Testing Fiber Optic Cables

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Testing Fiber Optic Cables

The Goal: A network

- LAN, WAN, MAN, ...
Testing Fiber Optic Cables

*The OSI Reference Model*

- **Physical**:
  - Ethernet Physical Layer (Optical Fiber, Twisted Pair, Coaxial cable), Sonet/SDH, Modem, RS232, etc…

- **Data Link**:
  - IEEE 802.3(Ethernet), Token Ring, ATM, WiFi, etc…

- **Network**:
  - IP, ARP, IPX, X.25, etc…

- **Transport**:
  - TCP, UDP, PPTP, L2TP, SPX, etc…

- **Session**:
  - DNS, DHCP, NetBIOS-NS, etc…

- **Presentation**:
  - Data representation and encryption

- **Application**:
  - FTP, HTTP, TFTP, Telnet, NTP, etc…
Testing Fiber Optic Cables

*Measurements: What to look at?*

- **Overall Optical Loss (IL)@ wavelength (optical budget)**
  (Measured with OLTS)
- **Quality of Connectors**
  IL, Reflectance
  (Fiber Inspection Probe, OLTS, OTDR)
- **Quality of Splices**
  (Measured with OTDR)
- **Modal dispersion caused by distance**
  (Tested with BERT/Ethernet tester)
Cabling Standards:

The most prominent standards are listed here:

- **United States** TIA/EIA-568 (Telecommunications Industry Association/Electronic Industries Association), defines how to design, build, and manage a structured wiring system.

- **International** ISO/IEC 11801 (International Organization for Standardization/International Engineering Consortium) defines generic cabling for customer premises. It is being used in Europe, Asia, and Africa.

- **Europe Cenelec EN 50173** was derived from ISO 11801 and defines generic cabling and open-market cabling components.

- Different standards for FTTH (G983.2-G983.3), DWDM,...
Testing Fiber Optic Cables

Measurements: What’s Good or Bad?

- Cabling Standards:
  Some figures: ISO/IEC 11801

<table>
<thead>
<tr>
<th>Optical fiber cable type</th>
<th>Wavelength (nm)</th>
<th>Maximum attenuation (dB/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50/125 μm multimode</td>
<td>850</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
</tr>
<tr>
<td>62.5/125 μm multimode</td>
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<tr>
<td></td>
<td>1300</td>
<td>1.5</td>
</tr>
<tr>
<td>singlemode inside plant cable</td>
<td>1310</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td>1.0</td>
</tr>
<tr>
<td>singlemode outside plant cable</td>
<td>1310</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Maximum connector loss: 0.75 dB/pair
Maximum splice loss: 0.3 dB
Reflectance: -20 dB (MM), -26 dB (SM), -55 dB (CATV)
Testing Fiber Optic Cables

Measurements: What’s Good or Bad?

- Network Standards:
  Some figures:

### Networks Standards Limits

<table>
<thead>
<tr>
<th>Maximum insertion loss (dB)</th>
<th>50/125</th>
<th>62.5/125</th>
<th>SMF</th>
</tr>
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<tbody>
<tr>
<td>850</td>
<td>1300</td>
<td>850</td>
<td>1300</td>
</tr>
<tr>
<td>10GBASE-LX4</td>
<td>---</td>
<td>2</td>
<td>---</td>
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<tr>
<td>10GBASE-ER/EW</td>
<td>---</td>
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<td>---</td>
</tr>
<tr>
<td>10GBASE-SR/SSW</td>
<td>note1</td>
<td>1.6</td>
<td>---</td>
</tr>
<tr>
<td>10GBASE-LR/LW</td>
<td>---</td>
<td>---</td>
<td>6.2</td>
</tr>
<tr>
<td>1000Base-SX</td>
<td>6.8</td>
<td>12.5</td>
<td>---</td>
</tr>
<tr>
<td>1000Base-LX</td>
<td>---</td>
<td>2.35</td>
<td>---</td>
</tr>
<tr>
<td>100Base-FX</td>
<td>---</td>
<td>6</td>
<td>---</td>
</tr>
<tr>
<td>10Base-FB</td>
<td>8.8</td>
<td>12.5</td>
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<tr>
<td>10Base-FL</td>
<td>8.8</td>
<td>12.5</td>
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</tr>
<tr>
<td>FDDI PMD</td>
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<tr>
<td>FDDI SMF-PMD</td>
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</tr>
<tr>
<td>ATM-155</td>
<td>7.2</td>
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</tr>
<tr>
<td>ATM-622</td>
<td>4</td>
<td>2</td>
<td>4</td>
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<tr>
<td>Token Ring 48/16 Mbit/s</td>
<td>8</td>
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<td>13</td>
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<tr>
<td>Fiber Channel 1062 Mbit/s</td>
<td>4</td>
<td>---</td>
<td>4</td>
</tr>
</tbody>
</table>

