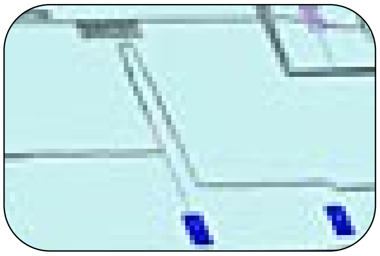
Optical Test Primer

Fiber Optic Cable and Test Equipment



Basic Concepts

COMPUTING

COMMUNICATIONS

VIDEO

Tektronix

Enabling Innovation

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Preface

The objective of this primer is to acquaint OSP technicians and network managers with the basics of fiber optic cable technology and its use in telecommunication systems. The primer also presents a practical guide to the use of an Optical Time Domain Reflectometer (OTDR) and techniques for the commissioning, troubleshooting and restoration of a fiber optic plant. This document is organized in five sections:

- Basic theory and technology of fiber optic cable.
- Common fiber optic cable test tools
- Introduction to the Optical Time Domain Reflectometer
- Advanced OTDR Functions
- Practical OTDR Test Strategies

A glossary of fiber optic terms is provided at the end.

Frequency and Wavelength

Electromagnetic waves can be described in terms of their wavelength or frequency, which are mathematically related. Wavelength, also referred to as “lambda”, or “λ”, is the distance of one complete cycle of a periodic signal frequency. Frequency is the number of complete cycles that occur per unit of time. Wavelength is measured in meters, frequency in cycles per second (called Hertz). We traditionally describe radio signals by their frequency (from about 1 kilohertz to 1 megahertz) and visible light waves by their wavelength (400 nanometers to 700 nanometers). A nanometer is equal to 10^{-9} (1 billionth) of a meter. Fiber optic systems use light sources with wavelengths in the infra-red part of the electromagnetic spectrum.

Section 1

Basic Fiber Optic Cable Theory and Technology

Many of today’s communication networks use fiber optic links to carry voice, video and data information at the speed of light. Fiber optic links incorporate multiple transparent glass or plastic fiber cables that guide modulated light waves through the network. In digital systems, message data is converted into a series of binary digits that are used to switch the light source on and off, creating a sequence of coded light pulses. A receiver at the other end of the cable decodes the light pulses back into digital ones and zeroes to reconstruct the original message data.

This section describes some of the basic characteristics of fiber optic cable and its use in communications networks.

Laser Light Sources

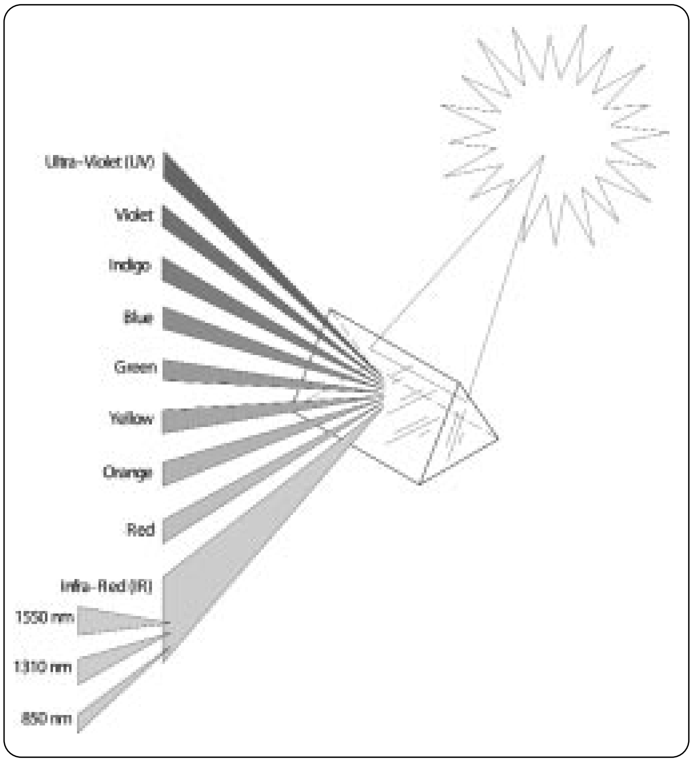
Most fiber optic communication networks use lasers as light sources. A laser is a device that creates a narrow, intense beam of coherent light - at a single or just a few frequencies going in one precise direction. The word laser is an acronym for light amplification by stimulated emission of radiation. Lasers are described by their wavelength in nanometers (nm) and by their output power levels.

Wavelengths

Three laser wavelengths are currently in use for fiber optic systems; 850 nm, 1310 nm and 1550 nm. All three wavelengths are in the infrared spectrum and are invisible to the human eye (see Figure 1).

The distances between network nodes and the number of connections determine the best selection of fiber type and laser wavelength. As a rule of thumb:

- Lasers with longer wavelengths can transmit over greater distances.
- Lasers with longer wavelengths cost more than lasers with shorter wavelengths.
- Long distance systems using higher bandwidth singlemode fiber require more expensive connectors.



▶ ***Figure 1:*** *Fiber optic spectrum*

Optical Power

The power (or brightness) of a laser determines how far a signal can be sent down a fiber and how much risk for eye damage it represents. Lasers are divided into three power classes:

- Class I lasers are inherently safe and will not cause damage to the human eye.
- Class II lasers have higher power output that can cause eye damage with exposure of more than three seconds.
- Class III lasers have the highest power output. They are inherently dangerous and require eye protection and other safeguards.

Most telecommunications systems use Class I lasers; Visual Fault Finders and some optical amplifiers use Class II. Most test equipment, including OTDR's, use Class I.

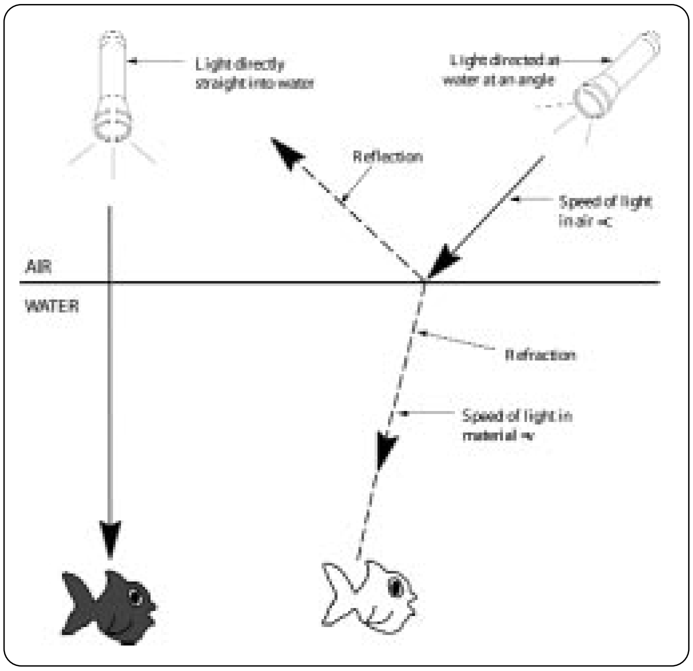
WARNING. Never look directly into any operating laser or lit fiber. Laser light can cause eye damage or blindness.

Fiber Optic Cable Characteristics

Refraction and Reflection

The speed of light is determined by the medium in which it is traveling. The index of refraction (ir) for a material is expressed as the ratio of the speed of light in a vacuum (c) to the speed of light in the material (v), where ir = c/v. Values of ir are approximately 1.333 for water, 1.473 for glycerin and 2.417 for diamond. In fiber optic glass, the index of refraction ranges from 1.46 to 1.6. Light waves bend (refract) or bounce (reflect) when they meet the boundary between two materials with different indices of refraction.

The angle at which the light strikes the boundary affects the amount and direction of light that is refracted and/or reflected. Figure 2 illustrates a familiar example of light at the boundary of air and water.



▶ ***Figure 2:*** *Example of refraction and reflection using air and water*

Angles of refraction and reflection vary according to the wavelength of the light source. We see the results of this property in a prism as it separates sunlight into its component colors and in a rainbow where light is refracted by raindrops into an orderly sequence of colors from violet to red– each at a different angle.

Light reflected from a glass-air boundary is called a Fresnel (pronounced fra/-nell), reflection. The detection of Fresnel reflections can be very useful when testing fibers because they reveal the glass-air boundaries at the ends of fibers and at junctions such as connectors and mechanical splices.

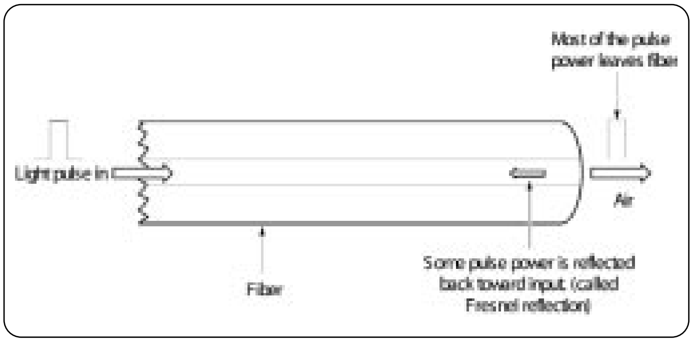


Figure 3: *Fresnel reflection*

Optical Fiber Construction

An optical fiber consists of a thin strand of glass or plastic ("core") surrounded by glass or plastic "cladding" material that contains and reflects light down the center of its core with minimum attenuation. The index of refraction of the cladding is different from that of the core in order to contain the light waves within the fiber - an effect known as total internal reflection. Most fibers are covered with buffer coatings and/or jackets to protect them from moisture and damage.

Figure 4 shows the construction of a typical telecommunications single-mode optical fiber. The fiber consists of:

Core: The light-carrying core of an optical fiber is made of glass with a typical index of refraction of 1.47.

Cladding: The cladding is also made of glass and surrounds the core.

Buffer: The buffer is a shock-absorbing protective covering, made of a polymer such as Kevlar, to protect the core and cladding from damage.

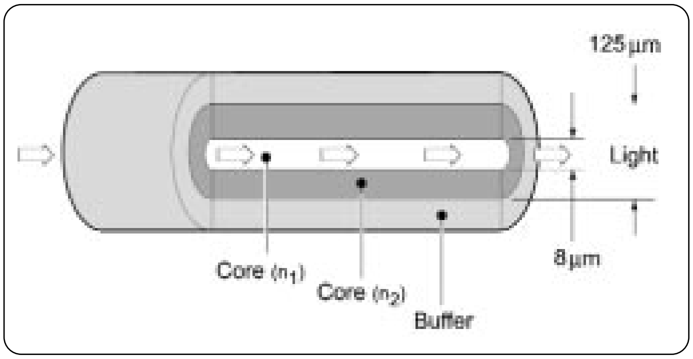


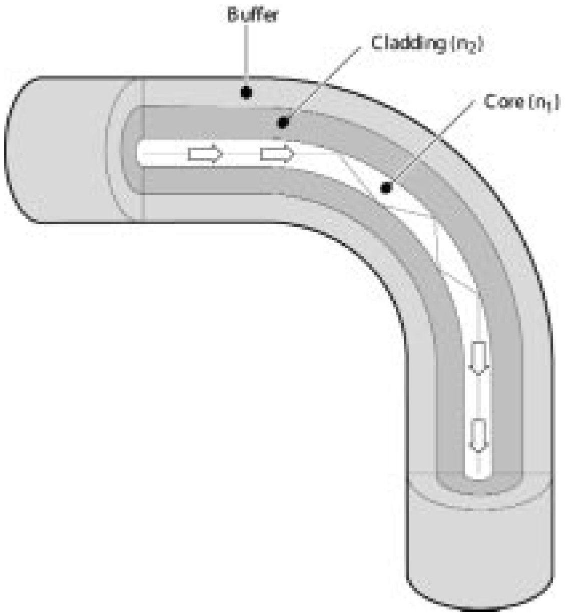
Figure 4: *Fiber construction*

Bends

Optical fiber has great lateral strength and it can be stretched significantly without problems. Unfortunately, it is susceptible to failure when it is bent, leading to unpredictable system outages. Bends or kinks in the fiber create cross-sectional stress points that can separate into breaks over time or create excessive loss with drops in temperature, especially at longer wavelengths.

Bends can be created during installation, caused by unintended twists in the cable or by external objects (like rocks) impacting the cable when it is buried. They can also occur at termination or splice points where fiber may be spooled with too small a radius or bent around objects after leaving the cable sheath. The risk of negative effects from bends increases with colder temperatures and when the external line is physically stressed.

When light strikes the boundary between the core and the cladding, it either reflects and travels down the core or refracts and escapes from the core. As long as it is used within its specifications, fiber can be bent and flexed without losing much light, as illustrated in Figure 5. The small size and round shape core causes most of the light to strike the boundary at a small angle and reflect down the core with very little of the light escaping. The fiber transmits light as long as the tubular shape of the fiber is not distorted; however, light will escape if the fiber is cracked, kinked or bent below its specified minimum radius.



▶ ***Figure 5:*** *Light travelling through a bent fiber*

Packaging of Fibers into Cable for Telecommunication Networks

Optical fibers are packaged into cables of different configurations to address the variety of needs in a typical optical plant. Table 1 lists the packaging methods for fiber optic cable typically used in telecommunications applications.

