CHAPTER 5

FIBER OPTIC MEASUREMENT TECHNIQUES

LEARNING OBJECTIVES

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

1. Identify the prime reasons for conducting fiber optic manufacturing laboratory and field measurements.
2. Describe the optical fiber and optical connection laboratory measurements performed by the Navy to evaluate fiber optic component and system performance.
3. Describe the near-field and far-field optical power distribution of an optical fiber.
4. Describe optical fiber launch conditions and modal effects that affect optical fiber and optical connection measurements.
5. Understand the term optical time-domain reflectometry and the interpretation of an optical time-domain reflectometer (OTDR) trace.
6. Describe the procedure for locating a fiber fault using an OTDR.

FIBER OPTIC MEASUREMENTS

Fiber optic data links operate reliably if fiber optic component manufacturers and end users perform the necessary laboratory and field measurements. Manufacturers must test how component designs, material properties, and fabrication techniques affect the performance of fiber optic components. These tests can be categorized as design tests or quality control tests. Design tests are conducted during the development of a component. Design tests characterize the component's performance (optical, mechanical, and environmental) in the intended application. Once the component performance is characterized, the manufacturer generally only conducts quality control tests. Quality control tests verify that the parts produced are the same as the parts the design tests were conducted on. When manufacturers ship fiber optic components, they provide quality control data detailing the results of measurements performed during or after component fabrication.

End users (equipment manufacturers, shipbuilders, maintenance personnel, test personnel, and so on) should measure some of these parameters upon receipt before installing the component into the fiber optic data link. These tests determine if the component has been damaged in the shipping process. In addition, end users should measure some component parameters after installing or repairing fiber optic components in the field. The values obtained can be compared to the system installation specifications. These measurements determine if the installation or repair process has degraded component performance and will affect data link operation.

Whenever a measurement is made, it should be made using a standard measurement procedure. For most fiber optic measurements, these standard procedures are documented by the Electronics Industries Association/Telecommunications Industries Association (EIA/TIA). Each component measurement procedure is assigned a unique number given by EIA/TIA-455-X. The X is a sequential number assigned to that particular component test procedure. System level test procedures are assigned unique numbers given by EIA/TIA-526-X. Again the X is a sequential number assigned to that particular system test procedure.

LABORATORY MEASUREMENTS

Providing a complete description of every laboratory measurement performed by manufacturers and end users is impossible. This chapter only provides descriptions of optical fiber and optical connection measurements that are important to system operation. The list of optical fiber and optical connection laboratory measurements described in this chapter includes the following:

- Attenuation
- Cutoff wavelength (single mode)
- Bandwidth (multimode)
- Chromatic dispersion
- Fiber geometry
- Core diameter
- Numerical aperture (multimode)
- Mode field diameter (single mode)
- Insertion loss
- Return loss and reflectance

End users routinely perform optical fiber measurements to measure fiber power loss and fiber information capacity. End users may also perform optical fiber measurements to measure fiber geometrical properties. Optical fiber power loss measurements include attenuation and cutoff wavelength. Optical fiber information capacity measurements include chromatic dispersion and bandwidth. Fiber geometrical measurements include cladding diameter, core diameter, numerical aperture, and mode field diameter. Optical connection measurements performed by end users in the laboratory include insertion loss and reflectance or return loss.

Attenuation

Attenuation is the loss of optical power as light travels along the fiber. It is a result of absorption, scattering, bending, and other loss mechanisms as described in chapter 3. Each loss mechanism contributes to the total amount of fiber attenuation.

End users measure the total attenuation of a fiber at the operating wavelength (λ). The **total attenuation (A)** between an arbitrary point X and point Y located on the fiber is

$$A = 10 \log \frac{P_x}{P_y} \text{dB}$$

P_x is the power output at point X. P_y is the power output at point Y. Point X is assumed to be closer to the optical source than point Y. The total amount of attenuation will vary with changes in wavelength λ.

The **attenuation coefficient (α)** or attenuation rate, is

$$a = \frac{A}{L} \text{dB/km}$$

L is the distance between points X and Y. α is a positive number because P_x is always larger than P_y. The attenuation coefficient will also vary with changes in λ.

CUTBACK METHOD.—In laboratory situations, end users perform the cutback method for measuring the total attenuation of an optical fiber. The cutback method involves comparing the optical power transmitted through a long piece of test fiber to the power present at the beginning of the fiber.

The cutback method for measuring multimode fiber attenuation is EIA/TIA-455-46. The cutback method for measuring single mode fiber attenuation is EIA/TIA-455-78. The basic measurement process is the same for both of these procedures. The test method requires that the test fiber of known length (L) be cut back to an approximate 2-m length. This cut back causes the destruction of 2-m of fiber. This method requires access to both fiber ends. Each fiber end should be properly prepared to make measurements. EIA/TIA-455-57 describes how to properly prepare fiber ends for measurement purposes.

Figure 5-1 illustrates the cutback method for measuring fiber attenuation. The cutback method begins by measuring, with an optical power meter, the output power P_1 of the test fiber of known length (L) (figure 5-1, view A). Without disturbing the input light conditions, the test fiber is cut back to an approximate 2-m length. The output power P_2 of the shortened test fiber is then measured (figure 5-1, view B). The fiber attenuation A_T and the attenuation coefficient α are then calculated.

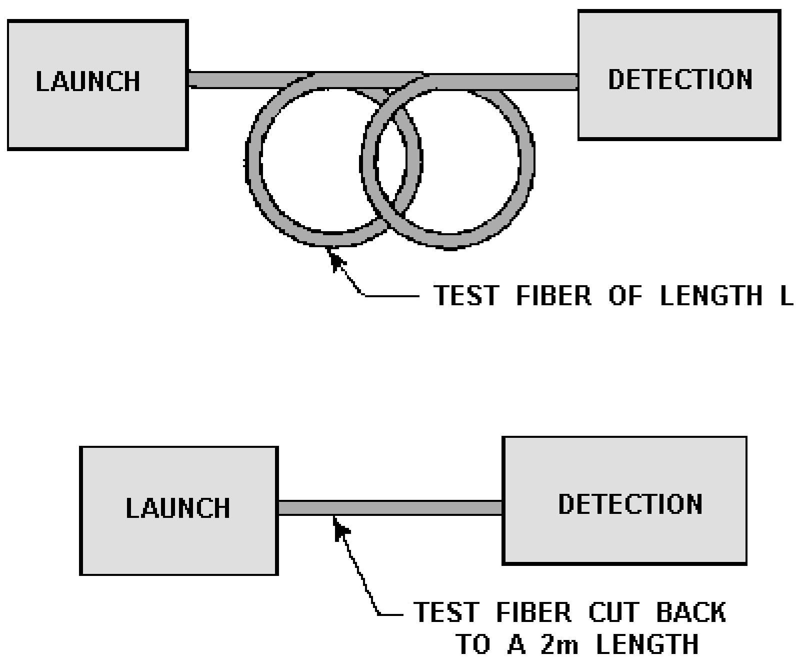

Figure 5-1.—Cutback method for measuring fiber attenuation: A. Test measurement; B. Cut-back measurement.

LAUNCH CONDITIONS.—Measurement personnel must pay attention to how optical power is launched into the fiber when measuring fiber attenuation. Different distributions of launch power (launch conditions) can result in different attenuation measurements. This is more of a problem with multimode fiber than single mode fiber. For single mode fiber, optical power must be launched only into the fundamental mode. This is accomplished using a mode filter on the fiber. For multimode fiber, the distribution of power among the modes of the fiber must be controlled. This is accomplished by controlling the launch spot size and angular distribution.

The **launch spot size** is the area of the fiber face illuminated by the light beam from the optical source. The diameter of the spot depends on the size of the optical source and the properties of the optical elements (lenses, and so on) between the source and the fiber end face. The **angular distribution** is the angular extent of the light beam from the optical source incident on the fiber end face. The launch angular distribution also depends on the size of the optical source and the properties of the optical elements between the optical source and the fiber end face.

Multimode optical fiber launch conditions are typically characterized as being underfilled or overfilled. An underfilled launch concentrates most of the optical power in the center of the fiber. An **underfilled** launch results when the launch spot size and angular distribution are smaller than that of the fiber core. Underfilling the fiber excites mainly low-order modes. Figure 5-2 illustrates an underfilled launch condition.

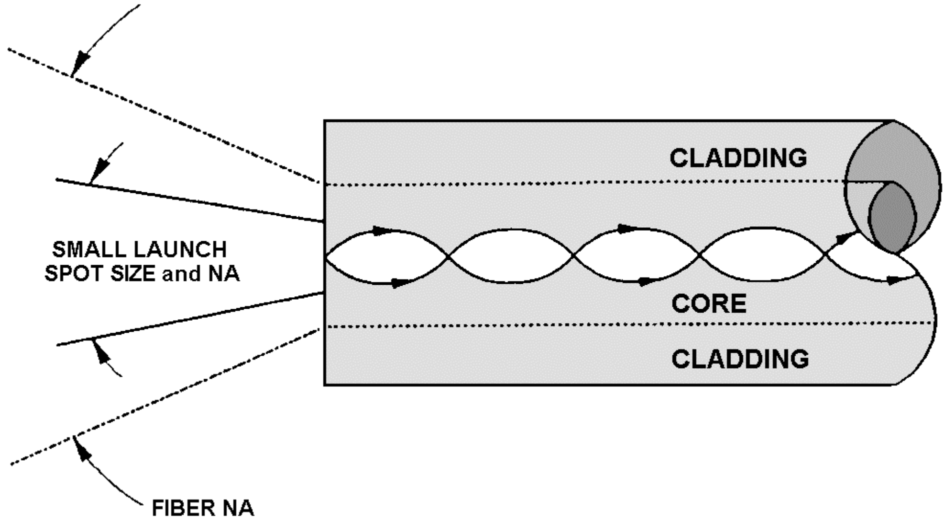

Figure 5-2.—Underfilled launch condition.

Overfilling the fiber excites both low-order and high-order modes. Figure 5-3 illustrates an overfilled launch condition. An **overfilled** launch condition occurs when the launch spot size and angular distribution are larger than that of the fiber core. Incident light that falls outside the fiber core is lost. In addition, light that is incident at angles greater than the angle of acceptance of the fiber core is lost.

