Fiber Optics Demystified
OTDR Fundamentals

Apr-2024

Part 2

April 23rd, 2024, 2pm EST

“From Glitches to Glory: OTDR Problem-Solving Strategies”

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OTDR Basics – Presentation Outline

Characteristics of Fiber Optic Networks

- Attenuation (Loss)
- Reflections (Reflectance & ORL)
- Rayleigh Scattering & Fresnel Reflections
- Wavelength-dependent fiber loss
- Bend-dependent fiber loss
- Connectors & Splices

OTDR Overview

- OTDR Theory of Operation
- Why Use an OTDR?
- When & Where to Use an OTDR?

OTDR Test Settings & OTDR Performance

- Dynamic Range & Dead Zone
- Automatic, Expert & Real-time Test Modes
- Range, Pulse Width, Averaging Time

Interpreting an OTDR Trace

- Trace Overview – Reflection & Loss vs. Distance
- Link Length, Loss & ORL
- Event Location, Loss & Reflectance
- UPC & APC Connectors
- Fusion & Mechanical Splices
- Macro-bends & Micro-bends
- Splitters

Interpreting OTDR LinkMap & Event Table

- Understanding the Icons
- Pass/Fail Analysis

Saving, Downloading & Reporting Results

- OTDR File Formats
- Report Generation Software

Fiber Optic Network Characteristics

Key Factors Affecting Fiber Optic Network Performance

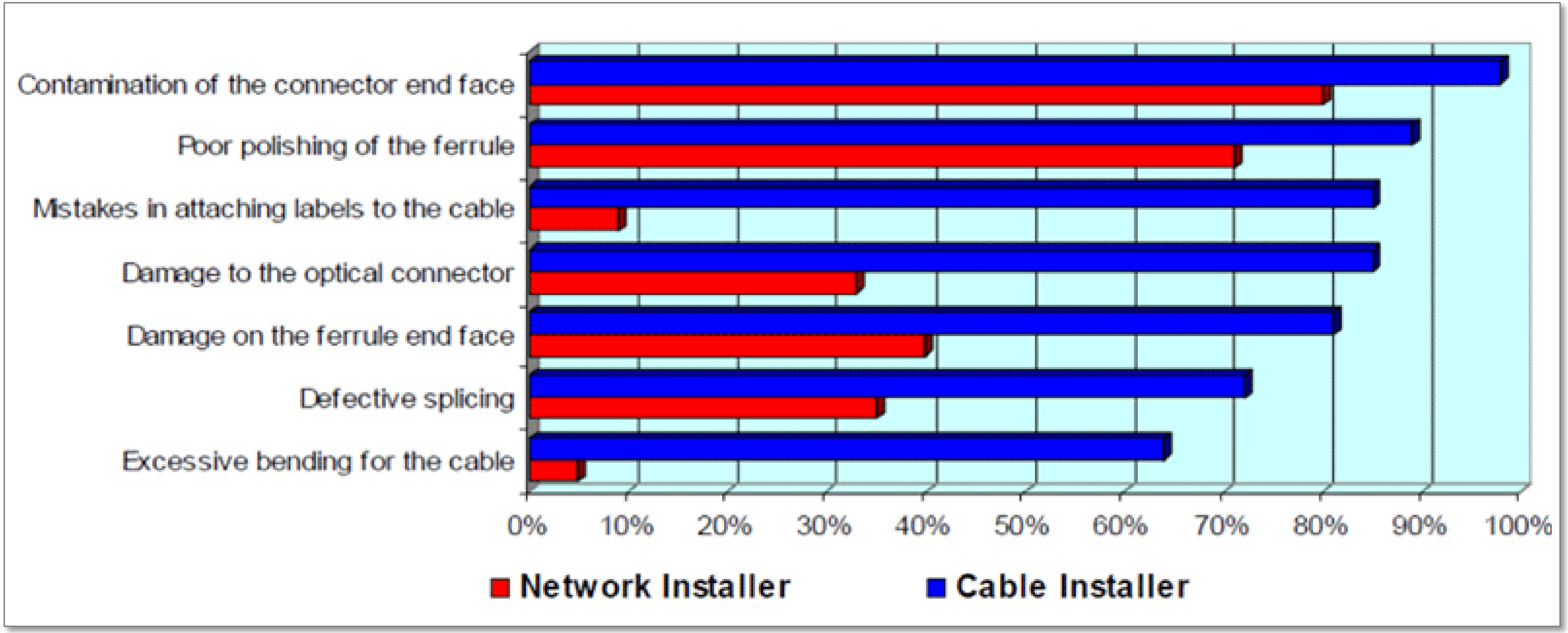
- What are **Key Optical Network Factors** affecting fiber optic system performance?
  - **RX Power Level / Optical Loss** through the network
  - **Reflections** in the network
  - Chromatic Dispersion / Polarization Mode Dispersion (**CD/PMD**)

- How do low power, excess loss, reflection and dispersion impact performance?
  - Optical System performance degrades
    - Bit Error Rate increases
    - Packet loss & retransmission increases in packet-based networks (IP, Ethernet)
  - Communication fails (signal lost) when RX power too low (too much optical loss)

- What to do when system performance degrades or fails?
  - Check System Power Levels
    - Check TX Power Level – If absent or too low, replace optical TX
    - Check RX Power Level – If absent or too low and TX power OK, check for excess loss in optical network
  - If RX Power OK, check for excess reflections in optical network
  - If no excess reflections, possibly check CD/PMD (for networks operating at 10 Gb/s or higher)

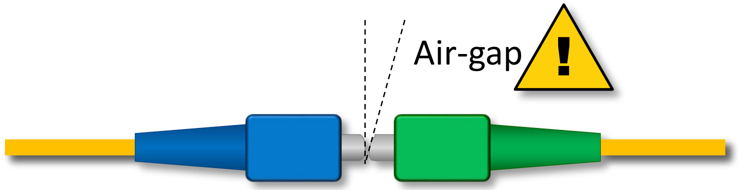
Primary Causes of Optical Network Failures

Poor connections & splices are the primary causes of optical network failures



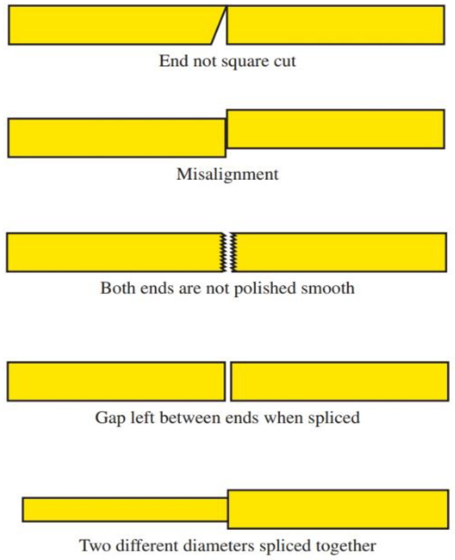
Source: NTT Advanced Technology

Causes of Optical Loss in Fiber Networks



- **Dirty, Damaged, or Mismatched Connectors**
  - Always clean connectors before mating
  - Never mate PC (blue) to Angled PC (APC; green)
  - Fully seat connectors in bulkhead adapters
  - Replace damaged connectors with factory-polished connectors

- **Poor Splices**
  - Strip, clean, cleave in that order
  - Clean and maintain fusion splicer
  - Rotate cleaver blade when worn
  - Core alignment machines produce better splices than cladding alignment

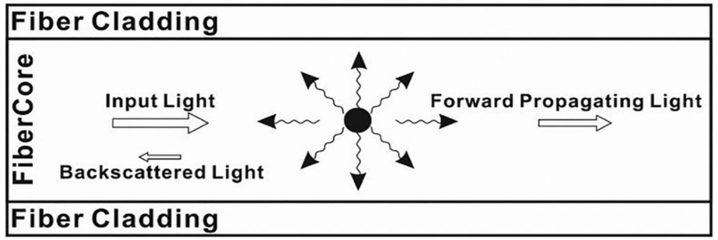


- **Fiber Breaks**
  - "Backhoe fade"
  - Rodents
  - Maintenance activity / unintended disconnect