Table 1: Fiber-optic cable packaging

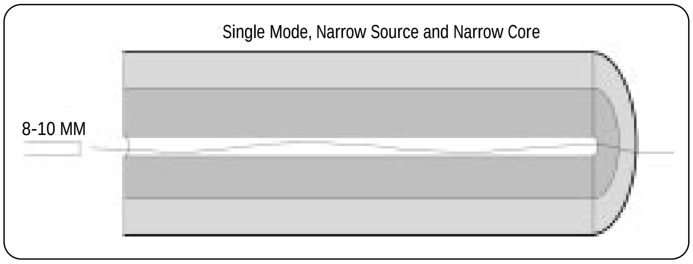
Package	Advantages
Loose tube "ribbon" (outside plant)	Gel filled to protect against water intrusion Small cable size Convenient to interconnect and identify individual fibers More adaptable to mass fusion splicers Easier to handle Uses smaller splice box
Loose tube "individual" (outside plant)	Gel filled to protect against water intrusion Sturdier and less prone to degradation Less expensive May be modified to ribbon shape where necessary for mass splicing
Tight-buffered (inside plant)	Jacketed, single strands High fiber count, dense, compact Not gel filled, more convenient for splicing Able to form tighter bend radiuses Fire-, smoke-, moisture-, toxic-resistant jacket (to meet safety and fire codes)

Modes and Modal Dispersion

Light traveling down the core of the fiber can follow one or more paths or "modes" depending on the diameter of the fiber. There are two categories of fiber used in communications systems – singlemode and multimode. Glass cores are used in both types; although some new plastic-core multimode cables promise performance for very short runs similar to glass and at a lower cost.

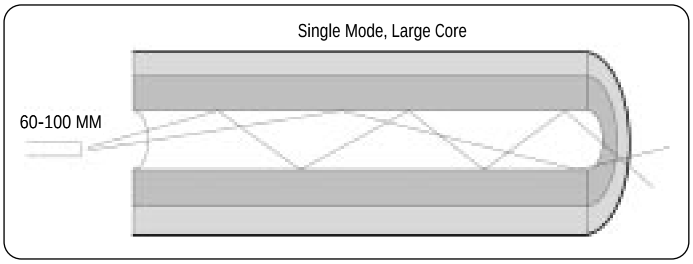
Singlemode cable is a single stand of glass fiber with a relatively narrow diameter (nominally 9 microns), through which only one mode will propagate. The small core and single light wave virtually eliminate any distortion that could result from overlapping light pulses, providing the least signal attenuation and the highest transmission speeds of any type of fiber cable.

Singlemode fiber carries higher bandwidth and lower spectral dispersion than multimode and requires a light source with a narrow spectral width. It supports a higher transmission rate and up to 50 times more distance than multimode. However, single mode connectors and splices have very little tolerance for core misalignment, making them significantly more expensive to manufacture and install. Singlemode fibers operate at wavelengths from 1300 to 1550 nanometers and are used primarily for telecommunications and CATV applications.



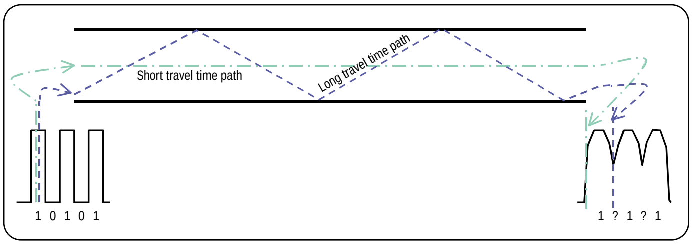
▶ ***Figure 6:*** *Singlemode fiber*

Multimode fiber provides high bandwidth at high speeds over short distances. Typical multimode fiber core diameters are 50, 62.5, and 100 micrometers and operate with light source wavelengths from 850 to 1300 nanometers. Although multiple paths can become an undesired effect, the larger core permits the use of less expensive connectors and allows less critical tolerances for manufacturing and installing the connectors. Multimode cable is usually preferred in systems such as Local Area Networks (LAN's) that incorporate many connectors with short fiber runs. In cable runs greater than 3000 feet (914 meters), the multiple paths of light can cause signal distortion at the receiving end, resulting in an unclear and incomplete data transmission.



▶ ***Figure 7:*** *Multimode fiber*

Modal dispersion is the result of a light pulse being spread out over time because it has traveled multiple paths simultaneously, as in a multimode fiber. Multiple path dispersion can cause events to blend into one another or eliminate some events altogether. An important consideration for multimode cable is its bandwidth versus length specification. For example, a cable specified at 100 MB/s for a 1 kilometer link would carry 200 MB/s over a 0.5 km link, or 50 MB/s in a 2 km link. Therefore, multimode links are bandwidth limited to prevent data points from getting too close together and being lost. This bandwidth limitation is acceptable for many LAN applications but not for high-speed links between major systems.



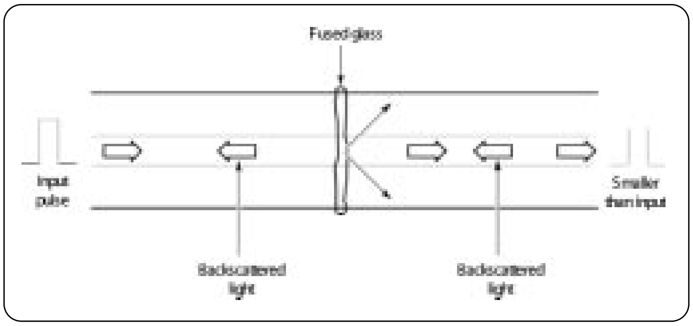
▶ ***Figure 8:*** *Modal dispersion*

Junctions in Fiber Optic Cables

The junctions formed by either splices or connectors have a significant effect on the performance of a fiber optic cable. Three basic techniques are used to join fibers: fusion splices, mechanical splices, and connectors.

Fusion Splices

Fusion splices are formed by welding two cleaved fiber ends together in a permanent union - they have the lowest loss of the three methods and produce extremely low reflections (see Figure 9). Fusion splices are most often used to construct and restore permanent cable runs.



▶ ***Figure 9:*** *Fusion splices*

Mechanical Splices

Mechanical splices employ physical couplers to hold two fiber ends in contact with each other. A special fluid called index matching gel (or oil) is often added to the splice to fill the air gap between the fiber ends and reduce Fresnel reflections. Rotary and Fiberlok are two examples of mechanical splices. Mechanical splices are simple, install quickly, and have relatively low loss. They are typically used to restore damaged cables and in aerial applications where fusion techniques would be impractical.

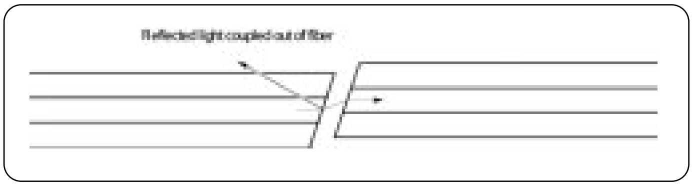
Connectors

Connectors provide fiber optic junctions that can be disconnected and reconnected as necessary. They are adaptable, convenient and are typically used at patch panels and for electronic systems and test equipment. Installing a connector requires special tools and training.

The “ferrule” is the protruding connector part that houses the fiber and normally includes a spring that provides axial pressure when two connectors are mated. The end face of the fiber/ferrule is finished (polished) to minimize reflections from the mating surfaces. Each surface of the plane-polished ferrule reflects about 4% of the light incident upon it. In coherent systems, the total reflection can be as high as 15%, or it can be made extremely low. The amount of reflection depends on the gap between the ends of the fibers, the cleave and the quality of the polish.

Physical contact (PC) connectors use a rounded polish to better ensure that the ends of the fiber make contact without a gap. This reduces the reflection from the connection and improves measurement repeatability.

If the end of the fiber is polished at an angle, the reflected light will be directed into unguided modes (light paths that don’t travel very far) and light will be lost from the fiber. This results in very low reflectance for guided modes. Some manufacturers improve on this design even more by polishing the ends of the fibers into angled hemispheres.



▶ ***Figure 10:*** *Angled connection*

Junction Losses

The amount of light lost in a junction is affected by:

- The alignment of the fibers in the splice
- The sizes of the two fiber cores
- The alignment or shapes of fiber cores—most are circular, some are oval
- The properties of the fibers—scattering coefficients can vary from fiber to fiber

Proper core alignment is strongly influenced by consistent and tightly controlled fiber geometry. When splicing two fibers together, more exact core alignment yields a better, lower-loss splice. Core/clad concentricity is a measure of how well the core is centered in a cable; tighter tolerances mean that the fiber core is more precisely centered in the cladding glass.

Tight concentricity tolerance is especially important when using splicing technologies and equipment that do not actively align the fiber cores before splicing, as with mechanical splices and v-groove alignment fusion splices (single or mass). For example, as many as 12 fiber splices are made simultaneously in a mass splice, with no opportunity to individually align each fiber core.

In single-fusion splicing techniques, tighter core/clad concentricity means splices are done right the first time, every time. Geometrically optimized fiber provides superior and more consistent splices, thereby reducing or even eliminating the need for splice loss verification.

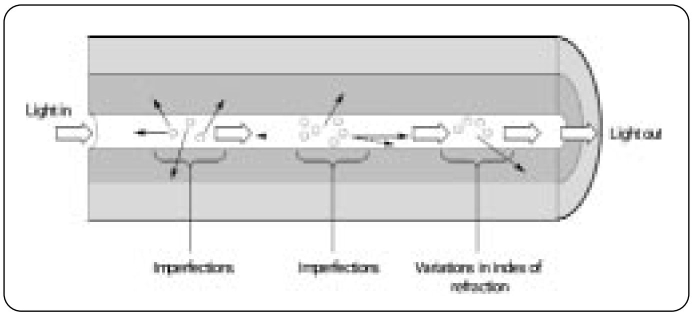
Backscatter and Optical Power Loss

Even coherent laser light is subject to power loss as it propagates through a fiber. The glass in fiber optic cable is produced from silicon and other elements to make it thin and flexible. Optical fiber, although much higher in quality than window glass, is not pure - it contains imperfections, impurities, and variations in its index of refraction. These flaws can cause some of the light traveling down the fiber to be scattered in all directions, resulting in the loss of power.

Scatter that is directed back toward the laser source is called “backscatter”, a property that is very useful for fiber cable measurements. Light traveling through a uniform section of fiber produces backscatter that decreases uniformly over the fiber length due to attenuation of the return signal. Splices or connectors create distinctive deviations in the backscatter caused by attenuation of the return signals from the far side of the junctions. These deviations are detected as “events” whose characteristics can be used to identify their properties and locations.

Glass is transparent to some wavelengths of light and absorbs others. Scattering varies with the color of the light. As the wavelength gets longer (toward the red end of the spectrum) the scattering diminishes - doubling the wavelength reduces scattering by a factor of sixteen. The 1310 nm and 1550 nm wavelengths used in fiber optics communications systems were selected for their ability to pass through the glass in optical fiber with the least amount of loss. The 850 nm wavelength is used because the light sources are relatively inexpensive.

Figure 11 shows how impurities in a fiber attenuate the power of the light passing through it.

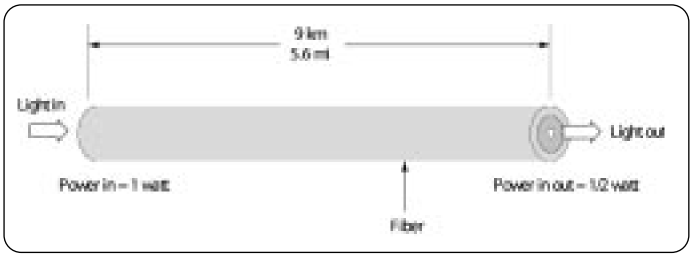


▶ ***Figure 11:*** *Light loss in a fiber*

Power in fiber is measured in decibels (dB) - logarithmic units of powers of 10. The equation for power gain or loss is:

Loss = 10 $\log_{10}$ (Output Power/Input Power)

Figure 12 shows an example of a loss of one half of the power in a 9 km fiber link – a power loss of ~3 dB [10 $\log_{10}$ (1/2) = 10 $\log_{10}$ (0.5) ≈ 3.]



▶ ***Figure 12:*** *Example of power loss in a fiber*

Signal Conditioning Elements in an Optical Network

Amplifiers and multiplexers are used to improve the quality and capacity of optical communication networks. Amplifiers strengthen optical signals to restore power that has dissipated over long distances. Multiplexers allow multiple signals to be carried simultaneously through a single fiber.

Amplifiers

Amplifiers are used to strengthen the communication signal as they pass through the fiber without breaking the signal path. Most amplifiers employ special erbium-doped fiber elements that combine energy from an external light source with the signal to increase its energy. Newer Raman amplifiers use backscattering properties within normal fibers to amplify the signal.

Dense Wavelength Division Multiplexing

Wavelength Division Multiplexers (WDM) provide a method of sending more than one light signal down a fiber at the same time – each at a different wavelengths. WDM's are passive optical component modules that use specially treated and notched sections of fiber called "diffraction gratings". They are bi-directional - the same device combines wavelengths in one direction for transmission and separates them for reception in the other. (see Figures 13 and 14). The light waves can also be shifted to other wavelengths and added to other fibers to suit various applications.

Dense Wavelength Division Multiplexing (DWDM) enables service providers to increase bandwidth without the cost of installing additional fiber. DWDM communication systems use multiple WDM's to transmit multiple laser lines (channels) through fiber optic cables, allowing the fiber to carry more information. Current DWDM systems are capable of combining multiple channels into a single fiber.

