTP-171).

For the EIA FOTP-107 test procedure, one needs a calibrated coupler which can be used to inject a source into the testcable or pigtail and measure the light reflected back up the fiber, along with a standard. power meter and laser source. The coupler split ratio must be calibrated to know how much of the return signal goes to the power meter and how much is diverted to the source side of the coupler to calculate the total amount of back reflection. Due to the dynamic range required to measure return losses in the range of -25 to -60 dB, a. high poWer laser source is necessary, And the source must· be stable enough to allow making accurate measurements over relatively long times required for the experiment.

To measure return loss, measure the amount of power transmitted to the end of the cable (Pout) and the power reflected back up through the coupler test port (Pback) with a fiber optic power meter. To calibrate out any crosstalk in the coupler or the back reflections öf any intermediate connectors or splices, dip the connector end being tested in· an index matching fluid (alcohol works well and isn't messy to clean up) and record the power at the coupler test port (Pzero). tf the coupler split ratio is .Rspltt (the fraction of the light that goes to the measurement port when transmitting in the back direction), the return loss is:

optical return loss (dB) = pback _ pzero ... (2.1)

State-of-the-artconnectorswill have a return loss of about 40-60 dB, or about one-ten thousandth·to one millionth of the light is reflected back towards the source. Measurementssetups need to be carefully controlled to get valid data. The test connector being used to test other connectors or jumper cables must be kept clean and periodically repolished to insure as perfect a surface finish as possible. Purists will note that measurements· of Pout ignore the fresneJ reflection from the end of the test cable fiber and perhaps even the window of the detector, which can add a few percent to. the errors.

The measurement .of opticalireturn loss is not a precise measurement. The coupling ratios are hard toicalculate,reflections in the coupler and connectors are hard to zero out, any dirf or wear on the test connector will affect measurements and the dynamic range of the measurements are so large that uncertainties of up to +/-1 dB are common.

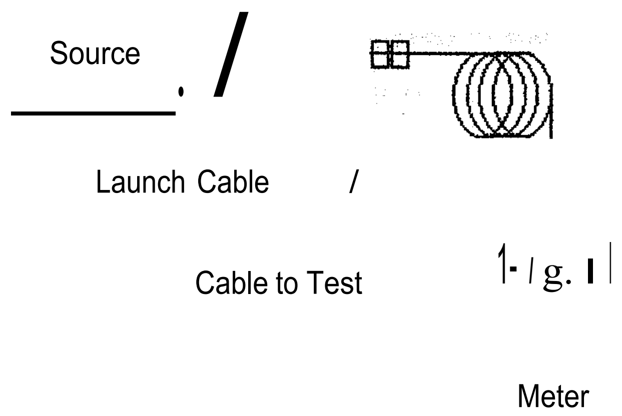
Like all fiber optic power measurements, instrument makers have been guilty of providing too much· instrument resolution than that warranted by the uncertainty of the measurement. Manufacturers also offer dedicated instruments to measure ORL, but the measurement can be made easily with a standard meter and laser source.

While the techniques mentioned above refer to testing connector or splice return loss using sources and power meters, the techniques also refer to testing connectors on jumper cables. However, they do not refer to tests on connectors or splices which are installed in a link. Once they are installed, testing should be done with an.

The spike seen when viewing a connectoron an OTDR can be measured with respect to the backscatter signal on the OTDR. Most OTDRs are calibrated to make this measurement directly. The coupler/laser source/meter technique (sometimes rererreo to as "optical continuous wave reflectometry" or OCWR) cannot be used once the components are part of a cable plant, since the continuous backscatter from the fiber masks the effects of any one component. Besides, if you have a problem, you need to know where it is, and only the OTDR can give that information.

2.2 Connectorized Cable Testing

After connectors are added to a cable. testing must include the Joss of the fiber in the cable plusthe>loss of the connectors.ön very short cable assemblies (up to 10 meters>long),the loss of the connectors will be the only relevant loss, .While fiber will contribute to the overall losses in longer cable assemblies. In an installed .cabıe plant, one· ~ust testme entire cable from end to end, .including every·component in it, such as splices, couplers, and connectors intermediate patch panels.



.Figure 2.5 Connectorized cable testing

Obviously one cannot test cable assemblies in the same manner as fiber .connectors alone, since those tests are destructive. Instead of using a cutback test, one uses a source with a launch cabl~ attached to calibrate the power being launched into the cable under test.

This method was not used at first; a cable substitution test was used. In this method, one attaches a reference cable of short length (about t m) and high quality to the source and records the power. After removing this cable from the source, the cable to be tested is then attached to the source and the power measured. The loss of the cable is them referenced to the first cable. This method was abandoned, since it often lead to confusion when the cable under test was better than the reference cable and had a "gain" not a loss, the coupling to the source was.highly.unrepeatable, and the test did not adequately test the centering geometry of the fiber in the ferrule of the connector.

A better test, FOTP-171 was developed along the lines of FOTP-34 for connectors. One begins by attaching a launch cable to the source made from the same size fiber and connector type as the cables to be tested. The power from the end of this "launch cabfe" is measured by a power meter to calibrate the launch power for the te_st. Then the cable to test is attached and pôwer measured at the end again. One can calculate the loss incurred in the connectors rnating to the launch cable and inthe fiber in the cable itself.

Since this only measures the loss in the connector mated to the launch cable, one can add a second cable at the power meter end, *called* a receive cable, so the cable to test-is between the launch and receive cables. Then one measures the loss at both connectors and in everything in between. This is commonly called a "double-ended" loss test.

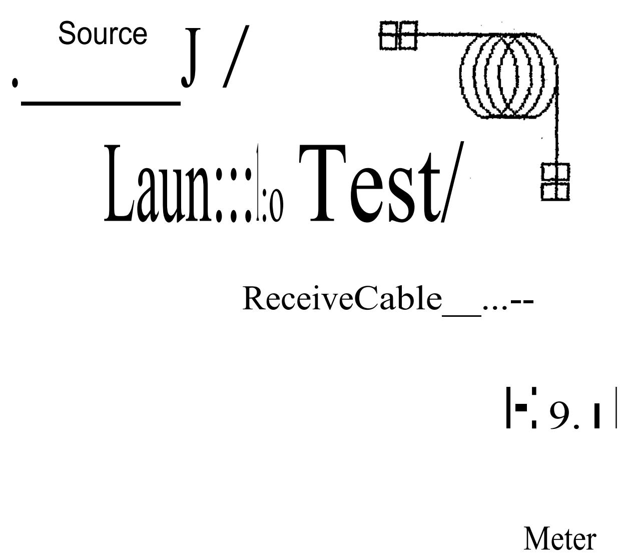


Figure2.6 Double-ended loss test

There have been two interpretations of the calibration of the output of the source in. th!s test. One interpretation is that one attaches the launch cable to the source and the receive cable to the meter. The two are then mated and this becomes the "0 dB" reference. The second method only attaches the launch cable to the source and measures the power from the launch cable with the power meter.

With the first method, one has two new measurement uncertainties. First, this method underestimates the loss of the cable plant by the loss of one connection, since that is zeroed out in· the calibration .process. Secondly, if one has a bad connector on one or both of the test cables, it becomes masked.by the calibration, since even if the two connectors have a loss of 10 dB, it Is not seen by the calibration method used.

In the second method, the launch power is measured directly by the meter. This also allows one to measure both connectors on the test cable, since power is referenced to the output power of the launch connector. In addition, one can test the mating quality of the test cables' connectors by attaching the receive jumper to the meter and then measuring the loss of the connection between the launch and receive jumpers. If this loss is high, one knows there is a problem with the test connectors that must be.fixed before actual cable loss measurements should be made.

Obviously, the second method is preferred. Both methods are detailed in OFSTP:-14,the extension of FOTP-171 to include installed cable plants which also discusses the problems associated with mode power distribution.

2.2.1 Finding Bad Connectors

If a test shows a jumper cable to have high loss, there are several ways to find the problem. If you have a microscope, inspect the connectors for obvious defects like scratches, cracks or surface contamination. If they look OK, clean them before retesting. Retest the launch cable to make certain it is good. Then retest the jumper cable with the single-ended method, using only a launch cable. Test the cable in both directions. The cable should have higher loss when tested with the bad connector attached to the launch cable, since the large area detector of the power meter will not be affected as much by the typical loss factors of connectors.

2.2.2 Mode Power Distribution Effects on Loss in Muitimode Fiber Cables

The biggest factor in the uncertainty of mu!timode cable loss tests is the mode power distribution caused by the test source. VVhen testing a simple 1 m cable assembly, variations in sources can cause 0.3 to 1 dB variations in measured loss. The effect is similar to the effect or. fiber loss discussed earner. since the concentration of light in the lower order modes as a result of EMO or mode filtering will minimize the effects of gap, offset and angularity on mating loss by effectively reducing the fiber core size and numerical aperture.

While one can make mode scramblers and filters to control mode power distribution when testing in the laboratory, it is more difficult to use these in the field. An alternative technique is to use a special mode conditioning cable between the source and launch cable that induces the proper mode power distribution. This can be done with a step index fiber with a restricted numerical aperture. Experiments with such a cable used between the source have been shown to greatly reduce the variations in mode power distributions between sources. This technique works well with both lab tests of connector loss and field tests of loss in the installed cable plant.

2.2.3 Choosing a Launch Cable for Testing

Obviously, the quality of the launch cabte wii! *affect* measurements of loss in cables assemblies tested against it. Good connectors with proper polish are obviously needed, but can one improve measurements by specifying tight specifications on the fiber and connectors? If the fiber is closer to nominal specifications and the connector ferrule is tightly toteranced. one should expect more repeatable measurements.

It seemed obvious to the committee specifying the cable plant for FDDI in the mid 1980s that one could get more precise data on cable plant loss and power coupled in to the cable by a transmitter by specifying a precision cable assembly.

In a series of tests performed on a large sample of cables, it was shown that the tightness of fiber and connector tolerances had little effect on the variability of the cables when intermated. In fact, the least variability came from a set of cables manufactured using off the shelf components, but with a cable design which had a much stiffer jacket than the other cables, which reduced the bending loss changes at the backshell of the connector

it seems that the large number of factors involved in mating losses makes controlling these tolerances impossible. Therefore, it is recommended that launch cables be chosen for low loss, but not specified with tighter tolerances in the fiber or connector characteristics. It is probably much more important to carefully handle the test cables and inspect the end surfaces of the ferrules for dirt and scratches regularly.

2.2.4 Optical Return Loss Testing of Cable Assemblies

Testing the optical return loss of cables and cable assemblies is very important for singlemode laser systems, since light reflected back into the laser may cause instability, noise or nonlinearity. \Nhi!e testing the ORL of a cable assembly is similar to that of a connector, using either FOTP-107 or the OTOR method, several factors should be noted to minimize errors.

First, be certain that the launch connector is of the finest quality obtainable, and inspect it often for dirt contamination .and scratching. Repolishing is possible for most keyed, ceramic ferrule connectors and will often improve measurements. Also insure the splice bushing used is kept clean and does not show wear.

Remember to terminate the connector on the far end of the cable assembly, otherwise it will reflect light and give false readings. Dipping the connector into index matching fluid or gel will usually do, but putting several tight turns in the fiber to create attenuation will also minimize the reflection effects.

OTDRs are limited in their usefulness. in testing jumper cables, since the jumpers are often too short for the resolution of the OTDR. This can be helped by using a long launch cable and carefully terminating the open connector to prevent it reflecting light which would be included in the single spike seen by the OTDR. On the installed cable plant, make certain that the OTDR back reflection spike does not exceed the dynamic range of the OTDR, or the measurement will underestimate the reflection.