\*note1: 1.6dB for OM2 and 2.6dB for OM3 (see following table for OM definitions)

### Maximum fiber Length (m)

<table>
<thead>
<tr>
<th>50/125</th>
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<td>33</td>
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<tr>
<td>10GBASE-LR/LW</td>
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</tr>
<tr>
<td>1000Base-SX</td>
<td>550\textsuperscript{a}</td>
<td>275\textsuperscript{b}</td>
</tr>
<tr>
<td>1000Base-LX</td>
<td>---</td>
<td>550\textsuperscript{a}</td>
</tr>
<tr>
<td>100Base-FX</td>
<td>---</td>
<td>2000</td>
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<tr>
<td>10Base-FB</td>
<td>1514</td>
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<tr>
<td>10Base-FL</td>
<td>1514</td>
<td>---</td>
</tr>
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<td>1000\textsuperscript{a}</td>
<td>2000</td>
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<td>300\textsuperscript{a}</td>
<td>330</td>
</tr>
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<td>Token Ring 48/16 Mbit/s</td>
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</tr>
<tr>
<td>Fiber Channel 1062 Mbit/s</td>
<td>500\textsuperscript{a}</td>
<td>---</td>
</tr>
</tbody>
</table>

\*note1: 82m on OM2 and 300m on OM3 (see following table for OM definitions)
\textsuperscript{a} OM2 fiber
\textsuperscript{b} OM1 fiber
Testing Fiber Optic Cables

Four ways to do the job

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Telecommunications Test and Measurements
Four ways to do the job

Table of content

- Test Methods
- Comparison
- Sources of measurement uncertainty
- Virtual Hands-On
- Additional Tools
Four ways to do the job

The Test Methods

- The various international standards (EIA/TIA and ISO/IEC) describes four ways to test installed cable plants

- All four methods give different results and different uncertainty.
  - Three of them use powermeter/lightsource
    - The insertion loss measurement method
    - Difference is made by the way the 0 dB reference is taken

- The fourth uses OTDR
  - The reflective measurement method

- Installers are confused or are not aware of the different methods

- Let’s look at the methods…
Four ways to do the job

**Method 1: PM/LS**

Setting “0 dB Loss” Reference, Method B

1. No connectors are included in the reference setting.
2. Measures cable plant loss including connectors at both ends.
3. This method is specified by all network test specifications and EIA/TIA 568 Appendix H.

Note: this method connects directly to the FO Power Meter. The connection to the meter effectively has no loss, so the reference is the actual output of the reference cable.

_EIA/TIA-526-14 test method B (multimode fiber) or EIA/TIA-526-7 (single mode fiber).

Method B is the PREFERRED method but method A and C (see next pages) also allowed if properly documented_
Four ways to do the job

Method 2: PM/LS

1. Sets reference with both launch and receive cables while connected to each other.
2. Has one unknown connector loss included in reference.
3. The measured loss of the cable plant is diminished by the unknown connector loss value included in the reference.
4. Unknown connector loss in reference causes greater measurement uncertainty.
5. If reference connectors are dirty, then cleaned, can result in "gain" not loss.

Note: This method is often used with connectors that are different from the interface connections on the source and power meter, e.g. testing LC connectors with a test set that has ST connectors.
Four ways to do the job

**Method 3: PM/LS**

Setting "0 dB Loss" Reference, Method C

**Figure 4. 3 Cable Reference (Method C)**

1. Set reference with launch and receive cables plus a "golden cable" reference.
2. Remove "golden cable" and replace with cable under test to make measurement.
3. Includes two unknown connector losses in reference value.
4. The measured loss of the cable plant is lower by the losses of the two unknown connections in the reference measurement.
5. Unknown connector losses in reference causes higher measurement uncertainty.
6. If reference connectors are dirty, then cleaned, can result in "gain" not loss.

