WHITE PAPER

Understanding Optical Time Domain Reflectometers (OTDR) Specifications

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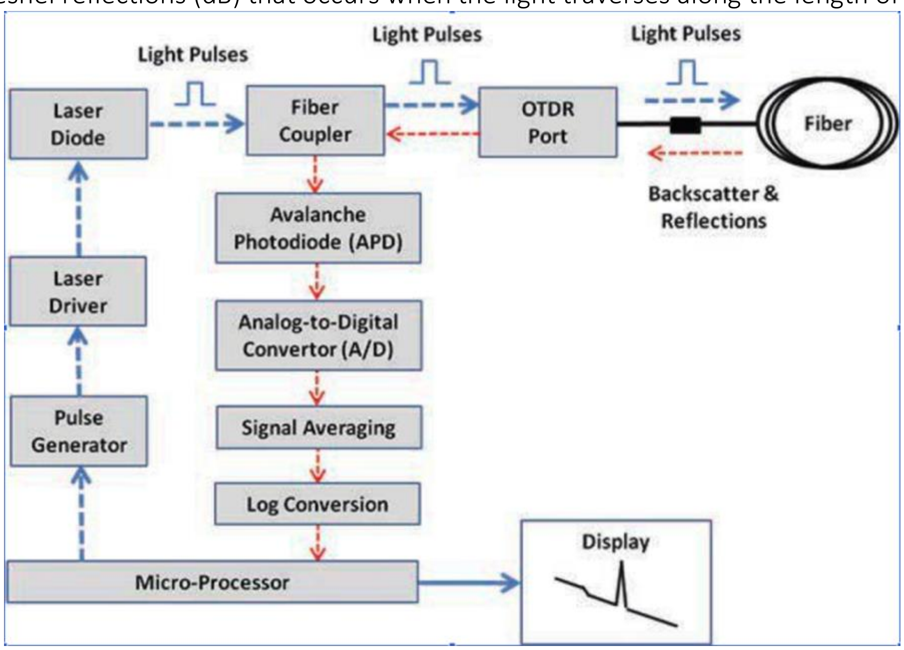
OTDR Fundamentals

There are a variety of optical test sets that can be used to ensure quality of service (QoS) on fiber optic networks, but only the Optical Time Domain Reflectometer (OTDR) supports singled ended fiber testing to characterize fibers when measuring total loss, optical return loss (ORL), latency and fiber length. Since the 1980s, OTDRs have been used to characterize fiber links, identify optical events, measure event loss, location, reflectance and identify events that can impact the fiber optic network service using one or two moveable cursors. As networks topology have evolved, OTDR hardware and software analysis too have been forced to adapt to be able to properly report events correctly. OTDRs are required to test basic Point-to-Point, Point-to-Multi-Point Links (PON) that have single or multi-splitters with up to 128 drop fibers, and xWDM links that have 2 or 4 mux/demux optical components. Many users erroneously choose OTDRs because of perceived maximum measurement distance based on Point-to-Point links only to find out after significant investment that the OTDR they purchased is not adequate for their PON or xWDM test applications. This guide will help users understand key OTDR specifications and the impact each specification has when applied to real world application testing.

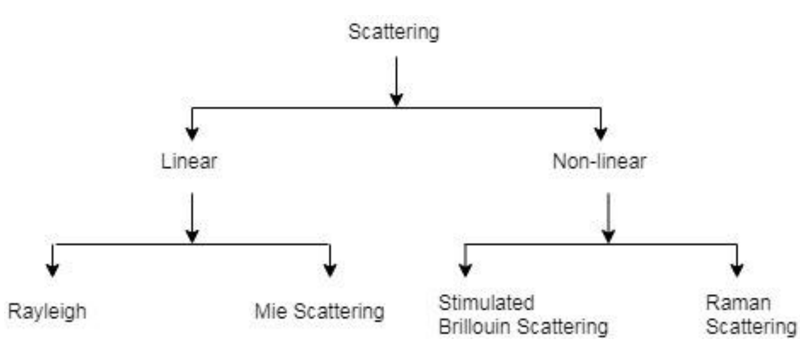
OTDR Basics

An OTDR injects a short light pulse into a fiber and routinely measures reflected light from Rayleigh back scatter (dB/km) and/or Fresnel reflections (dB) that occurs when the light traverses along the length of fiber.