2.3 Couplers and Switches

2.3.1 Fiber Optic Couplers

Couplers split or combine light in fibers. They may be simple splitters or 2 x 2 couplers, or up to 64 X 64 ports star couplers. Most are made by fusing fibers under high temperatures while monitoring light transmission through the fibers to get the proper coupling ratios. The fusing of the fibers causes light to split or combine in appropriate ratios. Others have been fabricated by diffusing Ught paths into a glass substrate and attaching fibers to it.

Relevant specifications for couplers are the coupling ratios of each port or the consistency across au the ports, crosstalk and the excess loss caused by ttie fusing. 'Excess loss is the difference between the sum of all the outputs and the sum of all the inputs. When used in laser based systems, couplers may need testing for optical return loss and wavelength dependence also.

Thus, testing couplers involves coupling a test source to each input port in turn and measuring all the outputs for consistency, then summing all the output powers .and subtracting that number from the input power to calculate excess loss.Connectorized couplers are tested like connectorized cables, using a launch cable, while couplers with bare fibers must use a cutback method or a pigtail and temporary splice to couple the launch source.

Single mode couplers have another characteristic that must be considered: they are very wavelength sensitive. Most couplers are optimized at one.wavelength unless they are specially designed for both 1300 and 1550 nm operation. Some are even· built to be wavelength division multiplexers, coupling light from· 1300 and 1550 nm lasers into separate output ports. Therefore, sources for testing couplers must be accurately characterized for wavelength to minimize measurement uncertainty.

2.3.2 FiberOptic Switches

Switches may use one of several techniques to transfer light from one fiber to another. Some merely use fibers on the arm of a relay with v-bock alignments to change from one fiber output to another. Others lise l~n~r~~nd prisms to collimate the light from the incoming fiber and switch it to the outgoing fiber. Like couplers, switch testing involves measuring the light lost in the switch by measuring the input from a source and the appropriate output for each switch position.

Again, these components are very sensitive to mode power distribution. For single mode couplers or switches, coupling ratios will be sensitive to whether the incoming light is really singlemode. In multimode components, mode power distribution can cause wide variation in switch losses or coupling ratios. Mode filters are necessary in singlemode tests and mode scrambler and filter combinationsare needed in multimode tests to insure minimal effect from unknown mode power distribution.

3. APPLICATIONOF FOC

3.1 FiberOptic

Optical fiber is composed of a light carrying core and a cladding that traps the light in the core, causing total internal reflection. Fiber has two basic types, multimode and single mode. Multimode fiber means that light can travel many different paths (called modes) through the core of the fiber, which enter and leave the fiber at various angles. The highest angle that light is accepted into the core of the fiber defines the numerical aperture (NA).Two types of multimode fiber exist, distinguished by the index profile of their cores and how light travels in them.

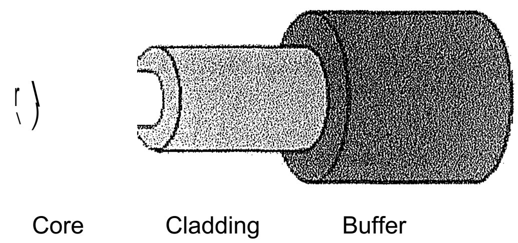


Figure 3.1 Fiber Structure

Step index multimode fiber has a core composed of one type of glass. Light traveling in the fiber travels in straight lines, reflecting off the core/cladding interface. The numerical aperture is determined by the differences in the indices of refraction of the core and ciadding and can be calculated by Snell's law. Since each mode or angle of light travels a different path link, a-pulse .oflight is dispersed while traveling through the fiber, limiting the bandwidth of step index fiber.

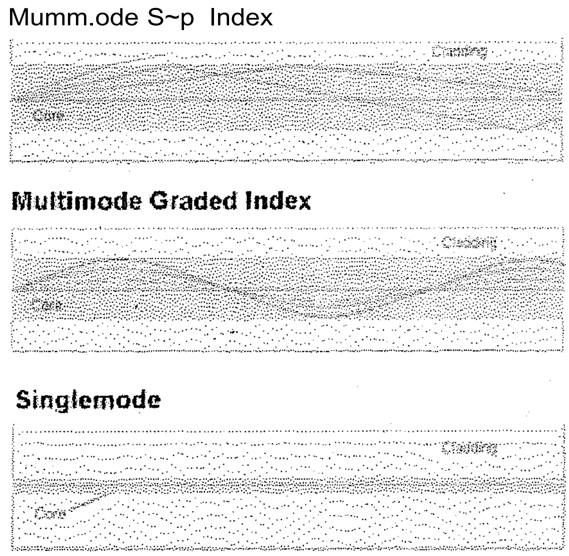


Figure 3.2 Fiber Optic Types

In graded index multimode fiber, the core is composed of many different layers of glass, chosen with indices of refraction to produce an index profile approximating a parabola. Since the light travels faster in lower index of refraction glass, the light will travel faster as it approaches the outside of the core. Likewise, the light traveling closest to the core center will travel the slowest. A properly constructed index profile will compensate for the different path lengths of each mode, increasing the bandwidth capacity of the fiber by as much as 1b0 times that of step index fiber.

Single mode fiber just shrinks the core size to a dimension about 6 times the wavelength of the fiber, causing all the light to travel in only one mode. Thus modal dispersion disappears and the bandwidth of the fiber increases by at least another factor of 100 over graded index fiber.

Each type of fiber has its specific application. Graded index fiber is used where large core size and efficient coupling of source power is more important than low loss and high bandwidth. It is commonly used in short, low speed datalinks. It may also be used in applications where radiation is a concern, since it can be made with a pure silica core that is not readily affected by radiation,

Table 3.t Fiber Types and Typical Specifications

Fiber Type	core/Cladding Diameter (microns)	Attenuation Coefficient (dBkm) 850 nm	1300 nm	1550 nm	Bandwidth @ 1300.nm (MHz-km)
Step Index	200/240	16	NA	~-·-r	50@850
Multimode	150/125	--13----~---	r	NA	~00
Graded Index	~2.5/125	13	Jt-	NA	1500
	\8_51125*	r-	11	NA	~----
	---~ı;....1_00_11_4_0*_	f	1	NA	>1300
Single mode	-18-9/125	NA	o.5	o.3	high
Plastic,	1l mm	(1 d8/m@665 nm)			Low

* Obsolete designs

While there have been four graded index multimode fibers used over the history of fiber optic communications, one fiber now is by far the most widely used, 62.5/125. Virtually all multimode datacom networks use this fiber. The first multimode fiber widely used was 501125, first by the telephone companies who needed its greater bandwidth for long distance phone lines. Its small core and low NA ·made it difficult to couple to LED sources, so many datalinks used 100/140 fiber. It worked well with these datalinks, but its large core made it costly to manufacture, and its unique cladding diameterreqı.iired connector manufacturers to make connectors specifically for it. These factors led to its declining use. The final multimçde fiber, 85/125 was designed by Corning to provide efficient coupling to LED sources but use the same connectors as other fibers. However, once IBM standardized on 62.5/125 fiber for its fiber optic products, the usage of all other fibers declined sharply.

The telcos switched to single mode fiber for its better performance at higher bit rates and its lower loss, allowing faster and longer unrepeatered links for long distance telecommunications. Virtually all telecom applications use single mode fiber. It is also used in CATV, since analog CATV networks use laser sources designed for single mode fiber. Other high speed networks are using single mode fiber, either to support gigabit data rates or long distance links.

3.1.1 Optical Fiber Testing

For optical fiber, testinq includes fiber geometry, attenuation and bandwidth. The most fundamental parameter for optical fiber is geometry, since the dimensions of the fiber determine its ability to be spliced and terminated. The core diameter, cladding diameter and concentricity are the most important factors on how well one can connect or splice two fibers. Thus manufacturers work very hard to control these parameters, including continuous testihg throughout the manufacturing process.

While testing diameter and concentricity may sound simple, measurements must be made to submicron precision. The process is complicated by the fact that the material is transparent and the dimensions are small enough to reach the limits of optical measurements.

3.1.2 Attenuation

The attenuation of the optical fiber is a result of two factors, absorption and scattering. The absorption is caused by the absorption of the light and conversion to heat by molecules in the glass. Primary absorbers are residual. OH+ and dopants used to modify the refractive index ofthe glass. This.absorption occurs at discrete wavelengths, determined by the elements.absorbing the light. The OH+ absorption is predominant, and occurs most strongly around 1000 nm, 1400 nm and above1600 nm.

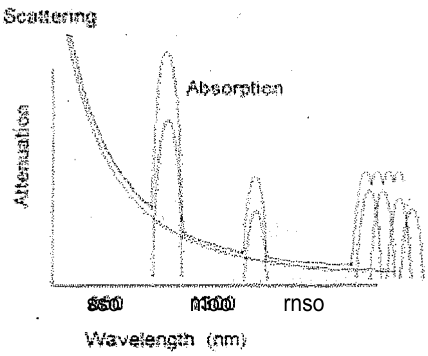


Figure 3.3 FiberAttenucıtion

The largest cause of attenuation is scattering. Scattering occurs.when light collides with individual atoms in the glass and is anisotropic. Light that is scattered at angles outside the numerical aperture of the fiber will be absorbed into the cladding or transmitted back toward the source Scattering is also a function of wavelength, proportional to the inverse fourth power of the wavelength of the light. Thus if you double the wavelength öf the light, you reduce the scattering losses by 2 to the 4th power or 16 *times:* Therefore, for long distance transmission, it is advantageous to use the longest practicalwavelength for minimal attenuation and maximum distance between repeaters. Together, absorption and scattering producethe attenuation curve for a typical glass optical fiber shown above,

Fiber optic systems transmit in the "windows" created between the absorption bands, at 850 nm, 1300 nm and 1550 nm, where'·.physics also aııows one to fabricate lasers and detectors easily. Plastic fiber has a more limited wavelength band, that limits practical use to 660 nm LED sources.

3.1.3 Sources for Loss Measurements

On the test source, two factors must be controlledto mlnimlze measurement uncertainty, the spectral output and modal characteristics. The spectral output characteristics obviously incfude wavelength, as seen in the spectral attenuation curve, but may also include the spectral width. A wide spectral width source suffers absorption over a larger range of wavelengths, making it more difficult to obtain precise data on spectralattenüatiön at any specific wavelength. Monochromators are used as sources for spectral loss testing, since the spectral width of the source can be controlled exactly.

For single wavelength measurements the source can be a fixed wavelength LED or laser. Generally, attenuation measurements will be made with a source appropriate to the fiber. Most multimode fiber systems use LED sources while single mode fiber systems use laser sources. Thus testing each of these fibers should be done with the appropriate source. Lasers should not be used with multimode fiber, since coherent sources like lasers have high measurement uncertainties in multimode fiber caused by modal noise. The wide .spectralwidth of LEDs sometimes overlap the single mode fiber cutoff. wavelength (the lowest wavelength where the fiber supports only one mode) at lower wavelengths a~d the 1400 nm OH: absorption band at the upper wavelengths.

The additional absorption at either end of the LEDs spectral output may bias the measurements of attenuation on single mode. fiber substantially. Tests from Bellcore showed the effects of sources on measurementsof single mode fiber loss. The LED spectrum covers from the singlemode cutoff wavelength around 1200 nm well into the OH absorption band, while the laser concentrates all it~ power in an extremely narrow spectral band where the fiber is actually used. Over the range covered by the LED output, the fiber loss varies by 0.2 dB/km, ignoring the OH absorptiori band. Bellcore tests showed an error of loss caused by the use of the LED of 0.034dB/km.

Even with laser sources, the loss varies substantially according to the wavelength of the source. Again Bellcore tests showed a variation of loss of 0.05 dB/km with source variations of 29 nm (1276 and 1305 nm), within the range of typical sources used in the network. So testing should be done with sources as close to the system wavelength as possible, especially with longer links. (Peters, Bellcore reference).