Note: This method is often used with duplex male/female connectors that are different from the interface connections on the source and power meter, e.g. testing MT-RJ connectors with a test set that has ST connectors.
Four ways to do the job

Method 4: O.T.D.R.

OTDR Testing, Single Ended

Figure 5. OTDR Test

1. Reference cable is launch cable (sometimes called pulse suppressor) which allows OTDR initial pulse to settle down and measurement of first connector on cable to test
2. First cursor precedes reflection peak from cable plant under test
3. Second cursor precedes reflection peak from last connector
4. Calculates loss implied from backscatter measurement.
5. Does not include connector on far end unless you use a receive cable, now required in ISO/IEC standards. That will add another connector loss.
6. Used laser which typically has lower loss than LEDs in multimode fiber.
7. Measurements are directional - loss may be different in each direction.
Four ways to do the job

**Method 4: O.T.D.R.**

**OTDR Testing, Double-Ended**

**Figure 5. OTDR Test (With receive cable)**

1. Reference cable is launch cable (sometimes called pulse supressor) which allows OTDR initial pulse to settle down and measurement of first connector on cable to test.
2. Receive cable added to far end makes testing more relevant but much less convenient.
3. First cursor precedes reflection peak from cable plant under test.
4. Second cursor follows reflection peak from last connector.
5. Calculates loss implied from backscatter measurement.
6. Does include connector on far end.
7. Used laser which typically has lower loss than LEDs in multimode fiber.
8. Measurements are directional - loss may be different in each direction.
How much does the loss of a cable plant change with the different methods?

Experiment:
- Test of a 520 m MM fiber @ 850 nm
- Each method repeated several times
- PM/LS methods repeated with 10 different reference cable sets
- Result: Average per test method shows what different test crews would find

Results:
- One cable reference method has
  - highest loss (includes FUT but also connectors on both side)
  - Very low uncertainty (no connectors in reference)
- Two and three cable reference methods have
  - Lower loss (includes FUT but connector loss(es) subtracted when taking 0 dB reference)
  - Uncertainty much higher (directly related to the quality of the reference connectors)
- OTDR method shows much lower loss (note: includes only FUT and one connector)
  - Why? OTDR uses laser injecting light in the centre of the core of the fiber where loss is lower
Four ways to do the job

*Let’s compare*

- What’s the loss of the cable plant ????
  - All four methods are according to international standards
    - *So you can take your choice*
  
  - HOWEVER...
    - *Most network specs have been written around a loss test using One cable reference test as does EIA/TIA-526-14 method B (multimode fiber) or EIA/TIA-526-7 (single mode fiber).*
  
  - BUT...
    - *If your testers have different connectors then the FUT:
      Two or Three cable reference may be the only choice.
      Don’t forget to add an estimated loss (0.3 to 0.5 dB) to calculate the overall loss.*
Four ways to do the job

Sources of measurement uncertainty

- **Measurement method** (as explained before)
- **Technician’s understanding**
  - Needs to understand test methods, equipment used, network to be tested,…
- **Equipment used**
  - Calibration, maintenance (instrument connectors may not be dirty/damaged as this may result in faulty measurements)
- **Cleanliness**
  - Tolerance to dirt is ZERO
  - Airborne particles are about the size of the core of SM fiber and usually silica based.
    - If connectors are not cleaned they may scratch the connector and cause permanent damage.
    - Equipment connectors require hundreds of connections: Keep them clean !!!!!
- **Mismatched fibers**
  - MM (62.5/125 and 50/125) and SM often found together
  - Patching of cables done with same type
Four ways to do the job

**Sources of measurement uncertainty**

- **Reference Cables**
  - Vitally important to keep in top quality (THIS IS THE REFERENCE)
  - Should be tested daily or after every 20-100 measurements

If result > 0.5 dB: Bad reference cable
- Should be cleaned each time used
- Use same type of fiber and connector as FUT
  - **Testing 50/125 MM fiber with 62,5/125 MM reference cables gives virtually no loss**
  - **Testing 62,5/125 MM fiber with 50/125 MM reference cables gives 2 ...4 dB loss**
  - **Testing SM fiber with MM reference cables gives 15...20 dB loss**
Mode Power Distribution on Multimode Fiber

- MM is called ‘Multimode’ because it transmits light in many ‘modes’ or ‘rays’ of light.
- Some rays of light stay closer to the centre of the core (Low Order Modes).
- Others go closer to the edge of the core (High Order Modes).