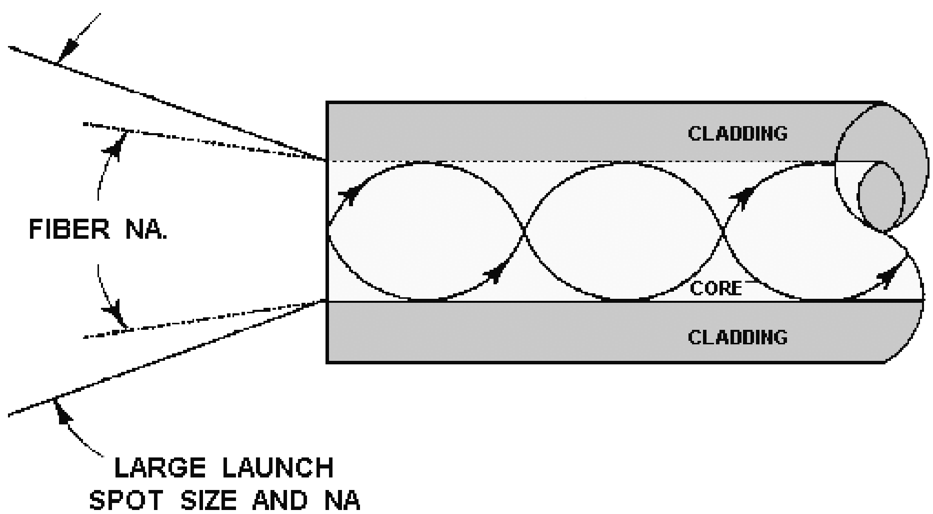

Figure 5-3.—Overfilled launch condition.

In attenuation measurements, cladding-mode strippers and mode filters eliminate the effects that high-order modes have on attenuation results. A **cladding-mode stripper** is a device that removes any cladding mode power from the fiber. Most cladding-mode strippers consist of a material with a refractive index greater than that of the fiber cladding. For most fibers, the fiber coating acts as an excellent cladding-mode stripper.

A **mode filter** is a device that attenuates specific modes propagating in the core of an optical fiber. Mode filters generally involve wrapping the test fiber around a mandrel. For multimode, tight bends tend to remove high-order modes from the fiber. This type of mode filter is known as a **mandrel wrap mode filter**. For multimode fibers, mode filters remove high-order propagating modes and are individually tailored and adjusted for a specific fiber type.

For single mode fibers, a mode filter is used to eliminate the second-order mode from propagating along the fiber. The propagation of the second-order mode will affect attenuation measurements. Fiber attenuation caused by the second-order mode depends on the operating wavelength, the fiber bend radius and length.

The two most common types of mode filters are free-form loops and mandrel wraps. Figure 5-4 illustrates the free-form loop and mandrel-wrap types of mode filters. Mandrel wraps for multimode fibers consist of several wraps (approximately 4 or 5) around a mandrel. A 20-mm diameter mandrel is typically used for 62.5 μm fiber. Mandrel wraps for single mode fibers consist of a single wrap around a 30-mm diameter mandrel. Another common mode filter for single mode fibers is a 30-mm diameter circular free-form loop. Additional information on multimode and single mode filters (and launch conditions) is available in EIA/TIA-455-50 and EIA/TIA-455-77, respectively.

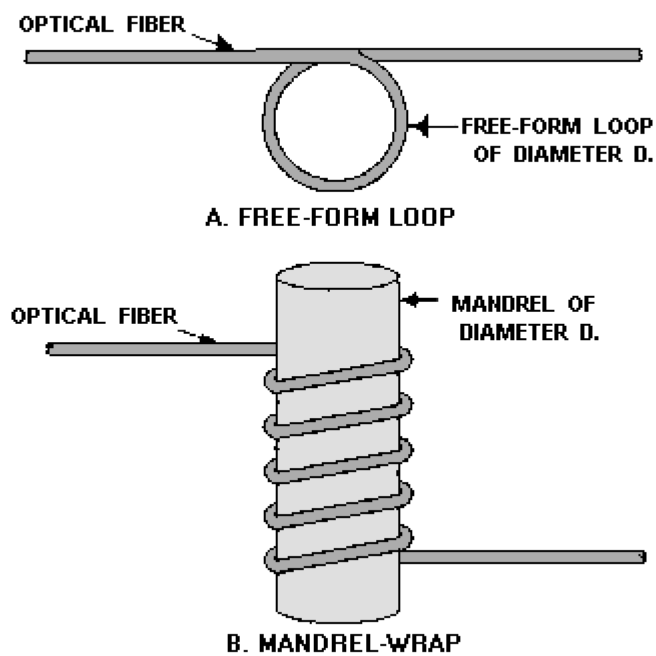

Figure 5-4.—Types of mode filters: A. Free-form loop; B. Mandrel-wrap.

Launch conditions significantly affect the results of multimode fiber attenuation measurements. If the fiber is underfilled, high-order-mode power loss has minimal effect on the measurement results. If too much power is launched into high-order modes, the high-order-mode power loss will dominate the attenuation results. Generally, fiber attenuation measurements are performed using an underfilled launch condition. Power in high-order modes is eliminated by either controlling the input spot size and angular distribution or using mode filters to remove high-order mode power.

Cutoff Wavelength

The wavelength at which a mode ceases to propagate is called the cutoff wavelength for that mode. However, an optical fiber is always able to propagate at least one mode, the fundamental mode. The fundamental mode can never be cut off. The **cutoff wavelength** of a single mode fiber is the wavelength above which the fiber propagates only the fundamental mode.

Determining the cutoff wavelength of a single mode fiber involves finding the wavelength above which the power transmitted through the fiber decreased abruptly. This power decrease occurs when the second-order mode propagating in the fiber is cut off. The cutoff wavelength of single mode fibers depends on the fiber length and bend conditions. The effects of length and bending are different on different fibers depending on whether they are matched-clad or depressed-clad in design. The cutoff wavelength of matched-clad fibers is more sensitive to bends than the cutoff wavelength of depressed-clad fibers. The cutoff wavelength of depressed-clad fibers is more sensitive to length than the cutoff wavelength of matched-clad fibers.

Cutoff wavelength may be measured on uncabled or cabled single mode fibers. A slightly different procedure is used in each case, but the basic measurement process is the same. The test method for uncabled single mode fiber cutoff wavelength is EIA/TIA-455-80. The test method for cabled single mode fiber cutoff wavelength is EIA/TIA-455-170. The fiber cutoff wavelength (λ) measured under EIA/TIA-455-80 will generally be higher than the cable cutoff wavelength (λ) measured under EIA/TIA-455-170. The difference is due to the fiber bends introduced during the cable manufacturing process.

Each test method describes the test equipment (input optics, mode filters, and cladding-mode strippers) necessary for the test. Cutoff wavelength measurements require an overfilled launch over the full range of test wavelengths. Since the procedures for measuring the cutoff wavelength of uncabled and cabled single mode fibers are essentially the same, only the test method for measuring the cutoff wavelength of uncabled fiber is discussed.

Measuring the cutoff wavelength involves comparing the transmitted power from the test fiber with that of a reference fiber at different wavelengths. The reference fiber can be the same piece of single mode fiber with small bends introduced or a piece of multimode fiber. If the same fiber with small bends is used as the reference fiber, the technique is called the **bend-reference technique**. If a piece of multimode fiber is used as the reference fiber, the technique is called the **multimode-reference technique**.

For both techniques, the test fiber is loosely supported in a single-turn with a constant radius of 140 mm. Figure 5-5 shows this single-turn configuration. The transmitted signal power $P_s(\lambda)$ is then recorded while scanning the wavelength range in increments of 10 nm or less. The launch and detection conditions are not changed while scanning over the range of wavelengths. The wavelength range scanned encompasses the expected cutoff wavelength.

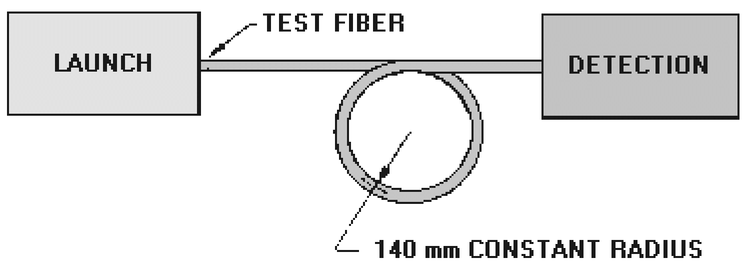

Figure 5-5.—Single-turn configuration for the test fiber.

The reference power measurement is then made. For the bend-reference technique, the launch and detection conditions are not changed, but an additional bend is added to the test fiber. The test fiber is bent to a radius of 30 mm or less to suppress the second-order mode at all the scanned wavelengths. For the multimode-reference technique, the single mode fiber is replaced with a 2-m length of multimode fiber. The transmitted signal power $P_r(\lambda)$ is recorded while scanning the same wavelength range in the same increments of 10 nm or less. The attenuation $A(\lambda)$ at each wavelength is calculated as follows:

$$A(\lambda) = 10 \log \frac{P_s(\lambda)}{P_r(\lambda)} \text{dB}$$

Figure 5-6 shows an example attenuation plot generated using the bend-reference technique. The longest wavelength at which $A(\lambda)$ is equal to 0.1 dB is the fiber cutoff wavelength (λ_{cf}). λ_{cf} is marked on figure 5-6.