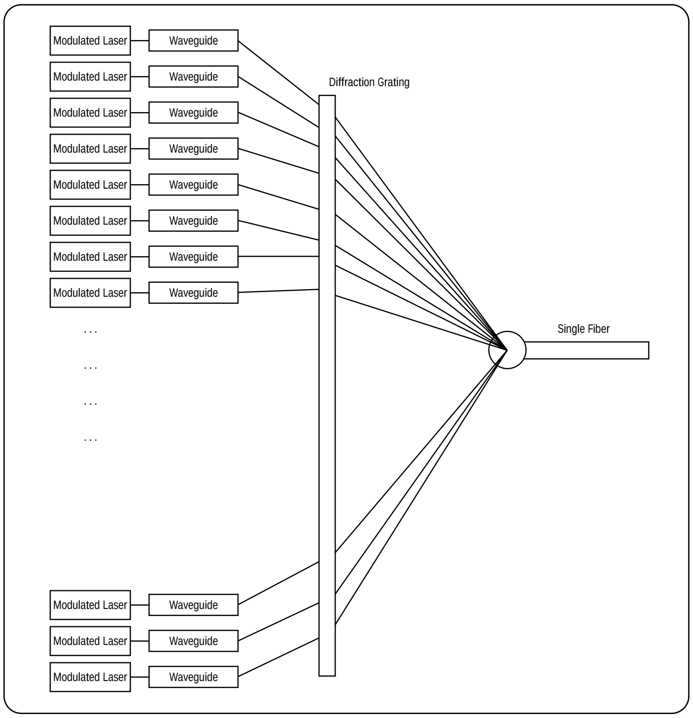


Figure 13: *Dense Wavelength Division Multiplexing Transmitting*

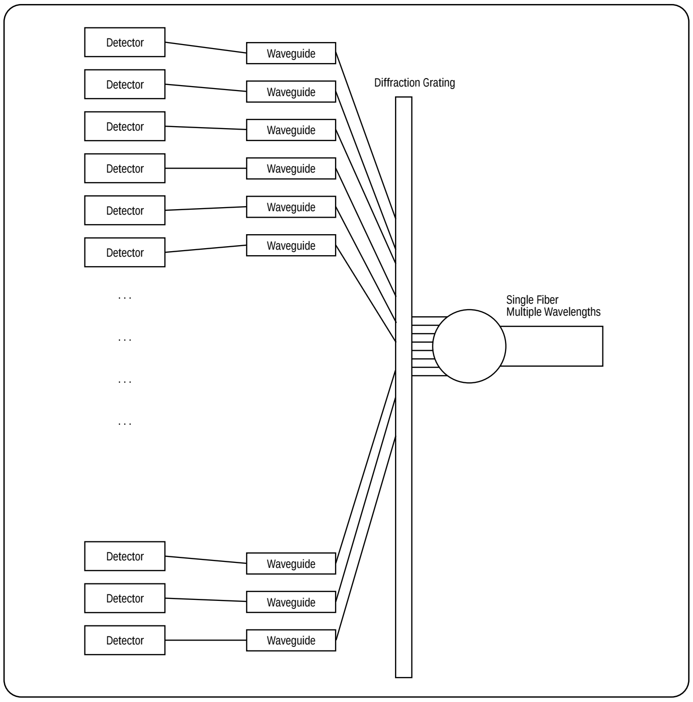


Figure 14: *Dense Wavelength Division Multiplexing Receiving*

Section 2

Common Fiber Optic Cable Test Tools

This section is a brief summary of some basic test tools that are used to install and maintain fiber optic cable systems.

Fiber Scopes

Fiber scopes are microscopes designed to let you visually inspect the ends of fibers or connectors.

Visual Fault Finders

Simply shining visible light from the end of a fiber onto a surface such as a wall or the palm of your hand can ensure that there are no breaks in the fiber. A visual fault finder (or locator) transmits a visible laser light wave through the fiber to permit an observer to see a break by the light leaking through the shield. Visual fault finders (VFF) use Class II lasers and should never be used for any other purpose. VFF's have a range of only about 1 km, so their use is limited to short links of fiber that can be seen; typically to the troubleshooting of panels and jumper cables.

WARNING. Never look directly into any operating laser or lit fiber Laser light can cause eye damage or blindness.

Fiber Identifiers

Fiber identifiers are simple clip-on devices that recognize signals on a fiber. They identify the presence of:

- Data traffic
- CW tone
- Optical tone (2 kHz signal)
- Dark fiber (no signal at all)

Optical Power Meters

Power meters are used to measure the loss or attenuation of the entire fiber system including all bends, splices, and connectors between two points. Power is measured at each end of the link and compared. Excessive power loss can indicate fiber-link problems such as bad splices, broken fiber and poor connections, but the measurement can not reveal where the problems are located.

Optical Sources

Optical sources are stabile light sources that are used to perform system loss measurements in conjunction with a power meter, qualify the performance of a new system and troubleshoot existing systems. The power output level of an optical source is much more stable than that of a transmitter. Optical sources are available in all common wavelengths and transmitter types in order to match the type of system being tested.

Loss Test Sets

Loss test sets combine an optical power meter and light source into a single kit. A kit is used at both ends of a fiber to perform 2-way power loss measurements,.

Optical Return Loss (ORL) Meters

Optical return loss (ORL) meters measure the total reflected power from a fiber system. The ORL tests the fiber from one end without needing a source or technician at the other end. Excessive return loss can indicate system faults but not where they have occurred.

Automated Fault Finders

Automated fault finders are dedicated testers for detecting the locations of major fiber losses. They use reflected light techniques to measure the distance to the first major fault or the total length of a fiber. They are simple handheld devices that are configured for a single wavelength and display test results in symbolic or alpha-numeric readouts. Their overall range is about 60km.

Some fault finders detect only Fresnel reflections rather than backscatter. They are able to measure cable lengths, but have difficulty sensing and locating non-reflective faults.

Section 3

The Optical Power Meter

One of the most basic tools for installing and maintaining fiber optic networks is the optical power meter (OPM). This is the optical equivalent of voltmeters used on electric communication systems. It is often combined with a stabilized light source, the equivalent of a test battery, providing the reference power.

During system installation, OPMs are used in conjunction with light sources to measure system loss. OPMs and light sources in the same instruments are sometimes referred to as a “loss test set”. Because of its testing capabilities, an OPM used with a light source can make better system loss tests than an OTDR.

OTDRs need to see fiber cable on both sides of a connector to make a measurement. They can see the system from after the first connector to before the last connector. The OTDR does not see the end-connectors, a key part of the system loss, unless set up specially.

OPM and light source tests from the outside of the end-connectors to ensure the loss of those events and every thing in between. However, they only return the total loss to avoid visibility of the state of individual connectors, splices, etc.

A full system installation test needs to include the OTDR to measure components, and OPM to measure full system loss.

Basic Operation

The first step is to zero out the meter to ensure that its connectors are not included in the measurements. If the source and meter start from the same location, connect them with jumper cables that will be used in the final measurements. This eliminates the jumpers from the final measurement.

Connect the source to the power meter through the jumper cables and a bulk-head style connector. Store the reference level for each wavelength you will be testing. Use the power meter’s Set Reference or Store function to save the current power level as the source power (0 dB).

If the units are not at the same location, use a second meter to measure the amount of light from the source using the dBm scale. You can use this number later to convert the power readings from the far end into relative, dB units.

dBm, W, and dB

Most OPMs support three types of units: Watts, dBm, and dB. Watts and dBm are absolute scales – they show how much power without needing a reference. Watts is used more in lab and design applications where dBm is used more often in system testing and is becoming a more common measurement unit. Watts is a linear power scale, whereas dBm is a logarithmic scale that works more effectively for power measurements.

dB is a referenced power measurement where zero power is set to an external reference. dBm is dB using a 1mW level as zero. In the case of system loss measurements, the reference is the power into the system (from the stable light source). The final dB measurement is the difference between the power level and the light out of the far end of the system. Setting or storing the reference reads the current power level and calls that 0dB.

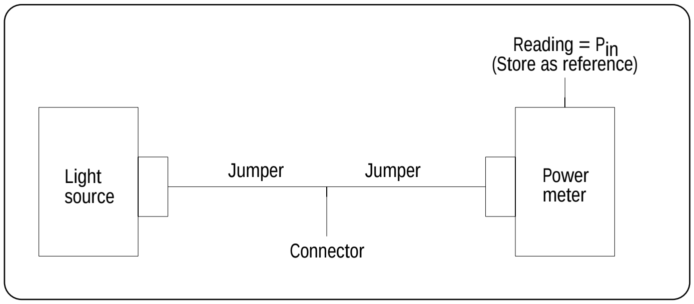


Figure 15a: *Setting reference*

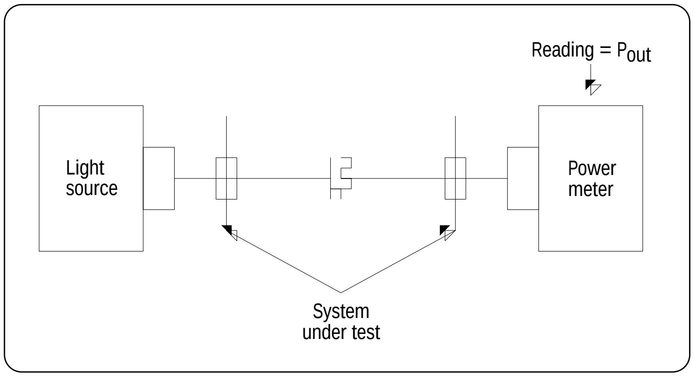


Figure 15b: *PC connector*

Once the source output power is saved or recorded, move the power meter to the opposite end of the system. The difference between the reading at the far end and the reference is the system loss – including the end connectors. Record the system loss value for each fiber. Smart power meters feature a measurement save feature saves the value using the power meter's software.

1310nm	A	B	C	D
1	-12.727 dBm	-13.188 dBm	-12.906 dBm	-14.714 dBm
2	-13.714 dBm	-12.749 dBm		
3	-13.112 dBm			
4				
5				

Figure 16: *Save Measurement Table from Tektronix YOPM100*

To perform maintenance tests or to test for system degradation, repeat the installation test using the light source and OPM. The system transmitter usually does not have a stable enough power output to be able to differentiate between it's changes and changes to the system. Precise measurements require the use of the stable source.

If there is a system outage, the power meter becomes the first tool to use to segment the network to see which section is bad. For example:

1. Put the transmitter in a test mode. Check to see if an appropriate power level is coming out of the transmitter. If not, then the problem is in the transmitter section.
2. If the transmitter is OK, then check the power coming out of the fiber at the receiver end. If there is none, or not enough power, then the cable section is bad – use an OTDR to find out where.
3. If the power level coming out of the cable into the receiver is good, then the problem is in the receiver section.

Section 4

The Optical Time Domain Reflectometer (OTDR)

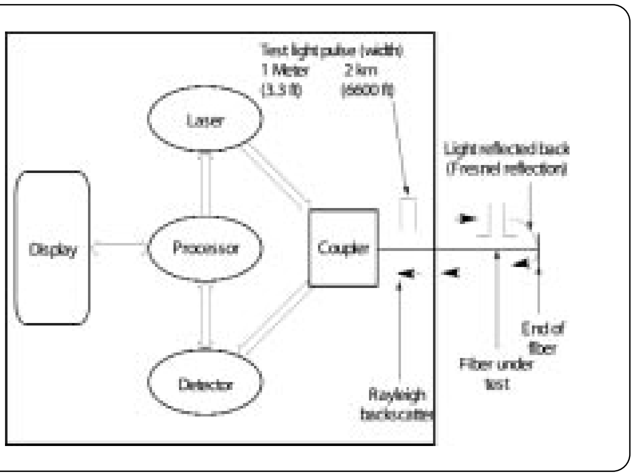
The Optical Time Domain Reflectometer (OTDR) is an instrument that uses the inherent backscattering properties of an optical fiber to detect faults and categorize its condition. The OTDR sends high-power pulses of laser light down the fiber and captures the light that is reflected back (much like a radar system). By measuring the timing and power levels of the return pulses, the instrument correlates the reflected information with physical locations along the fiber and displays a "trace" that shows optical power versus distance. Attenuation of the fiber is displayed as the slope of the trace. Interruptions such as splices, connectors, bends, breaks or flaws in the fiber appear as transitions ("events") that represent their nature and location. Because it operates from a single location, the OTDR eliminates the expense and complication of separate transmitters/receivers and personnel at each end of the fiber.

OTDR's are used in fiber optic networks to:

- Commission (map and document) the network at installation
- Verify quality of service (QoS) operating parameters such as attenuation, losses and reflectance
- Detect problems such as cuts, bends and defective splices or connectors
- Pinpoint the location and nature of events to facilitate repairs
- Restore the network after repairs are made

Basic Operation

The basic components of an OTDR are shown in Figure 17.



▶ ***Figure 17:*** *Components of OTDR*

The processor controls the system elements to perform sequences of operations and to display test results. It sets up the magnitude, duration and timing of light pulses from the laser into the fiber, captures the returned energy and displays the reflected signal amplitude versus time.

The laser produces light at a specific wavelength compatible with the fiber-under-test. The coupler directs outgoing light pulses to the fiber and reflected light to the detector. The detector is a light receiver that quantifies the power characteristics of the return signal.

The measurement range and resolution are functions of the wavelength, power and duration of the laser pulses and the characteristics of the fiber under test. Stronger and longer duration pulses are able to detect events further down the cable; shorter pulses can resolve more closely spaced events.

As with radar or sonar, the time between the transmitted and returned pulses is related to the distance between the OTDR and the feature that caused the reflection. The processor creates a graphical display of reflected optical power in decibels (dB) on the vertical scale versus distance on the horizontal scale.

The overall slope of the trace describes the attenuation properties of the fiber – power loss versus length of fiber. Deviations in the traces, referred to as "events", are the results of reflections from discontinuities such as:

- Splices
- Connectors
- Cracks or breaks
- Bends
- End of fiber

Some OTDR's contain additional features to enhance the measurements. Among the most useful are:

- Multiple pulse widths and wavelengths
- Direct reading displays of distances between fiber features
- Composite traces from multiple measurements
- Dual-trace displays to highlight changes
- Limit overlays to highlight faults that exceed acceptable tolerances

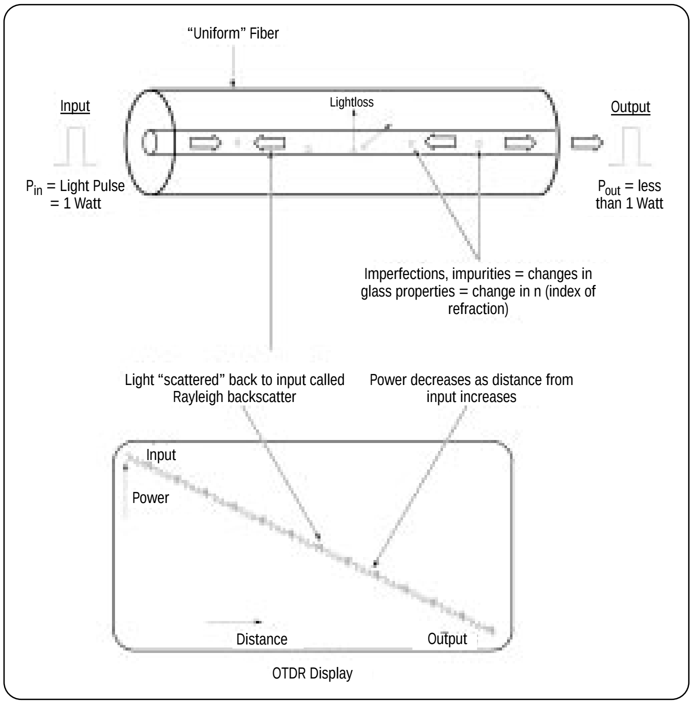
Basic Measurements and OTDR Traces

This section illustrates common OTDR traces and the information they provide.