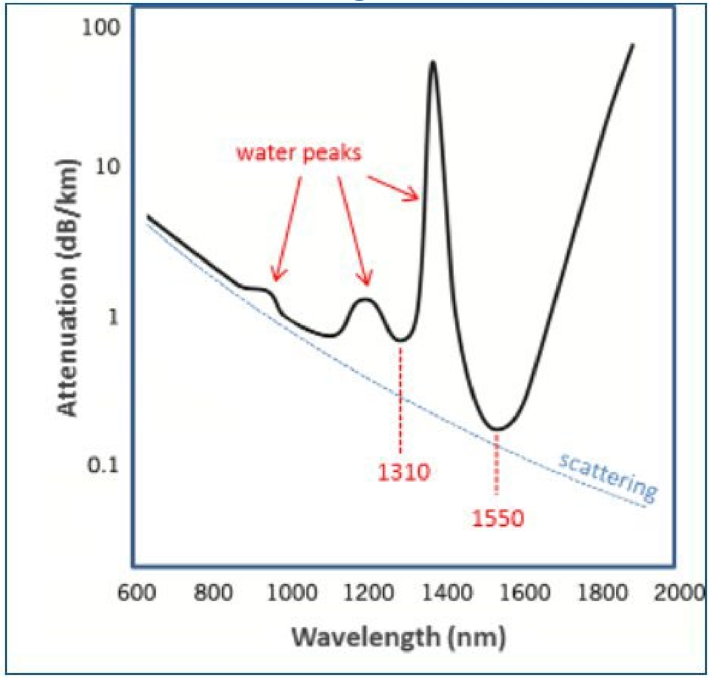
Causes of Optical Loss in Fiber Networks (cont.)

- Fiber loss due to **Rayleigh Scattering**
  - Primary source of loss along the full length of the fiber
  - Loss/distance (dB/km) is higher at 1310 than 1550 nm
  - Captured backscattered light is used by OTDR to measure loss
- Fiber loss due to **Micro-bends** or **Macro-bends**
  - Micro-bends: Due to cabling, pulling or environmental stress
  - Macro-bends: Due to tight bends typically in cabinets & closures
  - Bending loss increases at longer wavelengths
  - Tighter bends create higher loss

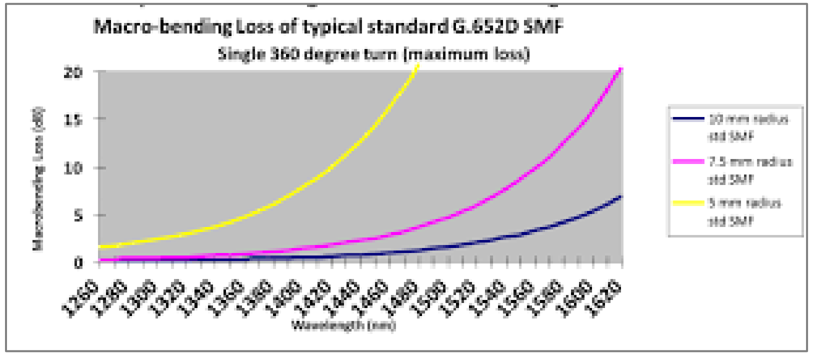
Rayleigh Scattering

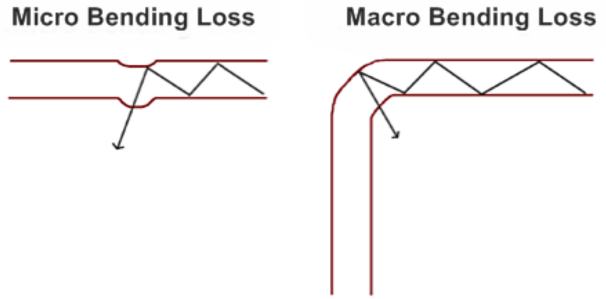


Fiber Loss vs. Wavelength



Bending Loss vs. Wavelength & Bend Radius

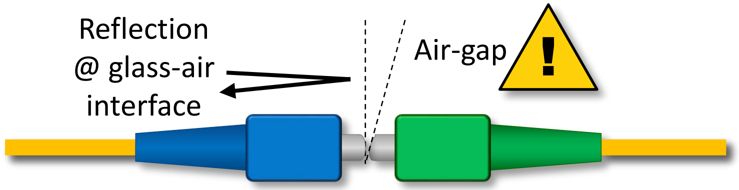




Reflections in Optical Networks

- **Fresnel Reflections** occur due to mismatch in Group Index-of-Refraction (GIR or IOR)
  - Glass and air have different index of refraction
  - Difference in IOR results in 4% reflection at glass-air interface
  - Slight IOR mismatch between polished & unpolished glass causes small reflection at mated connectors
  - Reflections from open PC connectors are guided back up the fiber
  - APC connectors prevent reflections from being guided back up the fiber

- Multiple reflections degrade optical system performance
  - Impact of reflections is more serious at higher data rates



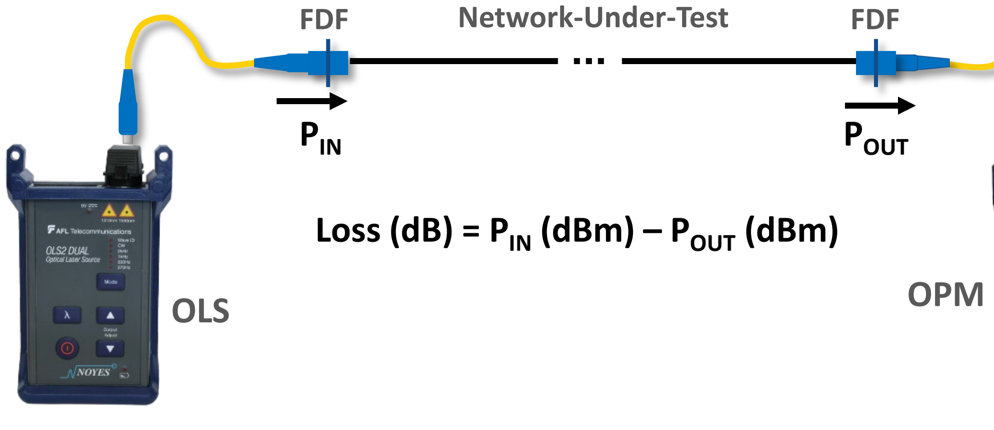
- Preventing reflections
  - Inspect and clean connectors before mating
  - Never mate PC or UPC (blue) to APC (green) connectors
  - Terminate fibers with factory-polished connectors
    - If field-polishing, ensure epoxy is cleaned & polished off connector end-face
    - Don't over-polish as this may dimple fiber core creating an air gap

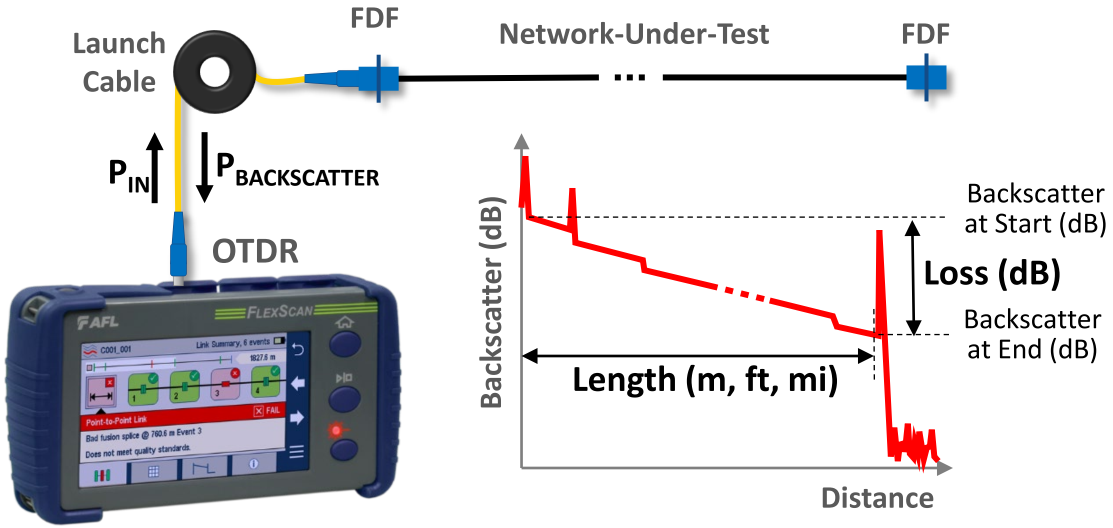
FUSEConnect®

FASTConnect®

Measuring End-to-end Length & Insertion Loss

- Sum of *all* losses through the network
- Most accurately measured using **Optical Source (OLS)** and **Optical Power Meter (OPM)**
  - ☑ Simple, fast, pass/fail test (loss is OK, or loss exceeds loss budget)
  - ☒ Cannot identify or locate sources of excess loss or reflection
  - ☒ Requires two people, one at each end of the network
- Can be measured nearly as accurately using an **OTDR**
  - ☑ Can be completed by one person at one end of the network
  - ☑ Can identify and locate sources of excess loss & reflections
  - ☒ Requires more skilled technician