3.1.4 Modal Effects on Attenuation

In order to test rrn.ıfürnode fiber optic cables accurately and reproducibly, it is necessary to understand modal distribution, mode control and attenuation correction factors. Modal distribution in multimode fiber is very important to measurementreproducibilityand accuracy.

3.2 Fiber Modal Distribution

In multimode fibers, some light rays travel straight down the axis of the fiber while all the others wiggle or bounce back and forth inside the core-In step index fiber, the off axis rays, called "higher order modes" bounce bac:kand<forth from core/cladding boundaries as they are transmitted downthe fiber. Since these high ordermodes travera longer distance than the axial ray, they are responsible for the dispersion that limits the fiber's bandwidth.

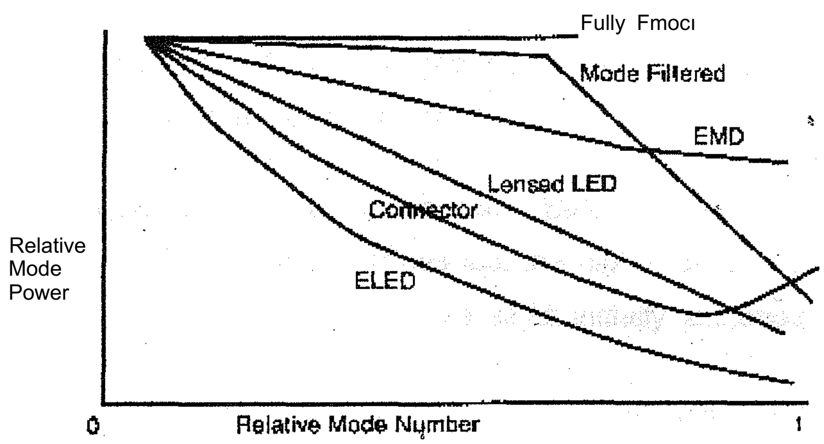


Figure 3.4 Fiber Modal Distributions

:In graded index fiber;the reduction of the index of refraction of the core as one approaches the cladding causes the higher order modes to follow a curved path that:is ıongerthah the axial ray (the "zero order mode"), but by virtue of the ıower:index of refraction away from the axis, light speeds up as it approaches the cladding and it takes approximately the same time to travel through the fiber. Thus the "dispersion° or variations in transit time for various modes, is minimized and bandwidthof the fiber is maximized.

However, the fact that the higher order modes travel farther in the"glass core means thatthey. haver a greater likelihood of being scattered or absorbed, the two .primarycauses *:of* attenuation in optical fibers. Therefore, the higher order rrıodes Will have greater attenüation than lower order modes, and.a long length.Of fiber that was:fully filled (all rriôdes had the same pôwerlevel launched into them)wiU have a lower amount of p.owerin· the higher order modes than will a short length of the same fiber.

"'IThis; change in "modal distribution" between long and short fibers can be describedas a ".transientloss", and can make big differences in the measurements one;makeswith the 'fiber. It· not only changes the modal distribution,·it changes·the effective core diameter and numerical aperture also.

The·.. term· "equilibrium modal distribution" (EMO) is used to describe the modal distribution ih a long fiber which has lost the higher order modes'.'A "long" fiber is one in EMO, while a "short' fiber has all its initially launched higher order modes.

3.2.1 WhatDoes System Modal Distribution Lookt ..ike?

System modal distribution depends on your source, fiber, and the intermediate"components"such as connectors, couplers and switches,·all of which affect tne: modahdistributionof fibers they connect. Typical rrıôdaldistributions for various fiber optic components are shown here.

rn the laboratory, a critical optical system is used to fully fill the fiber modes and a "mode filter", usually a mandrel wrap which stresses the fiber and increases loss for the higher order modes, is used to simulate EMO conditions. A "mode scrambler", made by fusion splicing a step index fiber in the graded index fiber near the source can also be used to fill all modes equally.

In a system, such controlled conditions obviously do not exist. In fact some work presented by Corning at a recent EIA Standards meeting shows how far the real world is from what we expected it to be.

It has been accepted as "common knowledge" that microlens LEDs (as used with most multimode datacom systems) overfill fibers, and when we use them as test sources, we are testing with an overfilled launch. Not so. Tests ()rl niiCrdıehs LEDs indicate that they underfill compared to EMO. And edge-emitter LEDs, typical of the high speed emitters at 1300 nm, concentrate their power even more into the lower order modes.

Other facts that come out of the Corning project shows that connectors mix some power back into the higher order modes due to angular misalignment and switches strip out higher modes. In a simulated FOOi system usin.g 8 fiber optic switches and 20 pairs of connectors, with fiber lengths of 1 0 to 50 meters between them, the majority of system power was concentrated in the lower order modes.

What conclusions can we draw? The most significant conclusions are that it may not be prudent to design datacom and LAN systems on the worst-case loss specifications for connectors and switches. In actual operation, the simulated system exhibited almost 15 dB less loss than predicted from worst case component specifications (obtained with fuUy filled launch conditions).

And, when testing systems, using a LED source similar to the one used in the system and short launch cables may provide as accurate a measurement as is possible under more controlled circumstances, since the LED approximates the system source. Alternately, one may use a mode modifier or a Fotec universal launch cable (ULC) to establish consistent modal distributions appropriate for testing the cables.

Relative Modal Distribution of Multimode Fibers: Sources and Mode Modifiers

A fully filled fiber means that all modes carry equal power, as shown by the line across the top of the graph. A long length of fiber loses the higher order modes faster, leading to the gently sloping "EMO" curve. Mode filtering strips off the higher order modes, but provides only a crude approximation of EMO. The rnicrolensed LED , often thought to overfill the modes, actually couples most of its power in lower order modes. The ELED (edge-emitting LED) couples even more strongly in the lower order modes. Connectors are mode mixers, since misalignment losses cause some power in lower order modes to be coupled up to higher order modes.

3.2.2 The Effect on Measurements

If you measure the attenuation of a long fiber in EMO (or any fiber with EMDsimulated launch· conditions) and compare it to a normal fiber with "overfill launch conditions" (that is the source fills ail the modes equally), you will find the differ~nce is about 1 dB/km, and this figure is the "transient loss". Thus, the EMO fiber, measurement gives an attenuation that is 1 dB per Km less than the overfill conditions.

Fiber manufacturers use the EMO type of measurement for fiber because it is more reproducible and is representative of the losses to be expected in long lengths of fiber.

But with connectors, the EMO measurement can give overiy optimistic results, since it effectively represents a situation where one launches from a smaller diameter fiber of lower NA than the receive fiber, an ideal situation for low connector loss.

The difference in connector loss caused by modal launch conditions can be dramatic. Using the same pair of biconic or SMP.. connectors, it is possible to measure 0.6 to 0.9 dB with a fully filled launch and 0.3 to 0.4 dB with a EMO simulated launch. Which is a valid number to use for this connector pair's loss ?

That depends On the application. If you are connecting two fibers near a LED source, the higher value may be more representative, since the launch cable is so short. But if you are connecting to a cable one km away, the lower value may be more valid.

3.3 Mode Conditioners

There are three basic "gadgets" to condition the modal distribution in multimode fibers:

Mode stripperswhich remove unwanted cladding mode light,

Mode scramblers which mix modes to equalize power in all the modes,

Mode filters which remove the higher order modes to simulate EMO or steady state conditions.

3.31 Cladding Mode Strippers

Cladding mode strippers are used to remove any light being propagated in the cladding to insure that measurements include only the effects of the core. Most American fibers are "self.stripping"; the buffer is chosen to have an index of refraction that will promote the leakage of light from the cladding to the buffer.. If you are using at least 1 meter of fiber, claddihg modes will probably not be a factor in measurements. One can easily tell if cladding modes area factor. StarfWith 10 meters of fiber coupled to a source and measurethe pôwertrarısmitted through if Cut back to 5 meters and then 4, 3, 2, and 1 meter, measuringfüe:powerat every cutback. The loss in the fiber core is very srnaıl in 10 meters;abôüf<0.03.. 0.06 dB. But if the power measured increases rapidly, the additiôhaF'Uğhtmeasl.lred is cladding light, which has a very high attenuation, and a cladding>modestripper is recommendedfor accurate measurements if short lengths of fiber rtıl.Jsfbeiüsed.

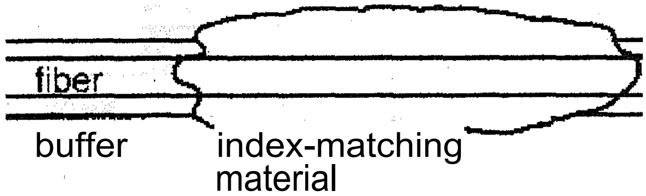


Figure 3.5 Mode Stripper

To make a cladding mode stripper, strip.off the fiber's buffer for 2 to 3 inches (50 to 75 mm) and immerse the fiber in a substance of equal or higher index of refraction than the cladding. This can be done by immersing the fiber in alcohol or mineral oil in a beaker, or by threading the fiber through a common soda straw and filling the straw with index matching epoxy or an optical gel (Note: stripping the buffer away from the end of a fiber is easily done, using a chemical stripper. If the fiber cannot be chemically stripped, like those with Teflon buffers, check with the fiber manufacturer for instructions.) A caution. Do not stress the fiber after the mode stripper, as this will reintroduce cladding modes, negating the effects of the mode stripper. Mode stripping should be done last if mode scrambling and filtering are also done on a fiber under test.

3.3.2 Mode Scramblers

Mode scrambHngis an attempt to equalize the power in all modes, simulating a fully filled launch. This should not be confused With a mode filter which simulates the modal distribution of a fiber in equilibrium modal distributiôrr(EMD). Both may be used together sometimes however, to properly simulate test conditions. Mode scramblers are easily made by fusion (or mechanical) splicing a short piece of step index fiber in between two pieces of graded index fiber being tested. One can also use methods that produce small perturbations on the fiber, such as running the fiber through a tube of lead shot. But these scramblers are difficult to fabricate and calibrate accurately. In the laboratory, they are usually unnecessary, since accurate launch optics are used to produce fully filled launch conditions.

Figure 3.6 Mode Scrambler

3.3.3 Mode Filters

Mode filters are used to selectively remove higher order modes to attempt to simulate EMD conditions, assuming that one starts with fully filled modes. Higher order modes are easily removed by stressing the fiber in a controlled manner, since the higher order modes are more susceptible to bending losses.

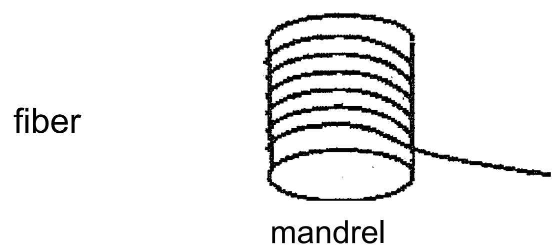


Figure 3.7 Mode Filter

The most popular mode filter is the "mandrel wrap", where the fiber is snugly wrapped around a mandrel several times. The size of the mandrel and the number of turns will determine the effect on the higher order modes. Other mode filters can be made where the fiber is subjected to a series of gentle S bends, either in. a form or by wrapping around pins in a plate or by actually using a long length of fiber attached to an overfilling source.

3.4 Bending Losses

Fiber and cable are subject to additional losses as a result of stress. In fact, fiber makes a very good stress sensor. However, this is an additional source of uncertainty when making attenuation measurements. It is mandatory to minimize stress and/or stress changes on the fiber when making measurements. If the fiber or cable is spooled/it will have higher loss when spooled tightly. It may be advisable to unspoolifarid respool with less tension. Unspooled fiber should be carefully placed Off a bench and taped down to prevent movement. Above all, be careful about how connectorlzed fiber is placed. Dangling fibers that stress the back of the connectorwill have significant losses.

