Fiber Optic Services And Products

EYE ON FIBER

How to Avoid Cursing at Cursers

-An Introduction To Interpretation of OTDR Traces

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The beauty of the optical time domain reflectometer, hereafter the OTDR, is its ability to provide power loss data on almost every element (i.e., cable segment, splice, connector pair or passive device) in a fiber optic link (Figures 1-3). These data are presented in the form of a trace. With these data, the network technician can 1) certify a network as being low loss and reliably installed and 2) identify locations of excessive power loss.

For an expanded presentation on this subject, see Chapter 13 of Successful Fiber Optic Installation- The Essentials.

Figure 1: Mainframe OTDR

Figure 2: Current Generation Mini-OTDR

Figure 3: Current Generation Mini-OTDR

There are four difficulties that can occur during use of the OTDR. First, the OTDR has no ability to tell the technician what he is seeing. The OTDR indicates locations and magnitude of power loss but does not indicate the origin of such power loss. In other words, the technician must interpret the trace.

Second, interpretation of OTDR traces can be complicated by the fact that trace features can have multiple causes. Herein lies the major difficulty in trace interpretation and the origin of much confusion. Because of this fact, the technician must interpret the trace from a map; he cannot create a map from the trace.

Third, the use of passive optical networks (PONs) with a transmitter feeding multiple receiving sites severely complicates the nature and interpretation of an OTDR trace.

And fourth, the technician can make accurate measurements and proper interpretations only if he knows the rules of proper curser placement. With improper curser placement, the technician will curse at the cursers. In this forty-five minute session, we will present the information you need to avoid such cursing.

Why test a fiber optic link with the OTDR? The simple answer is maximum reliability. Only the OTDR can reveal conditions that can reduce reliability. With knowledge of such conditions, network technicians can remove these conditions to maximize network reliability.

Does not the insertion loss test provide adequate information? The insertion loss test, the first test performed on an installed singlemode link, usually simulates the operation of the transmitter-receiver pair.[1] With this simulation, the insertion loss test can indicate a desirable condition: sufficient power without excessive power at the receiver. However, an acceptable insertion loss test could result from at least four situations, only one of which would be totally acceptable:

Low loss connectors and low loss cable

Very low loss connectors and high loss cable

High loss connectors and very low loss cable, or

Very low loss connectors, very low loss connectors and excessive cable loss due to improper installation.

Since the insertion loss test cannot indicate high reliability from proper installation, most network managers require an OTDR test as confirmation of proper installation. Such a test is inexpensive insurance against future link failures due to improper installation.

To understand the interpretation of the OTDR trace, we must understand the manner in which a fiber affects optical power. As photons travel through an optical fiber in a forward direction, some are scattered forwards and backwards towards the core cladding boundary. Those photons that strike the core-cladding boundary at an angle greater than the critical angle, which is defined by the numerical aperture (NA) of the fiber, escape from the core and are lost. This mechanism, known as Rayleigh scattering, is the main cause of power loss in an optical fiber.

To understand this mechanism, imagine that you are in a dark, dusty room with a high intensity flashlight and a friend. You shine the flashlight in a direction so that your friend is viewing the light perpendicular to the path. He sees the light because it is scattered in the direction of your friend by the dust. In a similar manner, light traveling in an optical fiber escapes from, and is lost from, the fiber core.

Fortunately, such power loss is low (Table 1). Low power loss enables long distance of transmission, which is one of the eight advantages of optical fiber transmission (Table 2).

Table 1: Maximum Attenuation Rates for Optical Cables

Core, µm	Wavelength, nm	Attenuation Rate, dB/km
8.2	1550	0.25
8.2	1310	0.40
50	1300	1.00
62.5	1300	1.0-1.5
50	850	3.00

62.5	850	3.50

Table 2: Advantages of Optical Fiber Transmission

Essentially unlimited bandwidth	Easy installation	Light weight
Long transmission distance	Dielectric construction	
EMI and RFI immunity	Low cost per bit	Small size

Figure 4: Some Scattered Light Travels Backwards

However, some of the photons are scattered backwards towards the input end of the fiber at an angle to the core-cladding boundary less than the critical angle. Reflected from this boundary, such light travels backwards towards the input end of the fiber by the mechanism of total internal reflection (Figure 4). The OTDR uses this back-scattered light to determine the power losses of elements in a link.