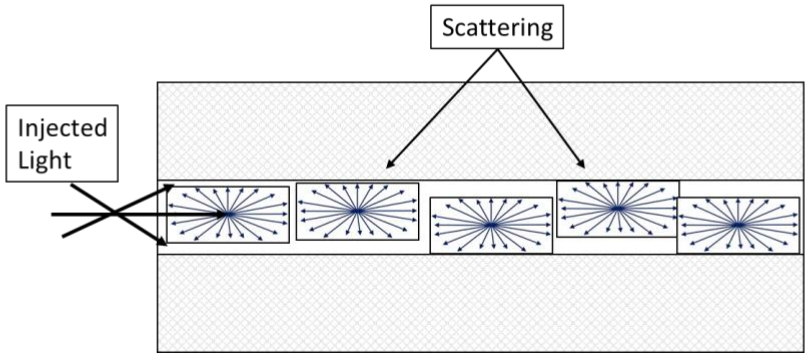


Rayleigh Scattering

Scattering losses in glass is due to microscopic variations in the material density; some areas in the core may contain either higher or lower molecular density from defects that occur during fiber manufacture. Scattering can be linear or non-linear, but in fiberoptic glass the foremost type of scattering is Rayleigh scattering.



Glass fiber is a composition of a random connection of molecules and this leads to the variation in the refractive index of the material at different points inside the fiber. The **variation in the refractive index** leads to Rayleigh scattering of the transmitted light. Light, rather being absorbed, is radiated in different directions thus termed as a scattering of light. OTDRs measure the back scatter to show a trace.



Fresnel Scatter

When light travels in glass and exits to air (i.e. optical connector), some of the light is reflected. Depending on the angle of incidence and the refractive indices of the air and the glass type the light is coming from (e.g., Corning glass SMF-28, n=1.467). The ratio of the reflected and transmitted light can be determined using the Fresnel equations. If the angle of incidence is perpendicular to the glass surface, the fraction of reflected light is given by the reflection coefficient or reflectance, R, with ng being the refractive index of the glass with light is coming from (e.g., Corning glass n=1.467 and the refractive index the connector end face (for air nair=1) , one can expect about 4% of the light is reflected or reflectance (R) = -13.979dB.

$$R = \frac{(n_g - n_{air})^2}{(n_g + n_{air})^2}$$

Pulse Width

The longer the pulse width (PW in nsec), the more energy is injected which allows for greater test distance. When a light pulse has had time to reach the test distance range and return, the OTDR will check system noise and then send another short pulse of light; this continues (averaging) until the desired test time is met. A clock is used to precisely calculate the time of flight of the light pulse which is converted into distance using this formula:

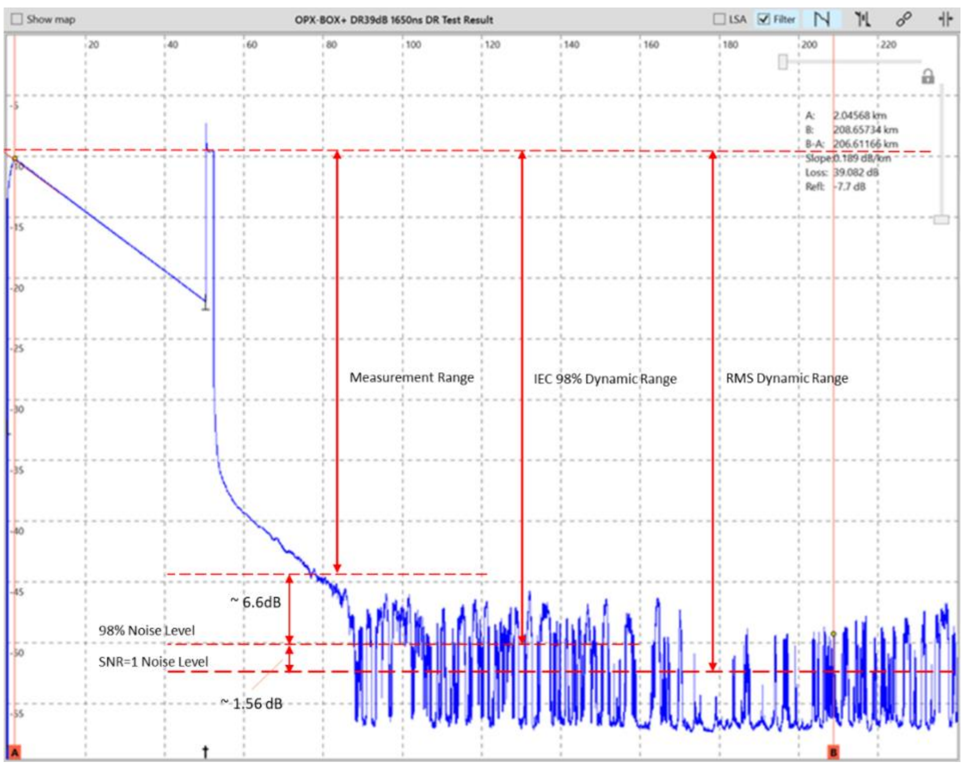
Distance = c * t / (2 * n), where
c = speed of light in a vacuum ~ $3x10^8$ m/sec
n = optical fiber index of refraction
t = time delay between when light pulse is emitted and registered by the detector (APD)