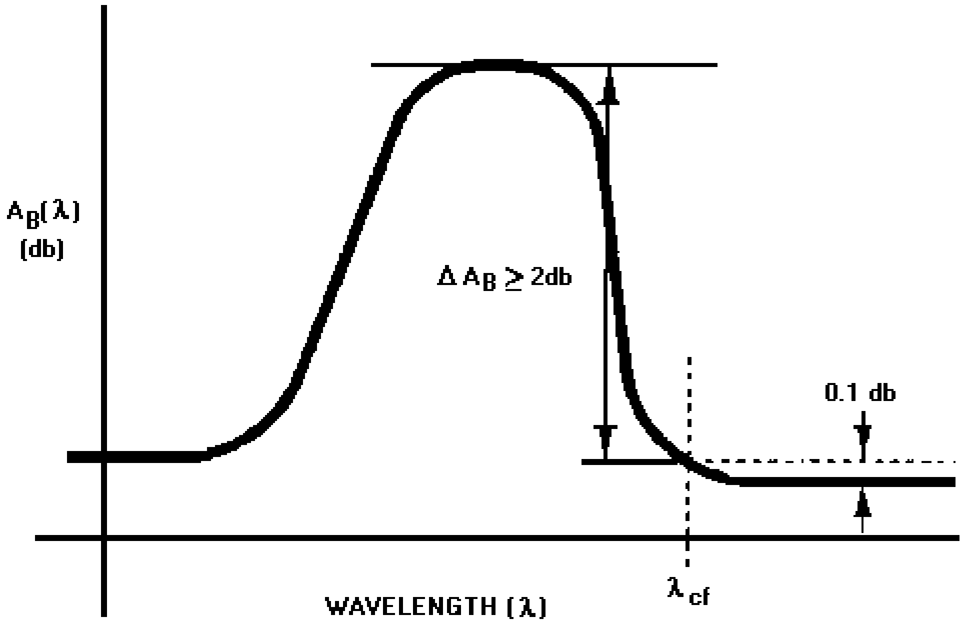

Figure 5-6.—Fiber cutoff wavelength determined by the bend-reference technique.

Figure 5-7 shows an attenuation plot generated using the multimode-reference technique. A straight line is fitted to the long-wavelength portion of A(λ). This straight line is then displaced upward by 0.1 dB. The point at which the straight line intersects the A(λ) plot defines the fiber cutoff wavelength (λ_{cf}).

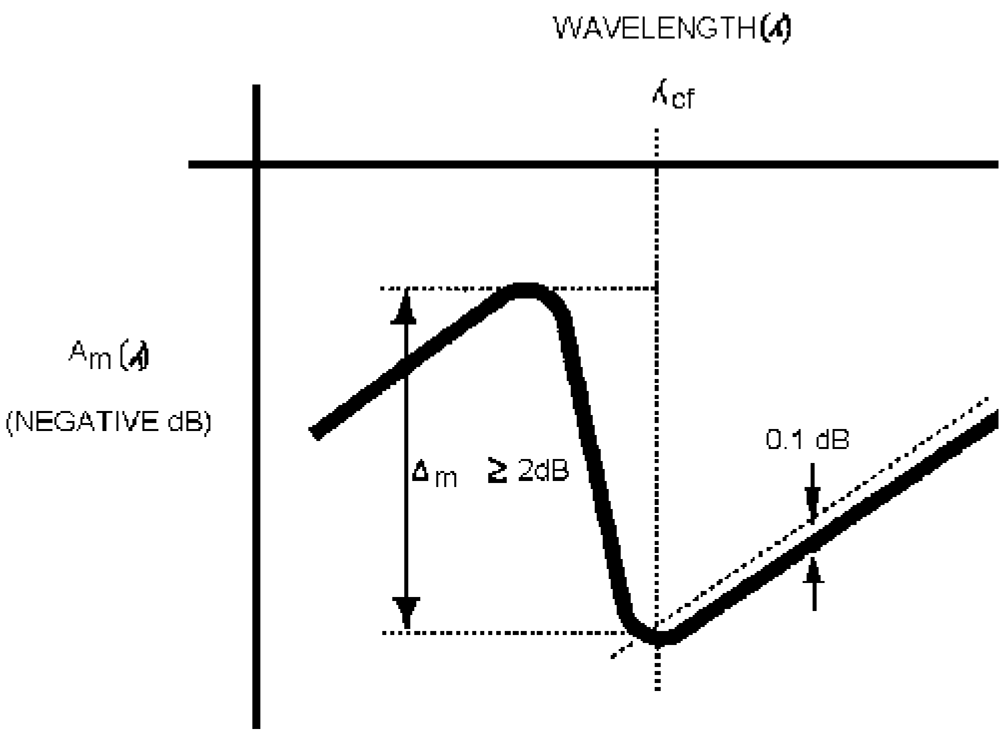

Figure 5-7.—Fiber cutoff wavelength determined by the multimode-reference technique.

Bandwidth

Dispersion reduces the bandwidth, or information-carrying capacity, of an optical fiber. **Dispersion** causes the spreading of the light pulse as it travels along the fiber (see figure 2-20). Fiber dispersion mechanisms include intramodal (chromatic) dispersion and intermodal (modal) dispersion. Multimode fiber bandwidth is a measure of the intermodal dispersion of the multimode fiber.

Intermodal dispersion is maximum when all fiber modes are excited. The source used for intermodal dispersion measurements must overfill the fiber. The optical source must also have a narrow spectral width to reduce the effects of chromatic dispersion in the measurement.

There are two basic techniques for measuring the modal bandwidth of an optical fiber. The first technique characterizes dispersion by measuring the **impulse response h(t)** of the fiber in the time domain. The second technique characterizes modal dispersion by measuring the **baseband frequency response H(*f*)** of the fiber in the frequency domain. H(*f*) is the **power transfer function** of the fiber at the baseband frequency (*f*). H(*f*) is also the Fourier transform of the power impulse response h(t). Only the frequency response method is described here.

The test method for measuring the bandwidth of multimode fibers in the frequency domain is EIA/TIA-455-30. Signals of varying frequencies (*f*) are launched into the test fiber and the power exiting the fiber at the launched fundamental frequency measured. This optical output power is denoted as $P_{out}(f)$. The test fiber is then cut back or replaced with a short length of fiber of the same type. Signals of the same frequency are launched into the cut-back fiber and the power exiting the cut-back fiber at the launched fundamental frequency measured. The optical power exiting the cutback or replacement fiber is denoted as $P_{in}(f)$. The magnitude of the optical fiber frequency response is

$$H(f) = \log_{10}\left[\frac{P_{out}(f)}{P_{in}(f)}\right]$$

The fiber bandwidth is defined as the lowest frequency at which the magnitude of the fiber frequency response has decreased to one-half its zero-frequency value. This is the -3 decibel (dB) optical power frequency (f_{3dB}). This frequency is referred to as the fiber bandwidth.

Bandwidth is normally given in units of megahertz-kilometers (MHz-km). Converting the –3 dB fiber bandwidth to a unit length assists in the analysis and comparison of optical fiber performance. For long lengths of fiber (>1km), the method for normalization is to multiply the length times the measured bandwidth.

Chromatic Dispersion

Chromatic, or intramodal, dispersion occurs in both single mode and multimode optical fibers. Chromatic dispersion occurs because different colors of light travel through the fiber at different speeds.

Since the different colors of light have different velocities, some colors arrive at the fiber end before others. This delay difference is called the differential group delay $\tau(\lambda)$ per unit length. This differential group delay leads to pulse broadening.

Chromatic dispersion is measured using EIA/TIA-455-168 in the time domain. Chromatic dispersion is also measured in the frequency domain using EIA/TIA-455-169 and EIA/TIA-455-175. These methods measure the composite optical fiber material and waveguide dispersion. To understand the contribution that material and waveguide dispersive mechanisms have on multimode and single mode fiber dispersion, refer to chapter 2. In this chapter we limit the discussion on chromatic dispersion to the time domain method described in EIA/TIA-455-168.

The chromatic dispersion of multimode graded-index and single mode fiber is obtained by measuring fiber group delays in the time domain. These measurements are made using multiwavelength sources or multiple sources of different wavelengths. A multiwavelength source could be a wavelength-selectable laser.

The pulse delay for both a long test sample fiber and a short reference fiber are measured over a range of wavelengths. The pulse delay for the reference fiber as a function of wavelength is $\tau_{in}(\lambda)$. The pulse delay for the test fiber as a function of wavelength is $\tau_{out}(\lambda)$. The group delay $\tau(\lambda)$. per unit length at each wavelength is

$$\tau(\lambda) = \frac{\tau_{in}(\lambda) - \tau_{out}(\lambda)}{L_s - L_{ref}}$$

where L_s is the test sample fiber length in kilometers (km) and L_{ref} is the reference sample length in km.

The fiber chromatic dispersion is defined as the derivative, or slope, of the fiber group delay curve with respect to wavelength. Generally, the group delay as a function of wavelength is fit to a simple mathematical function and the derivative calculated. The range of wavelengths over which meaningful data is obtained depends on the wavelength range of optical source(s) used. The zero-dispersion wavelength (λ_0) and the zero-dispersion slope (S_0) are determined from the chromatic dispersion curve.

Fiber Geometry

End users perform fiber geometry measurements to reduce system attenuation and coupling loss resulting from poor fiber fabrication. Fiber attenuation and intrinsic coupling loss result from mismatches in the inherent fiber characteristics of two connecting fibers. Fiber mismatches occur when manufacturers fail to maintain optical or structural (geometrical) tolerances during the fiber fabrication process. Fiber geometry measurements performed in the laboratory identify fiber mismatches before the optical fiber is installed.

The procedure for measuring multimode and single mode fiber geometry is detailed in EIA/TIA-455-176. The fiber-geometrical parameters measured include cladding diameter, cladding noncircularity, core-cladding concentricity error, and core noncircularity. Figure 4-8 (chapter 4) illustrates core noncircularity (ellipticity) and core-cladding concentricity error. The core noncircularity measurement is for multimode fibers only.

Other test methods are available for measuring other multimode and single mode fiber core parameters. Additional test methods exist for measuring multimode fiber core diameter and NA. For single mode fibers, the mode field diameter measurement replaces core diameter and NA measurements. Core diameter, numerical aperture, and mode field diameter measurements are identified and explained later in this chapter.

To make fiber geometry measurements, the input end of the fiber is overfilled and any cladding power stripped out. The output end of the fiber is prepared and viewed with a video camera. Generally the fiber is less than 10 m in length. An objective lens magnifies the output image (typically 20×) going to a video camera. The image from the video camera is displayed on a video monitor and is also sent to the computer for digital analysis.

The computer analyzes the image to identify the edges of the core and cladding. The centers r_c and r_g of the core and cladding, respectively, are found. The **cladding diameter** is defined as the average diameter of the cladding. The cladding diameter is twice the average radius (R_g). The **core diameter** is defined as the average diameter of the core. The core diameter is twice the average core radius (R_c).

Cladding noncircularity, or ellipticity, is the difference between the smallest radius of the fiber (R_{gmin}) and the largest radius (R_{gmax}) divided by the average cladding radius (R_g). The value of the cladding noncircularity is expressed as a percentage.