Backscatter

Backscatter is a fundamental optical property of a fiber. The OTDR measures backscatter that has been reflected to the laser source and uses it to generate the trace displayed on the screen The time it takes for the light to reach a given point along the fiber and be scattered back to the OTDR is converted to distance and shown on the OTDR's display x axis. Optical power, in dB, is displayed on the y axis.

Light traveling through a uniform section of fiber with no splices or connectors produces uniform backscatter from imperfections and impurities in the fiber. The power of the scattered energy decreases with distance from the OTDR, producing the characteristic sloping backscatter trace (see Figure 18).

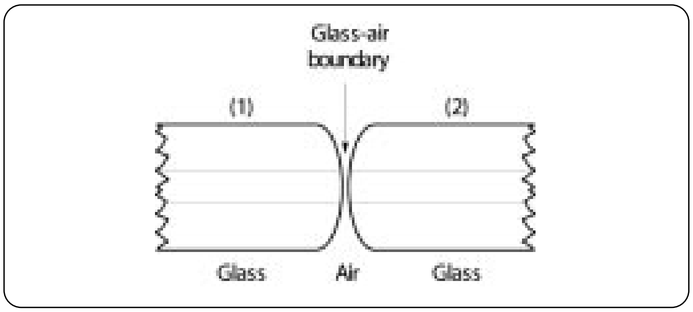


▶ ***Figure 18:*** *Backscatter*

Glass-Air Boundary Reflections

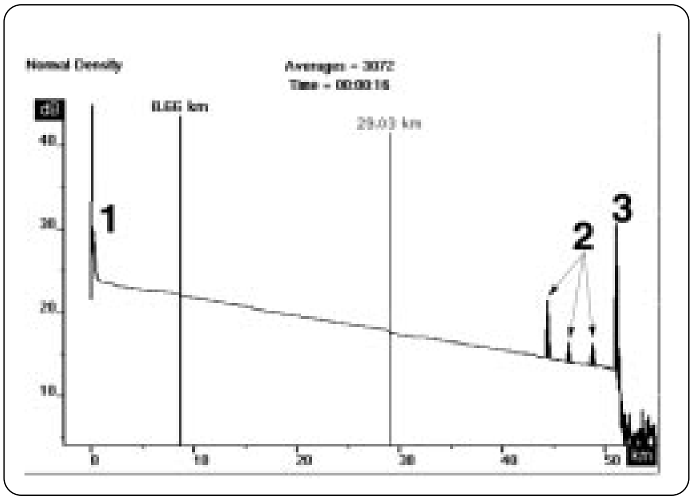
Light reflected from a glass-air boundary causes a spike to appear on an OTDR trace. A polished 90° cleave at the end of a fiber reflects a small portion of the pulse power back toward the input – known as a Fresnel reflection. Significantly less light is reflected from the end of the fiber if it is not polished or it has been broken.

Glass-air boundaries from connectors and mechanical splices can also cause Fresnel reflections, which appear as spikes of varying heights on a trace. Although mechanical connectors or splices can physically couple two fiber ends close enough to touch, they still leave a glass-air boundary, as shown in Figure 19.



▶ ***Figure 19:*** *Glass–air boundary*

The trace in Figure 20 is an example of an OTDR trace showing a connector (1), three mechanical splices (2), and the end of the fiber (3).



▶ ***Figure 20:*** *Glass–air reflections*

Reflectance

Reflectance (or return loss) for a reflective event is defined as the ratio of reflected power to input power, in dB. Typical values range from -20 dB (large reflectance) to -50 dB (small reflectance). The OTDR measures the reflected pulse height from an event to determine the reflected power and then divides it by the input pulse power to calculate the reflectance, converting the ratio to dB.

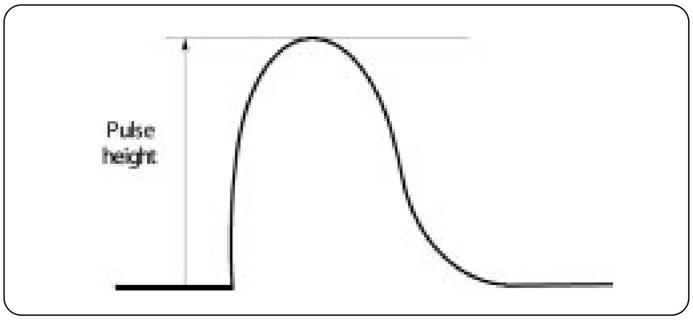


Figure 21: Reflected pulse on an OTDR display

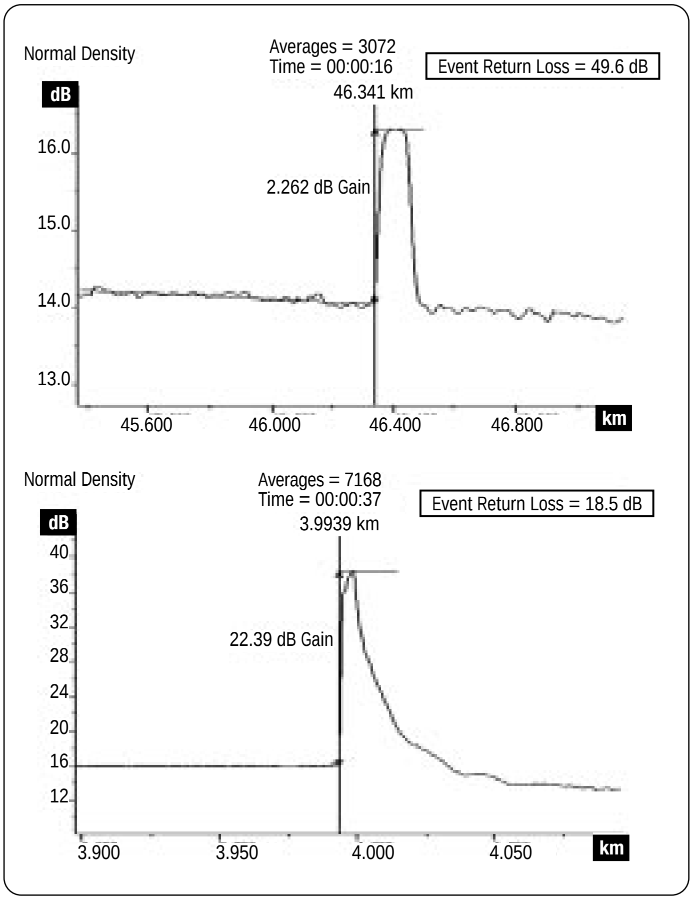


Figure 22: Return loss traces

Connectors

The return loss spikes on an OTDR trace from three types of mechanical connectors are shown in Figure 23. A physical connection (PC) is the junction where the two fibers touch. The return loss from a flat-polished end is shown for reference. These return-loss values are typical of connectors:

Angled PC	-60 to -70 dB
Super PC	-45 dB
PC	-35 dB
Flat polish	-25 to -14 dB

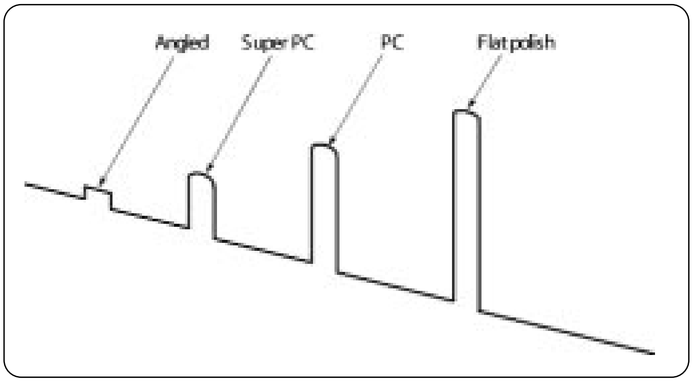
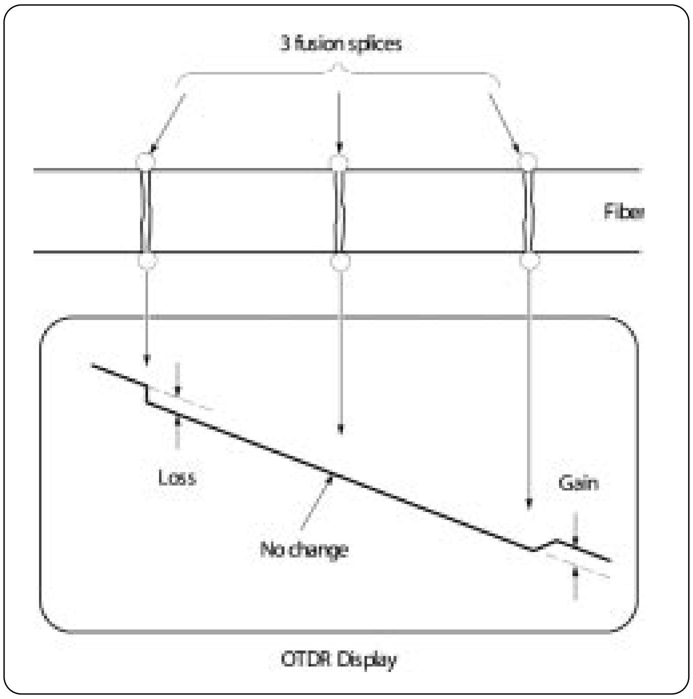


Figure 23: Typical connector traces

Fusion Splices

A fusion splice in a fiber can produce any of three different return loss results on an OTDR trace – a loss, no change or a gain. Usually, fusion splices exhibit losses that are very low – on the order of 0.03 to 0.2dB. When fibers with different properties are fused, the variations in scattering coefficients can cause apparent gains at one end of a spliced fiber and complimentary losses at the other end (where the coefficients are reversed). Gains are usually quite low – from 0.03dB to 0.07dB. No change in return loss indicates either a perfect alignment and splice or compensating alignment losses and coefficient gains across the junction.



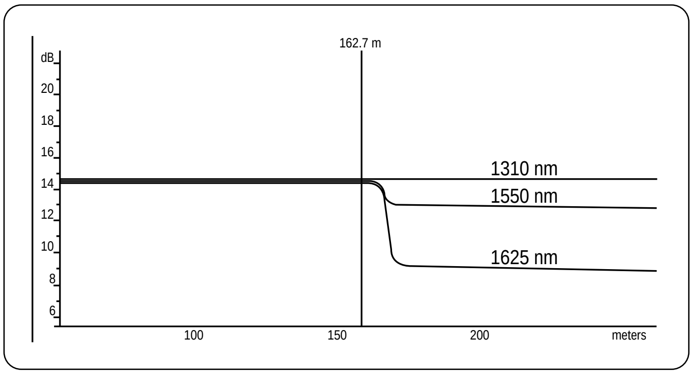
▶ ***Figure 24:*** *Fusion splice traces*

Bends

Losses from bends increase substantially at higher wavelengths, making them much easier to spot. For example: a bend will lose three times as much power at 1550 nm as it will at 1310 nm and a bend at 1625 nm loses three times as much energy as it would at 1550 nm. This property is very useful for separating out the effects of bends from those of splices and connectors, which do not vary with wavelength.

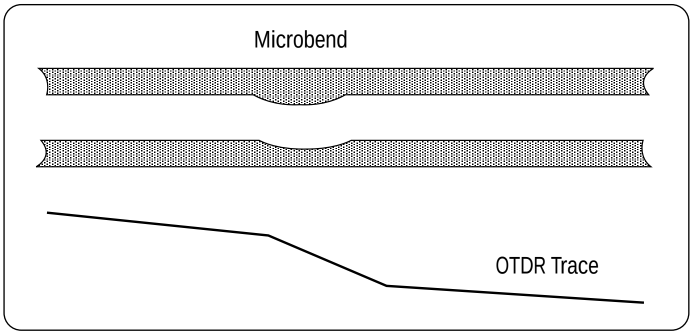
There is a similar relationship between temperature and bend loss. Lower temperatures cause a much greater loss from bends than do warmer temperatures, so higher wavelength testing can be used to anticipate problems at communication wavelengths that will crop up later as temperatures fall.

Figure 25 shows measurements of a 2cm diameter bend in a fiber at 1310, 1550, and 1625nm. At 1310nm the event is not even visible, at 1550nm it shows just under 2dB loss, but at 1625nm the event exhibits 6dB loss.



▶ ***Figure 25:*** *Cable bend tested at different wavelengths*

Microbends are very small distortions in the fiber. They are typically defects caused during manufacturing and appear similar to very small fusion splices on the OTDR display.



▶ ***Figure 26:*** *Microbends*

Macrobends occur when a fiber is bent beyond its minimum radius bend and leaks light from the fiber core. Figure 27 illustrates the relationship between the physical bend and the OTDR trace, Figure 28 compares the loss with that of a fusion splice.