Every optical element that occurs in a passive optical link (fiber, splice, connector, splitter, or MUX) is then averaged and a waveform is displayed in a graph that shows the relationship between return light power (dB) and length (km or feet). GR-192-CORE defines the correct measurement procedures for many key OTDR parameters to ensure measurement consistency, but in some instances manufacturers may use their own procedures, so it is important to pay attention to all footnotes on datasheets.

Dynamic Range vs. Measurement Range

Dynamic range is one of the most important OTDR specifications and is an optical limitation. This specification will determine if the OTDR will have the ability to measure to the end of a fiber. Dynamic range is typically measured using 3-minute test time and 20 µsec laser pulse width. However, the standards failed to stipulate the data sampling (resolution) interval required when making this measurement. Increasing data point resolution spacing can result in improved dynamic range results. Dynamic range is sometimes confused with measurement range, which is the specification that defines the OTDR's ability to measure a 0.1 dB non-reflective splice.

There are several methods to calculate dynamic range. Most standards organizations use the "98% Noise Level" method, but the latest IEC standard now allows both 98% Noise **and** SNR=1. "98% Noise Level" describes the point at which the backscatter level just starts to get mixed up with the noise level of the instrument. "SNR=1" (Signal-To-Noise Ratio) is like the 98% noise method, but provides a greater dynamic range value of approximately 1.56 dB more. The SNR=1 method indicates the point at which the backscatter level of the trace is further down in the instrument's internal noise level. This means you will not be able to clearly distinguish details in the trace at the end of the fiber.