The **core-cladding concentricity error** for multimode fibers is the distance between the core and cladding centers divided by the core diameter. Multimode core-cladding concentricity error is expressed as a percentage of core diameter. The core-cladding concentricity error for single mode fibers is defined as the distance between the core and cladding centers.

Core noncircularity is the difference between the smallest core radius (R_{cmin}) and the largest core radius (R_{cmax}) divided by the core radius (R_c). The value of core noncircularity is expressed as a percentage. Core noncircularity is measured on multimode fibers only.

Core Diameter

Core diameter is measured using EIA/TIA-455-58. The core diameter is defined from the refractive index profile n(r) or the output near-field radiation pattern. Our discussion is limited to measuring the core diameter directly from the output near-field radiation pattern obtained using EIA/TIA-455-43.

The near-field power distribution is defined as the emitted power per unit area (radiance) for each position in the plane of the emitting surface. For this chapter, the emitting surface is the output area of a fiber-end face. Near-field power distributions describe the emitted power per unit area in the near-field region. The near-field region is the region close to the fiber-end face. In the near-field region, the distance between the fiber-end face and detector is in the micrometers (µm) range.

EIA/TIA-455-43 describes the procedure for measuring the near-field power distribution of optical waveguides. Output optics, such as lenses, magnify the fiber-end face and focus the fiber's image on a movable detector. Figure 5-8 shows an example setup for measuring the near-field power distribution. The image is scanned in a plane by the movable detector. The image may also be scanned by using a detector array. Detector arrays of known element size and spacing may provide a display of the power distribution on a video monitor. A record of the near-field power is kept as a function of scan position.

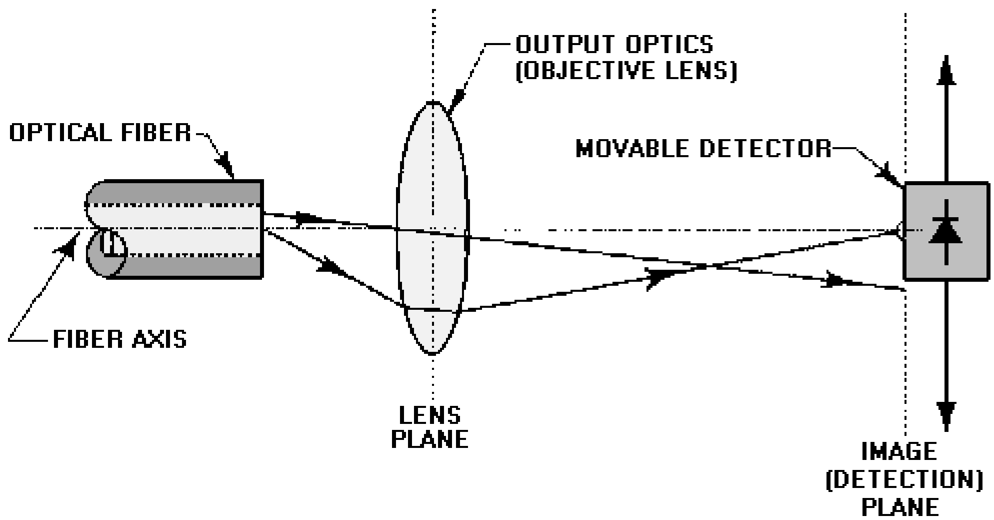

Figure 5-8.—The measurement of the near-field power distribution.

The core diameter (D) is derived from the normalized output near-field radiation pattern. The normalized near-field pattern is plotted as a function of radial position on the fiber-end face. Figure 5-9 shows a plot of the normalized near-field radiation pattern as a function of scan position.

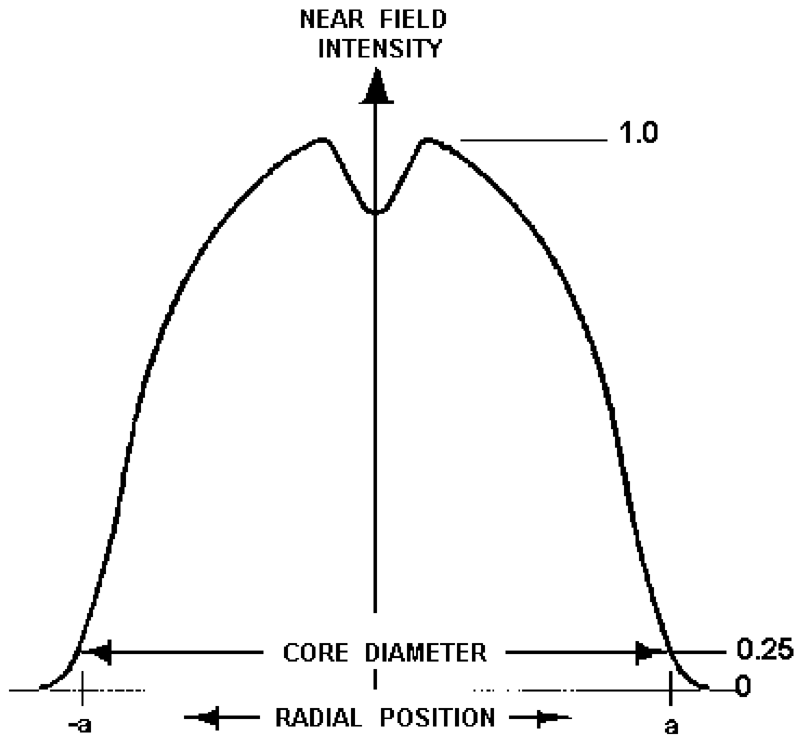

Figure 5-9.—Near-field radiation pattern.

The core diameter (D) is defined as the diameter at which the intensity is 2.5 percent of the maximum intensity (see figure 5-9). The 2.5 percent points, or the 0.025 level, intersects the normalized curve at radial positions – a and a. The core diameter is simply equal to 2a (D=2a).

Numerical Aperture

The numerical aperture (NA) is a measurement of the ability of an optical fiber to capture light. The NA can be defined from the refractive index profile or the output far-field radiation pattern. Our discussion is limited to measuring the NA from the output far-field radiation pattern.

The NA of a multimode fiber having a near-parabolic refractive index profile is measured using EIA/TIA-455-177. In EIA/TIA-455-177, the fiber NA is measured from the output far-field radiation pattern. The far-field power distribution describes the emitted power per unit area in the far-field region. The far-field region is the region far from the fiber-end face. The far-field power distribution describes the emitted power per unit area as a function of angle Θ some distance away from the fiber-end face. The distance between the fiber-end face and detector in the far-field region is in the centimeters (cm) range for multimode fibers and millimeters (mm) range for single mode fibers.

EIA/TIA-455-47 describes various procedures, or methods, for measuring the far-field power distribution of optical waveguides. These procedures involve either an angular or spacial scan. Figure 5-10 illustrates an angular and spacial scan for measuring the far-field power distribution.

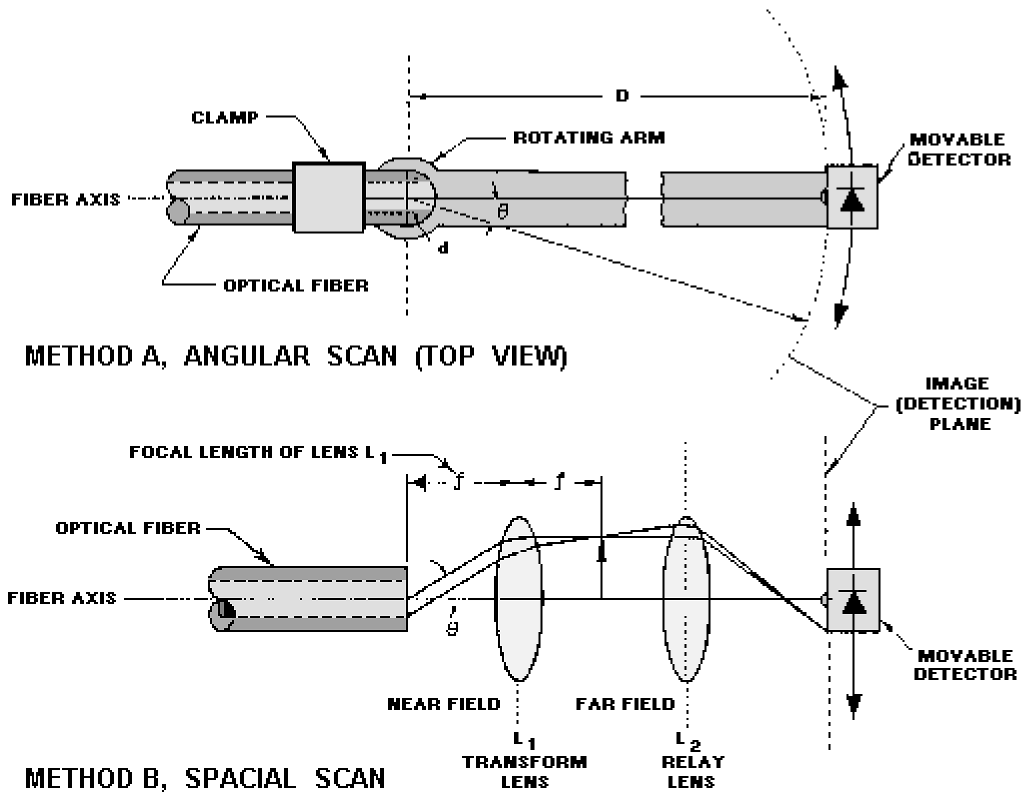

Figure 5-10.—Angular and spacial scan methods for measuring the far-field power distribution.

Figure 5-10 (method A) illustrates a far-field angular scan of the fiber-end face by a rotating detector. The fiber output radiation pattern is scanned by a rotating detector in the far-field. The detector rotates in a spherical manner. A record of the far-field power distribution is kept as a function of angle Θ.

Figure 5-10 (method B) illustrates a far-field spacial scan of the fiber-end face by a movable (planar) detector. In a far-field spacial scan, lens L_1 performs a Fourier transform of the fiber output near-field pattern. A second lens, L_2, is positioned to magnify and relay the transformed image to the detector plane. The image is scanned in a plane by a movable detector. The scan position y in the Fourier transform plane is proportional to the far-field scan angle Θ. A record of the far-field power distribution is kept as a function of the far-field scan angle.

The normalized far-field pattern is plotted as a function of the far-field scan angle Θ. Figure 5-11 shows the plot of the normalized far-field radiation pattern as a function of scan angle.