This back-scattered light enables interrogation of almost all elements in a fiber link from one end. For instance, by measuring the back-scattered power levels at the beginning and end of a segment, the OTDR can calculate the attenuation rate of that segment. In addition, by determining the back-scattered power levels before and after a connection,[2] the OTDR can determine the power loss of that connection. In summary, the OTDR can provide power loss measurements of almost every element in a fiber optic link from one end. By comparing these measurements to certification values,[3] or to as built values, the technician can certify and troubleshoot a fiber optic link.

In order to make traces, the technician adjusts four parameters of the OTDR to match the capabilities of the OTDR to the operational characteristics of the link (Table 3).[4]

Table 3: OTDR Settings

Wavelength

Index of refraction

Pulse width

Number of repetitions or time for testing

The wavelength is the wavelength at which the link is to operate. The index of refraction, also known as the refractive index and the group index, is a measure of the speed of light in the core of the fiber. With this value, the OTDR can convert its time measurements to accurate fiber length measurements. In Table 4, we present typical values of IR for singlemode fibers.

Supplier	Product	1310 nm	1310 nm
Corning	SMF-28	1.4675	1.4681
Corning	SMF-DF	1.4680	1.4680
Corning	Titan	1.4675	1.4681
Lucent		1.4660	1.4670
Lucent	2136E	1.4670	1.4670
Lucent	215E	1.4670	1.4670
Alcatel		1.4640	1.4645

Table 4: Typical Singlemode Index of Refraction Values

The fiber to cable length ratio, which is equal to or greater than one, allows the technician to locate a feature identified by the OTDR. In most cables, the fiber length is greater than the cable length.

This length difference is due to two factors. The first factor occurs in loose tube cables, the type most commonly used in outdoor cable plants. In loose tube cables, the fiber spirals around inside of the loose buffer tube, making the fiber longer than the loose buffer tube. In most cables, both loose tube and tight tube, the buffer tubes spiral around the axis of the cable, further increasing the difference between fiber length and cable length. This ratio, which depends on the cable design and the cable manufacturer, ranges from 1.01 to 1.001.

The fiber to cable length ratio is not an input to the OTDR. However, the index of refraction can be modified by this value so that the OTDR indicates cable lengths.[5]

The technician sets the pulse width of the OTDR appropriate for the length of the cable being tested. A consequence of the low attenuation rate of optical fibers is a very low power level scattered back from the far end. In order that the OTDR receive enough power to provide accurate measurements from the far end of the cable, the technician must set the OTDR pulse width.[6]

Regardless of the settings, the power level from the far end is very low and will include noise from the OTDR electronics. In order to minimize the inaccuracy created by this noise, the OTDR is programmed to perform multiple tests of the cable.[7] The OTDR will average the back-scattered power from multiple tests to minimize the inaccuracy that results from low back-scattered power level.

Once set up, the OTDR can be used to interrogate a link. The result of this interrogation is a trace. The trace presents a picture of the optical power loss along the link.

Theory tells us, and millions of OTDR traces prove to us, that a plot of the logarithm (log) of the power vs. distance will create a straight-line trace with a negative slope (Figure 5). However, connections can create reflections. Reflections add power to the power scattered backwards from the atoms in the core of the fiber. When we add this reflected power to the back-scattered power, we obtain a trace with peaks, also called spikes or most accurately, reflections (Figure 6).

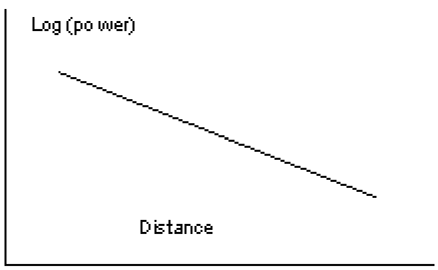

Figure 5: Theoretical Backscatter Trace

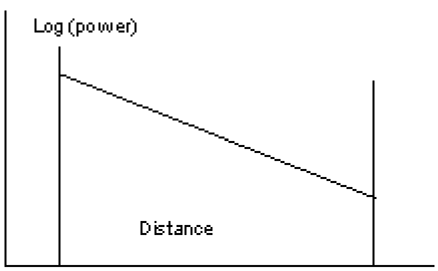

Figure 6: Theoretical Backscatter Trace With Reflections

However, Figure 6 indicates that the OTDR can respond from one power level to another, and then to a third power level in zero time. As we all know, electronics take time to respond to power changes. When we modify Figure 6 to allow for this response time, we obtain Figure 7. Figure 7 indicates that each peak, or reflection, has a width, both in time and in cable length. This width is called a ≥dead zone≤ and a ≥blind zone≤. This dead zone can range from a few meters, in multimode links, to thousands of meters, in long distance singlemode links.