SM OTDR	Time = 3 min, G.652 EOF=3dB	128K/256K/500K				256K/500K			
Test Settings		**30dB**	**35dB**	**40dB**	**45dB**	**30dB**	**35dB**	**40dB**	**45dB**
3nsec, 120km Low	0.5dB Meas. Range, (-6.6dB)	2.28	7.28	12.28	17.28	2.28	7.28	12.28	16.88
	98% Noise (-1.56dB)	7.32	12.32	17.32	22.32	7.32	12.32	17.32	22.32
	SNR=1 (RMS) Visual	**8.88**	**13.88**	**18.88**	**23.88**	**8.88**	**13.88**	**18.88**	**23.88**
5nsec, 120km, Low	0.5dB Meas. Range, (-6.6dB)	3.4	8.4	13.4	18.4	3.4	-36.72	13.4	18.4
	98% Noise (-6dB)	8.44	13.44	18.44	23.44	12.44	13.44	18.44	23.44
	SNR=1 (RMS) Visual	**10**	**15**	**-180**	**25**	**10**	**15**	**20**	**25**
10nsec, 120km, Low	0.5dB Meas. Range, (-6.6dB)	4.89	9.89	14.89	19.89	4.89	9.89	14.89	19.89
	98% Noise (-1.56dB)	9.93	14.93	19.93	24.93	9.93	14.93	19.93	24.93
	SNR=1 (RMS) Visual	**11.49**	**16.49**	**21.49**	**26.49**	**11.49**	**16.49**	**21.49**	**26.49**
25nsec, 120km, Low	0.5dB Meas. Range, (-6.6dB)	6.88	11.88	16.88	21.88	6.88	11.88	16.88	21.88
	98% Noise (-1.56dB)	11.92	16.92	21.92	26.92	13.92	16.92	21.92	26.92
	SNR=1 (RMS) Visual	**13.48**	**18.48**	**23.48**	**28.48**	**13.48**	**18.48**	**23.48**	**28.48**
100nsec, 160km, Low	0.5dB Meas. Range, (-6.6dB)	9.9	14.9	19.9	24.9	9.9	14.9	19.9	24.9
	98% Noise (-1.56dB)	14.94	19.94	24.94	29.94	14.94	19.94	24.94	29.94
	SNR=1 (RMS) Visual	**16.5**	**21.5**	**26.5**	**31.5**	**16.5**	**21.5**	**26.5**	**31.5**
200nsec, 160km, Low	0.5dB Meas. Range, (-6.6dB)	11.4	16.4	21.4	26.4	11.4	16.4	21.4	26.4
	98% Noise (-6dB)	16.44	21.44	26.44	31.44	16.44	21.44	26.44	31.44
	SNR=1 (RMS) Visual	**18**	**23**	**28**	**33**	**18**	**23**	**28**	**33**
300nsec, 160km, Low	0.5dB Meas. Range, (-6.6dB)	12.28	17.28	22.28	27.28	12.28	17.28	22.28	27.28
	98% Noise (-1.56dB)	17.32	22.32	27.32	32.32	17.32	22.32	27.32	32.32
	SNR=1 (RMS) Visual	**18.88**	**23.88**	**28.88**	**33.88**	**18.88**	**23.88**	**28.88**	**33.88**
500nsec, 240/250km, Low	0.5dB Meas. Range, (-6.6dB)	15.4	20.4	25.4	30.4	15.4	20.4	25.4	30.4
	98% Noise (-1.56dB)	20.44	25.44	30.44	35.44	20.44	25.44	30.44	35.44
	SNR=1 (RMS) Visual	**22**	**27**	**32**	**37**	**22**	**27**	**32**	**37**
1000nsec, 240/250km, Low	0.5dB Meas. Range, (-6.6dB)	16.9	21.9	26.9	31.9	16.9	21.9	26.9	31.9
	98% Noise (-1.56dB)	21.94	26.94	31.94	36.94	21.94	26.94	31.94	36.94
	SNR=1 (RMS) Visual	**23.5**	**28.5**	**33.5**	**38.5**	**23.5**	**28.5**	**33.5**	**38.5**
3000nsec, 240/250km, Low	0.5dB Meas. Range, (-6.6dB)	19.3	24.3	29.3	34.3	19.3	24.3	29.3	34.3
	98% Noise (-1.56dB)	24.34	29.34	34.34	39.34	24.34	29.34	34.34	39.34
	SNR=1 (RMS) Visual	**25.9**	**30.9**	**35.9**	**40.9**	**25.9**	**30.9**	**35.9**	**40.9**
10000nsec, 240/250km, Low	0.5dB Meas. Range, (-6.6dB)	21.9	26.9	31.9	36.9	21.9	26.9	31.9	36.9
	98% Noise (-1.56dB)	26.94	31.94	36.94	41.94	26.94	31.94	36.94	41.94
	SNR=1 (RMS) Visual	**28.5**	**33.5**	**38.5**	**43.5**	**28.5**	**33.5**	**38.5**	**43.5**
20000nsec, 240/250km, Low	0.5dB Meas. Range, (-6.6dB)	23.4	28.4	33.4	38.4	23.4	28.4	33.4	38.4
	98% Noise (-1.56dB)	28.44	33.44	38.44	43.44	28.44	33.44	38.44	43.44
	SNR=1 (RMS) Visual	**30**	**35**	**40**	**45**	**30**	**35**	**40**	**45**
Index: 1.4677/1.4682		**Optimize for:**		**DZ ~ -2dB**	**optimize DR**	*** reduce Dist. Range to get smoother trace**			