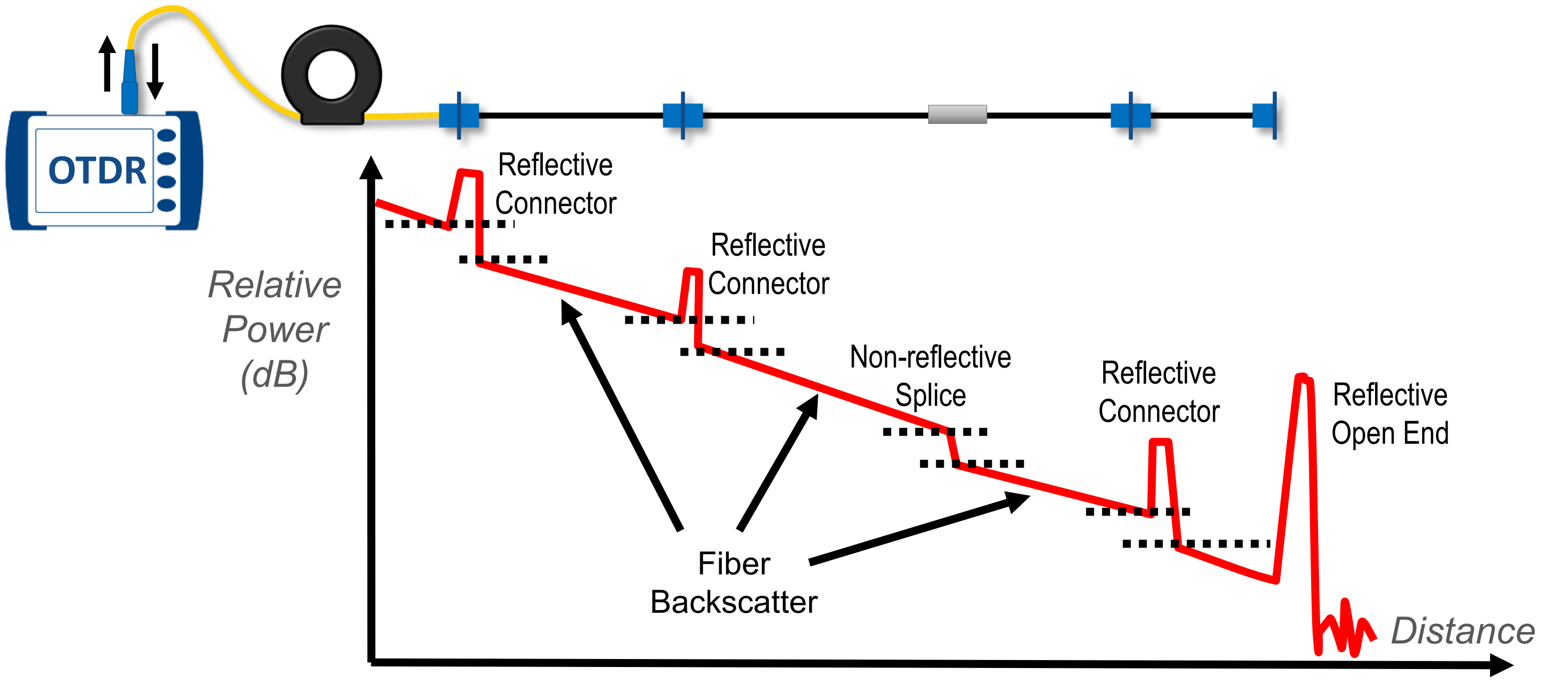


OTDR Overview

OTDR Theory of Operation

An OTDR is a one-dimensional optical radar

- Injects pulses of light, measures amplitude & time-of-flight of backscatter & reflections guided back up fiber
- Converts time-of-flight into distance based on speed of light in glass
- Plots returned signal level vs. distance
- Can measure loss of fiber sections, loss & reflectance of connections, splices, macrobends or breaks.

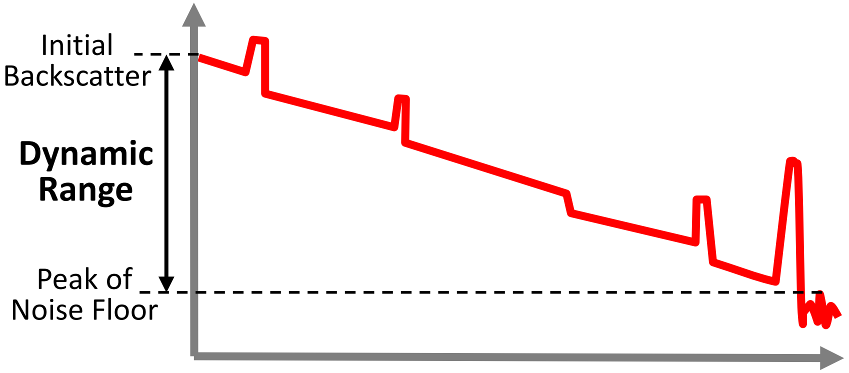


- ☑ Single-ended test
- ☑ Identifies and locates sources of excess loss and reflection
- ☒ More expensive test set
- ☒ More user skill required
- ☒ Loss meas less accurate

OTDR Dynamic Range & Dead Zone

What is **Dynamic Range**?

- **Dynamic Range** = Difference in dB between initial backscatter and peak of noise floor
- Dynamic Range depends on Pulse Width & Averaging Time
  - Wider pulse width increases dynamic range
  - Longer averaging time increases dynamic range
- **Loss Measurement Range** ≈ Dynamic Range – 6 dB
- **Distance Measurement Range** ≈ Loss Meas Range / 0.5 dB/km
  - Assuming no faults and no PON splitters



What is **Dead Zone**?

- **Event Dead Zone** – How close two reflective events can be and still be visually detected
- **Attenuation Dead Zone** – How closely small non-reflective event can be detected following a reflection
- Dead Zones depend on Pulse Width
  - Width of spike in OTDR trace due to a reflection is ≥ pulse width
  - Wider pulse width increases dead zone
  - Wider pulse width reduces ability to independently detect closely-spaced connectors & splices

OTDR Test Settings & Performance

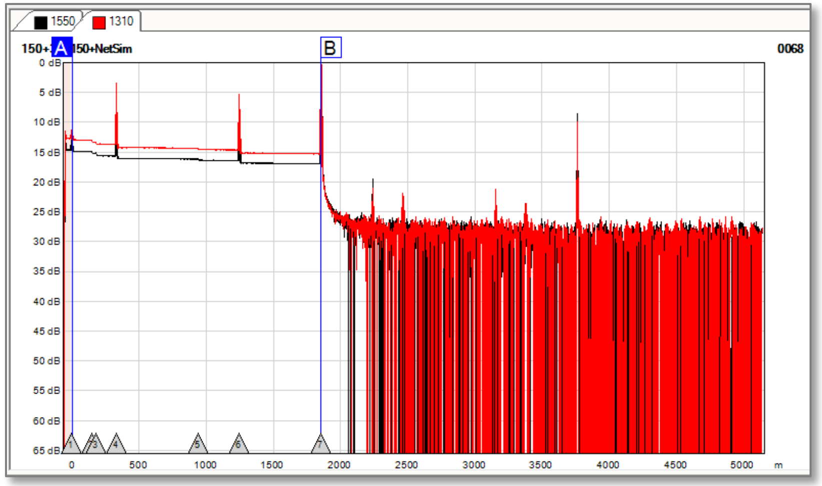
OTDR Test Modes

- **Automatic Mode** -- OTDR automatically sets Range, Pulse Width(s), and Averaging Time
  - ☑ Prevents users from selecting inappropriate settings
  - ☑ Typically completes test at both 1310 & 1550 nm wavelengths
  - ☑ Newer OTDRs complete automatic tests using both narrow, medium and wide pulse widths
  - ☒ May not be able to test short range on long fiber
  - ☒ May take longer to test short fibers
- **Expert Mode** – User manually sets Wavelengths, Range, Pulse Width & Averaging Time
  - ☑ User can tailor settings for best performance on a specific region of the fiber
  - ☑ User can reduce test time (e.g., test using a single wider pulse width, but shorter averaging time)
  - ☒ Poor test settings produce poor results (missed end, missed events) and may confuse user
  - ☒ Testing at a single wavelength will not detect macro-bends
- **Real-time Mode** – Real-time trace updates with little averaging
  - ☑ Allows OTDR user to verify fiber-under-test is the fiber a user in field is working on
  - ☑ Allows OTDR user to determine when mechanical splice is optimized for minimum loss & reflection
  - ☒ Doesn’t detect & evaluate events; Doesn’t save results