Result:
- High order modes are more attenuated than Low order modes (they travel through more glass).
- Light gets more concentrated as you go along the fiber (high order modes are more attenuated, leaving only the low order modes).

Two effects:
- Loss (dB/km) decreases as you go along the fiber (up to 1 dB/km difference at 850 nm).
- Geometric offset of connectors is less a factor as light gets more concentrated (connector loss measurement can have several tenths of dB difference).
**Four ways to do the job**

**Sources of measurement uncertainty**

- So if we use as a Lightsource:
  - **Laser:** Fiber is underfilled (Only Low order modes)
    To optimistic results on both fiber loss (dB/km) and IL (connector loss)
  - **LED:** Fiber is overfilled (High order & Low order modes)
    Fiber loss (dB/km) on short links and longer links will be different
    Same for IL (connector loss)

- Experiment on different mode launch conditions:
  - Graph shows Attenuation for 6 different mode launch conditions (MLC):
    - MLC0 is most overfilled
    - MLC6 is most underfilled
    - Difference is huge
Four ways to do the job

Sources of measurement uncertainty

- How can we get a correct measurement (on MM Fiber)?

Use of a Mandrel Tool

- The uncertainty caused by MPD led to the creation of standard test conditions: TIA-568-B defined test method (Are you aware of this method ?)
- Use LED source
- Launch reference cable wrapped around a Mandrel tool
  Mandrel tool eliminates high order modes in a controlled way
  Mandrel tool will make measured loss more predictable

TIA-568 Specified Mandrel Size

<table>
<thead>
<tr>
<th>Mandrel Size</th>
<th>Wrap 5 non-overlapping turns over the specified size mandrel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Size</td>
<td>Cable/Fiber Type</td>
</tr>
<tr>
<td>62.5/125 fiber</td>
<td>3mm Jacketed Cable, 22mm 900 micron Buffered Fiber</td>
</tr>
<tr>
<td>50/125 fiber</td>
<td>17mm, 20mm</td>
</tr>
</tbody>
</table>

- Conclusion:
  - Good method as results are more stable but
  - Not a practical solution and not everybody tends to use it
  - Light doesn’t travel that far

- Upcoming new test method : Encircled Flux
Four ways to do the job

Sources of measurement uncertainty

- How can we get a correct measurement (on MM Fiber)?

Encircled Flux method

- *Tries to establish a uniform launching-condition at the source* (LS, OTDR)
- *EF compliant Lightsources (with EF compliant reference jumpers) from different manufacturers give same results*
- *EF compliant Lightsources and O.T.D.R.’s (with EF compliant reference jumpers) give same results.*

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**Figure 2:** Underfilled launch conditions may not allow for the detection of ferrule-alignment problems in connector interfaces

**Figure 3:** Overfilled launch conditions may give unrealistic and overestimated loss readings

**Figure 5:** Light sources following the Encircled Flux standard are optimized to deliver accurate loss readings
Four ways to do the job

Sources of measurement uncertainty

- How can we get a correct measurement (on MM Fiber)?
  Encircled Flux method (EF)

- **Current Standard Status:**
  - Telecommunications Systems Bulletin *TIA TSB-178* which is a precursor to standard acceptance is public *(September 2008)*
  - *IEC 61280-4-1* Ed 1.0: Fibre-optic communication subsystem test procedures – (committee draft for vote) CDV approved in Kyoto, *Oct. 2008*
  - *FDIS* (final draft for international standard) circulated after Kyoto, *Nov. to Feb. 2009*
  - **Probable publication as an international standard:** *Summer 2009*
  - Once adopted, the EF template will probably **supersede** the ISO/IEC 14763-3 MPD template
  - *Multimode light sources in EXFO certification kits (TK-AXS-200/360 and TK-AXS-200/350) are EF compliant today*
Four ways to do the job