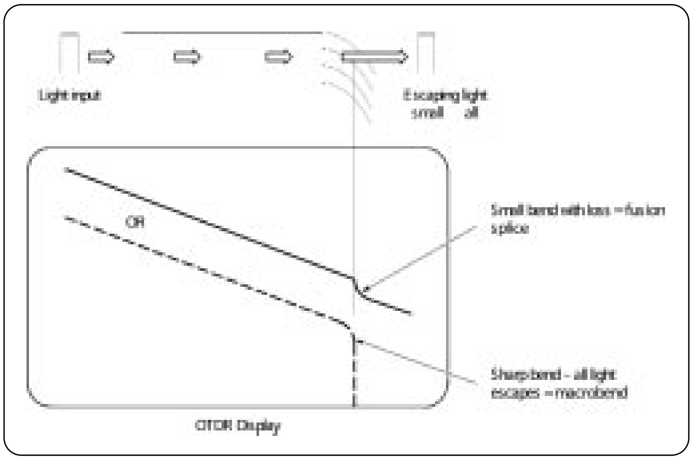


Figure 27: *Macrobends*

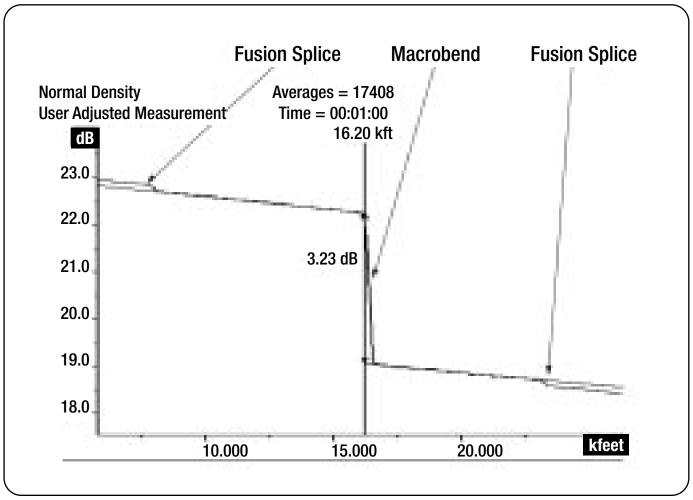


Figure 28: *Macrobend loss compared to fusion splice loss*

End of Fiber

The shape of the end, or termination, of a fiber has a significant effect on its appearance on the OTDR trace. A smooth and polished end reflects light as a single Fresnel event; a rough and unfinished end does not reflect light back down the fiber. Figure 29 shows the magnified appearance of a fiber end. Figure 30 shows the effect of the fiber end on the OTDR trace.

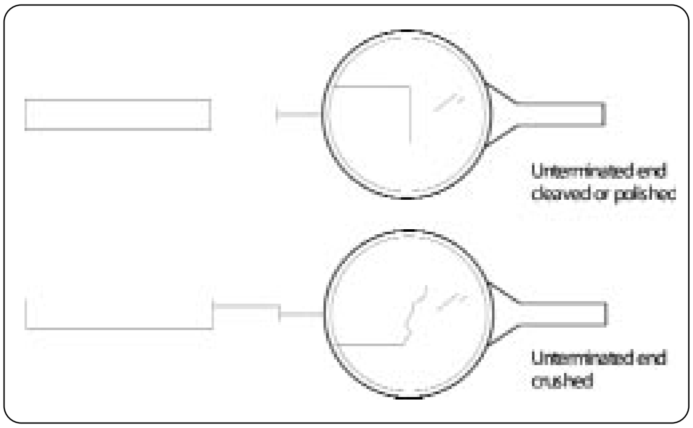


Figure 29: *Magnified end of fiber*

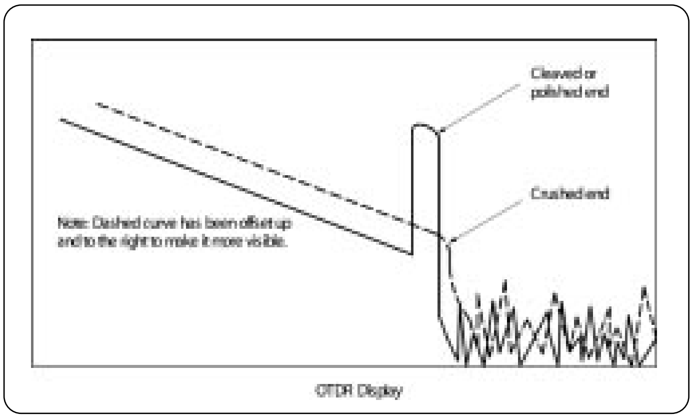


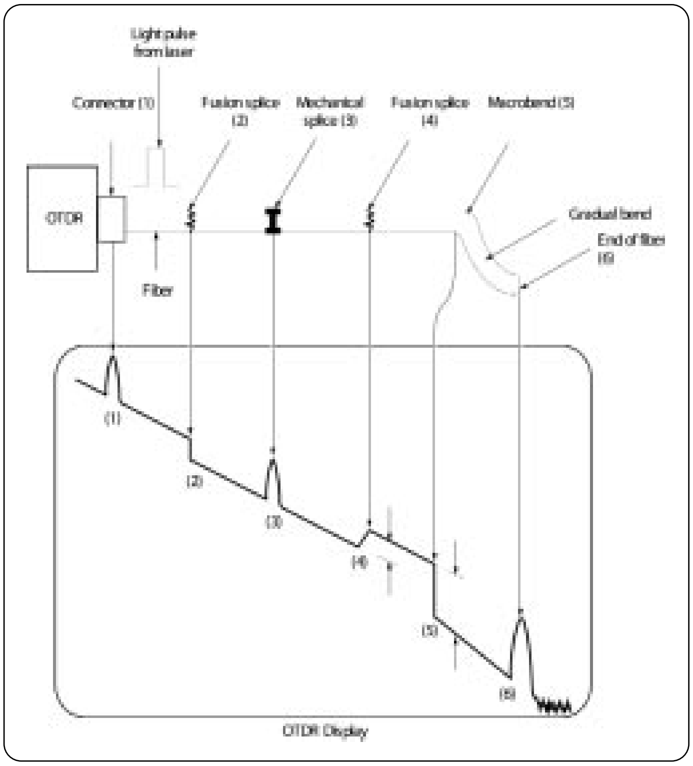
Figure 30: *OTDR display of fiber ends*

Trace of Common Fiber Events

Figure 31 illustrates typical trace characteristics for common fiber events:

1. Front panel connector
2. Fusion splice
3. Mechanical splice
4. Fusion splice
5. Macrobend
6. End of fiber

NOTE. *The loss slope between points 5 and 6 is greater than the rest of the trace because of the bend in the fiber.*



▶ ***Figure 31:*** *Typical features seen on an OTDR*

OTDR Parameters and Specifications

Several key parameters and specifications affect the performance of an OTDR. This section explains how to interpret each of these to ensure that an OTDR will provide accurate measurement results.

Pulse Width and Averaging

Pulse Width and Averaging are the two most critical operating parameters for effective OTDR operation.

The pulse width, or duration, of the laser output pulse determines the maximum range and the minimum resolution of the OTDR. Longer duration pulses are able to detect events further down the cable, while shorter pulses are able to resolve more closely spaced events. Experienced users adjust pulse width to achieve the most accurate measurement for a given fiber configuration. Table 2 summarizes the characteristics of pulse widths.

Table 2: Characteristics of OTDR pulse widths

	Short	Medium	Long
Pulse Duration (width)	10 ns to 50 ns (1 m to 5 m)	100 ns to 1,000 ns (10 m to 100 m)	4,000 ns to 20,000 ns (400 m to 2 km)
Relative Range	Lowest energy and range	Medium energy and range	Highest energy and range
Relative Resolution	Highest event resolution	Medium event resolution	Lowest event resolution

Averaging is the process of mathematically combining the results of many trace data sets into a single composite trace. This process reduces the effects of random system noise and improves resolution of low-loss events. Averaging also increases the measurement accuracy and range for a given pulse width - the more trace data sets that are averaged, the greater the benefit. See Figure 32.

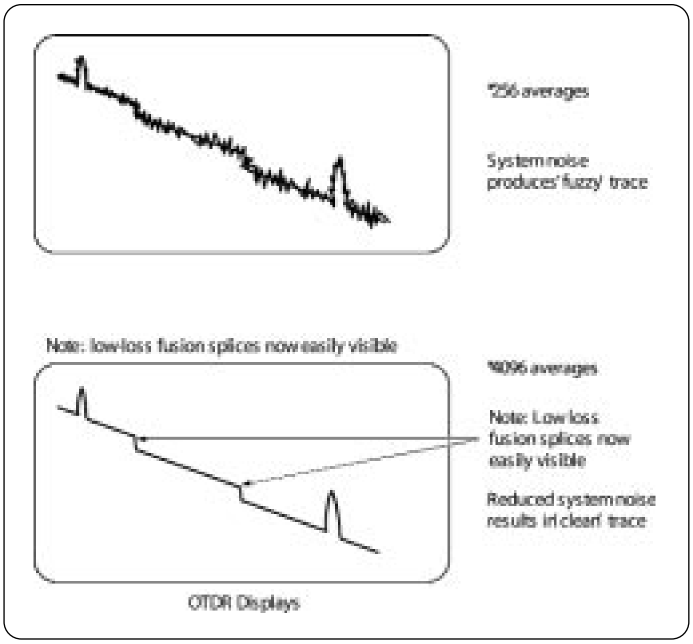


Figure 32: *Effects of averaging*

Figure 33 shows how a longer pulse width with a higher number of averages increases the signal–to–noise ratio of the upper trace, resolving fusion splices at about 43 km and 50 km that were undetectable on the noisier trace.

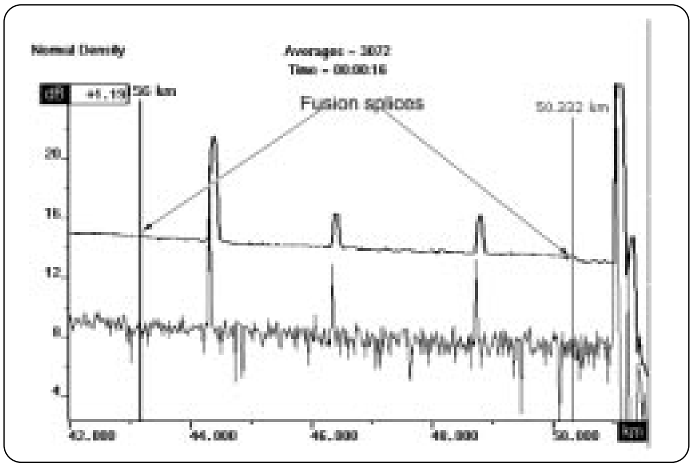
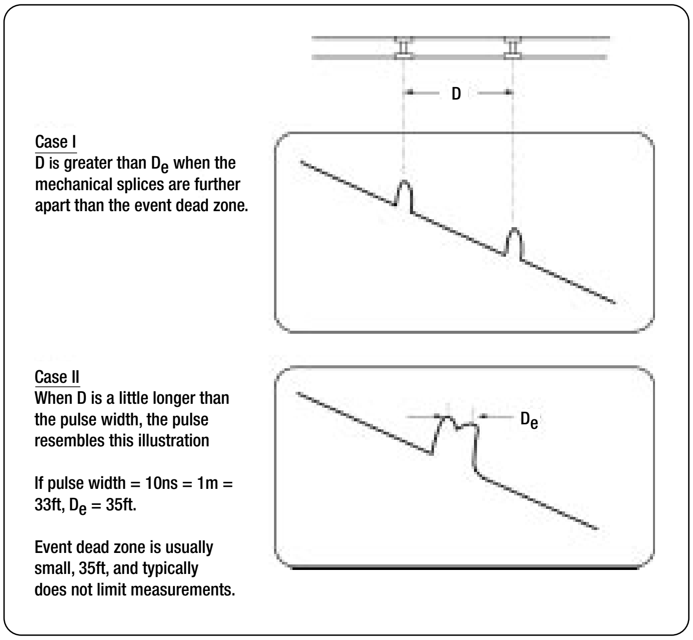


Figure 33: *Effects of pulse width and averaging*

Event Dead Zone

The minimum distance after an event that the OTDR can accurately measure the distance to the next reflective event is called the “dead zone.” If a second event occurs within the dead zone of a preceding event, the OTDR will not be able to detect it. Dead zones vary with pulse width – narrower pulses produce shorter dead zones.



Case I
D is greater than D_e when the mechanical splices are further apart than the event dead zone.

Case II
When D is a little longer than the pulse width, the pulse resembles this illustration

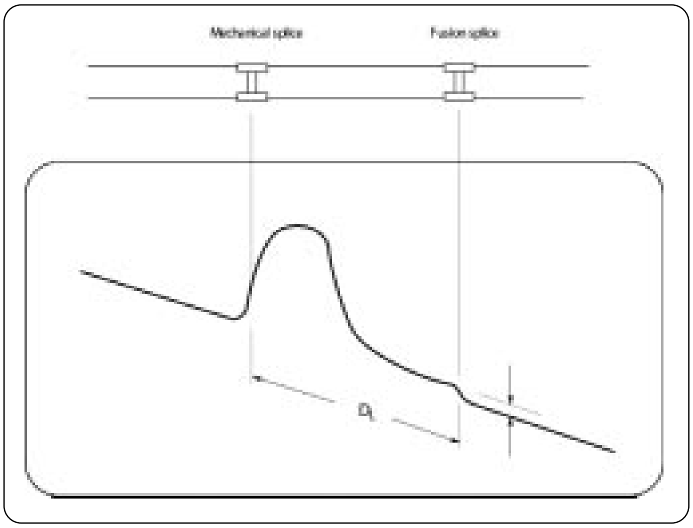
If pulse width = 10ns = 1m = 33ft, D_e = 35ft.

Event dead zone is usually small, 35ft, and typically does not limit measurements.