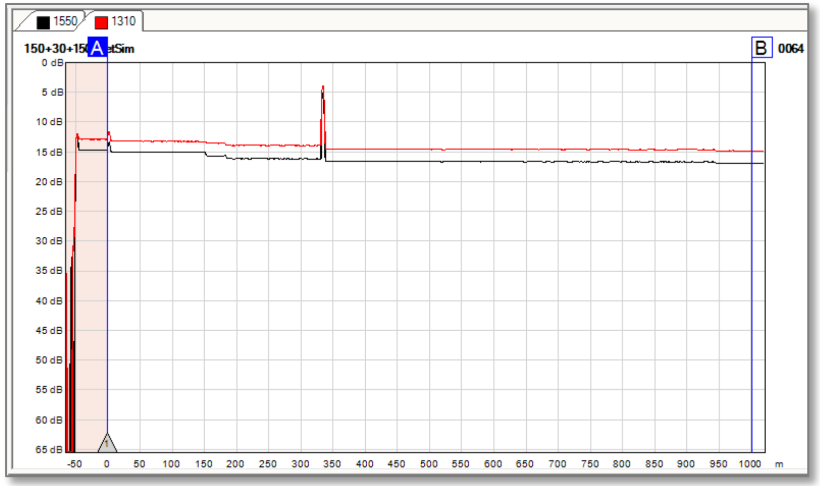
Expert & Real-time Range Selection

- Range too long
  - ☑ End & events found
  - ☒ Trace compressed at start
  - ☒ Lower resolution since data-spacing may be increased
  - ☒ Dynamic Range reduced since #pulses reduced for a given averaging time
- Range too short
  - ☑ Can use with shorter pulse widths to detect closely-spaced events near start of fiber
  - ☒ Misses the end of the fiber and events beyond test range
  - ☒ May alias reflections beyond end of test range into trace for selected range

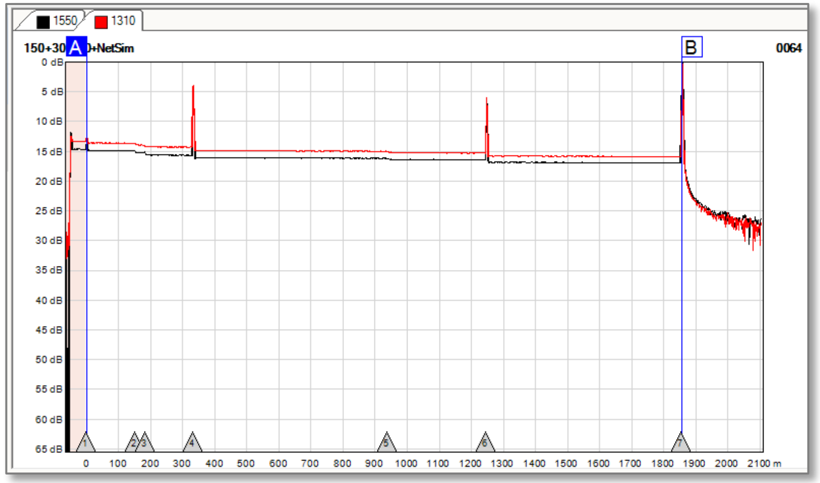
Range Too Long



Range Too Short (End not found)



Range Just Right (End & all events found)

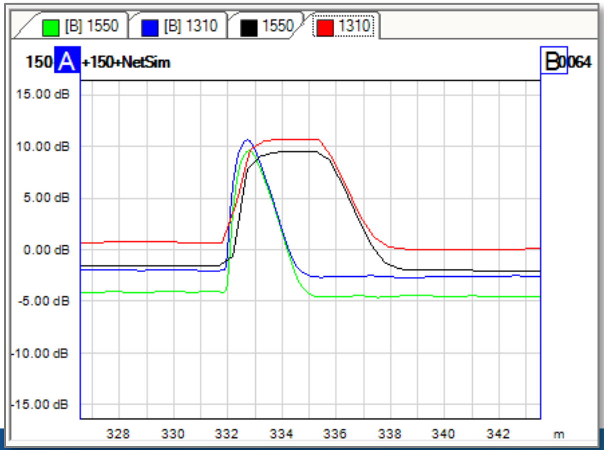


Manual Mode Pulse Width Selection

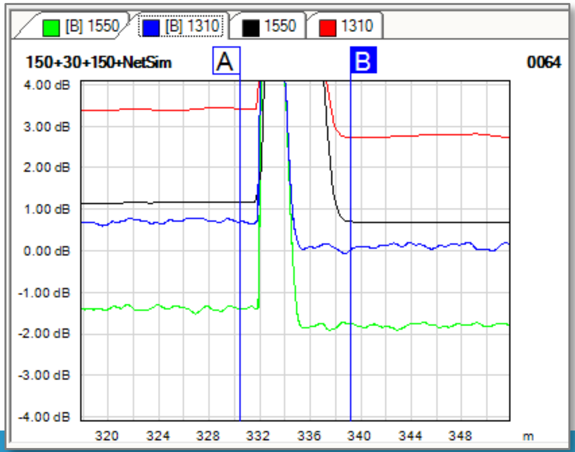
Pulse Width and Dead Zone:
- Round-trip speed of light in fiber ≈10 ns/m
- Dead zone from 10 ns pulse ≥1 m of fiber

Pulse Width	Pulse Dead Zone	
5 ns	> 0.5 m	> 1.6 ft
10 ns	> 1 m	> 3.3 ft
50 ns	> 5 m	> 16.4 ft
100 ns	> 10 m	> 32.8 ft
500 ns	> 50 m	> 164 ft
1 µs	> 100 m	> 328 ft
10 µs	> 1000 m	> 3,280 ft
20 µs	> 2000 m	> 6,560 ft

- Narrow pulses reduce dead zone
  - ☑ Prevents closely-spaced events from overlapping
  - ☑ Allows closely-spaced events to be independently detected and measure
  - ☒ Reduces backscatter level, reducing measurement range
- Wider pulses increase dynamic range
  - ☑ Raises backscatter level, increasing measurement range
    - Allows end and events to be found on longer fibers
    - Doubling Pulse Width improves DR by ≈1.5 dB (more accurate measurements)
  - ☒ Causes closely-spaced events to overlap, preventing independent event detection & measurement



30 ns vs. 5 ns Pulse:
- ☒ 30 ns increases dead zone
- ☒ 2 events 3m (10 ft) apart will overlap using 30 ns
- ☑ 2 events 3m (10 ft) apart will be detected using 5 ns



30 ns vs. 5 ns Pulse:
- ☑ 30 ns reduces noise
- ☑ Detects smaller events
- ☑ Tests longer fibers
- ☑ More reliably measures event loss