Virtual Hands-on: PM/LS

- Test Equipment Needed
  - Power Meter
  - Source (LED or Laser)
  - Fiber-optic adapters (FOA series)
  - Launch and Receive Reference Cables
  - Mating Adapters For Connectors
  - Wrap Mandrel (for MM)
  - Lint Free Pads And Alcohol (Alco Pads) or Cletop

- Step 1: 1-Jumper Reference
  - Attach a launch reference cable to the output of the source.
    (Make sure connector is fully seated and secured.)
  - Turn the source on and let it warm up for a minute
  - Connect the launch cable to the power meter
  - Make 5 turns around Mandrel (MM only)
  - Select correct wavelength(s) on both instruments
  - Measure the power level on the PM display
  - Take reference (for all wavelengths to measure)
  - Note: Never disconnect reference cable from source after taking reference (May change measurement)
Four ways to do the job

Virtual Hands-on : PM/LS

- Step 2: Check
  - Disconnect jumper 1 from PM
  - Insert a second jumper using an adapter
  - Verify reading (Max 0.5 dB (adapter between 2 jumpers))
  - If loss is greater than 0.5 dB: clean or replace jumpers
  - Repeat check for all wavelengths to measure

- Step 3: Test
  - Disconnect two jumpers at the adapter
  - Connect jumper#1 and jumper#2 to both ends of FUT
  - Value read= loss on FUT including both patch panel connectors
  - Repeat test for all wavelengths to measure

- If measurement is too high:
  - Verify connectors (Fiber inspection probe)
  - Use OTDR to pinpoint problem on the cable (bending, break, …)
  - Use Visual Fault locator to pinpoint local problems (cable break,…)

Equation:
\[ P_{\text{received}} = P_{\text{check}} - P_{\text{attenuation}} \]

\[ P_{\text{received}} = P_{\text{check}} - P_{\text{system att}} \]

\[ -16.0 \text{dBm} - (-16.4 \text{dBm}) = 0.4 \text{ dB} \]
Four ways to do the job

Virtual Hands-on : Fiber Certification Test Set

- Use of Exfo AXS200/350-360

- **Multimode and Singlemode Fiber Certification according to industry standards (cabling and network standards)**

  Offers user-configurable thresholds, consistent with industry standards: TIA/EIA-568-B.3, ISO/IEC-11801, 10GBASE-LX4, 10GBASE-L, 10GBASE-E, 10GBASE-S, 1000BASE-SX, 1000BASE-LX, 100BASE-FX, 10BASE-FB, 10BASE-FL, FDDI, ATM-155, ATM-622, Token Ring 4 and 16 Mbit/s, Fibre Channel 1062 Mbit/s, Corning plug and play.

- **Automatic Optical loss measurements at multiple wavelengths**

- **Pass/Fail result in just a few seconds**

- **Compliant with Encircled Flux test method (FLS-600)**
Four ways to do the job
Virtual Hands-on: Fiber Certification Test Set

- Use of Exfo AXS200/350 and AXS200/360

Network certification in four easy steps
1. Select a standard or an application
2. Follow the step-by-step fiber loss wizard
3. Set reference
4. Start the test
Four ways to do the job

Virtual Hands-on: Fiber Certification Test Set

- Use of Exfo AXS200/350 and AXS200/360
Four ways to do the job

Virtual Hands-on: Fiber Certification Test Set

- Use of Exfo AXS200/350 and AXS200/360
Four ways to do the job

Virtual Hands-on: Fiber Certification Test Set

- Use of Exfo AXS200/350 and AXS200/360

![Image of two screens showing loss measurements and cable identification with values 2.75 dB and -0.01 dB.](image-url)
Four ways to do the job

*Virtual Hands-on : Fiber Certification Test Set*

- Use of Exfo AXS200/350 and AXS200/360
Four ways to do the job

Additional Tools : FIP-400

- Fiber Inspection Probe FIP-400

**Connector inspection and cleaning**

It’s a fact! Most fiber network problems are caused by dirty, damaged or improperly installed connectors, which can lead to erroneous test results or poor transmission. Using a FIP to ensure connectors/adapter are clean and exempt of any defect is where accurate testing starts.