3.4.1 Transmission vs. OTDR tests

So far; we have only discussed testing attenuation by transmission of light from a source, butone can also imply fiber losses by backscattered light from a source using an optical time domain reflect meter (OTOR).

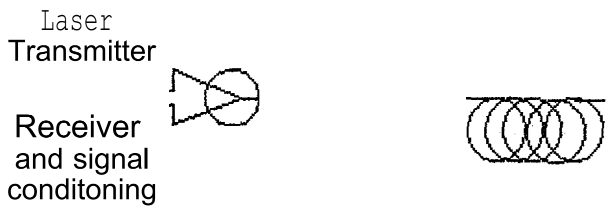


Figure 3.8 Transmission vs. OTOR tests

OTDRs are widely used for testing fiber optic cables. Among ~the common uses are measurin'gthe le·ngth of fibers, finding faults in fibers, breaks in cables, att~nuation offibers, and losses in splices and connectors. They are also used to optimize splices by monitoring splice loss. One of their biggest advantages is they produce a picture (called a trace) of the cable being tested. Although OTDRs are unquestionably useful for all these tasks, they have error mechanisms that are potentially large, troublesome and not widely understood.

The OTDR uses the lost light scattered in the fiber that is directed back to the source for its operation. Itcouples a pulse from a high poweredJaser source into the fiber througn a directional coupler. As the pulse of light pasşes through the fiber, a small fraction utthe light is scattered back towards the source. As it returns to, the OTDR, it is directecfby the coupler to a very sensitive receiver. The OTDR display shows the intensity of the returned signal in dB as a function of time, converted into distance using the average velocity of light in the glass fiber.

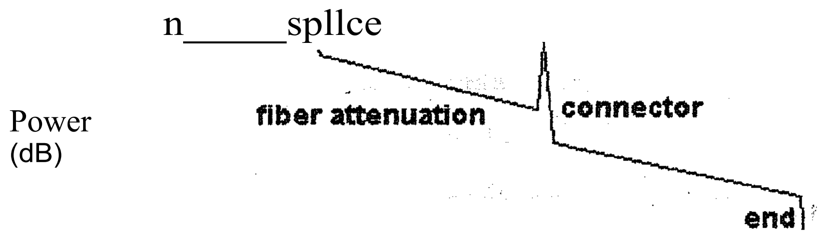


Figure 3.9 Distances

To understand how the OTDR arıows measurement, consider what happens to the light pulse it transmits. As it goes down the fiber, the pulse actually "fills" the core of the fiber with light for a distance equal to the pulse width transmitted by the OTDR. In a typical fiber, each nanosecond of pulse width equals about 8 inches (200 mm). Throughout that pulse, light is being scattered, so the longer the pulse width in time, the greater the pulse length in the fiber and the great~r will be the amount of backscattered light, in direct proportion to the pulse width. The intensity of the pulse is diminished by the attenuation of the fiber as it proceeds down the fiber, a portion of the pulse's power is scattered back to the OTDR and it is again diminished by the attenuation of the fiber as it returns up the fiber to the .OTDR. Thus the intensity of the signal seen by the OTDR at any point in time is a function of the position of the light pulse in the fiber;.

By looking at the reduction in returned signal over time, one can calculate the attenuation coefficient of the fiber being tested. Since the pulse travels öutand back, the attenuation of the fiber diminishes the signal in both directions, and the transit time from pulse out to return is twice the one way.trav1=.ı tirne. S9 bPth the intensityand distance scales must be divided by two to allow for .the· roundwtrip path of the light.

If the fiber has a splice or connector, the signal will be diminished as the pulse passes it, so the OTDR sees a reduction in power, indicating the light loss of the joined fibers. If the splice or connector reflects light (see optical return loss), the OTDR will show the reflection as a spike above the backscattered signal. The OTDR can be calibrated to use this spike to measure optical return loss.

The end of the fiber wiU show .as a deterioration of the backscatter signal into noise, if it is within the dynamic range of the OTDR. If the end of the fiber is cleaved or polished, one will also see a spike above the backscatter trace. This allows one to measure the total length of the fiber beingtested.

In order to enhance the signal.to noise ratio of the received sig:naıı the OTDR sends out many pulses and averages the ·returned signals. And to get to longer distances, the power in the transmitted pulse is increased by widening the pulse width. The longer pulse width fills a longer distance in the fiber as we noted above. This longer·pulsewidth masks all details within the length of the pulse, increasing the minimum distance between features resolvable with the OTDR.

3.4.2 Bandwidth

Fiber's information transmission capacity is limited by two separate components of dispersion: modal and chromatic. Modal dispersion occurs in step index multimode fiber where the paths of different modes are of varying lengths. Modal dispersion also comes from the fact that the index profile of graded index (GI) multimode fiber isn't perfect. The graded index profile was chosen to theoretically allow all modes to have the same gföup Velocity or transit speed along the length of the fiber. By making the outer parts >of the core a lower index. of refraction than the inner parts of the core, the highef ôfder rnôdes speed up as they go away from the center of the core, cotrıpeıısatiriğ for. their longer: path lengths.

In an idealized graded index fiber, all modes have the same groı..ıp velocity and no modal dispersion occurs. But in real fibers, the index·prôfile isia piecewise approximation and alF rıiodes are not perfectly fransmüted,: allôwiıg>sotrıe modal dispersion. Since the higher order modes have greater deviations, the modal dispersion of a fiber (and therefore its laser bandwidth) tends to bevery serısitive to modal conditions in the fiber. Thus the bandwidth of longer fibers degrades nonlinearlyas the higher order modes are attenuated more strongly.

The second factor in fiber bandwidth is chromatic dispersion. Remember a prism spreads out the spectrum of incident light since the light·travels at different speeds according to its color and is therefore refracted at different angles. The usual way of stating this is the index of refraction of the glass is wavelength dependent.Thus a carefully manufactured graded index mulfiı'rıodefiber can only be optimized for a single wavelength, usually near 1300 nm, and light of other colors will suffer from chromatic dispersion. Even light in the same mode will be dispersed if it is of different wavelengths.

Chromatic dispersion is a bigger problem with LEDs, which have broad spectral outputs, unlike lasers which concentrate most of their light in a narrow spectral range. Chromatic dispersion occurs with LEDs because much of the power is away from the zero dispersion wavelength of the fiber. High speed systems like FDDI, based on broad output surface emitter LEDs, suffer.such intense chromatic dispersion that transmission over only two km of 62.5/125 fiber can be risky.

3.5 Fiber Optic Standards

Accurate test and measurement always re~uires.is.~~;d~tdtestmethods .and good calibration standards. In fiber optics,,this means standardized test procedures for optical loss of fibers, cables, connectors arıcJ splices under many varying environmental conditions. Primary and transferis~rl~~r.d~ .for optical power, attenuation, bandwidth and the physical characteristics of fiber are also required.

These standards are developed by a variety of groups working together. Testing standards primarily come from the EIA in the US (Electronics Industries Assoclaüon), internationally from the IEC (International Electrotechnicaı

Commission), and other ğrôüps worldwide. Primary and transfer standards are developed by national standards laboratories such as NIST (National Institutes of Standards and Technology, formerly the US National Bureau of Standards) which exist in almost all countries to regulate all measurement standards. International cooperation is available to insure worldwide conformance to all absolute standards.

We can also discuss "de facto" standards", those generally accepted standards for components and systems that developed because there weren't any de jur standards yet and everyone accepted the work of a supplier, In fact, we want to discuss all of those and their status in today's fiber optic systems.

3.5.1 De Facto Standards Come First

In any fast developing technology like fiber optics, there is always resistance for developing standards. Critics say standards stifle technology development. Some critics object because it's not their standard that is proposed, and in some cases, nobody really knows what standards are best. Under these circumstances, users choose the best solutions for their problems and forge ahead.

In fiber optics, those who have gone ahead and committed heavily to the technology or who have marketing strength have established many of the standards for today. Thus most fiber optic telecom systems in the US are based on single mode fiber and 1300 nm lasers, These components offer the best soluüon for- the application, and had the largest suppliers and users behind them, so they became dominant. Overseas the government- controlled telecom authorities generally dictate the system configurations, but only the connectors seem to differ, with each country choosing its own national suppliers. The IEC has voted to recommend the SC style connector, which has already been adopted by several US telcos, but the singlemode ST and the FC connector still have their supporters.

In teıecom systems, there are many types of systems büta.11 are operating on singlemode fiber at 1300 or 1550 nm wavelengths. Bit rates of 1.544 Mbits/S up to 2.5 Gbits/S are already in operation, with up to higher rates promised. Today, there is virtually no compatibility between manufacturers of terminal equipment, but

SONET (Synchronous ©ptical Network) or SDH (Synchronous Digital Hierarchy) promises to relieve some ofthe system incompatibilityin tefecommunications.

In datacom systems (the generic category that includes datalinks and LANs), the situation is reaching consensus. Four multimode fibers have been used in datacom systems: 50/125, 62.5/125, 85/125 and 100/140 {core/clad in microns), but 62.5/125 fiber has become dominant. It was chosen as the preferred fiber for FOOi and ESCÖN, and the US government is using 62.5/125 in offices exclusively (FED STD 1070). Connectors have often been SMA, but AT&T's ST is now the muttimode connector of choice. Most datacom systems need a duplex connector, but so far none has become widely acceptable. Perhaps the FOOi connector will become the duplex standard. While short wavelength LED (820-850 nm) systems have been most popular to date, the higher bit rates of newsystems are requiring 1300 nm LED's due to the limiting effects of chromatic dispersion in the fiber. Higher speed standards like Fiber Channel will probably be based on singlemode fiber and 1300 nm lasers to accommodate the GB/s speeds of these networks.

3.5.2 Industry Standards Activities

In iight of these de facto standards, many groups are working to develop standards that are acceptable throughout the industry.

3.5.3 Primary Standards

The keeper of primary standards in the US is the Dept. of Commerce, National Institute of Standards and Technology (NIST). Although. some pptical standards work is done at Gaithersburg, MD, fiber .optic and laser activity is centered at Boulder, C©. Today, NIST is actively working.with all standards bodies to determine the primary reference standards needed and provide for them. With fiber optics applications, their concern has been with fiber measurements, such as attenuation and bandwidth, mode field diameter for single mode fiber, .and optical power measurements.

NIST standards. are in place for fiber attenuation and optical power measurements, the most important measurement in fiber optics. Since all other measurements require measuring power, several years ago NIST ran a "round-robin" which showed up to 3 dB differences (50%) in power measurements among participants. A optical power calibration program at NIST has resulted in reliable transfer standards at 850, 1300 and 1550 nm. Using new transfer standards, measurements of better than 5% accuracy should be easily obtained.

3.5.4 Component and Standards

Several bodies are looking at fiber optic testing standards, but the most active by far is the Electronic Industries Association. EIA F0-6 and F0-2 committees meet at least twice a year to discuss technical issues and review progress on the writing of standards test procedures and component specifications. At the current time, there are over 100 EIA FOTPs (fiber optic test procedures) in process or published and many component specifications are being prepared. The EIA publication "Component Bulletin 9F" provides a full summary of all EIA FOTP activity with cross references.

Besides being a standards writing body, the F0-6 and F0-2 committees are a forum for the discussion of technical issues, relevant to the FOTPs befng prepared, and are sometimes scenes of heated debate over these issues. But real progress is being made in defining relevant tests for fiber optic component and system performance.