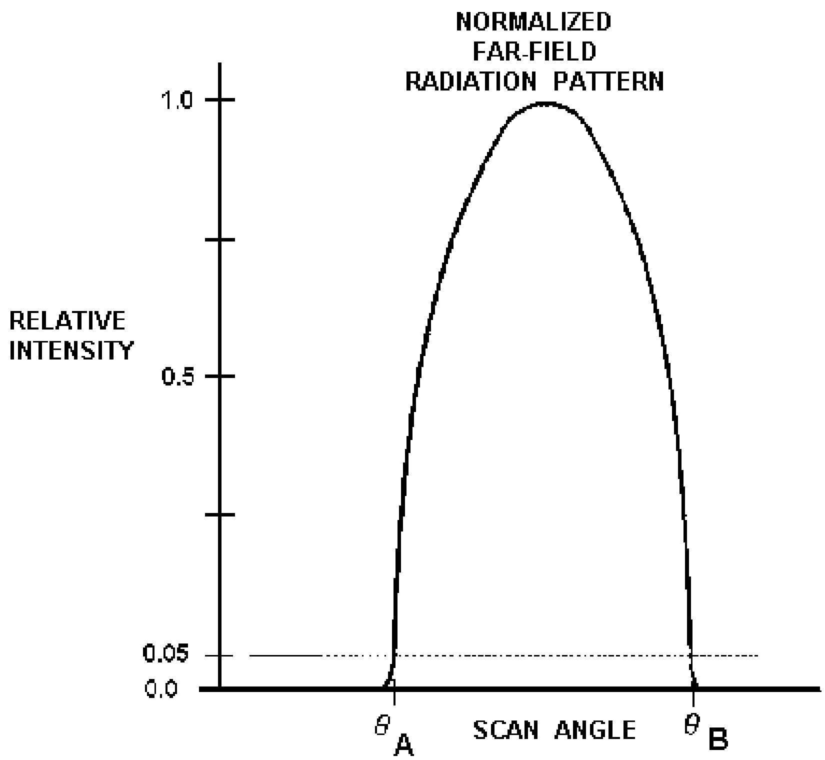

Figure 5-11.—Normalized far-field radiation pattern.

Fiber NA is defined by the 5 percent intensity level, or the 0.05 intensity level, as indicated in figure 5-11. The 0.05 intensity level intersects the normalized curve at scan angles Θ_A and Θ_B. The fiber NA is defined as

$$NA = \sin \Theta_5$$

where Θ_5 is the 5 percent intensity half angle. Θ_5 is determined from Θ_A and Θ_B as shown below:

$$\Theta_5 = \frac{\Theta_A - \Theta_B}{2}$$

Mode Field Diameter

The mode field diameter (MFD) of a single mode fiber is related to the spot size of the fundamental mode. This spot has a mode field radius w_0. The mode field diameter is equal to $2w_0$. The size of the mode field diameter correlates to the performance of the single mode fiber. Single mode fibers with large mode field diameters are more sensitive to fiber bending. Single mode fibers with small mode field diameters show higher coupling losses at connections.

The mode field diameter of a single mode fiber can be measured using EIA/TIA-455-167. This method involves measuring the output far-field power distribution of the single mode fiber using a set of apertures of various sizes. This far-field power distribution data is transformed into the near-field before using complex mathematical procedures. The mode field diameter is calculated from the transformed near field data. The mathematics behind the transformation between the far-field and near-field is too complicated for discussion in this chapter. Refer to EIA/TIA-455-167 for information on this transformation procedure.

Insertion Loss

Insertion loss is composed of the connection coupling loss and additional fiber losses in the fiber following the connection. In multimode fiber, fiber joints can increase fiber attenuation following the joint by disturbing the fiber's mode power distribution (MPD). Fiber joints may increase fiber attenuation because disturbing the MPD may excite radiative modes. Radiative modes are unbound modes that radiate out of the fiber contributing to joint loss. In single mode fibers, fiber joints can cause the second-order mode to propagate in the fiber following the joint. As long as the coupling loss of the connection is small, neither radiative modes (multimode fiber) or the second-order mode (single mode fiber) are excited.

Insertion loss of both multimode and single mode interconnection devices is measured using EIA/TIA-455-34. For Navy applications, an overfill launch condition is used at the input fiber. For other applications a mandrel wrap may be used to strip out high-order mode power. The length of fiber before the connection and after the connection may be specified for some applications. Power measurements are made on an optical fiber or fiber optic cable before the joint is inserted and after the joint is made. Figure 5-12 illustrates the mandrel wrap method of measuring the insertion loss of an interconnecting device in EIA/TIA-455-34.

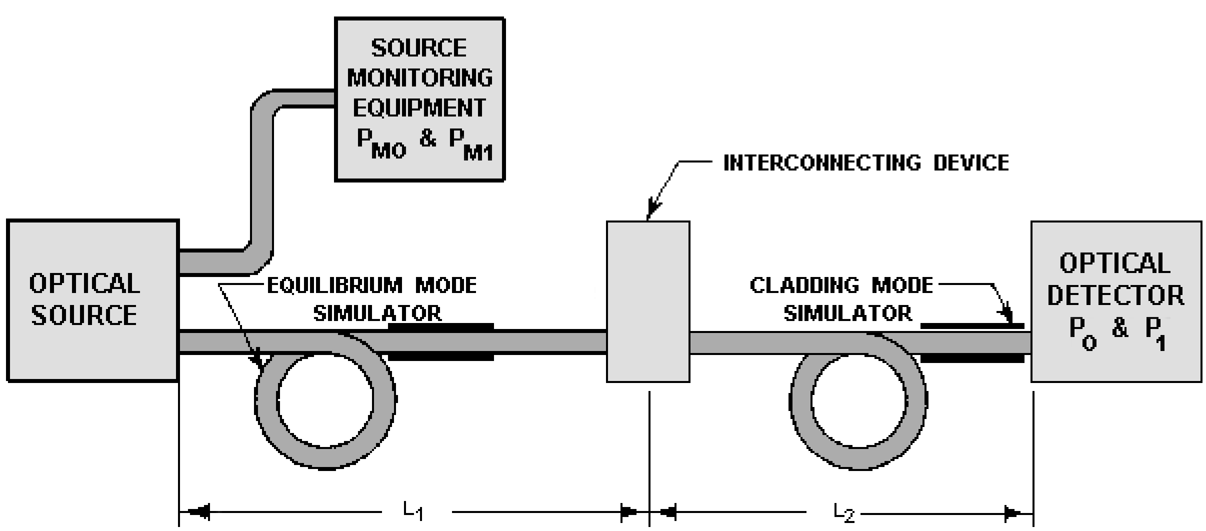

Figure 5-12.—Insertion loss measurement of an interconnecting device.

Initial power measurements at the detector (P_0) and at the source monitoring equipment (P_{M0}) are taken before inserting the interconnecting device into the test setup. The test fiber is then cut at the location specified by the end user. The cut results in a fiber of lengths L_1 and L_2 before and after the interconnection device that simulates the actual system configuration. After interconnection, the power at the detector (P_1) and at the source monitoring equipment (P_{M1}) is measured. The insertion loss is calculated as shown below:

$$\text{Insertion loss} = 10\log\left\{\frac{P_1}{P_o} \times \frac{P_{Mo}}{P_{M1}}\right\}$$

If the source power is constant, then the calculation of the insertion loss is similar to that of fiber attenuation.

Return Loss and Reflectance

Reflections occur at optical fiber connections. Optical power may be reflected back into the source fiber when connecting two optical fibers. In laser-based systems, reflected power reaching the optical source can reduce system performance by affecting the stability (operation) of the source. In addition, multiple reflections occur in fiber optic data links containing more than one connection. Multiple reflections can reduce data link performance by increasing the signal noise present at the optical detector.

Reflectance is a measure of the portion of incident light that is reflected back into the source fiber at the point of connection. Reflectance is given as a ratio (R) of the reflected light intensity to the incident light intensity. The reflectance ratio (R) for Fresnel reflection is discussed in chapter 4.

Return loss and reflectance are measured using EIA/TIA-455-107. They are measured using an optical source connected to one input of a 2×2 fiber optic coupler. Light is launched into the component under test through the fiber optic coupler. The light reflected from the component under test is transmitted back through the fiber optic coupler to a detector connected to the other input port. The optical power is measured at the output of the device under test (P_o) and at the input port of the coupler where the detector is located (P_r). P_o is corrected to account for the loss in power through the device under test. P_r is corrected to account for the loss in power through the coupler and any other connection losses in the path. The reflectance is then given by the ratio P_r/P_o.

Return loss is the amount of loss of the reflected light compared with the power of the incident beam at the interface. The optical return loss at the fiber interface is defined as

$$\text{Return loss} = -10 \text{ Log } R$$

Return loss is only the amount of optical power reflected and does not include power that is transmitted, absorbed, or scattered.

FIELD MEASUREMENTS

Field measurements differ from laboratory measurements because they measure the transmission properties of installed fiber optic components. Laboratory measurements can only attempt to simulate the actual operating conditions of installed components. Fiber optic component properties measured in the laboratory can change after the installation of these components on board ship. End users must perform field measurements to evaluate those properties most likely affected by the installation or repair of fiber optic components or systems.

The discussion on field measurements is limited to optical fiber and optical connection properties. Optical fiber and optical connection field measurements evaluate only the transmission properties affected by component or system installation or repair. Because optical fiber geometrical properties, such as core and cladding diameter and numerical aperture, are not expected to change, there is no need to remeasure these properties. The optical fiber properties that are likely to change include fiber attenuation (loss) and bandwidth. Bandwidth changes in the field tend to be beneficial, so field bandwidth measurement is generally not performed. If field bandwidth measurements are required, they are essentially the same as laboratory measurements so they will not be repeated. The optical connection properties that are likely to change are connection insertion loss and reflectance and return loss.

The installation and repair of fiber optic components on board ship can affect system operation. Microbends introduced during installation can increase fiber attenuation. Modal redistribution at fiber joints can increase fiber attenuation in the fiber after the joint. Fiber breaks or faults can prevent or severely disrupt system operation. Poor fiber connections can also increase insertion loss and degrade transmitter and receiver performance by increasing reflectance and return loss. End users should perform field measurements to verify that component performance is within allowable limits so system performance is not adversely affected.