Figure 34: *Event dead zone*

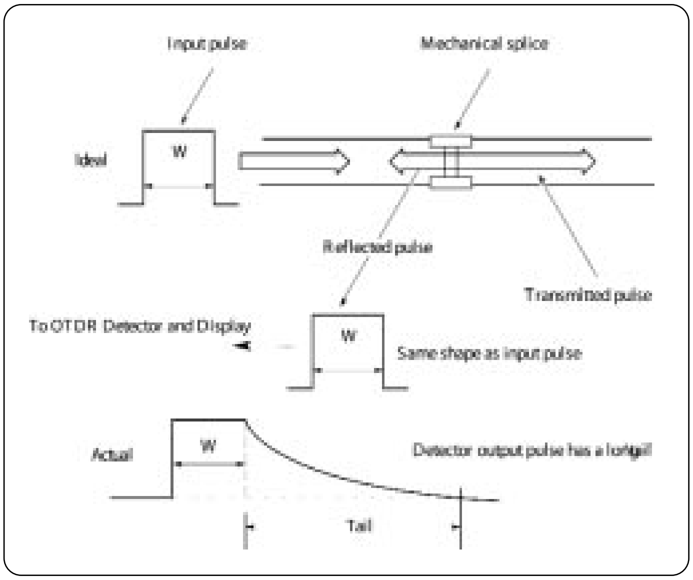
Loss or Attenuation Dead Zone and Tail Effect

The loss or attenuation dead zone is the minimum distance after an event that the OTDR can measure the loss due to a non-reflective event, such as a fusion splice. The loss dead zone is related to the effect of the reflected pulse on the OTDR detector. The detector can become saturated (blinded) by large reflected pulses and takes time (distance) before it can recover to detect the next loss event.



▶ ***Figure 35:*** *Loss dead zone*

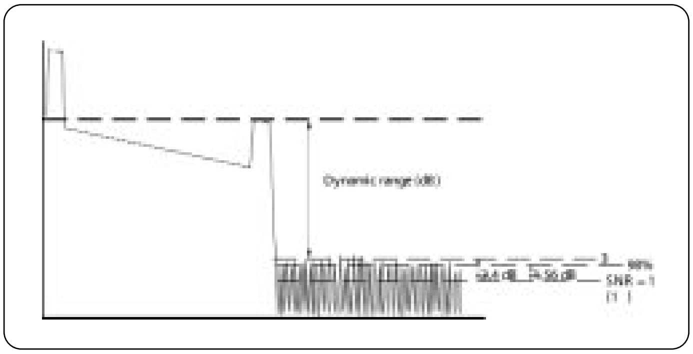
The loss dead zone is much greater than the event dead zone. The total time is equal to the pulse width plus the detector recovery "tail". In a typical OTDR, a pulse width of 13 feet can have a tail of up to 180 feet. For example, if a central office's vault splice is 75 to 150 feet from the patch panel on the fiber distribution frame (FDF), the fusion splice will be lost in the dead zone from the tail of the reflection event caused by the mechanical connectors on the FDF (Figure 36).



▶ ***Figure 36:*** *Tail effect described*

Dynamic Range

Dynamic range is a measure of the strength of the backscatter signal at the front panel compared to the noise floor. Dynamic range determines how long a fiber the OTDR can test and how well it can detect low loss events in the presence of noise.



► ***Figure 37:*** *Dynamic range*

The industry uses several definitions for dynamic range. Figure 37 illustrates the concept of dynamic range. Notice there are different ways of defining the noise floor, and each one affects the dynamic range specification. The most common noise floor definition is the signal-to-noise ratio equals 1 (SNR=1) level.

Besides the noise–floor definition, dynamic range also depends on OTDR acquisition parameters, such as pulse width and range. Increasing the pulse width will raise the backscatter level and more averaging will decrease the noise level, thus improving the dynamic range. However, both these actions involve tradeoffs against other key parameters. The larger pulse width increases the dynamic range, but reduces the ability of the OTDR to measure closely spaced events due to the increased dead zones. More averaging means it takes longer to analyze the fiber.

Remember these trade-offs when comparing OTDR specifications. A good practice is to look for dynamic range to be specified at defined averaging times and pulse widths.

Section 5

Advanced OTDR Functions

Optical time domain reflectometry can be a very useful technique for the characterization of fiber-optic networks – but older OTDR instruments often lead to misleading or inaccurate conclusions. Those instruments required a lot of time and patience from expert operators to get valid results, so their usefulness has been very limited.

The latest developments in OTDR design incorporate many innovative new functions that help locate more potential problems, more reliably and complete the measurement tasks in far less time than with previous technologies. New OTDR instruments use powerful software to perform a range of measurements with the push of a button. Even the novice OTDR operator can get complete valid measurement results in minutes and focus on optimizing the network itself.

This section describes the very latest OTDR technology and demonstrates how it can be used with confidence to maintain the best possible QoS in fiber optic networks.

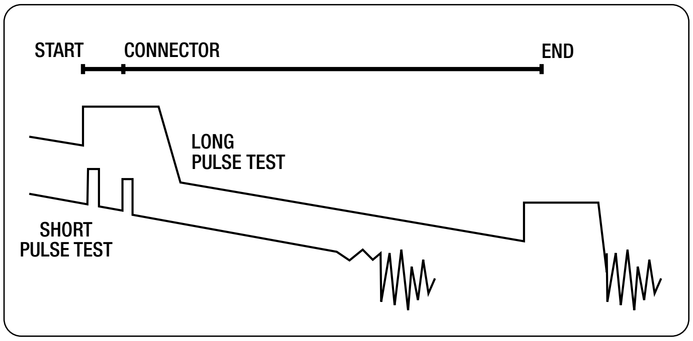
Automatically Optimized Measurements

In order to optimize fiber measurements with an OTDR, it is necessary to select measurement parameters based on the length and attenuation of the fiber under test. For all but the shortest fibers, the optimal parameters also vary in relation to the distance of the event from the instrument. Careful tradeoffs must be made between all of the following parameters in order to get good test data in a reasonable amount of time.

- Pulse width – the length of time that the OTDR laser is pulsed on for each acquisition. Using a long pulse width puts more power into a long fiber, but can overload the receiver and extend the time needed for it to recover in dead zones.
- Range – the length of time that the OTDR waits between laser pulses to allow light to travel to the end of fiber and back to the detector. Longer range is required to allow a laser pulse to reach the end of a long fiber and return, but this also increases the time to make a measurement.
- Averages – the number of individual acquisitions that are averaged together to reduce random noise in an OTDR trace. A lot of averaging reduces random noise to a very low level, but results in test times of several minutes or more.
- Setup time – the time it takes to complete a new test setup for the OTDR. More complex instruments take more time to adjust, but simpler devices may not yield the required results. Time spent fussing with the instrument distracts from the primary mission of optimizing the network.

Pulse Width and Range

A long fiber that has close-in splices as well as closely-spaced fusion or mechanical splices further out on the fiber demands both distance and resolution from an OTDR. If the OTDR uses long pulses it can see the end of the fiber, but fail to detect close-in splices. If it is switched to short pulses in order to have the resolution needed to measure the close-in and close-together splices, it won't be able to reach very far along the fiber.



▶ ***Figure 38:** Effects of pulse width on range and resolution*

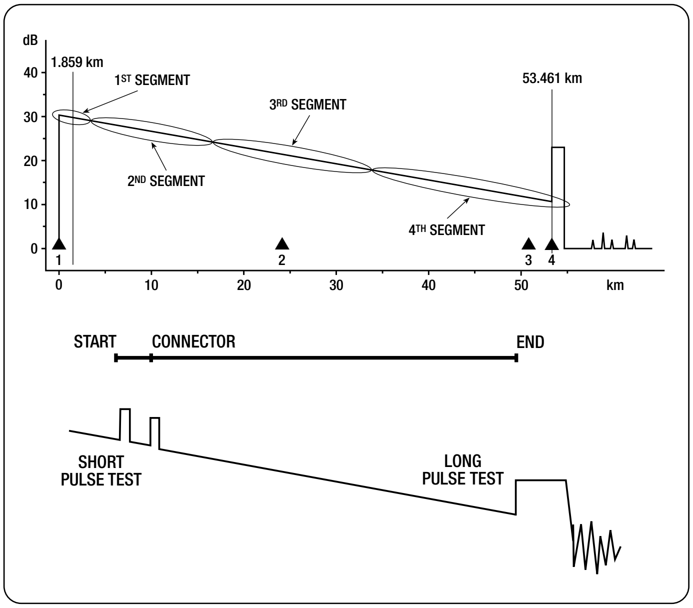
Figure 38 illustrates some of the tradeoffs that must be made when selecting OTDR pulse width parameters. The upper trace shows the results of testing a long fiber with a long pulse. The long pulse produced sufficient power in the fiber to detect the reflection from the fiber end, but the pulse was so long that that it obscured the reflection from a connector located close to the OTDR. The lower trace shows the results of testing a long fiber with a short pulse. In this case the connector close to the OTDR was detected, but there was insufficient power to detect the fiber end.

"IntelliTrace Plus" is the trade name for intelligent software that automates the fiber optic measurement process in the Tektronix NetTek OTDR. With the push of a button, IntelliTrace Plus^{TM} technology automatically selects optimal acquisition parameters for best resolution near the front of the fiber then changes the parameters to give optimal measurements in each range up to the end of the fiber. This patented approach selects different measurement parameters for up to four sections of a fiber. It tests the fiber using multiple pulse widths, automatically doing what an expert OTDR operator would do. The multiple measurement results are "spliced" together into a single set of data and composite trace.

IntelliTrace Plus technology analyzes the fiber by finding the end of the cable and then setting the appropriate test parameters for that length and type of fiber. It first analyzes with a short pulse in order to provide the best possible resolution for up-close and close-together splices. It can locate splices as close as five meters from the front panel and as close as 2.5 meters apart (for Multimode).

As the acquisition continues, IntelliTrace Plus continually monitors the returned signal. When the noise due to fiber attenuation approaches a level that could result in impaired measurement accuracy, IntelliTrace Plus designates a new fiber section and adjusts the pulse width, amplifier gain and the number of averages to maintain measurement integrity. As additional data is acquired, the display is updated.

Although each trace segment is acquired with a different set of acquisition parameters, IntelliTrace Plus Technology constructs a normalized waveform to provide the best possible view for characterization of the fiber. At the conclusion of the analysis, the screen shows a single composite trace with markers indicating the locations of all the events and a table with measurements and other information about each event.



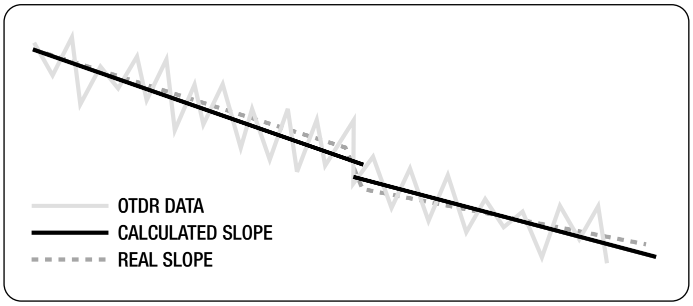
▶ ***Figure 39:** Multiple segment testing*

The figures above illustrate how IntelliTrace Plus technology separates the fiber into segments and the resulting improvement in the trace data.

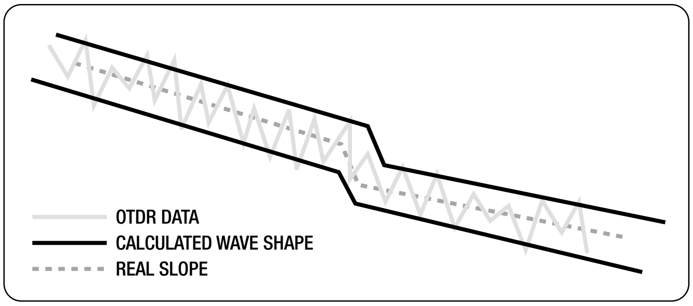
Advanced Waveshape Analysis Algorithms

Once IntelliTrace Plus has gathered the raw trace data, The NetTek OTDR employs proprietary "waveshape analysis" algorithms to detect events even when they are masked by noise. Waveshape analysis is a highly sophisticated method of data processing that accurately locates events based on inflection points in the data. Previous line-fit algorithms can give inaccurate measurements, or even miss events. Waveshape analysis overcomes the shortcomings of line-fit algorithms and can even locate closely spaced events that are located in the dead zones resulting from previous events.

Figure 40 illustrates the difficulty of accurately locating and measuring events when a line-fit algorithm is used on a noisy signal. Lines fitted to the noisy data may not accurately reflect the true slope and can result in inaccurate measurements.



▶ ***Figure 40:*** *OTDR splice measurement using line fit method*



▶ ***Figure 41:*** *OTDR splice measurement using waveshape analysis*

Figure 41 illustrates how the NetTek OTDR, using waveshape analysis, can accurately locate and measure events, even in noisy data.

As a general rule, an event's magnitude should be at least twice that of the noise in the data to be accurately located and measured by line-fit algorithms. With its waveshape analysis algorithms, the NetTek OTDR can accurately locate and measure events with magnitude of one half that of the noise in the data. This tremendous improvement in performance is achieved by analyzing the shape of the whole data and calculating the shape of the curve. Because noise is random, it generates an envelope after a minimal amount of averaging. This technique also produces superior amplitude measurements of the events.

In addition, waveshape analysis improves the accuracy of location (distance) measurements over line-fit techniques by identifying the leading edge (distance to event) between sample points. For most OTDR's, best case distance accuracy is limited to the sample spacing. The NetTek OTDR can actually locate events to within one tenth of the sample spacing.

Minimum Test Time Versus Precision and Accuracy

Most cables require multiple measurements using different parameters to completely and accurately characterize their properties. These tests take time, and time can be a precious commodity during a network emergency or a lengthy commissioning process. In some situations, a technician may be willing to trade precision for time. Looking for the end of the cable or spotting a major break does not require ultimate resolution –just a quick look. As technicians get closer to solving a problem, they are likely to spend more time in order to increase the accuracy.

IntelliTrace Plus automatically optimizes key test parameters with the touch of a single button. You can choose between two precision/time options:

- Fastest gives good test results in a minimal amount of time; useful to quickly locate the fiber end and any large events, such as mechanical splices, damaged or bent fiber, etc.
- Standard provides a more complete picture of the fiber under test and is sufficient to locate most small events, such as fusion splices, even in long fibers. Testing in the Standard mode typically takes 2-4 minutes depending on fiber length and attenuation.