Another body active in fiber optic standards is the US Dept. of Defense (DOD.) 'ihrough DESC (the Defense Eleçtronics Supply Center in Dayton, OH), they are evaluating the EIA work for applicability in the DOD and adopting or changing standards as needed. With the magnitude of the fiber optic projects in the military and government today, the DESC project has become very important. Fiber has such high priority at the NAVY, they are funding a project (NAVSEA 56ZC) to assess the standards requirements of the NAVY for the foreseeable future and develop those standards.

Within the I..JS}!Bell Communications Research (Bellcore), the spin-off R&D organization for the divested RBOCs (Regional Bell Operating companies), sets standards for its RBOCs by issuing Technical Advisories (TAs) on subjects of mutual interest. Bellcore is working on specifications covering cable, connectors and test equipment, as well as a variety of other fiber optic equipment. Work regarding transmission equipment standards is also being considered.

Internationally, almost every country has its own standards bodies, but most work through the IEC (International Electrotechnical Commission) to produce mutually acceptable standards. The IEC work is at least as large in scope as the EIA.

3.5.5 System Standards

Very few standard fiber optic systems have been proposed to date. Most systems are compatible to some electrical standards, such as T-3, RS-232, etc., but each manufacturer uses their own protocol on the optical part of the network. As a result, there is little-current compatibility in fiber optic systems. Even in telephone, fiber optic links developed as adapters for standard T-carrier systems, so each manufacturer used their own protocol. Bellcore has been working on developing SONETand CCITT works on SDH to provide a standard protocol for telephony.

Work is being done by ANSI and the IEEE on developing standard systems for computer networks. The ANSI FOOi (Fiber Distributed Data Interface, X3T9.5 committee) is a high bit-rate system for computer network that is reaching commercial reality. Another ANSI committee, X3T9.3, is working on the even faster Fiber Channel (not FIBER !) specification for GB/s datacommunicatlons. The IEEE considerations include a token-ring LAN (802.5), metropolitan area LAN (802.6) and fiber versions of Ethernet (802.3).

3.6 **Optical Power**

The most basic fiber optic measurement is optical power from the end of a fiber. This measurement-ls the basis for loss measurements as well as the power from a source or at a receiver. While optical power meters are the primary measurement instrument, optical loss test sets (OLTSs) and optical time domain reflectometers (OTDRs) also measure power in testing loss. EIA standard test FOTP-95 covers the measurement of optical power.

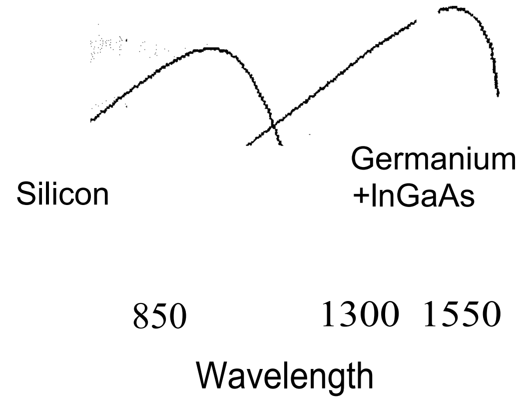
Optical power is based on the heating power of the light, and some instruments actually measure the heat when light is absorbed in a detector. While this may work for high power lasers, these detectors are not sensitive enough for the power levels typical for fiber optic communication systems. Table 1 shows typical power levels in fiber optic systems.

Table 3.1 Optical power levels of fiber optic communication systems

Network Type	Wavelength, nm	Power Range, dBm	Power Range, W
Telecom	1300, 1550	+3 to -45 dBm	50nWto2mW
Datacom	665,790,850, 1300	-10 to -30 dBm	1 to 100uW
CATV	1300,1550	+10 to-6 dBm	250 uW to 1OmW

Optical power meters typically use semiconductor detectors since they are extremely sensitive to light in the wavelengths common to fiber optics. Most fiber optic power meters are available with a crioıce of 3 different detectors, silicon (Si), Germanium (Ge), or Indium-Gallium-Arsenide{lnGaAs).

Silicon photodiodes are sensitive to light in the range of 400 to 1000 nm and germanium and indium-gallium-arsenide photodiodes are sensitive·to light in the range of 800 to 1600 nm.



Figuer3.10 Sensitivity of Detectors

Silicon detectors are very low noise detectors sensitive to light at approximately 400 to 1100 nm wavelength, depending on the exact method of fabrication. Thus, they are useful for standard datacom links using 820 nm LEDs and glass fiber or 665 nm LEDs and plastic fiber. They can also be used with older telecom systems that used 850 nm lasers. Silicon detectors have inherently low noise, low leakage currents and therefore very low noise floors when used with transimpedance amplifiers in power meters. Typical noise floors on fiber optic instruments using Si detectors are -70 to -90 dBm, or about 1 to 100_picowatts.

Germanium detectors are sensitive to light in the 800 to 1800 nrri wavelength, making them useful for all systems using glass fiber, including 1300 and 1550 nm single mode systems. Ge detectors are noisier however, creating a higher noise floor for low level measurements. This noise is proportional to detector area, so by using a smaller detector, one obtains a lower noise floor. However, smaller detectors require positioning the fiber end very close to the window of the detector and centered accurately over the detector eenslnve area. The noise·of a 2 mm Ge detector is typically 10 to 50 times lower than room temperature 5 mm Ge detectors.

Some manufacturers of fiber optic power meters have chosen to cool these large Ge detectors to reduce the noise and get lower measurement limits. This leads to more sensitive measurements but with a penalty of increased circuit complexity, .instrumel'Ifweighfand short battery life, since one must provide up to 1 amp current to thettıermôelectric cooler in the Ge detector package.

Another .solution for extremely low level measurements at 1300 and 1550 nm is to utilize In.GaAs detector technology, , which has been developed for the receivers of high speed !ong wavelength communication systems. InGaAs detectors have the same sensitivity range as Ge, but are much less noisy. With InGaAs detectors, measurements can be made to -65 dBm (less than 0.5 nW) with ease. However, InGaAs detectors are very expensive, limiting their usage to only the most expensive instruments.

Table 3.2 Characteristics of detectors used in Fiber Optic Power Meters

Detector Type	Wavelength Range (nm)	Power Range (dBm)	Comments
Silicon	400-1100	+10 to -70	
Germanium	800-1600	+10 to-60	-70 with small area detectors, +30 with attenuator windows
InGaAs	800-1600	+10 to -70	Small area detectors may overload at high· power (.0 dBm)

3.6.1 Calibration

Calibrating fiber optic power measurement equipment requires setting up a reference standard traceable to the US National Institute of· Standards and Technology for comparison purposes while calibrating every power meter or other instrument. The NIST standard for all power measurements is an ECPR, or electrically calibrated pyroelectric·radiometer, which measures optical power by comparing the heating power .Qf me light to the well-known heating power of a resistor. Calibration is done at 8.50, 1300 and 1550 nm. Sometimes, 1310 nm is used, a holdover from the early 1980s when the telcos and AT&T used 1310 nm as a standard, but. today the standard is 1300 nm. To conveniently transfer this measurement to fiber optic power meter manufacturers calibration laboratories, NIST currently uses.a Hewlett-Packard laboratory type optical power meter with a cooled germanium detector.

To transfer from this transfer standard to production instruments, power meter manufacturers use calibrated detectors or power meters which are regularly checked against one another to detect any one detector's.varlabüity, and all are periodically recaJibrated to NIST's transfer standards.

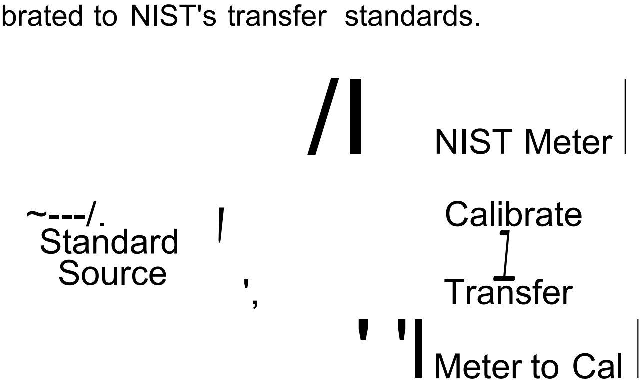


Figure 3.11 Calibrations Traceable to NIST

In order to transfer the calibration, one needs a source of known characteristics. Typically laser sources at 850, 1300 and 1550 nm pigtailed to single mode fibers are used. The laser sources have very narrow spectral width to allow accurate wavelength calibration, and the single mode fiber controls the output beam presented to the detector of the instrument. Each of these sources is checked for wavelength regularly to insu~ that no drift has occurred. The output power of these lasers is precisely controlled by an optical feedback circuit to insure stability. Even the temperature of the laser is often controlled precisely to insure no drift in output power or wavelength occurs during the calibration process.

Using the sources described above, one measures the output of one of the lasers on a standard meter or detector andrecord the value. The instrument under test is then adjustşd/Jpfead the same value as the standard detector and a single point calibration is dqoe.

for ali power meters, especially those with autoranqinç, one must calibrate on every range, double checking to insure that the meters ilave a smooth transition between ranges to prevent calibration discontinuities. Calibration is therefore checked at several points near the top and bottom of the range for every meter.

Meters calibrated in this manner have an uncertainty of calibration of about +/- 5%, compared *to* the NIST primary standards. Limitations in the uncertainty are the inherent inconsistencies in optical coupling, about 1% at every transfer, and siight variations in wavelength calibration. NIST is working continuously with instrument manufacturers and private calibration labs to try to reduce the uncertainty of these calibrations.

Recalibration of instruments should be done annually, however experience has shown that the accuracy of meters rarely changes significantly during that period, as long as the electronics of the meter do not fail. Unfortunately, the calibration of fiber optic power meters requires considerable investment in capital equipment and continual updating of the transfer standards, so very few private calibration !abs exist today. Most meters must be returned to the originai manufacturer for calibration.

3.S.2 Understanding *FO* power meter measurement uncertalnty

Much attention has been paid to deveioping transfer standards for fiber optic power measurements. The US NIST in Boulder, Colorado and standards organizations of most other countries have worked to provide good standards to work from. \Ne can now assure traceability for our calibrations, but even so tile errors involved in making measurements are substantial. Understanding those errors and their probable causes wi!l ınsurs a realistic viewpoint on fiber optic power measurements.

The first source of error is optical coupling. Light from the fiber is expanding in a cone. it is important that the detector to fiber geometry be such that all the iight from the fiber hits detector, otherwise the measurement wi!l be lower than the actual value. But every time light passes through a glass to air interface, such as the window on the detector, a small amount of the light is reflected. Some is lost, but some can be re-reflected by the polished end surface of the connector back into the detector, the amount dependent on the type of connector and the quality of its polished surface. And although detectors have an antireflection coating, some light is reflected from the detector surface, which can be re-reflected from the window, connector, etc. Finally, the cleanliness of the optical surfaces involved can cause absorption and scattering. The sum total of these potential errors will be dependent on the connector type, wavelength, fiber size and NA.

Beyond the coupling errors. one has errors associated with. the wavelength calibration. Semiconductor detectors used in fiber optic instruments (and systems too) have a sensitivity that is wavelength dependent. Since the actual source wsvelerıçın is rarely known, there is an error associated with the spectra! sensitivity of the detector. By industry convention, the three cardinal wavelengths .(850, 1300 and 1550 nm) are used for all power measurements, not the exact source 'vavelenqth. The source has a finite spectrai width, verı narrow for lasers, quite broad for a LED. !n order to accurately measure the power of the· source, one needs to know the spectral power distribution of the actuat source being measured, the sensitivity of the detector and perform a complicated integration of the two.