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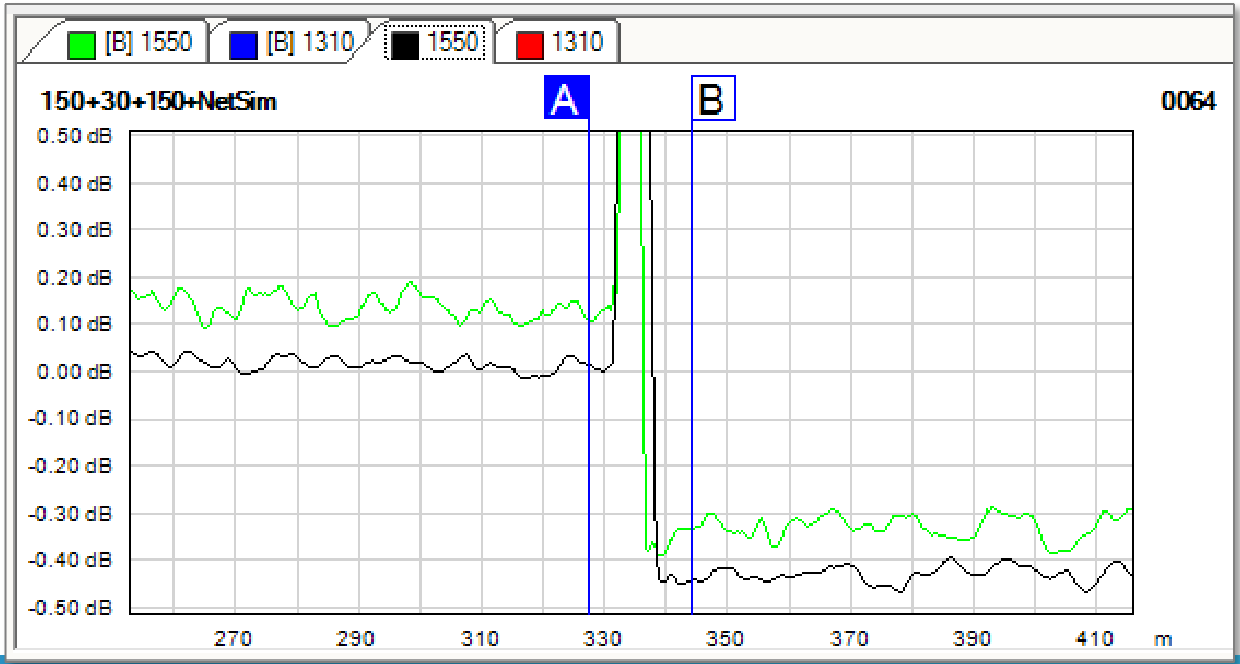
Manual Mode Averaging Time Selection

- Short Averaging Time produces noisy traces
  - ☑ Shorter test time
  - ☒ Less reliable event detection
  - ☒ Less accurate measurements
- Increasing Averaging Time reduces noise in traces
  - ☑ More reliable event detection, especially on longer fibers
  - ☑ More accurate measurements
  - ☒ Longer test time
  - ☒ Diminishing returns
    - Doubling Avg Time improves DR 0.75 dB

- 5 sec Avg Time
- 30 sec Avg Time



Using and Configuring Launch and Receive Cables

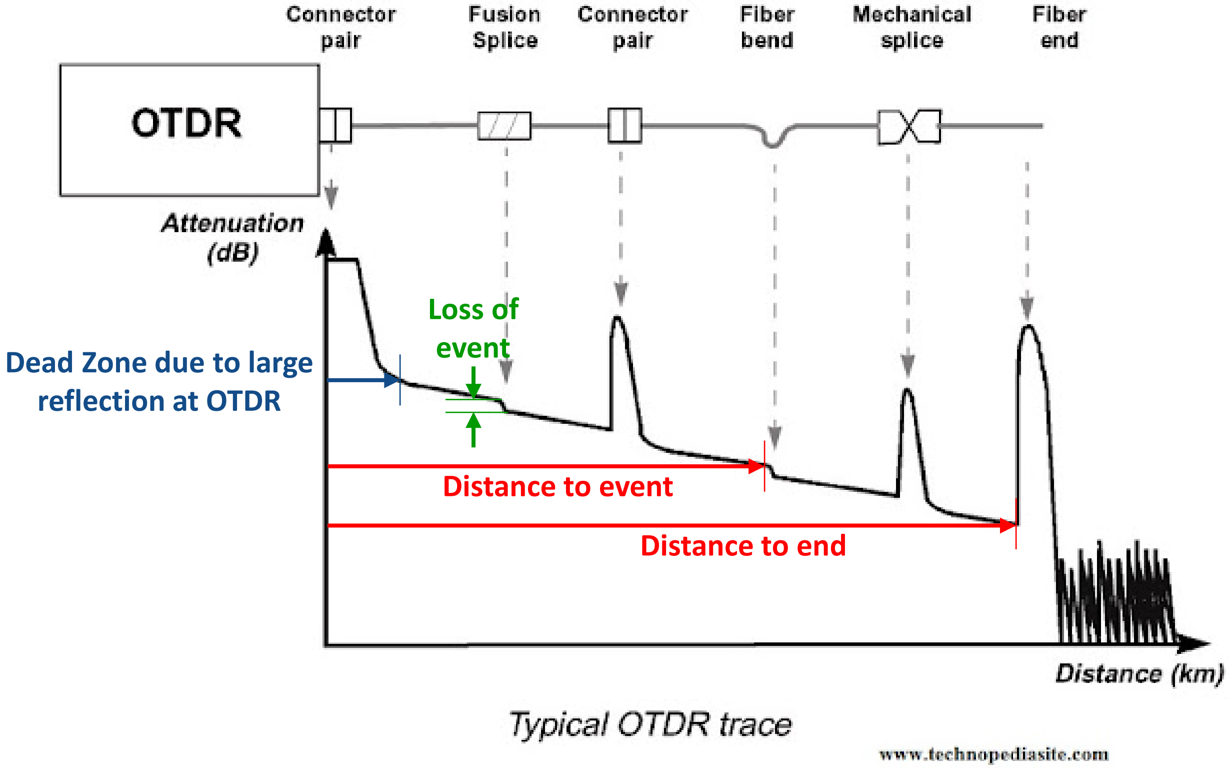
- Why use a **Launch Cable**?
  - Launch cable separates OTDR connection from connection to network-under-test
  - Moves network-under-test connection beyond dead-zone due to OTDR connection
  - ☑ Allows loss & reflection of connection to network-under-test to be measured
  - ☒ If short jumper used to connect OTDR to network, first connector will be in OTDR’s dead zone
  - ☒ If launch cable shorter than OTDR test pulse width, first connector will be in OTDR’s dead zone
- Why use a **Receive Cable** (aka **Tail Cord**)?
  - Loss of open connection at far end cannot be measured
  - Receive cable adds fiber beyond far-end connector
  - ☑ Allows loss & reflectance of far-end connection to be measured
  - ☒ If receive cable too short, receive cable end will be in dead-zone of connection to receive cable
  - ☒ Drawback: Requires technician at far-end to connect receive cable
- Configuring Length of Launch & Receive cables
  - Launch cable length should be 3-5 x short pulse widths (≤ 100 ns); 1.5 – 2 x longer pulse widths
  - Configure OTDR for length of connected launch and receive cables
    - If unsure of launch cable length, connect launch cable and run OTDR test to measure its length
  - OTDR 0.0 distance at launch cable connection to network-under-test
  - ☒ Misconfigured launch or receive cable lengths will result in incorrect length & location measurements

150m (492 ft)
Launch Cable

Interpreting OTDR Trace, LinkMap & Event Table

Interpreting the OTDR Trace

- OTDR Trace plots Loss (Attenuation) vs. Distance
- Make manual loss & distance measurements using A&B cursors
- Spikes at reflective connectors & mechanical splices
- Small drop at non-reflective splices and APC connectors
- Large spike at poor connectors & open ends