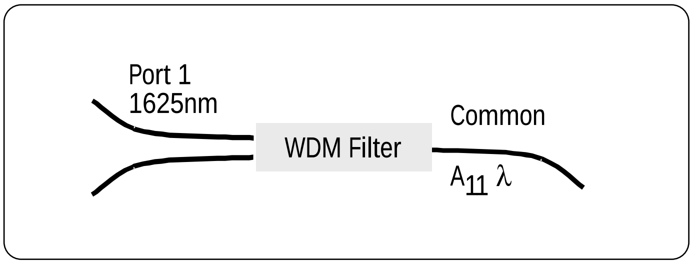
Testing Live Fiber, Detecting Bends

As bandwidth requirements increase and fiber optic networks operate at or near capacity, the need to perform live testing and maintenance on active fibers has become critical. The importance of each fiber has increased with the amount of traffic it carries. "Dark fibers" are no longer available for monitoring as they have been taken over by growing commercial traffic.

Advanced OTDR's offer test signals at non-commercial wavelengths to test fiber optic cables while the network continues to operate in full service. The most obvious advantage of out-of-band testing is the ability to test live fibers while they are carrying commercial traffic – eliminating costly disruptions and down time. Systems can be tested at 1550nm (in the presence of 1310nm traffic) or 1625nm, depending upon the selection of test connections; otherwise, the configuration and techniques are the same. The use of the 1625nm wavelength for out-of-band testing offers another significant advantage – it greatly improves the ability to detect bends in the cable before they develop serious problems such as stress breaks or thermal degradation.

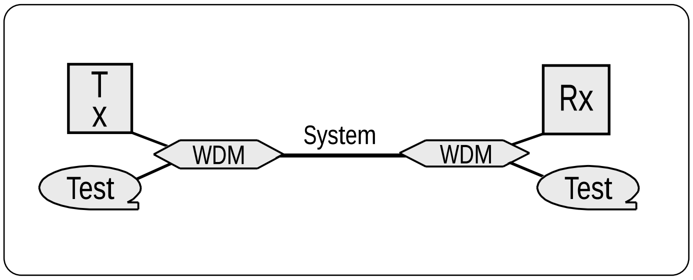
Wavelength Division Multiplexers (WDM) provide the test connections for out of band testing. These are the same devices that are used in DWDM communication systems to transmit multiple laser lines (i.e., channels) through fiber optic cables, allowing the fiber to carry more information. Out-of-band test connections can be permanently installed in the network and available whenever they are needed – in fact, they are often included in the original system configurations.

Figure 42 shows a typical WDM that has been configured to carry a 1625nm test signal through one of its ports and the 1310-1550nm commercial communication signal through the other. Each of the ports acts as a filter to isolate the signals from one another.



▶ ***Figure 42:*** *WDM for testing at 1625nm*

Figure 43 illustrates the use of two identical bi-directional WDM devices – one to multiplex communication and test signals at the transmission end of the fiber, the other to separate the signals as they are received.



▶ ***Figure 43:*** *WDM system configuration*

The degree of isolation provided by the WDM determines the accuracy of the OTDR measurements and the protection of the commercial traffic from interference by test signals. To obtain usable and safe OTDR tests, there should be at least 30dB of separation between the commercial communication signal and the test bandwidth. More isolation provides a faster, more accurate test. Less isolation slows the test, makes it less accurate due to noise and increases the chance for interference.

Another significant specification is directivity - higher isolation from one direction than from the other. Systems can be configured to use directivity as additional isolation to help prevent interference. When the system is correctly configured, maintenance testing can be done using out-of-band wavelengths while the network is active.

Analysis and documentation at every stage

One of the most significant factors in maintaining the optimum QoS of a fiber optic network is a foundation of complete and reliable documentation for commissioning and restoration. At commissioning, documentation defines how well the system will handle today's communication requirements. For maintenance and restoration, it ensures that the system can be kept at or returned to its original state. Complete and accurate documentation will also predict how well the system can handle upgrades and future enhancements without the need for repeating the tests.

Once test data is acquired, the results must be analyzed in order to identify problems. Searching through hundreds of tests with thousands of measurements to find problems can be as slow and laborious as finding the proverbial needle in the haystack. Misleading or erroneous test results can force the repetition of the entire test cycle. Manual documentation of multiple separate OTDR measurements is time-consuming and prone to error.

Building a solid foundation of documentation is a major challenge for any organization. Tektronix' TARGET1 (Trace Analysis, Report Generation and Emulation Tool) Report Generation software handles the extensive OTDR trace data sets with ease. TARGET1 runs on a conventional PC in the familiar Windows operating environment.

TARGET1 is a software package that transforms fiber cable measurement data into reports that are comprehensive, meaningful, and ready to read or publish. When the day's OTDR measurements are completed, TARGET1 simplifies offline reporting work and saves time. It gathers all the files needed and combines the information in one place for easy evaluation and archiving.

Section 6

Practical OTDR Test Strategies

For Commissioning

Installation/acceptance of a new cable plant requires the most extensive testing and documentation of the three stages, often requiring thousands of test results to be acquired and evaluated for every node in the system (see side bar). Testing is performed to confirm that every cable system component has been installed correctly and is operating at specified QoS levels. Results are documented and stored for subsequent comparisons.

Steps in the Commissioning stage:

- Test all fibers in the system
- Evaluate tests for problems
- Fix problems
- Repeat above until no problems remain
- Generate acceptance reports to prove that the system meets specifications
- Pass test data and reports over to system maintainers
- Archive the data for comparisons with future tests

For Ongoing Maintenance

The tests for maintenance should be identical to those used for commissioning, but a different strategy is needed to make the best use of the time available. Automatic retrieval of setups and test sequences ensures uniform results that can be compared with specifications and with previous test results. Pass/fail limit tests perform routine checking for degradation to highlight potential problems quickly and easily. Detailed diagnostic testing is used only during scheduled repair activities.

Steps in the Maintenance stage:

- Test all fibers in the system to verify operation within QoS specifications
- Generate reports to prove that the system still meets specifications
- When tests reveal degradation or problems:
  Document the levels of degradation versus previous test results
  Schedule further testing to isolate and correct them
- Archive the data for comparisons with future tests

A common maintenance challenge is to check for cable or splice degradation during scheduled periods. The NetTek's test sequences ensure that you can get uniform reliable test data in the least amount of time. TARGET1 automatically generates a difference report that compares old and new tests and highlights changes for quick, on the spot analysis.

Thousands of Test Results Per Node

A system with 124 fibers per cable, 140 km between nodes with splices every 3 km, plus end connectors is to be tested at 2 wavelengths from each end. You would need to capture more than 23,000 loss measurements in 496 separate test files in order to evaluate this one node of the system completely!

2 wavelengths X 2 directions X 48 (46 fusion splices & 2 connectors) X 124 fibers = 23,808 results

The process is repeated for every node and between every amplifier, repeater, or central office.

For Restoration

Even the best maintenance won't prevent all cable breaks or faults. Restoration is the most time and quality critical of the three stages - the network is usually down until this work is completed. Testing is performed to find and correct cable faults, confirm that repairs meet quality goals and ensure that the system will once again operate at specified QoS limits.

The tests for restoration/re-acceptance should be identical to those used for installation, but a different strategy is used to return the system to working condition as quickly as possible. For restoration, automatic setups and test sequencing locate breaks/faults precisely - helping you direct the repair crew to the correct spot as quickly as possible. Testing to confirm repair quality must also run quickly. For re-acceptance, results are fully documented and stored for subsequent comparisons.

Steps in the Restoration stage:

- Identify and precisely locate breaks/faults as quickly as possible
- Test to confirm that repairs meet standards
- Repeat above until no problems remain

For re-acceptance:

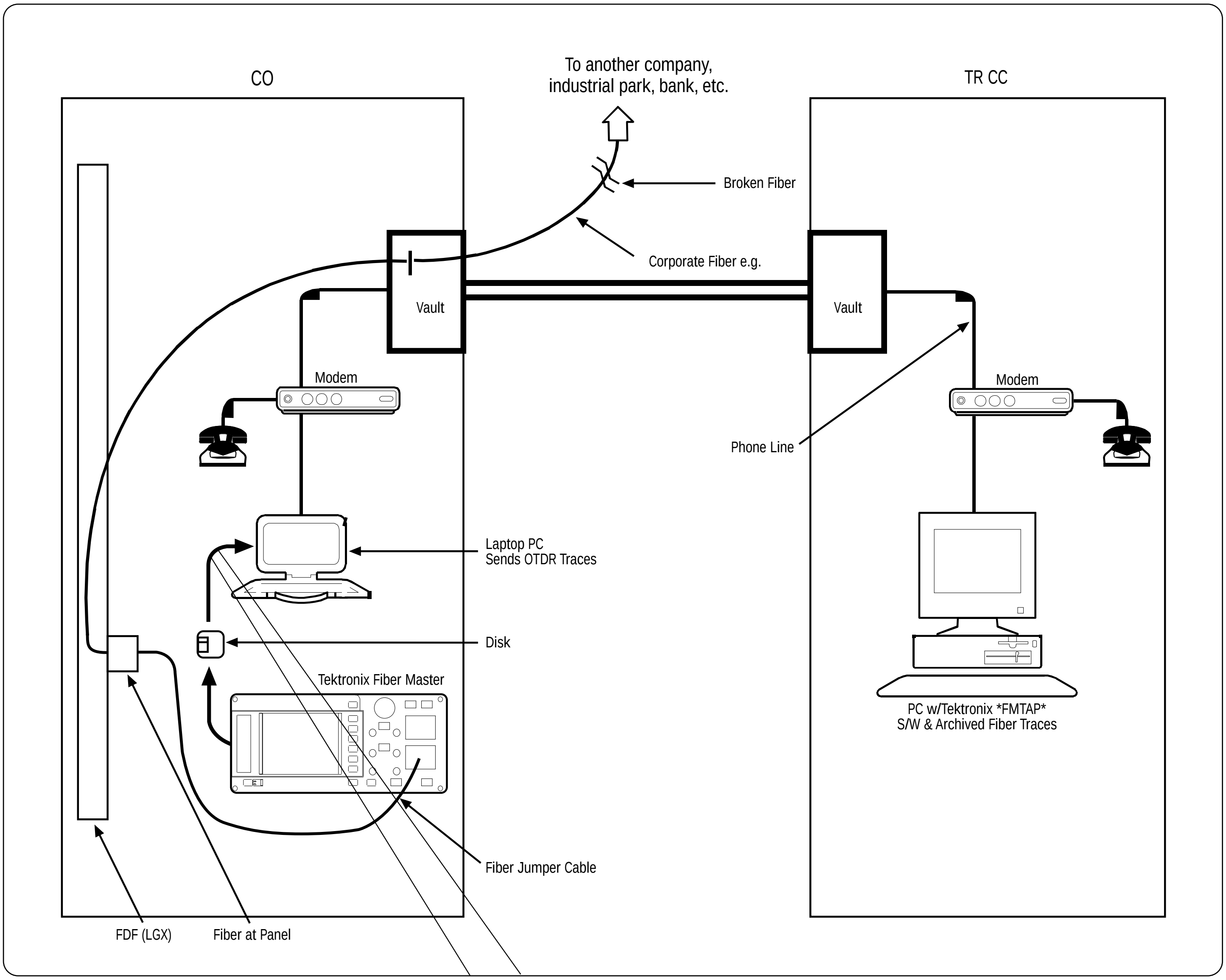
- Test all fibers in the system to verify operation within QoS specifications
- Generate reports to prove that the system again meets specifications
- Archive the data for comparisons with future tests

An Example of a Fault Location and Restoration

Fault location is a significant part of the time it takes to restore a damaged fiber. While many fiber outages are related to trauma from excavations and other obvious physical damage, some faults cannot be located by visual inspection of a cable route. Optical power meters can detect excessive power loss in the link caused by fiber-link problems such as bad splices, broken fiber and poor connections, but the measurements can not reveal where the problems are located.

Proper installation documentation of fiber routes with OTDR traces of fibers linked to physical locations (manholes, poles, etc.) along these routes can significantly reduce the time to locate a fault. When a problem occurs, test results from the problem link(s) can be compared with the database of OTDR traces obtained for all fibers when they were in working order. Faults can then be readily located a known distance from a particular pole, manhole, buried closure, remote terminal, etc.

Figure 44 illustrates a typical comprehensive fault locating process. An OTDR is used to test the fiber and a laptop computer is used to download the trace(s) via modem to the control center. A trained operator/engineer prepares the control center personal computer with the archives of all fiber trace records on disk for comparison.



▶ ***Figure 44:*** *Fault location system*

Process Prerequisites:

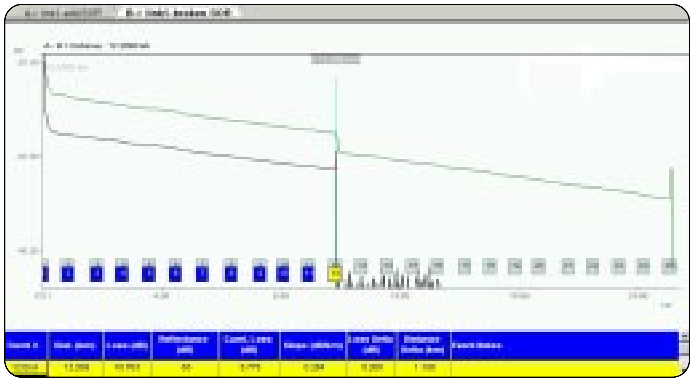
- All fibers have been documented with OTDR trace information related to physical locations.
- All information is stored in a common database in a central location, such as transmission restoration control center (TRCC) that can be accessed from any Central Office (CO).
- All COs in the area and/or fiber crews have computers that can be linked to the control center via modem.
- OTDR's are available to CO personnel, maintenance crews, and construction people for testing on an emergency basis.

Table 3 lists the sequence of events that take place when a fiber outage is detected.