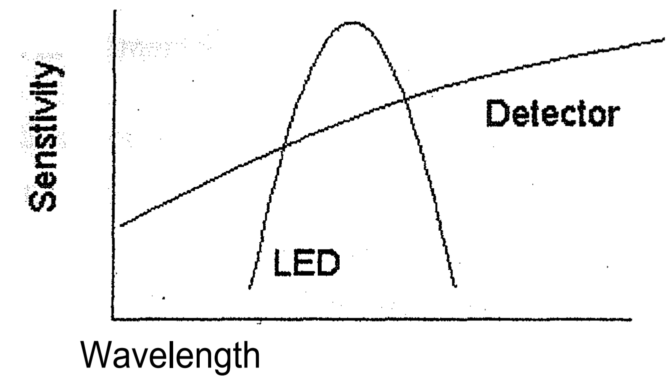


Figure 3.12 Spectral Sensitivity Errors

Another source of error exists for high and low level measurements.Athigh levels, the optical power may overload and saturate the detector, caüsiııg<the measurement to be in error on the IOW >side. Consistent overload may even permanently damage the detector, especially with small area detectors. This is particularly a problem with CATV systems, where the transmitter power is extremely high to get good signal to noise performance at the receiver. CATV power levels are high enough to damage the detector in many power meters, especially those with small area InGaAs detectors. Specialized CATV meters exist where the detector window has been replaced by a calibrated attenuator of approximately 20 dB. Thus they can make measurements at high power levels, up to +20 or +30 dBm, but sacrifice low level power measurements.

At low levels, the inherent detector noise adds to the signal and becomes an error.. ff the signal is 10 dB above the noise floor (10 time the noise), the offset error is 10% or 0.4 dB. Fotec has always specified the measurement range of its fiber optic power meters as 10 dB abeve the noise. floor, but at least one manufacturerspecifies it as only 3 dB, which can cause an errorof50%!

Even when two FOPMs are calibrated within specifications, the uncertainty may be+/- 5% (about 0.2 dB) on each meter. A worst case ~cen~tio could have two metersdeviatingfrom nominal in opposite directions, leading to a potential 10% (0.4 dB) error when measuring the same source and fiber combination. A similar error can occur in a P©PIVI When amplifiers autorange, unless the manufacturer includes a balanceadfustmentfor calibration of the meter.

When one considers why F© power is measured (determining source output or receiver power to determine if a system in within margin or measuring loss}, the impact of errors becomes apparent. But without knowing the system source spectral output, system detector spectral sensitivity and the spectral attenuation characteristics of the fiber, one cannot accurately predict system performance anyway.

How does one cope with all this uncertainty? On short systems, design the system with adequate margin. On long systems, specify system and test source wavelength and test the cable at that wavelength (or correct for variations in system sources and test source Wavelengths.) And remember that the error in optical power measurement may be small to the unknown variations in system components.

Fiber optic components are sensitive to physical stress which can induce loss. One can see the effects of physical movement of fiber optic cables and connectors on fiber optic assemblies. A simple bend in singlemode fiber cable can induce several dB losses. All connectors are very sensitive to forces acting ön the cable as it exits the backshell. Just handling fibers to make measurements can cause readings to vary by several tenths of dB.

3.6.3 Instrument Resolution vs. Measurement Uncertainty

Considering the uncertainty of most fiber optic measurements, instrument manufacturers have provided power and loss meters with a measurement resolution that is usually much greater than needed. The uncertainty of optical power measurements is about 0.2 dB (5%), loss measurements are more likely to have uncertainties of 0.5 dB or more, and optical return loss measurements have a 1 dB uncertainty. Instruments which have readouts with a resolution of 0.01 dB are generally only appropriate for laboratory measurements of very low losses such as connectors or splices under 1 dB or for monitoring small changes in loss or power over environmenta!Chariges Within the laboratory, a resolution of 0.01 dB can be extremely useful, sirıce one often measures the loss of connectors or splices that are under 0.1 0 dB ör changes in loss under environmental stress that are under 0.1 dB. *Stability* of sources and physical stress on cables limits measurement uncertaintyto about Ö.02 to 0.05 dB per day, but 0.01 dB resolutions can be helpful in determining small changes in component performance.

Field instruments are better when the instrument resolution is limited to 0.1dB, since the readings will be less likely to be unstable when being read and more indicative of the measurement uncertainty and especially important since field personnel are usually not as well trained in the nuances of measurement uncertainty

3.6.4 Non-Intrusive Power Measurements

Since one can induce loss in the fiber or cable by bending it, this lost power can be measured. By using a clip-cm detector, such as used in fiber identifiers, the induced loss can be measured. However, the uncertainty of the measurement is very high, due to the uncertain percentage of the power in the fiber that will be coupled out of the core by the induced stress, the amount Of pöwer thafwfübe transmitted through the buffer of the fiber (especially with colored buffers) aııtfthe jacket of the fiber. Thus this type of measurement is only used as a qualitative indicatorof systems power presence, not quantitative measure of system power.

4. NETWORKING

4.1 Fiber Optic Data Links

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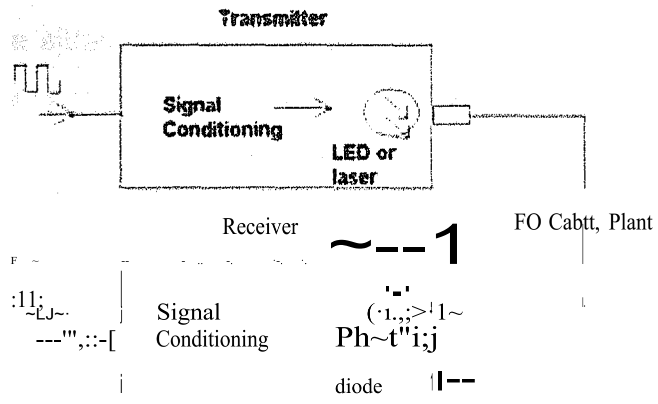

Figure 4.1 Fiber optic Link

Fiber optic transmission systems all work similar to that shown above. They consist of a transmitter which takes an electrical input and converts it to an optical output from a laser diode or LED. The light from the transmitter is coupled into the fiber with a connector and is transmitted through the fiber optic cable plant. The light is ultimately coupled to a receiver where a detector converts the light into an electrical signal which is then conditioned properly for use by the receiving equipment. Just as with copper wire or radio transmission, the performance of the fiber optic data link can be determined by how well the reconverted electrical signal out of the receiver matches the input to the transmitter.

The ability of any fiber optic system to transmit data ultimately depends on the optical power at the receiver as shown below, whith shows th~ data link bit error rate as a function of optical power at the receiver. Either töölitı:le ôrtôô much power will cause high bit error rates. Too much power, ahdthe>füceivefaföplifıer saturates, too little and noise becomes a problem. This receiver pdwefdepehds on two basic factors: how much power is launched into the fiber by the tfahsföitter and how much is Jost by atterıuatiôrı in the optical fiber cable that [illegible] the transmitter and receiver.

Datalinks can 0e either analog or digital in nature. Both have some common critical parameters andsorne major differences. For both, the optical loss margin is most important.This is determined by connecting the link up with an adjustable attenuator in the cable plant.and varying the loss until one can generate the curve shown below. Analog datalinks will be tested for signal to noise ratio to determine link margin,while digitaLlinks use bit error rate as a measure of performance. Both ünks.require testing over the full bandwidth specified for operation, but most data linksare now·.specifiecFfôta specific network application, like AM CATV or RGB color monltorsJor analogJinks and SONET, Ethernet, FOOi or ESCON for digitaf links.

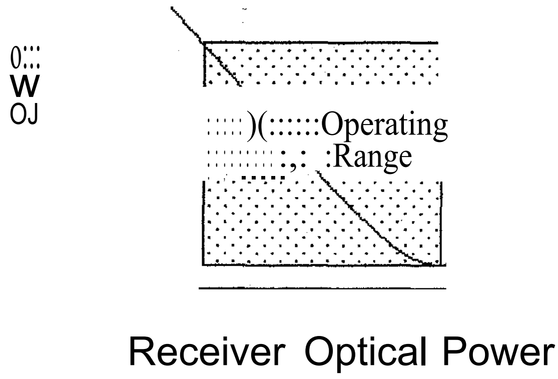

Figure 4.2 ·BER of Fiber Optic Link

The optical power margin of the link is determined by two factors, the sensitivity ofthe receiver, which is determined in the bit error rate curve above and the output power of the transmitter into {be fiber. The minimum power level that produces an acceptable bit error rate determines the sensitivity the receiver. The power from the transmitter coupled into the optical fiber determines the transmitted power. The difference between these two power levels determines the loss margin of the link. If the link is designed to operate at differing bit rates, it is necessary to generate the performance curve for each bit-rate. Since the total power in the signal is a function of pulse width and pulse width will vary with bit-rate (higher bit-rates means shorter pulses), the receiver sensitivity will degrade at higher bit-rates.

Every manufacturer of datalinks components and systems specifies them for receiver sensitivity .(perhaps a minimum power required) and minimum power coupled into the fiber from the source. Typical values for these parameters are shown in Table 7.1. In order to test them properly, itIs necessary to know the test conditions. For data link components, it includes input frequency or bitrate and duty cycle, power supply voltages and the type of fiber coupled to the source. For systems, it will be the diagnostic program needed by the system.

Table 4.1 Typical Fiber optic link/system performance parameters

Link type	Source/Fiber Type	Wave-length (nm)	Transmit Power (dBm)	Receiver Sen-sitivity (dBm)	Margin (dB)
Telecom	laser/SM	1300	+3 to -6	-40 to -45	34 to 48
		1550	0 to -10	-40 to -45	40 to 45
Datacom	LED/MM	850	-10 to -20	-30 to -35	10 to 25
		1300	-10to-20	-30 to -35	10 to 25
CATV(AM)	laser/SM	1300	+10 to 0	0 to -10	10 to 20

Within the datacommunications links and networks, there are many vendor specific fiber optic systems, but there are also a number of industry standard networks. These networks have agre~d upon specifications common to all manufacturers' products to insure interoperability. Table 7.2 shows a summary of these systems.

Table 4.2 Fiber Optic Datacommunications Networks

Network	IEEE802.3 FOIRL	IEEE802.3 10baseF	IEEE802.5 Token Ring	IEEE802.3 100base-FX	ANSI X3T9.5 FOOi	ESCON IBM
Bitrate (Mb/s)	1	10	4/16	100	100	200
Architecture	Lirik·.	Star	Ring	Star	Ring	Branch
Fiber Type	MMi62'.5	MM. 62.5	MM, 62.5	MM,62.5	MM/SM	MM/SM
Link Length(km)	2	-	-	2	2/60	3/20
Wavelen~th (nm).	850	850	850	1300	1300	1300
Margin (dB,MM/SM)	8	-	12	11	11/27	8*{11)/16
Fiber BW{MHz~km)	150.·:	150	150	500	500	500
Connector	SMA.	ST	FOOi	SC/ST	FOOi	ESCON

*IBM specifies a nonstandard method of testing cable plant loss that reduces the loss to .8 dB,max. Hôwever, the component specifications are similar to FOOi, so testing to FOOi margins is appropriate.

4.2 Installing & Testing the Fiber Optic Cable Plant

:•-;ju7-+rc+--able ~- patch panel

/ \ work area outlet

Terminal equipment

trunk cable

Figure 4.3 Typical Building Cable Design

Typical fiber optic cable plants are composed of a backbone cable connecting patch panels and several short jumper cables which connect the equipment onto the cable plant Building and campus systems look like the figure above, where the backbone fiber is terminated in wiring closets and short jumpers connect wall outlets or directly to the equipment. These installations often have no splices at all, since distances are short. Telco cable plants look more like the figure below, where the cable runs are long, requiring splices every 2-4 km. In addition, the fibers are not terminated directly, but high quality factory made pigtails are spliced onto the backbone cable. The process of testing any fiber optic cable plant during and after installation includes all the procedures covered so far. To thoroughly test the cable plant, one needs to test it three times, before installation, each installed segment and complete end to end loss.