Avoid failing certification testing thanks to the FIP port on the AXS-200/360. Just plug EXFO’s efficiently designed, unmatched FIP-400 Fiber Inspection Probe and you are all set! You will get the best ever optical resolution. Moreover, keep snap shots of your connectors for future reference and documentation.

!!!!!!! Easy verification of connectors.

Eliminates:
- IL and Reflectance problems
- need for Tier 2 equipment / technicians
- An newly approved method in ISO/IEC 14763-3
Four ways to do the job

**Additional Tools : FIP-400**

- Fiber Inspection Probe FIP-400
Four ways to do the job

Additional Tools: FLS-240

- Visual Fault Locator

Applications
- Break and macrobend location
- Fiber identification

Key Features and Benefits
- Detects faults over distances of up to 5 km
- Bright red laser at 635 nm
- Pulsed and CW operation for up to 50 hours (typical)
- Universal connector for 2.5 or 1.25 mm ferrule

SIX WAYS TO USE A VISUAL FAULT LOCATOR

- Detects breaks in OTDR dead zone.
- Highlights sharp bends where losses occur.
- Optimizes mechanical/fusion splices.
- Detects defective connectors.
- Ensures end-to-end fiber identification in multifiber cables.
-detects major scratches on connector surfaces.
Four ways to do the job

Additional Tools: LFD-300/TG-300

Life fiber detector / Tone generator (LFD-300/TG-300)

Disadvantage of traditional LFD’s
- A thumb-activated function bends the fiber at a fixed angle, and the detector reads the power leaking from the jacket.

- The bending could cause one of several problems:
  - excessive loss
  - unreliable fiber detection
  - unreliable tone or traffic detection
  - possible permanent damage to the fiber
Exfo LFD using FiberFinder Technology
- Precision-step motor (rather than human power) fiber bending
  - Power loss is monitored as angle is changed
  - Producing different angles automatically optimized for all fiber types and all wavelengths.
- Advantages:
  - Max loss of 1 dB for most jacket types and wavelengths
  - No damage to fiber, bending is minimal, fiber released when no power detected
  - Traffic detection and direction
  - In line power estimation
  - Optimized for 900 µm, 1.6 mm, 3 mm jackets.
  - No need to replace headpiece
  - Ambient light sensor makes it less sensitive to ambient light

Figure 1: By monitoring the loss, the LFD-300 can stop bending the fiber when sufficient light is ejected and thus control the loss.
Four ways to do the job

Additional Tools: LFD-300/TG-300

- Pinpoint live and dark fibers
  - Reason:
    - Determining whether a fiber is active prior to maintenance
    - Fiber mislabeling, poor record keeping
  - Dark fibers:
    - Use LFD300 together with TG300 or modulated source
    - Use tone generation/recognition of 270 Hz, 1 kHz, or 2 kHz

Figure 2: Pinpointing a specific live fiber can be puzzling without the right tool.
Four ways to do the job

Additional Tools: LFD-300/TG-300

- Pinpoint live and dark fibers
  - Live fibers:
    - Use LFD300 together with TG300 only for reliable results
    - Uses Exfo Patented FiberFinder Technology
      - Adds 0.25 dB signature to live signal by applying a LF modulation pressure to the fiber

*Figure 3: Impossible until now, locating a specific live fiber is now an easy task with the FiberFinder.*
Four ways to do the job

**Additional Tools**: LFD-300/TG-300

- **Measure Power**
  - Insertion loss measurement depends on:
    - Angle of fiber bending (motor controlled and measured)
    - Coupling efficiency factor. For example, 3-mm jackets absorb more than 1.6-mm and 900-µm fibers.
    - Known by measuring position of the motor
  - Result: Repeatability of 1 dB, regardless of the fiber type or wavelength.