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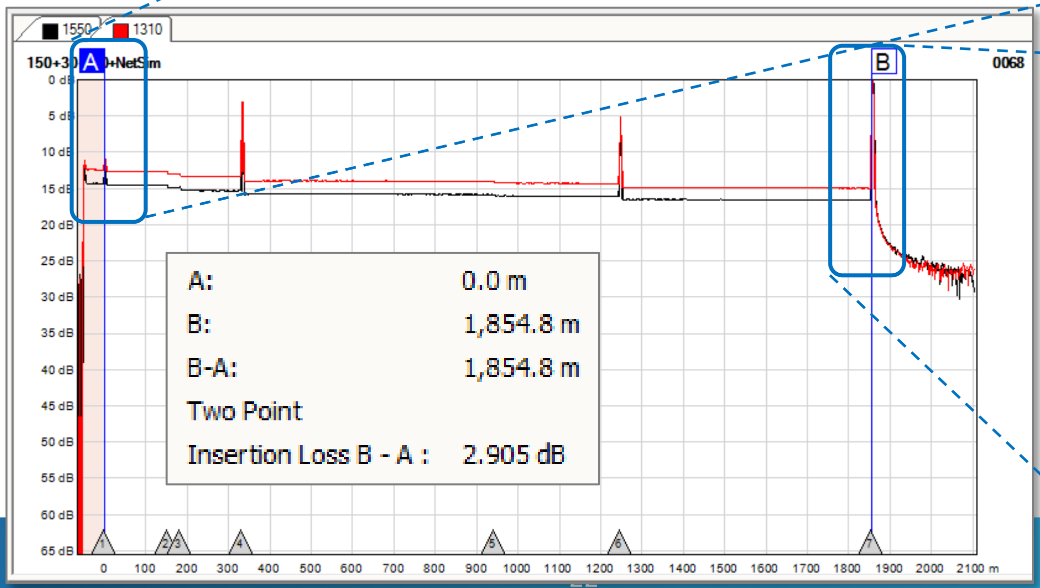
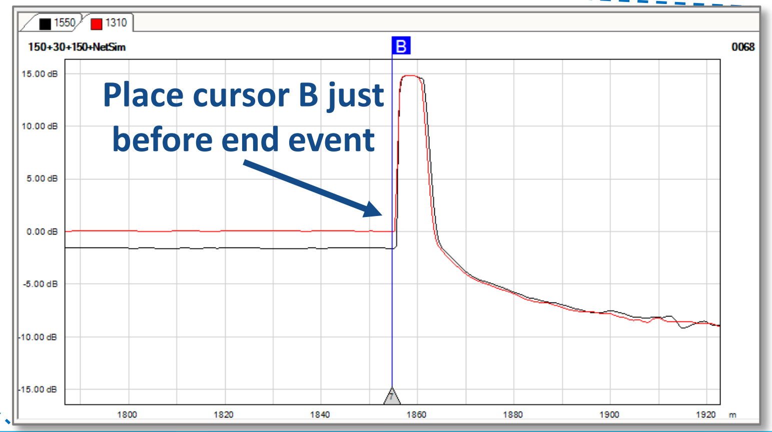
Measuring End-to-End Length & Loss using the OTDR Trace

Where to place A & B cursors?

- Place **Cursor A** on left (beginning) edge of **Start** event
  - If launch cord used, place cursor A at launch cable connection to network
  - Loss measurement will include loss of connection to network
  - Zoom in on trace for more accurate cursor placement
- Place **Cursor B** on left (beginning) edge of **End** event
  - Loss measurement will not include loss of last connector
  - If tail cord used, place cursor B after receive cable connection to include loss of last connector in end-to-end loss measurement





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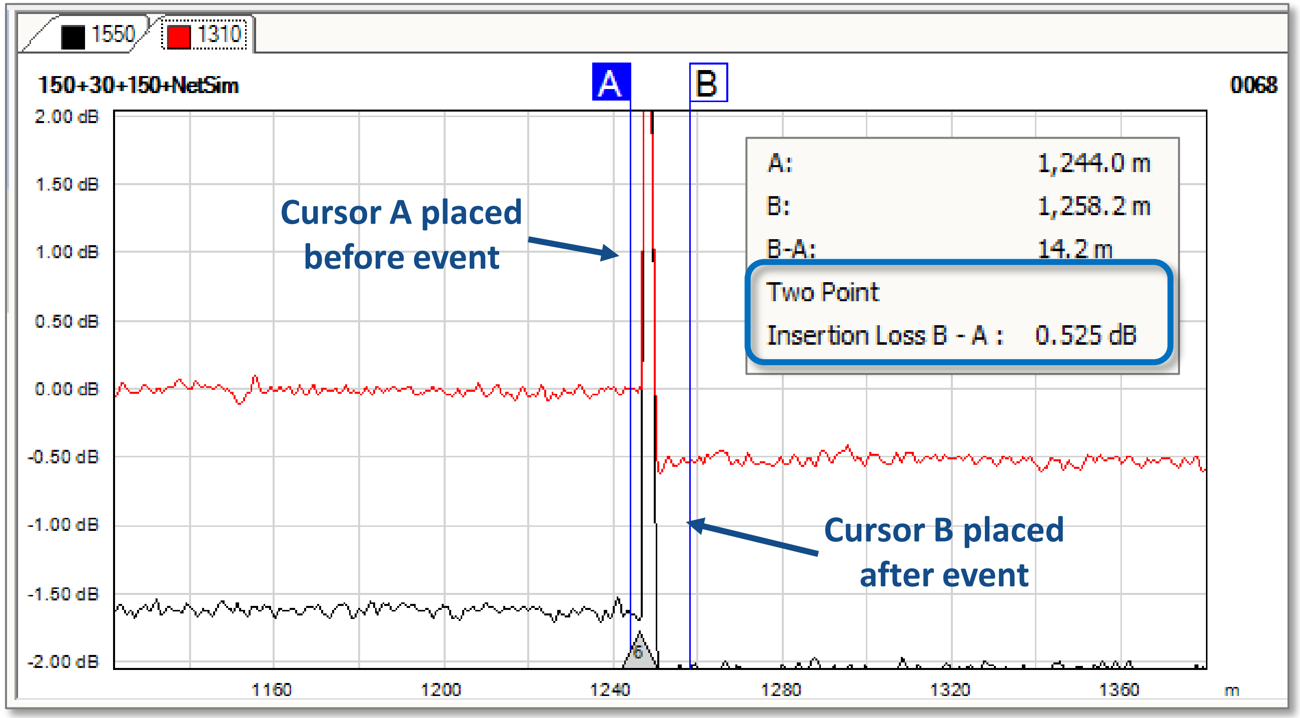
Measuring Splice & Connector Loss using OTDR Trace

Two-point loss measurements

- Place the **Cursor A** on backscatter at **event start** – not on rising edge of reflective events
- Place the **Cursor B** on backscatter **after the event** at earliest point where trace returns to backscatter level
- **Event Location** corresponds with start of the event (cursor A location)
- **Event Loss** is the difference between backscatter level at A and B cursor locations

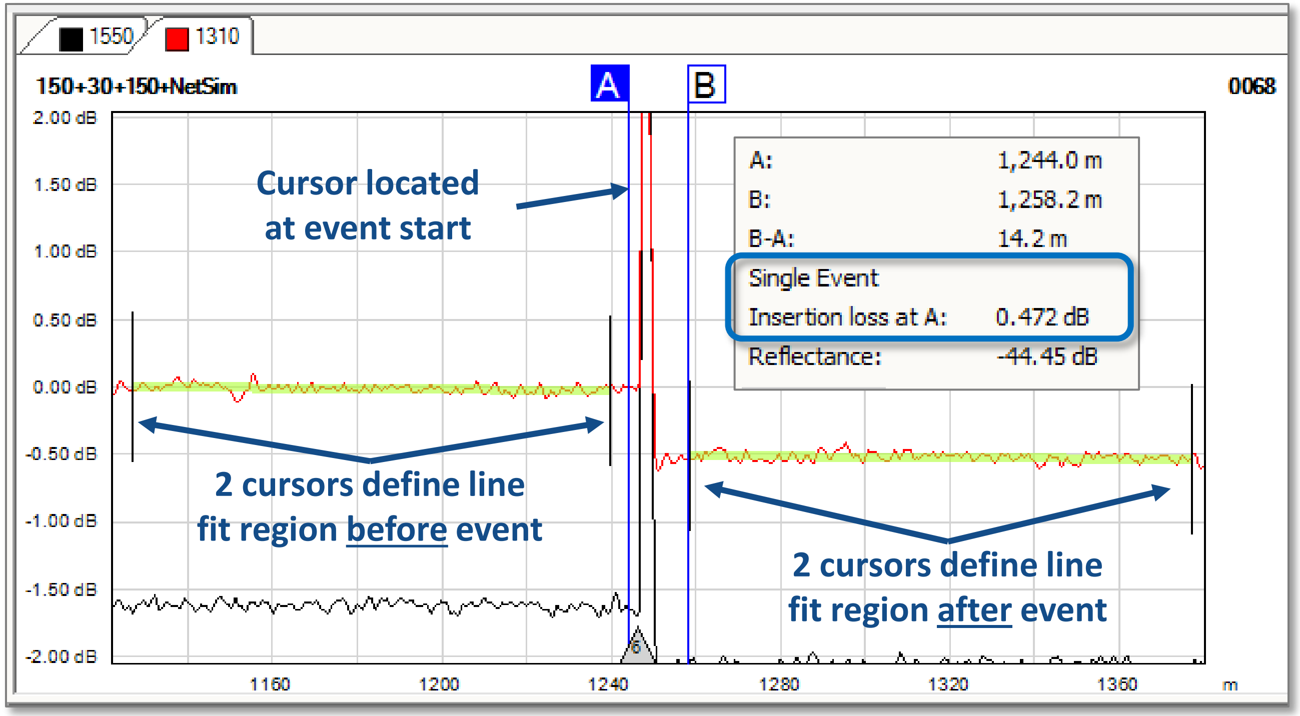


- ☑ Fast, easy manual loss measurement method
- ☒ Measurement error possible due to noise or wide pulse width (includes fiber loss between cursors)