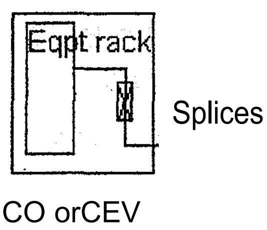

Figure 4.4 Outside Plant FO Cable Plant

One should test the cable on the reel for continuity before installing it, to insure no damage was done in shipment from the manufacturer to the job site. Since the cost of installation usually is high, often higher than the cost of materials, it only makes sense to insure that one does not install bad cable. If is generally sufficient to just test continuity, since most fiber is installed without contrectors and then terminated in place, and connectors are the most likely problem to be uncovered'by testing for ldss:.A.ftet installation and termination, each segment of the cable plant shouıct<betested individuaHyas it is installed, to insure each connector and cable is ~ood..

4.3 Testing Networks

Although fiber optic networks have .some major differences from copper-based networks, testing and troubleshooting them is actually very similar. The techniques can be easily mastered by technicians with some basic training in fiber optics and network testing. The basic procedures outlined below were originally developed by Fotec personnel in conjunction with the customer engineering groups of suppliers of fiber optic networks. These procedures have, therefore, been thoroughly field proven in thousands of installations.

4.3.1 Test Equipment Required

For all cables being tested, the equipment used will be a fiber optic test kit, which includes a fiber optic power meter and a LED or laser source. The source should be of the type and wavelength used· as transmitters in the network being tested. Instrument adapters provide the interface needed to the connectors used with the network. Reference test cables a~ needed as .ıa.ynch .and receive jumpers for testing the network cables, and a connector/coupling kit is required to interconnect the test jumpers with the cables to be tested.

4.3.2 Handling **and Cleaning Procedures**

Connectörs aı1a<ca6les should be handled with care. Do not bend cables too tightly, especially Heafffie côrınectors, as sharp bends can break the fibers. Do not drop the connectôfs,>asthey can be damaged by a blow to the opticalface. Do not pull hard on the cönnectors themselves, as this may break the fiber· in the backshellof the connector or cause pistoning if the bond between the fiber and the connectorferrule is broken.

If there is any question about the condition of the connectors, clean them before testing. A fiber optic inspection microscopewith appropriate stages to hold the connectors should be used to verify the condition of the connectors if there is any doubt about their cleanlinessor physical condition.

4.3.3 What Goes Wrong on FO Installations?

In assisting users in installing and testing FO networks, the first problem we routinelyencounter is incorrect fiber optic connections. A fiber optic link consists of two fibers, transmitting in opposite directions, to provide WII duplex communications. It is not uncommon for the transmit and receive·fibers to be switched, so you transmit to a transmitter and receive from a receiver, This doesn't work too well!

A visual tracer will make it easy to verify the·proper connections quickly. A visual tracer is a visible light that you shine down the fiber and use your eyeball to trace the fiber through the cables, patch panels, etc. tö the far end.

The tracer itself can be a flashlight (aıthoughit's really hard to hold the fiber in place to couple enough light to see it), a modlfled flashlighttor even microscope that will hold the fiber in place steadily and couple an adequate amount of power into the fiber, ora special test source using a bright redLEDilikethose used in plasticfiber links.c.(Do not worry about eye safety. The power level in these sources is not high enough to cause harm!)

The tracersicafıYallôwiyou to trace fibers up to 2-1/2 miles or 4 km: Besides tracing fıbers,.thestracericanbe used to check continuity and find broken fibers in cables. Another .füghly<recommended use is to check continuity of every fiber in multifiber cables before installation to insure all fibers are OK. Installing a cable with bad fibers caıtbe an embarrassing (and. expensive) proposition! Fiber.tracers are inexpensive and a valuable tool for every member of the installation crew.

There is also a more powerful tool available, a high power visible laser coupled to fiber, called a "visual fault locator" (or VFL). These use red lasers, either HeNe or diode lasers, with enough power to actually, show breaks in the fiber through the jacket of.the .fiber! They can also be used to optimize splices and splice type connectors for verification of proper termination.

4.3.4 The Installed Cable Plant

Fiber optic networks are always specified to operate over a range of loss, typically called thesystem margin. Either too much loss or too little loss can be a problem. If the loss is too high, the signal will be low at the receiver, causing a poor signal to noise condition in the receiver. ff the loss is too low, the power level at the receiver will be too high, causing receiver saturation. Both these .conotüons will cause high bit error rates in digital systems or poor analog signal performance.

Test the complete cable plant, including all individual jumper or trunk cables, Jor loss, using a power meter and source and the double-ended method described above in the chapter on testing the cable plant. Use the double-ended method, since .system margin specifications include the lôss of connectors ön both ends öf the fiber. If the end-to-end (transmitter to receiver) loss measlJremeıtfôr a giveıı fiber is within the network margin specifı~ation, the deaf~ st"iöi.ıl<:tifi~trec;C'lrdecfför future reference. If the loss is too low, notation should be made thaftfıatifibefWill probably need an inline attenuator to reduce receiver powerto acceptable ıeveıs. If the loss is too high, if will be necessary to retest each link of the complete cable run to find the bad link.

Possible causeşiôfhiğh>end-to-end link loss are bad connectors, bad splice bushings in patch panelş,ibables bent too tightly around corners, broken fibers in cables or even ba~>ıatınchor receive cables or instruments. There are only two ways to find the problem: test each segment of the cable individually to find the problem or and OTOR, if the lengths are long enough for viewing with the limited resolution of the OTDR.

Do not use an OTDR for measuring end,to end loss. It will not accurately measure actual link loss as seen by the actual transmitters and receivers of the fiber optic link. As normally used, the OTDR will not count the end connectors' loss. The OTDR uses a laser which has very restricted mode power distribution, which minimizes the loss of the fiber and the intermediate connectors. Finally, the difference in backscattering coefficients of various fibers leads to imprecise connector loss measurements.

4.3.5 Testing and Troubleshooting Networks

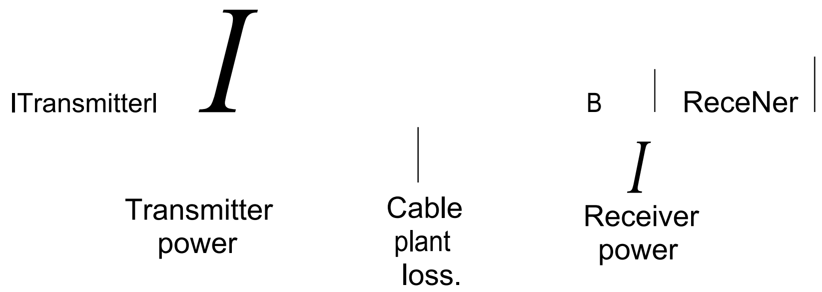

Figure 4.5 Fiber Optic Link Troubleshooting Networks

The installed network can be tested quickly and easily with a fiber optic power meter. The network transmitter needs to be set to transmit a clock output or other bit stream of known duty cycle. Set the power meter calibration on the proper wavelength and the reading units on watts. To test the received power, the most critical element in the network, merely disconnect the fiber optic cable connector at the receiver, attach the power meter, and measure the power.

If the receiver power is low, the transmitter power should be measured by disconnecting the source jumper cable at the first available connector and measuring the powerMı1ith:the fi.ber at that point. Alternatively, one can disconnect the cable at the transmitter and use a known good test jumper to measure the coupled power. If the output is measured through a short network jumper cable (less than 10 meters), no compensation for jumper loss is necessary. For longer jumpers. some compensation may be necessary.

If receiver power is low, but transmitter power is high, there is something wrong with the cables. They must be tested at every connection to isolate the bad cable(s) and or connectors. This can be done from either end. Starting from the transmitter or receiver end, follow the network cables to svery patch panel. Disconnect the connector and measure the power at each point. By making measurements in dB, one can easily calculate the loss of the cable network to each point by subtracting successive readings.

When a suspect cable is found, by noting a larger than expected loss in the cable link, the suspect cable needs testing by the appropriate method described above. If a cable has attenuation that is higher than specifications, but still transmits light, check connectors on a microscope to determine if they have been damaged and should be replaced. If the connectors look good, the best solution may be to replace the cable or switch to a spare. If a visual fault locator is available, it can be used to visually locate breaks in the fiber and find broken connectors. Under some circumstances, such as high loss in long jumper or trunk cables, an OTDR (optical time domain reflectometer) can be used to diagnose cable faults.

4.3.6 Transceiver Loopback Testing

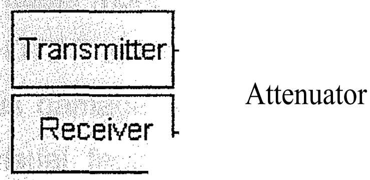

Figure 4.6 Loopback Testing

The datacom capabilities ofthe network can be tested with a loopback test. This test uses a .calibrated fiberôptic attenuator placed between the transmitter and receiver on a piece ofequipment to see if it can transmit data to itself. Many types of network equipment have<diagnosticsto do loopback testing. This will test the transmitter and receiver of the unit under standard data transmission conditions over the specltledllnk loss budget.

Some equipment.can also institute an electrical network loopback test, where the loopback path is inside the equipment and looping back over the entire datalink to the equipment on the far end of the link. If both ends of the link. pass a unit loopback test but fail a network loopback test, the problem is in the cables, which then need testing by the methods described above.

4.3.7 Surviving with Fiber Optics

Once the installation is complete, the cable plant tested, the network equipment running smoothly, what is likely to go wrong in a fiber optic network? Fortunately, not much. One of the biggest selling points for fiber optics hasbeen its reliability. But there are potential problems that can be addressed by the end user.

With the cable plant, the biggest problem is what the telcos call "backhoe fade", where someone mistakenly cuts or breaks the cable. While this most often happens when.an underground cable is dug up, it can happen when an. electrician is working on cablessnstdea building. Outdoors, the best defense is to mark where cables are buried and bury a marker tape above the cable which will hopefully be dug up first. Inside buildirığs, Using ôrahğe ör yellow jacket cable instead of black or gray will make the fıbef~ble more visible and distinctive. Oütside cable faults are best found by usrrıg ah OTDR to localize the fault, then having personhel scout the area looking föfobviôus damage. Inside buildings, the short distances make OTDRs unusable, so a visual fault locator is necessary. Another problem is breaking the cable just behind the connectors in patch panels. This is a difficult fault to find, but a visual fault locator is often the best way. Unless the jumper cables are quite long, an OTDR won't helpat all.

Within the fiber optic link, the most likely component to fail is the LED or laser transmitter, since it is the most highly stressed component in the link. Lasers are feedback stabilized to maintain a constant output power, so they terıd to fa.il allat once. LEDs will drop in power outpüt as they age, but the time frame ls quite löng, 1 OOK to 1 million hours. If there is no power at the receiver, the next place to check should be the transmitter LED or laser, just to isolate the problem to either the transmitter or the cable plant. Receivers are low stressed devices and highly reliable. But the electronics behind them can fail. If there is receiver power but no communications, a loopback test to see if the receiver is workingJsthe besttest .of its status.

4.4 Error Testing

Fiber opticreceivers translate the arriving light signal back intoan electrical signal. The wavelength öf the receiver must match the wavelength of the transmitter. A 1,31 0 nm receiver cannot receive a signal sent at 1,550 nm.