Table 3: Fault-location process

Central Office (CO)	Transmission Restoration Control Center (TRCC)
	Engineer contacts restoration crew to test fiber (corporate) with OTDR
Switchperson runs test of corporate fiber with OTDR using standard, written procedures.	
Switchperson contacts TRCC when fiber test is done; downloads OTDR test result files via computer to TRCC for analysis.	
	Engineer uploads trace files of damaged fiber to TRCC.
	Engineer verifies CO test was done correctly.
	Engineer compares archived original fiber trace to trace of damaged fiber using TARGET1 software.
	Fiber fault is isolated between two known physical locations (pole, etc.) and distance to each measured using TARGET1 software.
	Information relayed to restoration crew for corrective action.

Sample OTDR traces used in the fiber-fault-locating process just described are shown in figures 45, 46, and 47. The trace in figure 45 labeled "good fiber" is the archived test of the fiber measured after installation. The "cut fiber" trace is the current OTDR test of the same fiber showing the break at 12.269 km. The dual–trace display in these figures was produced by Tektronix' TARGET1 PC–based software.

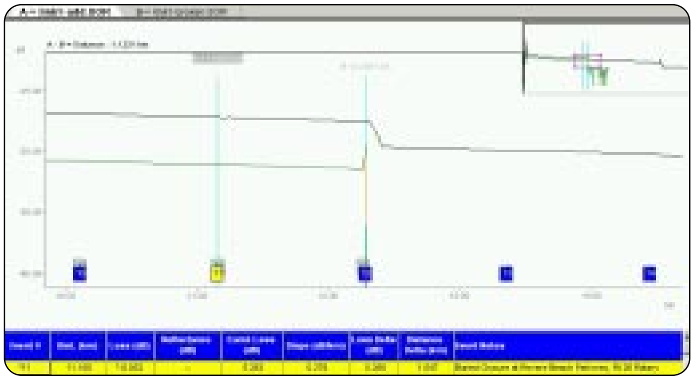


▶ ***Figure 45:*** *Fault–location process–distance to the cut*

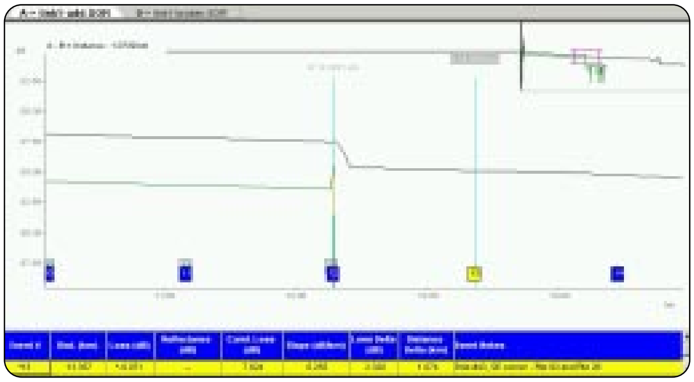
To determine the exact location of the break, the traces in figure 46 are expanded and displayed in figures 46 and 47. In figure 46, the distance from event 11, a buried closure, to the break is shown as 1.1231 km. In figure 47, the distance from the cut to event 13, pole #49, is given as 1.0739 km. The two views have bracketed the location of the fiber failure between two known physical locations, making it easier to find the fault.

While the example uses a central database, area garages could as easily provide this level of restoration support. In fact, the dual-trace capability of Tektronix' NetTek OTDR permits field analysis in the same manner without the need for an additional computer.

The key to minimizing fault location time is good fiber documentation at installation. Complete "as built" records not only assist in maintenance testing, but become the basis of an efficient restoration process.



▶ ***Figure 46:*** *Fault–location process–identifying the nearest landmark before the cut*



▶ ***Figure 47*** *Fault–location process–identifying the nearest landmark after the cut*

Translating OTDR Distance to Ground Distance

"Are the distance measurements accurate? I dont want to dig a big hole to find the break." This is a common concern about OTDR measurements. The issue is much more than the OTDR's accuracy; it involves matching the OTDR measurement with good documentation for the best physical location accuracy.

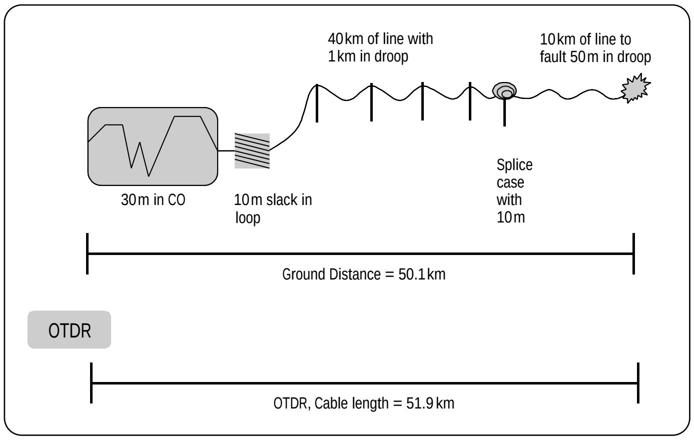
The OTDR's distance measurement to a cable fault is usually more accurate than we can measure ground distance. The OTDR measures the amount of glass fiber between where it is connected and the event on the trace. Its distance measurement is usually accurate to one meter and in the worst case may be ten meters. But this is glass length, not ground distance.

There will always be more glass fiber length than ground distance. Extra fiber cable is needed for:

- Cable snaking (in trenches and conduits)
- Line droop (in overhead lines)
- Slack loops
- Cable wrap factor (spiraling inside the cable bundle)
- Splice trays loops
- Cable routing in CO/Head-ends

All of these factors cause the ground distance to differ from the OTDR cable length measurement.

In the example shown in Figure 48, the OTDR distance measurement can be very accurate, and still differ from the ground distance due to cable layout. Cable routing, slack loops, line droop and splice cases have added 1,800 meters to the overall distance measurement of the OTDR between the test point and the fault.



▶ ***Figure 48:*** *Example of cable length versus ground distance*

How is a fault accurately located? The key is documentation. The longer the distance between the point of interest and a physical reference point (known as a "landmark"), the more the ground and cable lengths will differ. OTDR's contain features that let you document events on the trace. By measuring to the event from the closest known location, measurement differences are reduced.

In the example, the location of the splice case in our system documentation was noted. This could be a street address, map coordinates, GPS data, or other information that more accurately tells us where that reference point is located. The reflection from the splice on the OTDR trace can be seen. Measuring from that point to the fault is only a 50 m variation rather than the 1800 meter variation when measured from the CO.

To get even closer, for the extra cable caused by overhead droop, snaking, or spiraling in the bundle can be compensated for. These cable factors are often a consistent percentage of the cable length. In the example above the cable droop and other cable factors increase the cable length by 2.5%. By documenting that percentage and factoring it into the OTDR measurement we can get to within a few meters of the actual ground location.

Conclusion

New test equipment and techniques can be powerful allies in the task of maintaining a fiber optic network. The objective of this primer is to acquaint you with the basics of fiber optic technology and guide you through advanced testing methods for the commissioning, troubleshooting and restoration of a fiber optic plant.

We have compared common fiber optic cable test tools and illustrated the use OTDR functions and techniques to solve typical measurement challenges. The test descriptions and measurement examples in this primer were developed with the NetTek OTDR with IntelliTrace Plus technology and TARGET1 report generation and emulation software. For more information about the application of these products and our extensive family of advanced optical test solutions, contact us at the nearest Tektronix location or through our web site at www.tektronix.com/optical.

Glossary

Attenuation

A measure of the loss of optical signal power, expressed in decibels. Attenuation is a function of fiber length; increasing with distance. Attenuation is also related to the fiber's intrinsic material properties, impurities in the fiber and by extrinsic factors such as splices and physical bends in the cable.

Attenuation coefficient

The attenuation of an optical fiber per unit length, expressed in dB/km.

Backscatter

The portion of scattered light that travels in the opposite direction of the optical signal. (See Rayleigh scattering.)

Bandwidth

The capacity of an optical fiber to transmit information, expressed in either frequency (GHz) or data rate (Gb/s). Higher bandwidths can transmit more information in a given period.

Cladding

A layer of material such as glass or plastic that surrounds and is fused to the core of an optical fiber. Cladding has a lower refractive index than the core, which helps to contain the light within the center of the fiber.

Central Office (CO)

A main connection and switching point for communication circuits. Also known as a “wiring center” or “head end” in some types of networks.

Core

The center of an optical fiber where most of the light is carried.

Coupler

A device that connects the optical signal to a fiber cable or splits the signal from one fiber into two or more different fibers.

Dead zone, event

The minimum distance after a reflection before the OTDR can accurately measure the distance to a second reflection, sometimes called the “two-point spatial resolution.” The event dead zone is measured from the leading edge of the reflection to the point past the reflection where the level of the OTDR signal drops at least 1.5 dB from the top of the reflection.

Dead zone, loss

The minimum distance after a reflective event before the OTDR can accurately measure the loss of a non-reflective event. Typically, the loss dead zone is the distance from the leading edge of the reflection to the point past the reflection where the OTDR signal level returns to within 0.5 dB of the backscatter level.

Decibel

A decibel, or dB, is defined as ten times the base 10 logarithm of the ratio of two power levels. For example, a 3 dB loss is ~ 50% decrease in power, a 2 dB loss is ~ a 37% decrease in power, and a 1 dB loss is ~ a 21% decrease in power.

Detector, optical

A device that generates an electrical signal proportional to incident light.

Dynamic range

The measure of a system's ability to distinguish signals in the presence of noise. Several definitions exist for OTDR dynamic range. Bellcore defines the dynamic range as the displayed attenuation (in dB) from the backscatter level at the front panel to an imaginary line (past the end of the fiber) that lies just above 98% of the noise. Another common definition (based on Signal-to-noise ratio = 1) uses an imaginary line that lies just above roughly 63% of the noise.

Dynamic range, end detection

The maximum distance that an OTDR is able to detect the reflection from a cleaved fiber end. This is much greater than the distance over which the OTDR can make splice-loss measurements.

Event

Any break or connection in an optical fiber that appears on an OTDR display as change or discontinuity in the normal uniform backscatter signature of the fiber. Mechanical and fusion splices, connectors, bends, and breaks in the fiber can produce events in an OTDR trace.

Ferrule

The protruding connector part that houses the fiber and normally includes a spring that provides axial pressure when two connectors are mated. The end face of the fiber/ferrule is finished (polished) to minimize reflections from the mating surfaces.

Fiber slope

The attenuation coefficient of a fiber. The loss per section length (e.g. dB/km)

Fresnel reflection

Reflection resulting from a discontinuity in the fiber's index of refraction. A cleaved fiber end, unterminated connector, mated connector, and mechanical splices cause Fresnel reflections. On an OTDR, Fresnel reflections appear as sharp, upward-pointing spikes (events).

Fusion splice

A method of connecting two optical fibers that involves aligning and heating the fiber ends so the glass structures of each fiber melt and are permanently welded together.

Laser

Acronym for Light Amplification by Stimulated Emission of Radiation. A laser is a device that creates a narrow, intense beam of coherent light at a single or just a few frequencies going in one precise direction.

Macrobend

A bend or pinch in a fiber with a radius more than the core radius, causing light to escape from the fiber.

Mechanical splice

A method of connecting two optical fibers that involves mechanically joining or bonding the two ends of the fibers together. Often includes using matching gel to reduce reflections.

Multimode fiber

One of two fundamental types of optical fiber (see singlemode). A multimode fiber transmits multiple light paths (or modes) of light. Multimode fiber cores are between 50 and 100 microns in diameter, much larger than those of singlemode fibers.

Nanometer

A unit of length equal to one billionth of a meter (10^{-9} meter).

Optical fiber

Thin strands of ultra-pure glass or plastic designed to transmit light pulses at very high data rates for the transmission of voice, data, and video information.

Optical time-domain reflectometer

A versatile optical test instrument that measures the locations and losses of events on optical fiber from one end of the fiber. The OTDR sends pulses of light into a fiber, processes the light that is reflected back and displays the results as a waveform (trace). Advanced OTDR's also analyze the waveform and automatically locate and measure each of the events.

Plant

The complete fiber optic communication system, from transmitter through fiber links and components to receiver. "Inside plant" and "outside plant" differentiate sections of the system that are inside a building from external components.

Rayleigh scattering

Scattering produced by non-uniformities in optical fiber that are very small relative to the wavelength of the transmitted light. Rayleigh scattering is inversely proportional to the fourth power of the wavelength. (See also "backscatter")

Refractive index

The ratio of the velocity of light in a vacuum to the velocity of light in a given material. The refractive index can vary from fiber to fiber.

Return loss (or reflectance)

The ratio of the reflected power to incident power for a reflective event, expressed in dB. The integrated return loss is the ratio of the total reflected and scattered power from the entire fiber link to the total incident power.

Scattering coefficient

The ratio of backscattered power to the optical energy transmitted into a fiber. Like the refractive index, the scattering coefficient is characteristic of the specific fiber and varies from fiber to fiber.

Signal-to-noise ratio (SNR)

The ratio of the signal power to noise power in an optical detector or amplifier. (see also dynamic range).

Singlemode

One of two fundamental types of optical fiber (see multimode). A single-mode fiber transmits one light path (or mode) of light at a time. Singlemode core diameters range from 8 to 10 microns, much smaller than those of multimode fibers.

Splice

A permanent or semi-permanent joint between two optical fibers, as in fusion and mechanical splices.

Splice loss

The attenuation of optical power at the point where two optical fibers are joined, typically expressed in dB.

Tail

In an OTDR, the optical detector takes a finite amount of time to recover its full dynamic range after being saturated by a high level reflective event. This delay appears on the trace as a sloping region, or “tail”, from the top of the saturated event to the normal backscatter level. The tail contributes to the dead zone where backscatter cannot be measured accurately.

Two-point loss

The loss between two points on an optical fiber caused by fiber backscatter, connectors, and splices.

Wavelength

The distance between two crests or troughs of a periodic wave that describes one complete cycle.

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Updated 8 February 2002

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04/02 FLG5610/SFI 22W-15443-0

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