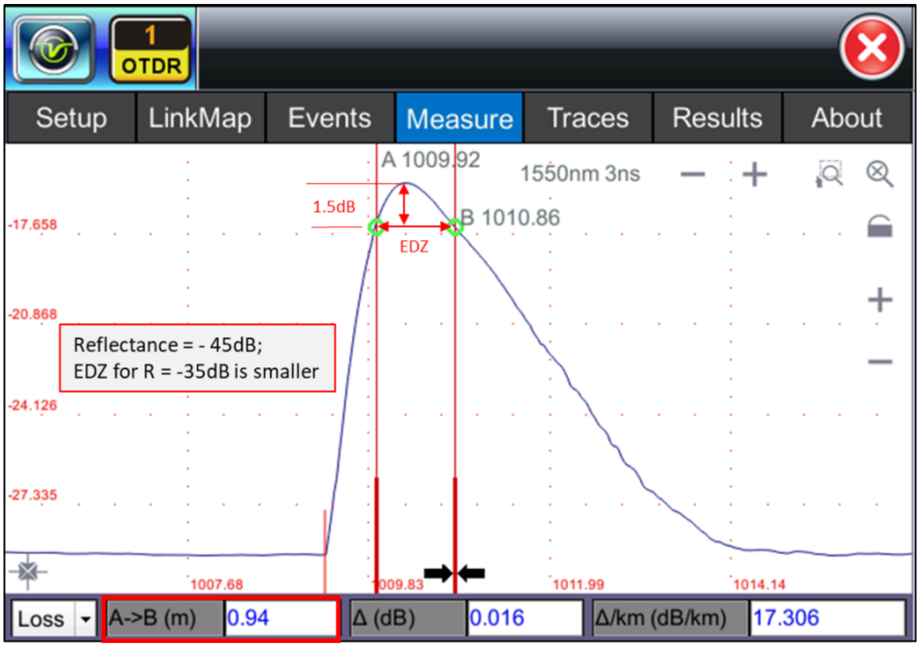
Dead Zones

OTDRs typically require some time (or distance) to recover from events. During this time, the OTDR cannot detect or precisely locate/measure any event on a fiber link. In general, dead zone is measured on a Fresnel reflection (occurs anytime there is glass/air transition) and the subsequent recovery time of the OTDR detector, which is measured in two methods: event dead zone (EDZ) and attenuation dead zone (ADZ). When a strong reflection occurs, the power received by the photodiode can be significantly higher than the backscattered power, which causes the OTDR detector to become saturated with excessive light. The time required to recover from saturation blocks the ability to measure backscatter levels, like what happens to the human eye when exposed to a bright flash of light. Pulse width affects the height of the reflection but does not impact reflectance. For similar pulse width, the higher the reflection the worst the reflectance. Longer pulses are used to increase dynamic range but will also result in longer dead zone. Dead zone measurements are usually performed reflective events with -45 dB reflectance.

When testing PON networks, there is a third type of dead zone, PON dead zone. More splits result in larger dead zone. In addition, larger pulse widths may be required to overcome the higher loss due to more splits.

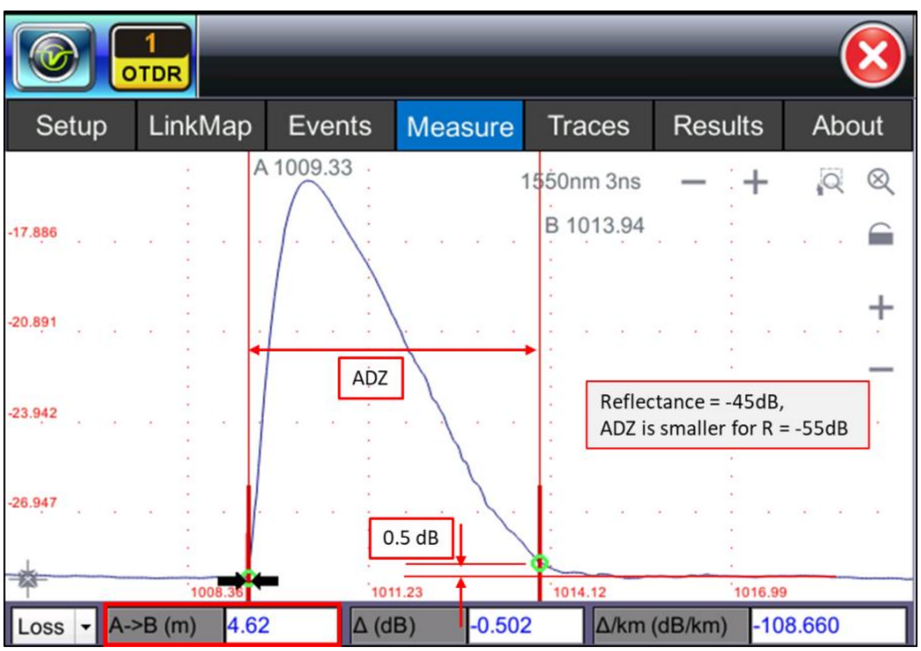
Event Dead Zone

The event dead zone (EDZ) is the minimum distance width 1.5 dB below the top of a reflective event, typically -45 dB. Most OTDRs use a 3 nsec PW but longer pulse widths can be used. When comparing OTDRs, PW and reflectance is required. A -45 dB reflectance will have a smaller EDZ than a -55 dB reflectance and a 3 nsec PW should show a smaller EDZ than a 10 nsec PW.