The significance of the dead zone is blindness to details. Since the peak is created by a limitation of the bandwidth of the receiver, the peak blinds us to the details of cable and connector loss in the peak.

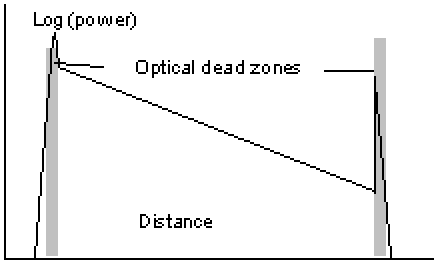

Figure 7: Realistic Trace With Dead Zones

Figure 7 represents a basic OTDR trace. The basic trace has five parts: two reflections at the ends, a straight line trace with a negative slope between the reflections, and two ≥dead≤ or ≥blind≤ zones after each peak. It is this blindness that forces us to describe the OTDR as enabling testing of ≥almost every element≤ of a fiber link. We shall return to the word ≥almost≤.

Most OTDR traces can be reduced to a combination of the elements of two common traces: a trace of multiple segments with a non-uniform, reflective event (Figure 8) and a trace of multiple segments with a non-uniform, non-reflective event (Figure 9). Each of these two common traces can have multiple interpretations. These multiple interpretations mean that the technician cannot create a map from the trace. Rather, he must interpret the trace from an accurate map.

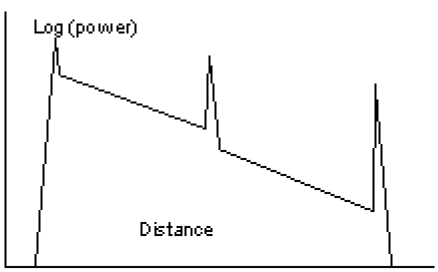

Figure 8: Trace With A Non-Uniform, Reflective Event

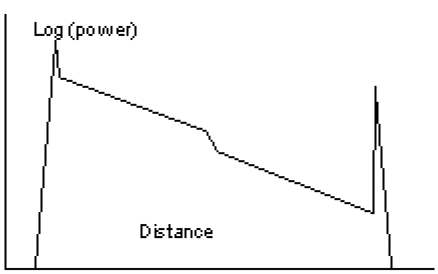

Figure 9: Trace With A Non-Uniform, Non-Reflective Event

The technician can interpret a trace with a non-uniform, reflective event in five ways (Figure 8). Such a trace can indicate:

A break in a tight tube cable,

A multimode mechanical splice,

A singlemode mechanical splice,

A fusion splice with a gas bubble,

Or a multiple reflection.

A break in a tight tube cable will result in a glass/air/glass path. Such a path always results in reflectance, or a peak in an OTDR trace.

A multimode mechanical splice must create a reflectance, since the core of the multimode fiber has multiple indices of refraction. The index matching gel in a multimode mechanical splice has a single index of refraction. Because the index of the gel is different from the index in part of the core, a reflection results.

A singlemode mechanical splice may, or may not, have gel with the same index of refraction[8] as the core of the fiber. If the gel has the same index, there will be no reflection; if not, there will be a reflection.

A fusion splice with a gas bubble has a glass/gas/glass light path. As such, there will be a change in the index of refraction, or the speed of light. Such a change results in a reflection.

Finally, a high reflectance connector at the OTDR can cause the light to take multiple round trips between the OTDR (Figure 10) and the first connector in the link before this power enters the OTDR. As such, this power creates a peak on the trace. This peak tends to occur at nearly exact multiples of the length of cable that produces the multiple reflections.[9]

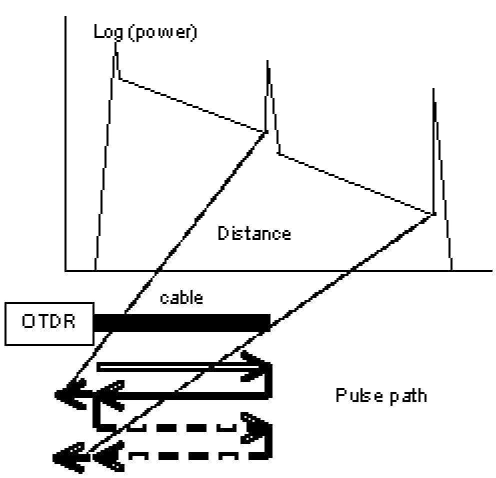

Figure 10: Origin of Ghost Reflections

The technician can interpret a trace with a non-uniform, non-reflective event (Figure 9) in four ways. Such a trace can indicate:

An angled physical contact (APC)[10] connector pair,

A fusion splice[11]

A singlemode mechanical splice with a loss,[12] or

A violation of a cable performance parameter[13]

APC connectors have an angled end face. This angle reflects all power backwards outside the critical angle, or NA, of the fiber. As such, APC connectors reflect no optical power back to the OTDR.

A properly made fusion splice exhibits no change in the speed of light across the splice. As such, there is no peak, or reflectance.

Many singlemode mechanical splices have gel with an index of refraction that is exactly the same as that of the singlemode core. In this situation, there will be no reflection.

A violation of a cable performance parameter could be a violation of the bend radius, the long-term use load, the temperature operating range, or the crush load. The location of the violation exhibits excess power loss on the OTDR trace as a power drop.

The OTDR software can analyze the trace to provide a table of attenuation rates, segment lengths, and connection losses. Because software is never perfect, the technician needs to know how to place cursers on the trace in order to make accurate measurements.

For most measurements, the technician will place two cursers on the trace: one curser at the ≥beginning≤ of an element, the second at the ≥end≤ of that element. The position of the curser will determine the fiber distance of the element from the OTDR. The power difference between the locations of the two cursers will determine either the attenuation rate or connection loss.

In order to determine distance from the OTDR, the technician will place a curser at the location of interest (Figure 11). The position of the curser will be the fiber distance of the feature from the OTDR.

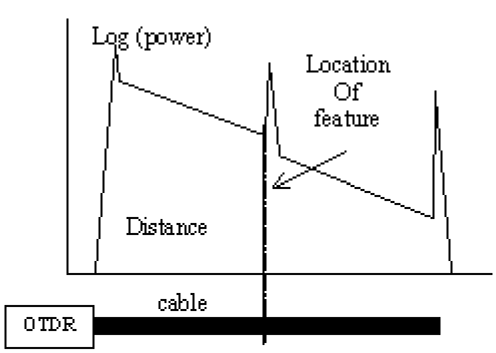

Figure 11: Location of Curser For Length Measurement

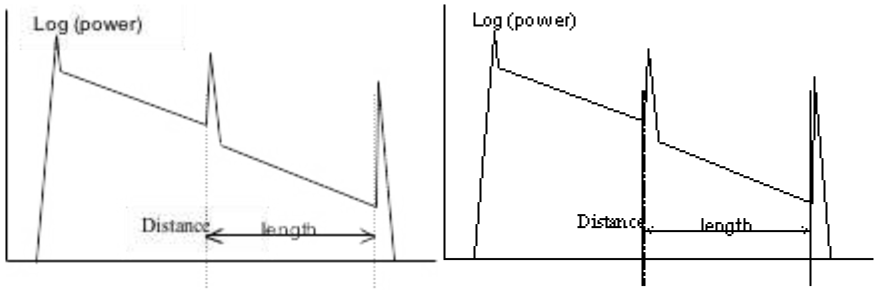

Figure 12: Curser Placement For Length Measurement, Reflective Event

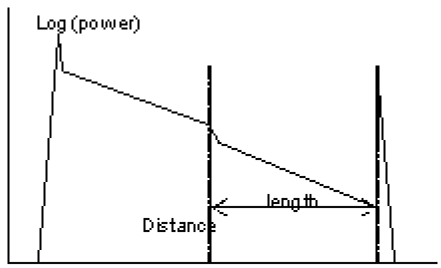

Figure 13: Curser Placement For Length Measurement, Non- Reflective Event

To determine a cable segment length, the technician will place two cursers at the beginning and end of the segment (Figures 12 and 13). The distance between the cursers will be the length of the segment. The basic rule is that segment length includes a peak or drop at the beginning and excludes a peak or drop at the end.

To determine cable attenuation rate, the technician will place two cursers in the same straight-line segment, with no features (reflections or drops) between the cursers (Figure 14). The cursers need to be as far apart as possible to produce a value that represents the attenuation rate of the entire segment. The computer in the OTDR will divide the power loss by the distance between the cursers to establish the attenuation rate.