There are additional differences in measuring optical fiber and optical connection properties in the field than in the laboratory. Field measurements require rugged, portable test equipment, unlike the sophisticated test equipment used in the laboratory. Field test equipment must provide accurate measurements in extreme environmental conditions. Since electrical power sources may not always be available in the field, test equipment should allow battery operation. In addition, while both fiber ends are available for conducting laboratory measurements, only one fiber end may be readily available for field measurements. Even if both fiber ends are available for field measurements, the fiber ends are normally located some distance apart. Therefore, field measurements may require two people.

The main field measurement technique involves optical time-domain reflectometry. An optical time-domain reflectometer (OTDR) is recommended for conducting field measurements on installed optical fibers or links of 50 meters or more in length. An OTDR requires access to only one fiber end. An OTDR measures the attenuation of installed optical fibers as a function of length. It also identifies and evaluates optical connection losses along a cable link and locates any fiber breaks or faults.

End users can also measure fiber attenuation and cable plant transmission loss using an optical power meter and a stabilized light source. End users use this measurement technique when optical time-domain reflectometry is not recommended. Measurements obtained with a stabilized light source and power meter are more accurate than those obtained with an OTDR. Measuring fiber attenuation and transmission loss using a power meter and light source requires access to both ends of the fiber or link. An optical loss test set (OLTS) combines the power meter and source functions into one physical unit.

Optical Time-Domain Reflectometry

End users use optical time-domain reflectometry to characterize optical fiber and optical connection properties in the field. In optical time-domain reflectometry, an OTDR transmits an optical pulse through an installed optical fiber. The OTDR measures the fraction of light that is reflected back due to Rayleigh scattering and Fresnel reflection. By comparing the amount of light scattered back at different times, the OTDR can determine fiber and connection losses. When several fibers are connected to form an installed cable plant, the OTDR can characterize optical fiber and optical connection properties along the entire length of the cable plant. A fiber optic cable plant consists of optical fiber cables, connectors, splices, mounting panels, jumper cables, and other passive components. A cable plant does not include active components such as optical transmitters or receivers.

The OTDR displays the backscattered and reflected optical signal as a function of length. The OTDR plots half the power in decibels (dB) versus half the distance. Plotting half the power in dB and half the distance corrects for round trip effects. By analyzing the OTDR plot, or trace, end users can measure fiber attenuation and transmission loss between any two points along the cable plant. End users can also measure insertion loss and reflectance of any optical connection. In addition, end users use the OTDR trace to locate fiber breaks or faults.

Figure 5-13 shows an example OTDR trace of an installed cable plant. OTDR traces can have several common characteristics. An OTDR trace begins with an initial input pulse. This pulse is a result of Fresnel reflection occurring at the connection to the OTDR. Following this pulse, the OTDR trace is a gradual downsloping curve interrupted by abrupt shifts. Periods of gradual decline in the OTDR trace result from Rayleigh scattering as light travels along each fiber section of the cable plant. Periods of gradual decline are interrupted by abrupt shifts called point defects. A point defect is a temporary or permanent local deviation of the OTDR signal in the upward or downward direction. Point defects are caused by connectors, splices, or breaks along the fiber length. Point defects, or faults, can be reflective or nonreflective. An output pulse at the end of the OTDR trace indicates the end of the fiber cable plant. This output pulse results from Fresnel reflection occurring at the output fiber-end face.

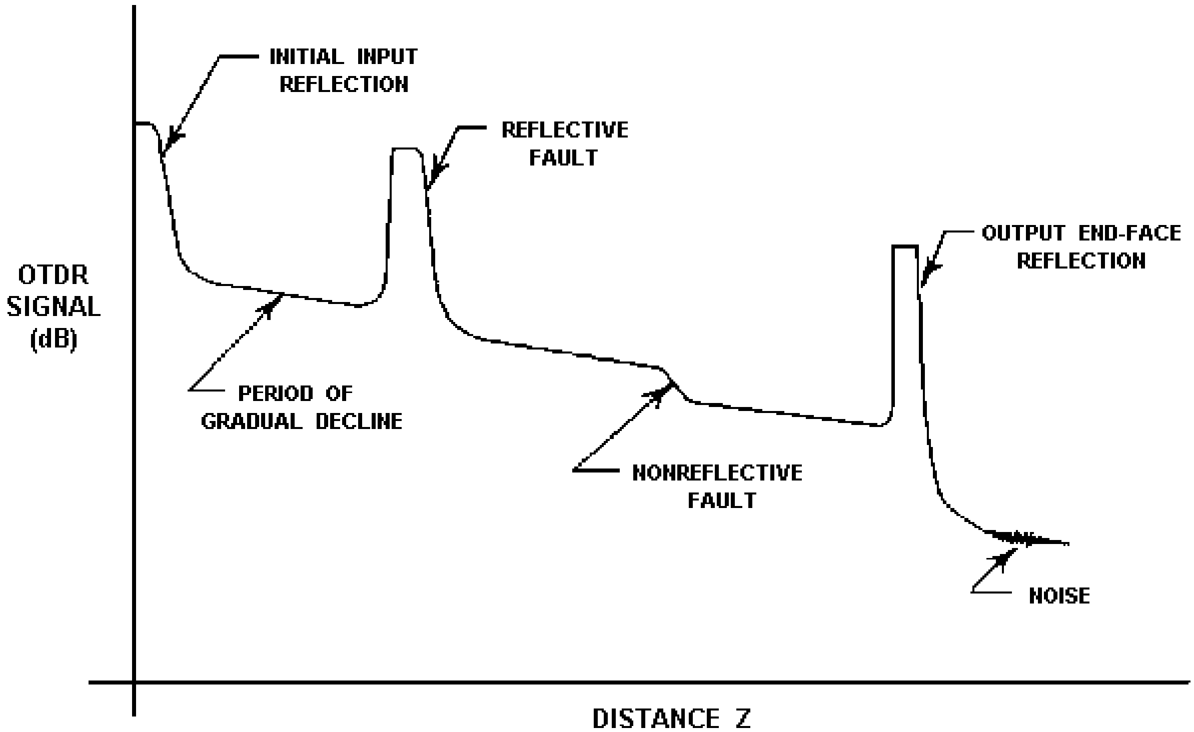

Figure 5-13.—OTDR trace of an installed cable plant.

ATTENUATION.—The fiber optic test method for measuring the attenuation of an installed optical fiber using an OTDR is EIA/TIA-455-61. The accuracy of this test method depends on the user entering the appropriate source wavelength, pulse duration, and fiber length (test range) into the OTDR. In addition, the effective group index of the test fiber is required before the attenuation coefficient and accurate distances can be recorded. The group index (N) is provided by fiber manufacturers or is found using EIA/TIA-455-60. By entering correct test parameters, OTDR fiber attenuation values will closely coincide with those measured by the cutback technique.

Test personnel can connect the test fiber directly to the OTDR or to a dead-zone fiber. This dead-zone fiber is placed between the test fiber and OTDR to reduce the effect of the initial reflection at the OTDR on the fiber measurement. The dead-zone fiber is inserted because minimizing the reflection at a fiber joint is easier than reducing the reflection at the OTDR connection.

Figure 5-14 illustrates the OTDR measurement points for measuring the attenuation of the test fiber using a dead-zone fiber. Fiber attenuation between two points along the test fiber is measured on gradual downsloping sections on the OTDR trace. There should be no point defects present along the portion of fiber being tested.

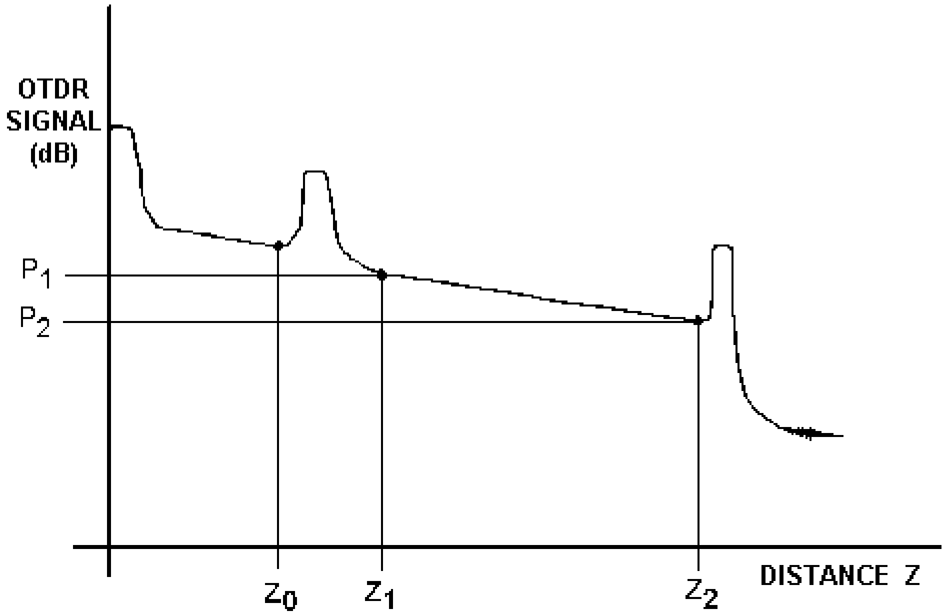

Figure 5-14.—OTDR measurement points for measuring fiber attenuation using a dead-zone fiber.

OTDRs are equipped with either manual or automatic cursors to locate points of interest along the trace. In figure 5-14, a cursor is positioned at a distance z_o on the rising edge of the reflection at the end of the dead-zone fiber. Cursors are also positioned at distances z_1 and z_2. The cursor positioned at z_1 is just beyond the recovery from the reflection at the end of the dead-zone fiber. Since no point defects are present in figure 5-14, the cursor positioned at z_2 locates the end of the test fiber. Cursor z_2 is positioned just before the output pulse resulting from Fresnel reflection occurring at the end of the test fiber.

The attenuation of the test fiber between points z_1 and z_2 is $(P_1 - P_2)$ dB. The attenuation coefficient (α) is

$$a = \frac{(P_1 - P_2}{(z_2 - z_1)} \mathrm{dB/km.}$$

The total attenuation of the fiber including the dead zone after the joint between the dead-zone fiber and test fiber is

$$\text{Attenuation} = (P_1 - P_2)\frac{(z_1 - z_o)}{(z_2 - z_1)} \mathrm{dB.}$$

If fiber attenuation is measured without a dead-zone fiber, z_0 is equal to zero ($z_0 = 0$).