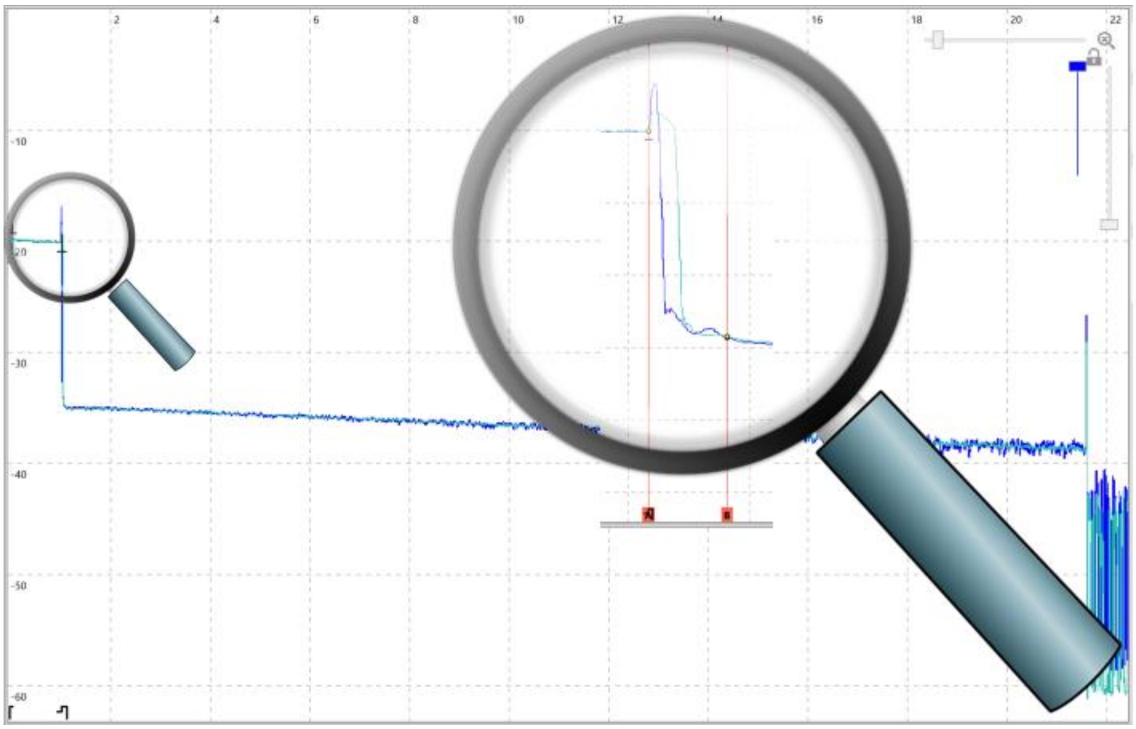
Attenuation Dead Zone

The attenuation dead zone (ADZ) is the minimum distance after a reflection, typically -45 dB, that a non-reflective event can be measured. It is the location where the signal is within 0.5 dB above or below the backscatter prior to the reflective pulse. Most OTDRs use a 3 nsec PW but longer pulse widths can be used. When comparing OTDRs, pulse width and reflectance is required. A -55 dB reflectance will have a smaller ADZ than a -45 dB reflectance. ADZ will always be larger than EDZ.



PON Dead Zone

The PON dead zone (PDZ) is the minimum distance to recover after a -13 dB non-reflective splitter loss (1x16 splitter). This value will change depending on actual test pulse width. The common pulse width used in making this measurement can vary from 25 (navy blue) to 100 nsec (aqua blue). A larger pulse width may be used, however this frequently results in a larger PDZ value as shown in a zoomed in view of the splitter in the image shown below. In addition, PDZ value increases with higher split counts.



A filtered 1625 or 1650 OTDR is required to test an active PON network. A PON network can have one or two splitters (cascade PON). The OTDR is usually connected at the customer site. The fiber plant between the OLT to the ONT is called the ODN. The maximum length cannot exceed 20km or the ODN loss budget of 29dB.

Splitter losses vary with the type of splitter. Balanced splitters can 1xN (N can equal 2, 4, 8 or up to 128 split ratios: 2xN splitters and power evenly distributed resulting in similar insertion loss on all drop fibers. Unbalanced splitters can be 5/95, 10/90, 15/85, 20/80, etc. split ratio so power split accordingly resulting in different insertion loss for each output fiber.