The Bit Error Rate is the expected number of errors occurring between transmitter and receiver; a typical rate is 10^{-9}, one error for every one billion bits transmitted. With native capacities in the gigabits per second, hundreds and thousands of errors will occur every day, even with Bit Error Rates of 1 0". Thorough testing ofthe fiber is critical, both to ensure service quality and to serve as a reference for .future troubleshooting and maintenance.

An Optical Time>Dôrnain• Reflectometer (OTDR) is a kind of optical radar used in installing and testing fiber. It emits light pulses then measures what comes back through the fiber. While it can find faults and measure splice and connector points, its attenuation:resuıtscan be erratic, so use an optical power meter (similar to a VOM device In electronics) to measure the actual attenuation.

4.4.1 Topologies

Several networking protocols can be used with fiber optic cable.

1. Ethernet-Devised by Intel and Xerox in the ?O's, it is an asynchronous data transmitter. Ethernet nodes constantly send and receive information, causing signal congestionwhich is counteracted by a collision detection scheme. A fiber Ethernet system uses a star topology, and can operate at either 10 Mbs or 100 Mbs.

2. Token Ring-Developed by IBM, Token Ring is also asynchronous, but is configured as a ring topology (data is passed from node to node in a circular fashion). Data is passed between nodes using tokens, which act as engines pulling data from one station to the next. Speeds for Token Ring are either 4 Mbs or 16 Mbs.

3. ESCON (Enterprise Systems Connection)-A star topology invented by IBM, ESCON is the intended successor to Token Ring. Tokens are no longer used to transmit data, and there is direct communication between hubs and peripherals. ESCON systems are capable of 150 Mbs.

4. FOOi (Fiber Data Distributed Information)-The first system developed specifically for-fiber optic communications, it uses a ring topology operating at 100 Mbs with a backup mechanism ensuring that a break in the main ring will not bring down the entire ring. FOOi supports older systems such as Ethernet, Token Ring, and ESCON.

5. ATM (Asynchronous Transfer Mode)-Capable of 155 Mbs, it can support voice as well as data services such as FOOi or digital video. Companies

such as 3Com are developing Gigabit ATM which can push gigabits of data per second through glass.

6. SONET (Synchronous Optical Network)-Designed by the telcos, SONET is a singlemode fiber network capable of huge variations in speed, ranging from 51.84 Mbs (OC-1) to 2.48 Gbs (OC-24). Like ATM, it can handle voice and data applications.

7. TOM (Time Division Multiplexing)-Also from the telecommunication industry, this method combines information of varying types into a single signal, and then sends it down the wire. The received signal is then demultiplexed into its original components. Data rates for this system are 1.54Mbs (T..1),u.6;16 Mbs (T-2), and 45 Mbs (T-3).

Fully explaining networking topologies is beyond the scope of this paper, but a few generalizations about topologies for fiber optic networking follow.

- Bus topology, where all nodes share a common line, should be avoided because any break in the cabling completely disables the network.
- Star topology generates the least attenuation and is th~ easiest>to troubleshoot and maintain.
- Ring topology minimizes the amount of cabling necessary, but does so at the cost of troubleshooting ease. Because of its looped configuration diagnosing breaks can be problematic.

Consult aninstaller when planning a fiber dptic system to best meet local needs.

So far, fiber optics has only played a small role in practical local Area Networks. Many papers have been published in scholarly journals describing experimental fiber optic LANs. A few companies even offer commercial fiber öptic LANs, but the few that have been installed are only a small fraction of LANs in use. local Area Networks themselves are not as widespread one might think. Fiber optics has been used in feworactical LANs but has been tested in many laboratory LANs.

This wm be changing. ly'lôstpresent terminals and personal computer require only modest transmission rates; Which often can be sent over telephone lines. CurrenttANs operate at speedsiabout 1OMbits/s, at which there is little benefit from:using optical fibers (excepfin some special cases). Future devices will require faster data transmission to aJlöWt>etterquality graphics, faster access to databases and more efficient sharing ofinfttrrlation. The need forJaster transmission will accelerate the development of l..ANs and their use of fiber optics. To get a good understanding of fiber optics in networks, we will have to see how finer optics can improve the capability of present and the next generation LANs being developed around fiber optics. Interest in higher speed transmission could motivate uses of fiber optics in networks.

,.Ethernet, developed by Digital Equipment, Intel and Xerox, was the first Local AreaNe:tvvorkto·gainmuch acceptance. Ethernet distributes digital data packets of variable length at 1OMbits/sto terminals dispersed along a coaxial cable bus, as shôwn:on the .figureon the right. Separate cables up to 50 metres long, c:o~tianing four ,twistedwire pairs, run from individual devices (e.g. terminals.or printers) to transceivers/joined to· the coaxial cable. The network has no overall controller; control functions are handled by individual transceivers.

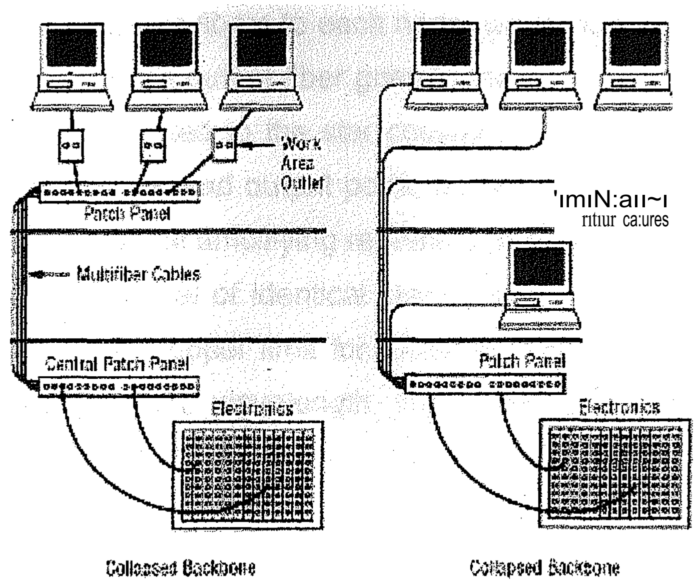

Figure4. 7 Ethernet Configuration

If a terminal is ready to send a signal, its transceiver checks if another signal is going along the coaxial cable. Transmission is delayed if another signal is present. If not, the terminal begins transmitting and continues until it finishes or detects a collision, the transmission of data at the same time by a second terminal. Such collision happen because it takes time, several nanoseconds a metre, for signals to travel along the coaxial cable. The terminal stops transmitting if it detects a collision and waits a random interval before trying again. Data signals contain an address header specifying the terminal to which they are directed. They pass through all transceivers but are sent only to the terminal to which they are directed. The choice of coaxial cable limits the Ethernet performance. Maximum terminal separation is 2.5 km, with no more than 500 m between terminals and no more than 1024 terminals altogether. This is adequate for most, but not all applications. Optical fibers can stretch transmission distances beyond the limit imposed by toss of the coaxial cable to limits imposed by delays in signal propagation.

One all-fiber-optic version of Ethernet is based on a central transmissive star coupler. This system relies on transmission directly between network nodes and the central passive star coupler, which mixes and distributes signatş throughout the network. The figure on the left shows a central star coupler. This network requires separate transmit and receive fiberş:tq.~cıch node, which has a separate fiber optic transmitter and receiver. The outplltfiber goes to the input of the transmissive star coupler; the input is connectedtothe.rstar coupler's output. The standard design uses a coupler with 32 input anc:JiQUtputpe>rts, but the number of connections can be increased by adding signal amplifying.repeaters and extra star couplers in place of nodes, With a second level of identical star couplers, the number of terminals can be raised to 1024, the upper. limit for Ethernet. The standard version of this system operates with short wavelength light emitting diodes. The receiver sensitivity is -28.2 dBm.

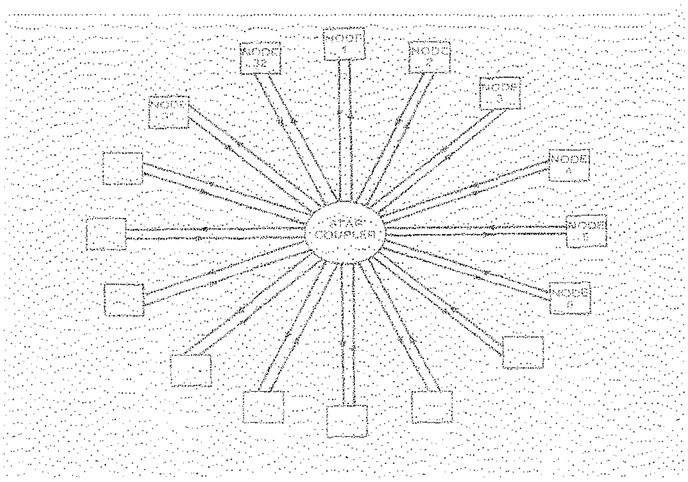

Figure 4.8 Fiber Optic Ethernet with Central Star Coupler

What advantage does the fiber optic approach give? Besides the typical ones for all data transmission that has been described, it also can deliver signals to nodes over an area up to 5 km^2, larger than possible than a coaxial cabled Ethernet. Apart from 'this, other all-fiber versions include one with a ring topology and one that uses an active star coupler, which contains receivers that detect input signals and amplify them for retransmission through the network. Fiber optic components can also be added to coaxial cable Ethernets. One standard product is an Ethernet extender, which uses fiber optic cable to extend transmission distance between an Ethernet transceiver and station to a kilometers from the standard 50 metres.

Fiber optic Local Area Networks based on Ethernet like concepts are used today. Some are small scale networks, used where fibers are essential because of problems such as ground loops and severe electromagnetic interference (EMI), which will be discussed in greater detail in a later chapter in this report. Others are designed to allow future upgrading._One of the largest system is one Southwestern Bell installed in its 44 story headquarters in St. Louis. Over 2000 terminals in. the 1.5 million tt2 building are connected by 144 km of fiber. Part of the network is an Ethernet like system carrying asynchronous data at 10 Mbits/s. The· rest of the network allows synchronous transmission between individual termirıc1ls and. ş central computer facility. Fiber was primarily chosen because of. the ~c:tşe of upgrading.

CONCLUSION

Fiber optic transmission has found a vast array of applications in computer systems. Some design considerations depend largely on the application. For certain terminal to terminal iapplication, crucial factors including maximising transmission speed and distanceahd minimising fiber and splice loss. By contrast, connector loss becomes important in local area networks that operate within buildings. In other systems, it is important to minimise the cost of cable, with the intention of reducing the cost ofterminal equipment. These system considerations make design and construction Of practical fiber optic systems a difficult task. Guidelines appropriate for one system is usually not suitable for another system.

There are a number of essential points about fiber optics that have been mentioned throughout this report. As we move towards a more sophisticated and modern future, the uses of fiber optics are going to grow in all computer systems as well as telecommunication networks. Modern information systems handle ever-increasing data loads which strain the data throughput ability of information systems. Designers have made significant progress in increasing processor speeds; however progress in the design of high-speed interconnection networks has lagged so much so that the most significant bottleneck in today's information systems is the low speed of communications between integrated chips. These low speed communications networks. consume increasing amounts of power in an effort to keep up with the faster processors. The slow communications speed is brought on by the small bandwidth available to existing communications networks based on the propagation of electrical signals through metallic lines.

Optical interconnections offer several advantages over metallic interconnections, they include: higher bandwidth; higher interconnection densities; lower crosstalk; crosstalk which is independent of data rate; inherent parallelism; immunity from electromagnetic interference and ground loops; the ability to exploit the third dimension; lower clock and signal skew; and a higher fan-in/fan-out capability. These advantages mean that optical interconnections have the potential to exhibit higher data rate communication, higher densities of interconnections with lower crosstalk, and lower power consumption.

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