At any point along the length of fiber, attenuation values can change depending on the amount of optical power backscattered due to Rayleigh scattering. The amount of backscattered optical power at each point depends on the forward optical power and its backscatter capture coefficient. The backscatter capture coefficient varies with length depending on fiber properties. Fiber properties that may affect the backscatter coefficient include the refractive index profile, numerical aperture (multimode), and mode-field diameter (single mode) at the particular measurement point. The source wavelength and pulse width may also affect the amount of backscattered power.

By performing the OTDR attenuation measurement in each direction along the test fiber, test personnel can eliminate the effects of backscatter variations. Attenuation measurements made in the opposite direction at the same wavelength (within 5 nm) are averaged to reduce the effect of backscatter variations. This process is called bidirectional averaging. Bidirectional averaging is possible only if test personnel have access to both fiber ends. OTDR attenuation values obtained using bidirectional averaging should compare with those measured using the cutback technique in the laboratory.

POINT DEFECTS.—Point defects are temporary or local deviations of the OTDR signal in the upward or downward direction. A point defect, or fault, can be reflective or nonreflective. A point defect normally exhibits a loss of optical power. However, a point defect may exhibit an apparent power gain. In some cases, a point defect can even exhibit no loss or gain. Refer back to figure 5-13; it illustrates a reflective fault and a nonreflective fault, both exhibiting loss. Figure 5-15 shows a nonreflective fault with apparent gain and a reflective fault with no apparent loss or gain.

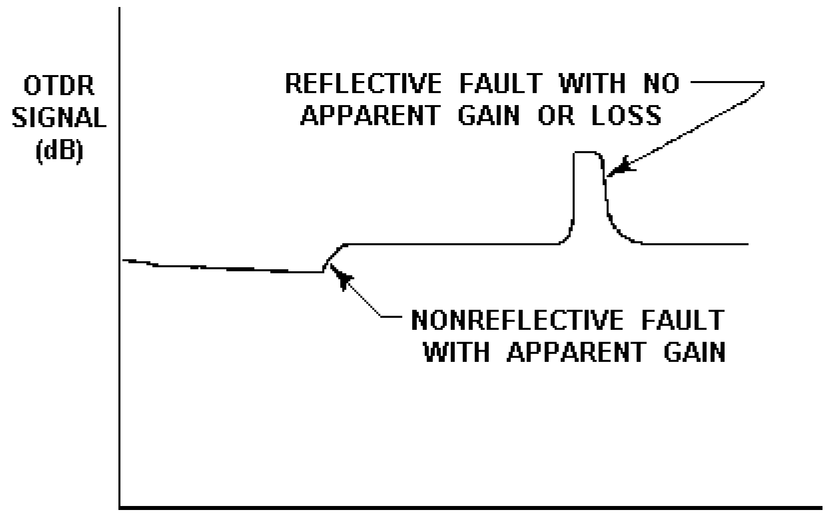

Figure 5-15.—An OTDR trace showing a nonreflective fault with apparent gain and a reflective fault with no apparent loss or gain.

Point defects are located and measured using EIA/TIA-455-59. Test personnel must enter the appropriate input parameters including the source wavelength, the pulse duration, and the fiber or cable group index into the OTDR. The nature of fiber point defects depends on the value of each parameter entered by the end user. The pulse duration usually limits the length of the point defect while other input parameters, such as the wavelength, can vary its shape.

If the length of the fiber point defect changes with the pulse duration, then the OTDR signal deviation is in fact a point defect. If the length remains the same, then the OTDR signal deviation is a region of high fiber attenuation. Regions of high fiber attenuation are referred to as attenuation non-uniformities.

Fiber point defects occur from factory fiber splices or bends introduced during cable construction or installation. For shipboard applications, manufacturers are not allowed to splice fibers during cable construction. Fiber joints are natural sources of OTDR point defects. However, fiber breaks, cracks, or microbends introduced during cable installation are additional sources of point defects.

Point defects that occur at fiber joints are relatively easy to identify because the location of a fiber joint is generally known. A reflective or nonreflective fault occurs at a distance equal to fiber joint location. In most circumstances, an optical connector produces a reflective fault, while an optical splice produces a nonreflective fault.

Reflective and nonreflective faults occurring at distances other than fiber joint locations identify fiber breaks, cracks, or microbends. A fiber break produces a reflective fault because fiber breaks result in complete fiber separation. Fiber cracks and microbends generally produce nonreflective faults.

A point defect may exhibit apparent gain because the backscatter coefficient of the fiber present before the point defect is higher than that of the fiber present after. Test personnel measure the signal loss or gain by positioning a pair of cursors, one on each side of the point defect. Figure 5-16 illustrates the positioning of the cursors for a point defect showing an apparent signal gain. The trace after the point defect is extrapolated as shown in figure 5-16. The vertical distance between the two lines in figure 5-16 is the apparent gain of the point defect.

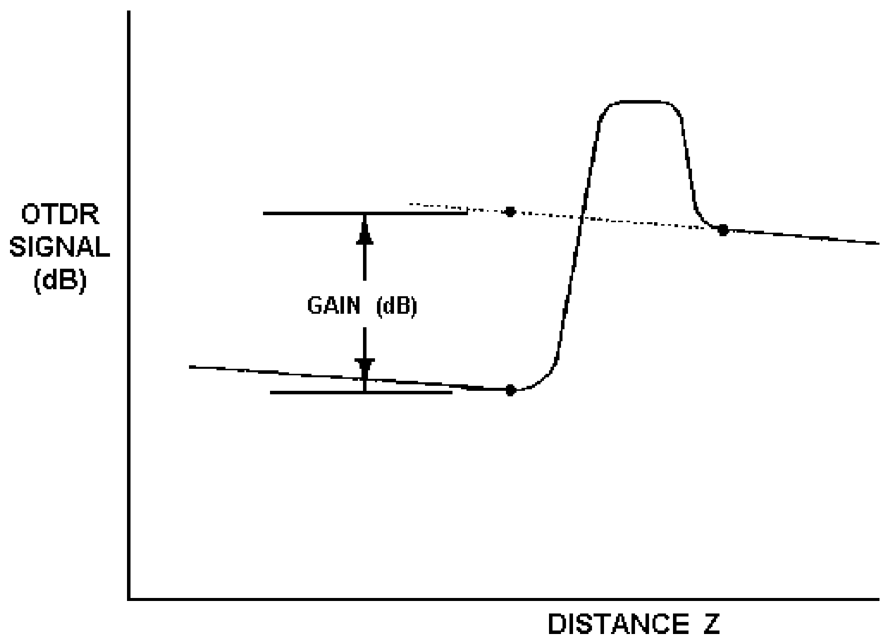

Figure 5-16.—Extrapolation for a point defect showing an apparent signal gain.

Point defects exhibiting gain in one direction will exhibit an exaggerated loss in the opposite direction. Figure 5-17 shows the apparent loss shown by the OTDR for the same point defect shown in figure 5-16 when measured in the opposite direction. Bidirectional measurements are conducted to cancel the effects of backscatter coefficient variations. Bidirectional averaging combines the two values to identify the true signal loss. Bidirectional averaging is possible only if test personnel have access to both ends of the test sample.

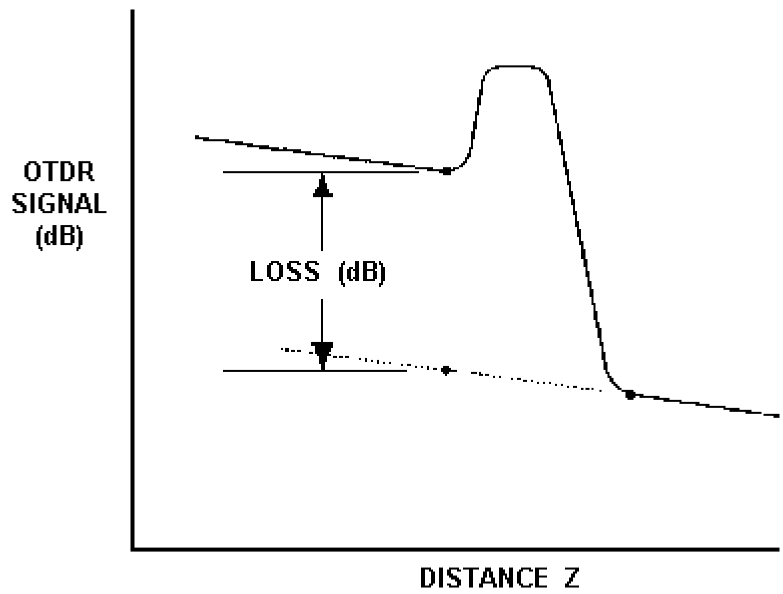

Figure 5-17.—The exaggerated loss obtained at point defects exhibiting gain in one direction by conducting the OTDR measurement in the opposite direction.

OTDRs can also measure the return loss of a point defect. However, not all OTDRs are configured to make the measurement. To measure the return loss of a point defect, the cursors are placed in the same places as for measuring the loss of the point defect. The return loss of the point defect is displayed when the return loss option is selected on the OTDR. The steps for selecting the return loss option depend upon the OTDR being used.

Power Meter

Test personnel also use an optical power meter and stabilized light source to measure fiber attenuation and transmission loss in the field. Optical power meter measurements are recommended when the length of an installed optical fiber cable or cable plant is less than 50 meters. A test jumper is used to couple light from the stabilized source to one end of the optical fiber (or cable plant) under test. An additional test jumper is also used to connect the other end of the optical fiber (or cable plant) under test to the power meter. Optical power meter measurements may be conducted using an optical loss test set (OLTS). An OLTS combines the power meter and source functions into one physical unit. When making measurements, it does not matter whether the stabilized source and power meter are in one physical unit or two.

Power meter measurements are conducted on individual optical fiber cables installed on board ship. The installed optical fiber cable must have connectors or terminations on both ends to make the measurement. If the installed optical fiber cable does not have connectors or terminations on both ends, an OTDR should be used to evaluate the cable. If the cable is too short for evaluation with an OTDR, cable continuity can be verified using a flashlight.

Power meter measurements for cable assembly link loss require that test personnel clean all optical connections at test jumper interfaces before performing any measurement. Test personnel should use cotton wipes dampened with alcohol to clean connectors and blow dry before making connections. End users should also ensure that test equipment calibration is current.