Measuring Splice & Connector Loss using OTDR Trace

LSA line fit loss measurements (5-cursor method)

- Place first two cursors on event-free backscatter preceding the event – wider spacing is better
- Place 3rd cursor at the start of the event
- Place the last two cursors on event-free backscatter following the event – wider spacing is better
- Loss computed by OTDR by projecting line fits to event start and measuring difference in projected lines



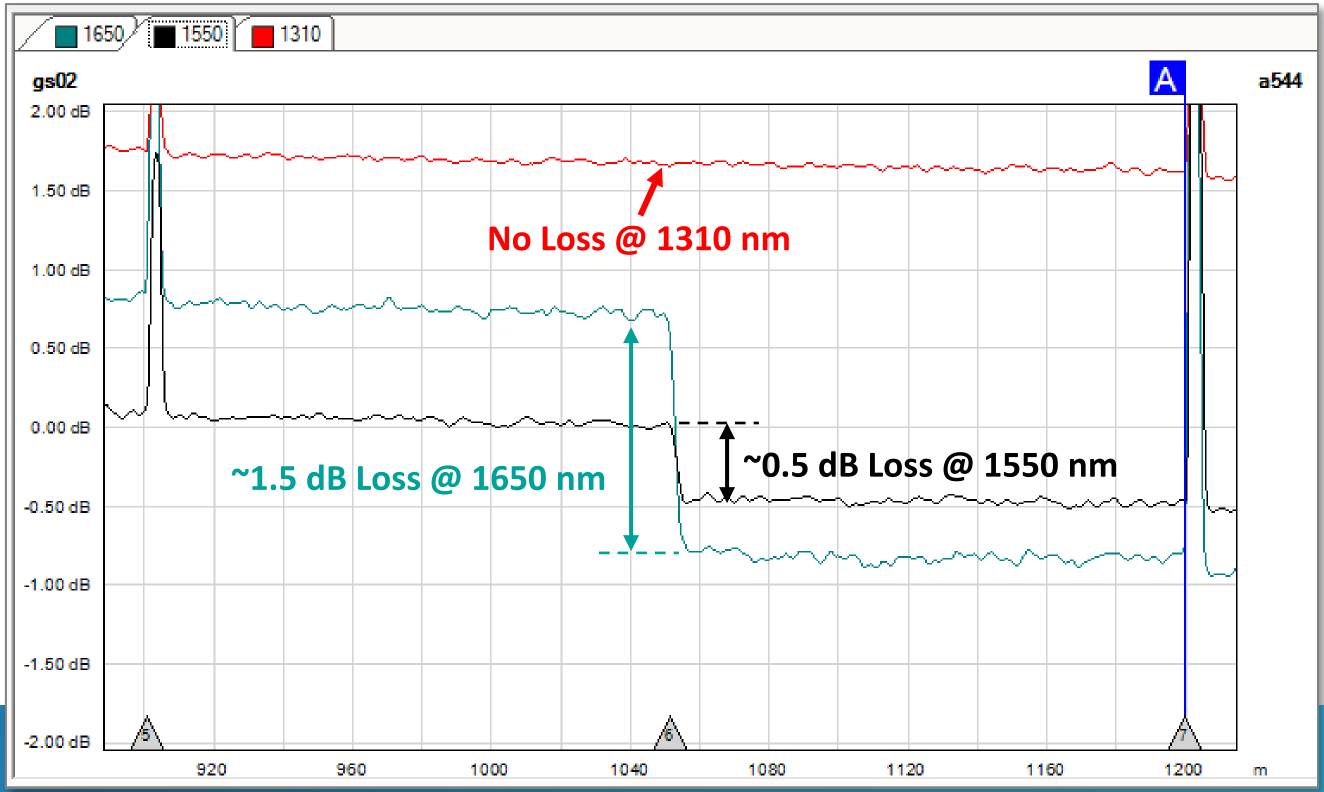
- ☑ More accurate loss measurements on noisy traces
- ☑ Corrects for fiber loss in dead zone of wider pulses
- ☑ Automated measurements typically use LSA line fit
- ☒ More complex (must place 5 cursors vs. 2 cursors)

Detecting and Measuring Macro-bends using OTDR Trace

- Must test at 2 wavelengths (typically 1310 & 1550 nm) to detect macro-bends
  - Macro-bends are detected by comparing traces at short (1310 nm) and long (1550 nm) wavelengths
  - Macro-bends identified as events with event loss at least 0.2 dB higher at 1550 nm than at 1310 nm
  - Macro-bend may show up as non-reflective loss at 1550 nm with no detectable event at 1310 nm
  - Macro-bends may occur at reflective or non-reflective events (connectors, splices or mid-span

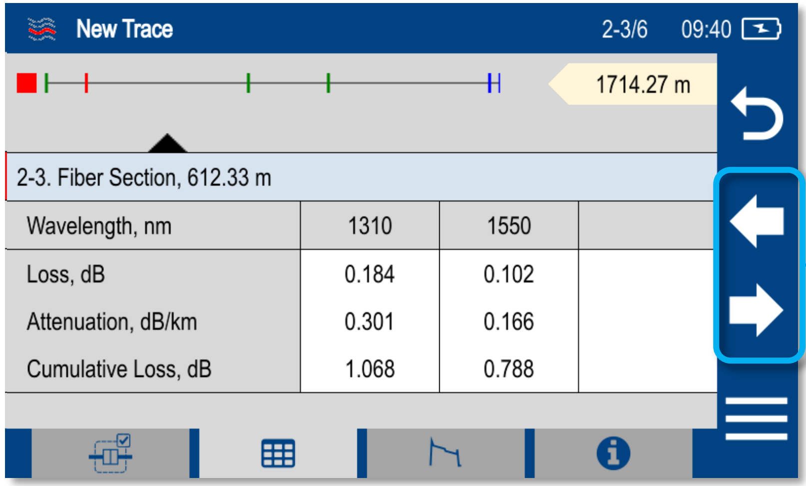
Longer λs more sensitive to bending loss:

- Bend not detected at **1310 nm**
- 0.5 dB loss at **1550 nm** due to bend
- 1.5 dB loss at **1650 nm** due to bend

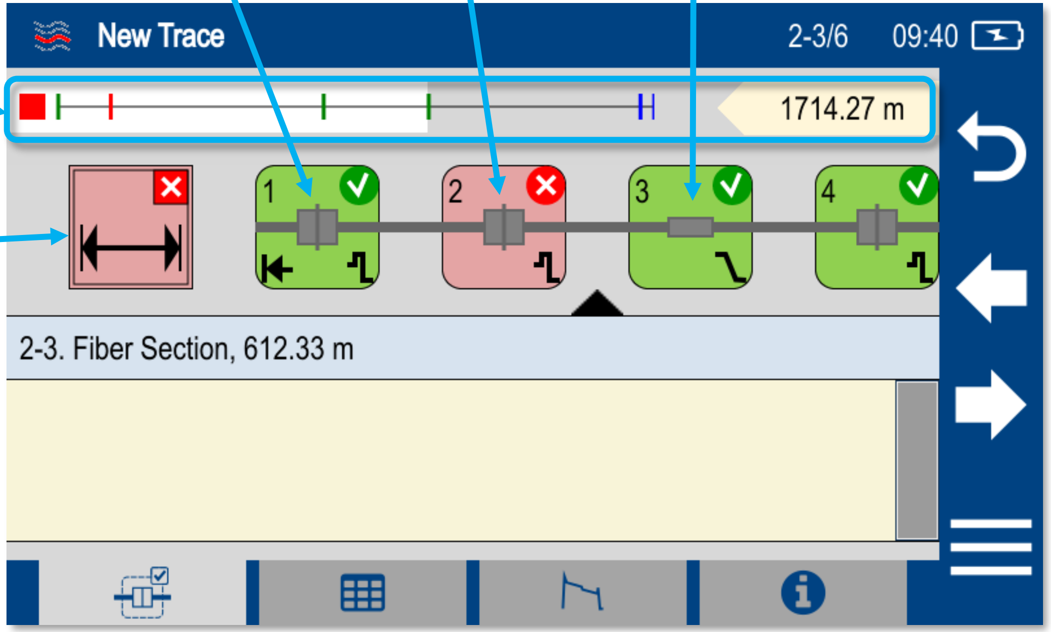


Newer OTDRs provide Icon-based Link Map & Event Table

- Thumbnail view shows proportionally-spaced events and overall fiber length
  - White-highlighted section corresponds to portion shown in larger link map
- 1st icon indicates overall pass/fail status
  - Touch Table View tab to display end-to-end Link Loss, ORL, Attenuation
- Subsequent icons identify event type and status
  - Touch an icon to view event type, location & recommendations
  - Touch Table View tab to view event's loss & reflectance
- Left/right arrows navigate to previous/next event
  - Results table also reports fiber section loss & attenuation