Balanced Splitter			
1xN Type	IL (dB)	2xN Type	IL (dB)
1x2	< 4	2x2	< 4.2
1x4	< 7.3	2x4	< 7.6
1x8	< 10.8	2x8	< 11.2
1x16	< 14.0	2x16	< 14.5
1x32	< 17.0	2x32	< 18.2
1x64	< 21.5	2x64	< 22.0
1x128	< 25		

1x2 Unbalanced Coupler	
Type	IL (dB)
5/95	13/0.23
10/90	10/0.458
20/80	6.99/0.969
30/70	5.229/1.549
40/60	3.979/2.218

How Distance Range and Resolution Affects Averaging Time

Distance Range

The distance range is simply the maximum display range that can be viewed on the screen. The distance range value should be set 20-25% longer than the actual test fiber resulting a user being able to view the entire fiber trace signature from start to the end followed by the noise floor. The distance range setting can influence distance accuracy, resolution, pulse width, resolution and test time (i.e. noise reduction).

The OTDR sends out one test pulse at a time and routinely measures any return signal at regularly spaced intervals of time (resolution) until all of the pulse return signals have been returned to the detector. The distance range determines the rate at which test pulses are sent out. This process is repeated over and over until the measurement time is completed. The noise floor is also measured between each test pulse. This is known as the pulse repetition rate (PRR). The faster the rate, the shorter the averaging time required to obtain noise improvement in trace (number of averages). A longer fiber requires longer pulse transit times, so the overall test time required to get the same averaging will be longer. The same can be true when testing a short fiber with high resolution as interlacing of multiple pulses may be required to get the higher resolution.

When a test fiber is measured using a distance range shorter than the actual fiber length, there is a possibility that the next test pulse will be sent into the fiber before all the return signals from the previous pulse is received by the OTDR detector. In this situation, the resultant signals can produce abnormal appearance or non-linearity in the trace displayed on the screen. It could also produce “ghosts” in the fiber trace, but this phenomenon is rare.

Resolution

Measurement resolution is the space between measurement data points. Resolution value can be manually selected by users if desired but can also be applied automatically by the OTDR. High resolutions (closer data points) will provide improved visibility/detail of events on a fiber, but high-resolution tests need longer test time than one made using low resolution to get same # of averages. The best resolution offered by an OTDR can be 3 cm (about 1.18 inches) between data points. The lowest resolution can be 16 meters (about 52.5 feet).

Resolution can be affected by the maximum number of data points that an OTDR can support. Higher resolution provides improved location accuracy of an event. If an OTDR takes measurements every 16 meters along a fiber, it is possible that a break could occur within 15 meters after the data point. The break on the trace would appear to begin at the data point 15 meters before the actual break since distance to a break is always located at the last backscatter point before an event. The actual location of the break (reflection) would then be off by 15 meters, or ~ 50 feet.

For example, if an OTDR distance range is 250,000 data points and the maximum datapoint is 256,000, then the highest resolution is 1 meter or ~3.3 feet. However, if the maximum data point is 500,000 then the highest resolution will improve to 0.5 meter or 1.64 feet.

Resolution should not be confused with cursor resolution or display resolution since cursor resolution is how short of a distance the cursor can be moved on the screen. Most cursor movement can be placed between data points and appear to offer a better resolution.

Index of Refraction

Index of refraction (IOR) is the ratio of the speed of light (299,792,458 meters per second) moving in a vacuum compared to the speed of light moving through a specific fiber type. Since light moves fastest in a vacuum (outer space), and slower in denser materials such as glass, this ratio is always greater than one (1). For fiber optic glass, the IOR ratio is typically 1.4 to 1.5. Light speed will change depending on the density of the material it is travelling through. Fiber density is determined by the amount and type of dopants used in the manufacturing process for a particular fiber type/model, but the added dopants may not be uniformly distributed throughout the entire fiber length and most certainly between different fiber cables, so it is not uncommon to see there are IOR variations between fibers and within the same fiber cable. IOR is a setting or "calibration" factor that tells the OTDR how fast the light should be travelling so it can make accurate distance measurements. The table below lists IOR values for many Corning type fibers that are currently available, but a user should always check with their fiber cable manufacturer regarding IOR values for each wavelength that that will be tested as changes in the fiber manufacturing processes can change the IOR values.