Power meter measurements connecting a test reference cable between the light source and power meter. The test reference cable has the same nominal fiber characteristics as the cable under test. The optical power present at the power meter is the reference power (P_1). Disconnect the test reference cable and connect the optical fiber cable under test between the light source and power meter using test jumpers. If possible, the test reference cable should be used as the input jumper cable for the test cable measurement. The test jumper fiber properties, such as core diameter and NA, should be nominally equal to the fiber properties of the cable being tested. The optical power present at the power meter is test power (P_2).

Test personnel use P_1 and P_2 to calculate the cable assembly link loss. The cable assembly link loss (B_{CA}) of optical fiber installed with connectors or terminations on both ends is

$$B_{CA} = (P_1 = P_2)\ \mathrm{dB}$$

The cable assembly link loss should always be less than the specified link loss for that particular link.

Besides measuring individual cables, test personnel measure the transmission loss of installed fiber optic cable plants. The transmission loss of fiber optic cable plants is measured using EIA/TIA-526-14 method B (multimode fiber) or EIA/TIA-526-7 (single mode fiber). The procedure measures the internal loss of the cable plant between points A and B, plus two connection losses. Figure 5-18 (A) illustrates the method described in EIA/TIA-526-14 method B for measuring the reference power (P_1). Figure 5-18 (B) shows the final test configuration for measuring the cable plant test power (P_2).

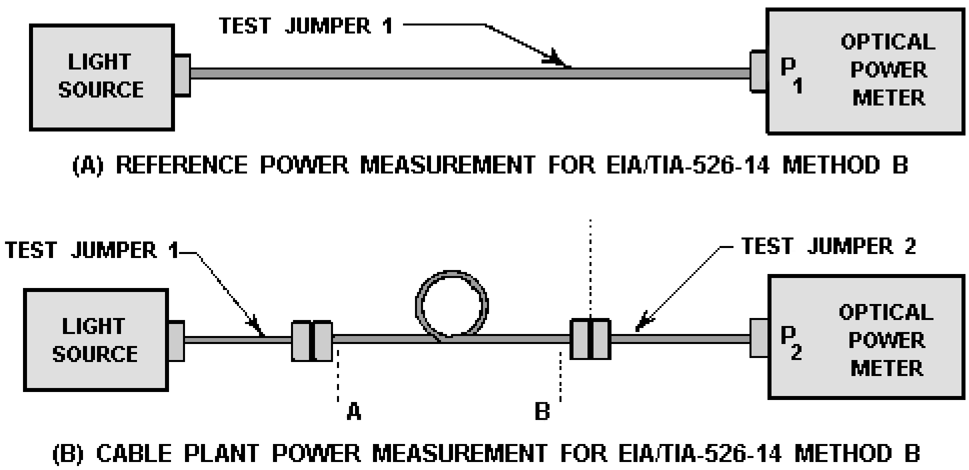

Figure 5-18.—EIA/TIA-526-14 methods for measuring the reference power (P_1).

The procedure is exactly the same as described for measuring the link loss of an individual cable assembly. The total optical loss between any two termination points, including the end terminations, of the optical fiber cable plant link is measured. The measured cable plant link loss should always be less than the specified cable plant link loss.

Test personnel should conduct cable assembly link loss, and cable plant transmission loss measurements in both directions and at each system operational wavelength. By performing these measurements in each direction, test personnel can better characterize cable and link losses. Unlike optical time-domain reflectometry, bidirectional readings are always possible when performing power meter measurements. In power meter measurements, by definition, end users have access to both ends of the cable or cable plant.

SUMMARY

Now that you have completed this chapter, let's review some of the new terms, concepts, and ideas that you have learned. You should have a thorough understanding of these principles before moving on to chapter 6.

END USERS (equipment manufacturers, shipbuilders, maintenance personnel, test personnel, and so on) should measure some component parameters upon receipt before installing the component into the fiber optic data link. In addition, they should measure some component parameters after installing or repairing fiber optic components in the field.

LABORATORY MEASUREMENTS of the optical fiber and optical connections performed by end users in the laboratory include attenuation, cutoff wavelength (single mode), bandwidth (multimode), chromatic dispersion, fiber geometry, core diameter, numerical aperture (multimode), mode field diameter (single mode), insertion loss, and reflectance and return loss.

ATTENUATION is the loss of optical power as light travels along the fiber. It is a result of absorption, scattering, bending, and other loss mechanisms.

The **LAUNCH SPOT SIZE** and the **ANGULAR DISTRIBUTION** may affect multimode fiber attenuation measurement results by affecting modal distributions.

An **UNDERFILLED** launch results when the launch spot size and angular distribution are smaller than that of the fiber core.

An **OVERFILLED** launch condition occurs when the launch spot size and angular distribution are larger than that of the fiber core.

A **CLADDING-MODE STRIPPER** is a device that removes any cladding mode power from the fiber.

A **MODE FILTER** is a device that attenuates a specific mode or modes propagating in the core of an optical fiber.

The **CUTOFF WAVELENGTH** of a single mode fiber is the wavelength above which the fiber propagates only the fundamental mode. The cutoff wavelength of a single mode fiber varies according to the fiber's radius of curvature and length. The fiber cutoff wavelength (λ_{cf}) will generally be higher than the cable cutoff wavelength (λ_{cc}).

PULSE DISTORTION is the spreading of the light pulse as it travels along the fiber caused by dispersion. It reduces the bandwidth, or information-carrying capacity, of an optical fiber.

Two **BASIC TECHNIQUES** are used for measuring the modal bandwidth of an optical fiber. The first characterizes dispersion by measuring the **IMPULSE RESPONSE h(t)** of the fiber in the time domain. The second characterizes modal dispersion by measuring the **BASEBAND FREQUENCY RESPONSE H(*f*)** of the fiber in the frequency domain.

The **LOWEST FREQUENCY** at which the magnitude of the fiber frequency response has decreased to one half its zero-frequency value is the -3 decibel (dB) optical power frequency (f_{3dB}).

CHROMATIC DISPERSION occurs because different colors of light travel through the fiber at different speeds. Since the different colors of light have different velocities, some colors arrive at the fiber end before others.

The **DIFFERENTIAL GROUP DELAY** $\tau(\lambda)$ is the variation in propagation delay that occurs because of the different group velocities of each wavelength in an optical fiber.

The **RANGE OF WAVELENGTHS** over which meaningful chromatic dispersion data is obtained depends on the wavelength range of optical source(s) used.

FIBER GEOMETRY MEASUREMENTS are performed by end users to reduce system attenuation and coupling loss resulting from poor fiber fabrication.

The **CLADDING DIAMETER** is the average diameter of the cladding.

CLADDING NONCIRCULARITY, or ellipticity, is the difference between the smallest radius of the fiber (R_{gmin}) and the largest radius of the fiber (R_{gmax}) divided by the average cladding radius (R_g).

The **CORE-CLADDING CONCENTRICITY ERROR** for multimode fibers is the distance between the core and cladding centers divided by the core diameter. The core-cladding concentricity error for single mode fibers is defined as the distance between the core and cladding centers.

CORE NONCIRCULARITY is the difference between the smallest radius of the core (R_{cmin}) and the largest radius of the core (R_{cmax}) divided by the core radius (R_c).

The **NEAR-FIELD POWER DISTRIBUTION** is defined as the emitted power per unit area (radiance) for each position in the plane of the emitting surface.

The **NEAR-FIELD REGION** is the region close to the fiber-end face.

The **CORE DIAMETER** is derived from the normalized output near-field radiation pattern. The core diameter (D) is defined as the diameter at the 2.5 percent (0.025) level.

The **NUMERICAL APERTURE (NA)** is a measurement of the ability of a multimode optical fiber to capture light.

The **FAR-FIELD POWER DISTRIBUTION** describes the emitted power per unit area as a function of angle Θ some distance away from the fiber-end face.

The **FAR-FIELD REGION** is the region far from the fiber-end face.

Single mode fibers with large **MODE FIELD DIAMETERS** are more sensitive to fiber bending. Single mode fibers with small mode field diameters show higher coupling losses at connections.

INSERTION LOSS is composed of the connection coupling loss and additional fiber losses in the fiber following the connection.

REFLECTANCE is a measure of the portion of incident light that is reflected back into the source fiber at the point of connection.

RETURN LOSS is the amount of loss of the reflected light compared with the power of the incident beam at the interface.

OPTICAL FIBER and **OPTICAL CONNECTION FIELD MEASUREMENTS** measure only the transmission properties affected by component or system installation or repair.

OPTICAL TIME-DOMAIN REFLECTOMETRY is recommended for conducting field measurements on installed optical fibers or cable plants of 50 meters or more in length.

An **OPTICAL LOSS TEST SET (OLTS)** combines the power meter and source functions into one physical unit.

An **OPTICAL TIME-DOMAIN REFLECTOMETER (OTDR)** measures the fraction of light that is reflected back because of Rayleigh scattering and Fresnel reflection.

A **FIBER OPTIC CABLE PLANT** consists of optical fiber cables, connectors, splices, mounting panels, jumper cables, and other passive components. A cable plant does not include active components such as optical transmitters or receivers.

A **POINT DEFECT** is a temporary or permanent local deviation of the OTDR signal in the upward or downward direction. Point defects are caused by connectors, splices, or fiber breaks. Point defects, or faults, can be reflective or nonreflective.

A **DEAD-ZONE** fiber is placed between the test fiber and OTDR to reduce the influence of the initial pulse resulting from Fresnel reflection at the OTDR connection.

The **AMOUNT OF OPTICAL POWER BACKSCATTERED** because of Rayleigh scattering at one point depends on the forward optical power and the fibers backscatter capture coefficient.

The **EFFECTS OF BACKSCATTER VARIATIONS** can be eliminated by test personnel by performing the OTDR attenuation measurement in each direction along the test fiber and averaging (bidirectional readings).

A **POINT DEFECT** may exhibit apparent gain because the backscatter coefficient of the fiber present before the point defect is higher than that of the fiber present after.

To **MEASURE FIBER ATTENUATION** and **TRANSMISSION LOSS** in the field, test personnel use an optical power meter and stabilized light source.

OPTICAL POWER METER MEASUREMENTS are recommended when the length of an installed optical fiber cable or cable plant is less than 50 meters.