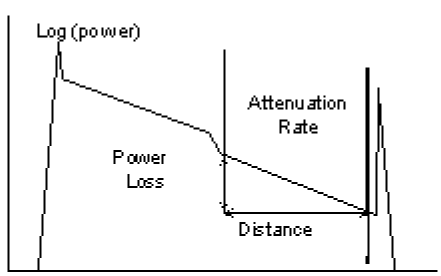

Figure 14: Curser Placement For Attenuation Rate Measurement

Some OTDR software will perform a least squares analysis (LSA) of the backscatter trace to determine the attenuation rate. This LSA will produce an attenuation rate value that is slightly different from that produced by the placement of two cursers. However, the interpretation of the attenuation rate value, either an acceptable or unacceptable value, will not change.

Occasionally, technicians have discomfort about curser placement for attenuation rate measurements. The technician can move the cursers slightly closer to one another. This new attenuation value will be slightly different from the value obtained with the cursers further apart. However, the interpretation of the attenuation rate will not change. In both cases, the rate will be acceptable or unacceptable.

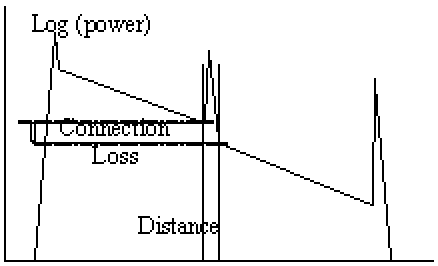

Figure 15: Curser Placement for Estimate of Reflective Loss

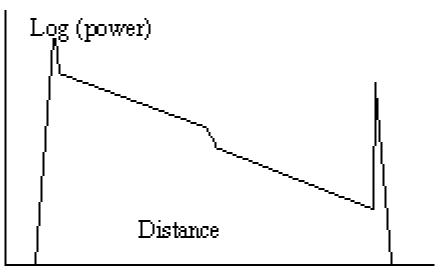

Figure 16: Curser Placement for Estimate of Non-Reflective Loss

To determine a connection loss, the technician will place two cursers in the straight-line trace segments that straddle the connection (Figures 15 and 16). The power loss between the two-curser positions is an overestimate of the connection loss.

This power loss is an overestimate because the two cursers are at different locations along the cable system. Between these two locations, the fiber attenuates the power. As such, a connection loss measurement made with two cursers is a slight overestimate of the actual power loss. The size of the overestimate is the product of the attenuation rate of the ≥downstream≤ fiber and the distance between the cursers.

To obtain an accurate power loss measurement of a connection, the technician needs to activate the ≥accurate≤ or ≥splice≤ loss measurement option.[14] With this option active, the computer in an OTDR makes least squares analysis (LSA) of the fiber attenuation trace beyond the connection and extrapolates this fit to the location of the curser (Figure 17). This method of measurement removes the attenuation between two cursers from the connection loss value.

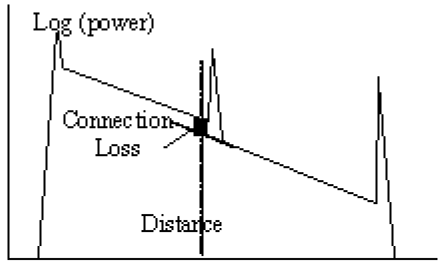

Figure 17: Curser Accurate Connection Loss Measurement

Because there are two methods for determination of connection loss, the technician must know the original method used when making troubleshooting or maintenance tests. Those tests should be made by the same method as the original connection loss.

All of the previous presentation presumes a single transmitter to receiver link. However, as we know, the FTTH system cost analysis favors a single transmitter to multiple receivers. In this case, the OTDR trace becomes more complex, and, understandably, more difficult to interpret.

Earlier in this presentation, we stated that the OTDR can measure the power loss of ≥almost≤ every element in a fiber optic link from one end of the link. In this section, we examine the meaning of the word ≥almost≤. The word ≥almost≤ derives from the optical dead zone of blind zone.   At any point in a network at which there is a sudden change in power level, the OTDR must respond to that change. Fortunately, or unfortunately, depending upon your perspective, such a change in power level takes time. The horizontal axis of an OTDR trace is actually a measure of time, which has been converted to a distance measurement by the index of refraction input to the OTDR.