	λ	IOR
Corning SMF-28 Ultra/Ultra 200	1310	1.4676
	1550	1.4682
Corning SMF-28 ULL	1285-1330/1310	1.4606
	1525-1575/1550	1.462
Corning TXF	1525-1575/1550	1.4655
	1550-1625/1625	1.4655
Corning SMF-28e Ultra	1310	1.4676
	1550	1.4682
	1625	1.4685
Corning SMF-28e+	1310	1.4674
	1550	1.4579
Corning SMF-28e+ LL	1310	1.4676
	1550	1.4682
Corning ClearCurve ZBL	1310	1.467
	1550	1.4677
Corning ClearCurve LBL	1310	1.467
	1550	1.4677
Corning LEAF	1310	1.464
	1525-1575/1550	1.4693
	1550-1625/1625	1.4683
Corning InfiniCor OM1 62.5µm	850	1.496
	1300	1.491
Corning ClearCurve OM2/OM3/OM4	850	1.482
	1300	1.477
Corning ClearCurve OM5	850	1.482
	1300	1.477

Distance Accuracy

There are four components to distance accuracy in an OTDR:

1. Clock accuracy
2. Data point spacing (resolution)
3. Zero km trigger
4. Index of Refraction (IOR) uncertainty

The accuracy of distance measurements depends on the stability and accuracy of the clock circuitry which monitors the time every pulse is triggered and the interval between recording measurements of light returning to the receiver. Clock accuracy is stated as a percentage, which relates to the percentage of distance measured.

Assume we measure a 100 km fiber with an OTDR that has a distance accuracy of ± (0.5 + resolution + $5x10^{-5}$ x L). The clock accuracy of $5x10^{-5}$ % of distance means that if the reported end of fiber length can vary as much as 5 meters due to the clock (100 km x 0.00005) from the actual length. Resolution also affects accuracy; the more datapoints an OTDR can capture over a fixed length, the more accurate the reported distance measurement can be. Zero km trigger is the accuracy of the OTDR to identify zero km regardless of wavelength, pulse, resolution, and initial connector reflectance. Reflective initial connectors tend to provide more consistent zero km value than high quality APC with -70 dBm reflectance. OTDRs that incorporate internal launch fibers will provide greater consistency in zero km detection. For example, an OTDR with 500,000 data points will have greater distance accuracy than an OTDR with 128,000 data points, especially measuring the same long fiber. The closer the data points are spaced, the more likely one of them will fall on or close to a REAL fault in the fiber.

Distance in an OTDR is calculated using the speed of light in the fiber, and the speed of light in fiber is calculated from the speed of light in free space (a constant value) divided by the IOR. This means that the IOR setting is critical in accurate measurement of distance. If the wrong IOR is used in a measurement, then the reported distance can exceed the distance accuracy. Because we know that the characteristics of a fiber can change slightly along its length, there can be additional distance inaccuracies even when using the correct manufacturer recommended IOR. This “fiber uncertainty” is due to the variance of IOR within the same fiber and between two or more fibers spliced together. The worst case for IOR variation is when two different manufacturers’ fibers are spliced together. So, the accuracy for measuring a 100 km fiber tested with 16m sampling will be ±21.5m plus any inaccuracy due to IOR variations.

Measurement Time vs. Averaging

Measurement time is often, erroneously confused with trace averaging. Measurement time is the test used to capture data given a specific wavelength and pulse as defined by the user or automatically by the OTDR. Averaging is required to get a noisy (fuzzy) trace into a smooth, cleaner-looking trace. The actual measurement time needed to achieve a specific amount of averaging can vary depending on available dynamic range as well as distance range, pulse width and sampling resolution. OTDRs send out lots of test pulses every second. Every pulse provides a set amount of data points that is averaged together with subsequent pulse results which results in a final set of datapoints to present a cleaner trace with improved signal-to-noise ratio (SNR).

Averaging takes time. Usually, a lot of averaging is required when a long fiber is being tested and when a short pulse width is being used. The same is true when users desire the highest resolution (optimized DZ) test modes. At times, users are looking to get rapid test results during construction, cable reel acceptance or service activation. In these situations, Real-time test mode can be used but users should ensure span loss is acquired using 2-Pt LSA settings to normalize loses across the span as opposed to point-to-point change.

Notes

About VeEX Inc.

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The VeEX team brings simplicity to verifying tomorrow's networks.