Wavelength, nm	1310	1550
Loss, dB	0.184	0.102
Attenuation, dB/km	0.301	0.166
Cumulative Loss, dB	1.068	0.788



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OTDR-generated Event Table

- Event detection software is continually improving, but not perfect
  - May miss events humans can detect
  - May report false events which humans can rule out
  - Missed or false events are usually low-loss events so not a concern
  - Improper manual mode settings can cause important events and faults to be missed
    - Range too short
    - Pulse width too narrow
    - Averaging time too short
    - Launch or receive cable length incorrectly configured
  - Improper Expert mode settings can cause important events to be reported at wrong location

Saving, Downloading & Reporting OTDR Results

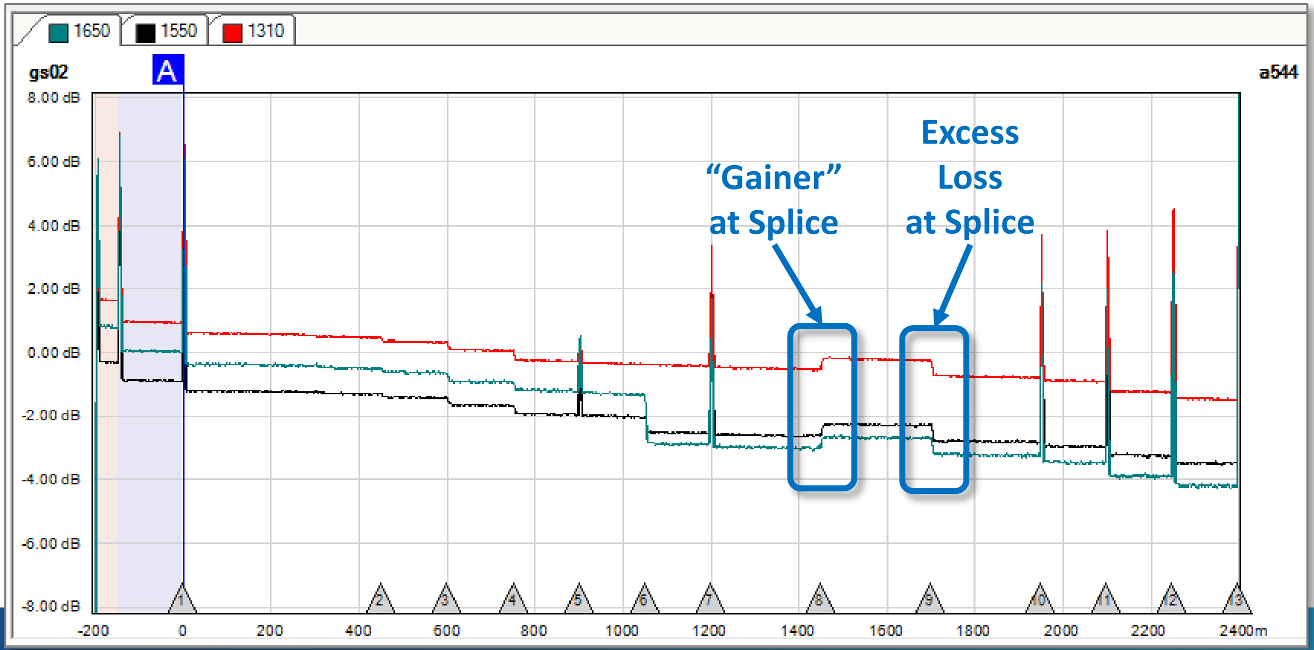
Saving & Downloading OTDR Results

- OTDR test results should be saved in Telcordia .SOR file format
  - .SOR is only standardized format supported by all OTDR manufacturers
  - Includes OTDR test settings, event table, and trace data
  - SOR standard supports vendor-proprietary extensions
  - Can be read by Trace Viewer and Reporting software
- Saved SOR files can be transferred to PC for viewing or reporting using PC software
  - Transfer via USB memory stick, USB cable, Bluetooth, or WiFi
- PC-based OTDR software supports offline analysis and reporting:
  - View and analyze downloaded traces
  - Compare multiple traces
  - Correcting event table (add missed events, delete false events, correct misconfigured launch cables, etc.)
  - Bidirectionally average traces obtained from each end of the network
  - Generate reports for single fiber, selected fibers or all fibers tested in a cable

Bidirectional Averaging: When & Why?

Why bidirectionally average traces obtained from both ends of a fiber?

- OTDR may miss events at far end of long fibers
  - Events missed in one direction may be detected when testing in the opposite direction
  - Averaging includes all events detected in each direction
- Networks may contain a mix of fiber types with different backscatter characteristics
  - When lower backscatter fiber connected to higher backscatter fiber, event may appear as “gain”
  - When tested in the opposite direction, event will appear as excess loss – may be identified as failing event
  - Averaging the event loss in both directions provides more accurate measure of true event loss



- Splicing dissimilar fibers may result in ‘gainers’ or excess loss
- ‘Gainer’ in one direction appears as excess loss in opposite direction
- Bidirectionally averaging produces more accurate splice loss measurements

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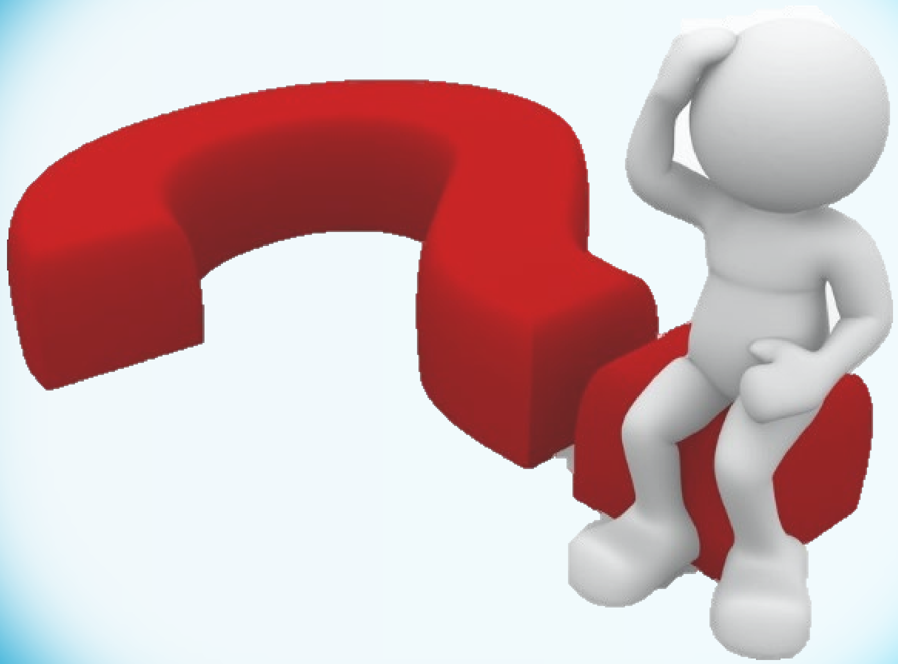
Your Turn:

Q&A



Part 2

April 23rd, 2024, 2pm EST

"From Glitches to Glory: OTDR Problem-Solving Strategies"

Thank You

Please feel free to ask any questions