Multiple events can occur within the distance defined by the dead zone. Any power loss measurement made by placing cursers that straddle the event will be a total loss measurement. As such, we will not be able to measure closely spaced, individual loss events that occur in a dead zone, as shown in Figure 18.

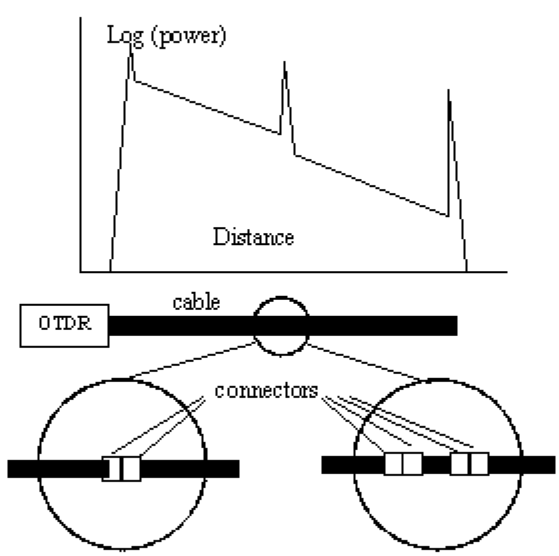

Figure 18: Example of Feature in Trace Concealed By Dead Zone

In addition, we cannot measure the loss of the connector at the far end of a link. To do so requires placement of two cursers in the straight lines that straddle the event. Since there is no straight-line trace after the far end connector, we cannot place a curser and make a measurement.

Of course, we can measure the loss of the far end connector if we move the OTDR to the far end. Then the far end connector will appear at the end of the launch cable.[15] Alternatively, we could attach a ≥lead out≤ cable to the far end connector.   With this additional cable, we can place the second curser in the straight-line trace (Figure 19).

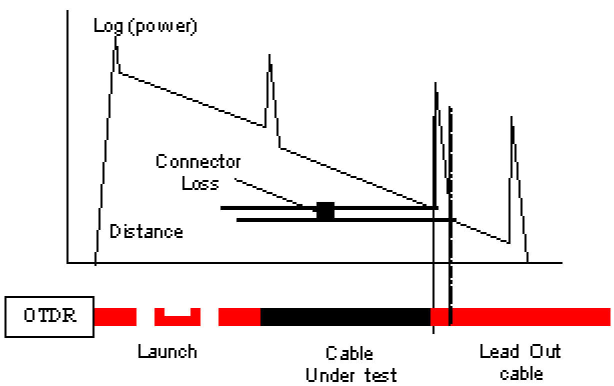

Figure 19: Measurement of Power Loss of Far End Connector

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Respectfully submitted for your consideration,

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[1] At this time, most singlemode transmitters and most singlemode insertion loss sources use laser diodes. With this commonality, insertion loss testing does reasonably simulate transmitter receiver pair operation. In the future, singlemode sources may be VCSELs. Laser diode test sources may not simulate the operation of VCSEL sources.

[2] A connection is either a connector or a splice.

[3] A completely different subject.

[4] There is a sixth parameter, the core diameter of the fiber being tested. The technician chooses a launch cable with the same core diameter and NA as the fiber being tested.

[5] It is our impression that few people apply this modification.

[6] The longer the cable is, the larger the pulse width must be.

[7] Typically, the number of repetitions can range from 1024 to 64,000. For some OTDRs, the time for the test is set instead of the pulse width.

[8] The index of refraction is defined as the ratio of the speed of light in a vacuum to that in the fiber. Typically, the index of refraction ranges from 1.46 to 1.52.

[9] Such a peak is also known as a ≥ghost≤ reflectance, or ghost peak. A ghost peak can appear in a link with the OTDR at one end but not at the opposite end. Since peaks, or reflections, represent ends of fiber, such appearance/non appearance indicates a ghost, rather than a real fiber end.

[10] APC connectors are singlemode connectors with an end face that has an 8∞ angle on the end.

[11] Properly made fusion splices, both singlemode and multimode, never create reflections.

[12] A singlemode splice may, or may not, create a reflectance.

[13] A violation of a cable performance parameter results in loss of power at a specific location.

[14] With some OTDRs, this option is automatic. With others, the technician must set the location of four points: two in the straight-line trace that precedes the connection and two in the straight-line trace that follows the connection.

[15] Common practice is use of a launch cable, also known as a pulse suppressor. Use of this cable reduces