<table>
<thead>
<tr>
<th>SPECIFICATIONS</th>
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<tbody>
<tr>
<td>Fiber type</td>
</tr>
<tr>
<td>Insertion loss (dB)</td>
</tr>
<tr>
<td>1.6 mm</td>
</tr>
<tr>
<td>900 µm</td>
</tr>
<tr>
<td>Power range (dBm)</td>
</tr>
<tr>
<td>Power measurement repeatability (dB)</td>
</tr>
<tr>
<td>Test time (s)</td>
</tr>
</tbody>
</table>

**GENERAL SPECIFICATIONS**

- **Size (H x W x D)**: 345 mm x 45 mm x 55 mm (13 3/8 in x 1 3/4 in x 2 1/8 in)
- **Weight (without batteries)**: 0.83 kg (1.8 lb)
- **Temperature**
  - Operating: 0°C to 50°C (32°F to 122°F)
  - Storage: -40°C to 70°C (−40°F to 158°F)
- **Relative humidity**: 6 % to 93 % non-condensing

**Notes:**

a. All specifications are typical and valid from 18°C to 25°C and at 55% RH unless otherwise specified.

b. Weight may vary by fiber type.

c. May vary with other fiber types.
Four ways to do the job

O.T.D.R. : How it works…

- The OTDR can be compared to a submarine radar; instead of sending an RF-signal:
  - *It sends short pulses of light to detect events in fiber*

- So, the O.T.D.R. doesn’t measure power but reflections
  - *Two types: Rayleigh backscatter and Fresnell reflections (see next slides)*

- This way it locates and identifies events along the fiber
  - *Connections, splices, losses, microbends, macrobends, etc.*
Four ways to do the job

O.T.D.R.: How it works...

- Rayleigh Backscattering
  - Comes from the natural reflection (attenuation) of the fiber
  - Used to measure the fiber’s attenuation (dB/km).

- Note:
  Higher wavelength is less attenuated by Rayleigh Backscatter

  Typical loss values according to wavelength:
  - 2.5 dB/km at 850 nm
  - 1.0 dB/km at 1300 nm
  - 0.35 dB/km at 1310 nm
  - 0.20 dB/km at 1550 nm
Four ways to do the job

**O.T.D.R. : How it works…**

- Fresnel Backreflections
  - *Abrupt changes in the IOR (e.g., glass/air)*
  - *Fiber break, mechanical splice, bulkheads and connectors*
- Are shown as a spike on the OTDR trace
- UPC reflection is typically -55 dB and APC -65 dB (as per ITU)
Four ways to do the job

**O.T.D.R. : How it works**

**Signal Processing and Trace Analysis**
- IOR
- Pulse width
- Acquisition time
- Wavelength
- Distance range
- Helix factor

**Diagram**

- Pulse Generator
- Laser
- Directional Coupler
- Converter
- Amplifier
- Avalanche Photodiode

OTDR PORT
Four ways to do the job

**O.T.D.R. : How it works…**

- Simplified OTDR Trace

![Diagram showing OTDR Trace with Power (dB) on the y-axis and Distance (km) on the x-axis. Key markers include OTDR connector, Fusion splice, Connector (P.P.), and End of link. The trace shows various features such as loss, reflection, and slope indicating fiber attenuation.]
Four ways to do the job

O.T.D.R. : How it works...

- Typical O.T.D.R. Trace
Four ways to do the job

**O.T.D.R. : Functions**

- Distance / Length Measurement
  - km, m, ft
- Fiber Loss Measurement
  - dB, dB/km
- Splice Loss Measurement
  - dB Loss
- Connector Loss Measurement
  - dB Loss
  - Return loss (reflectance)
Four ways to do the job

**O.T.D.R. : Functions**

- **Distance calculation:**
  - Time is correlated to distance:
    - \( D = \frac{c \times t}{2n} \)
    - \( ng = \frac{c}{n} \) \( \Rightarrow D = \frac{ng \times t}{2} \)
  - \( D \): Distance along the fiber
  - \( c \): Speed of light (in a vacuum)
  - \( t \): Time of the round trip of the light
  - \( n \): Index of refraction (IOR) of the core
    - *(depending on wavelength, type of fiber)*
  - \( ng \): Speed of light in the fiber
Four ways to do the job

**O.T.D.R. : Functions**

- **Distance measurement accuracy:**

\[ \Delta d = \frac{C T}{2} \left( \frac{1}{|OR_1|} - \frac{1}{|OR_2|} \right) \]

where:
- \( \Delta d \) - variation of distance (m)
- \( C \) - velocity of light (3.10^8 ms^-1)
- \( T \) - 2-way pulse time
- \( |OR_1| \) - Measured value
- \( |OR_2| \) - Reference value

now if: \( |OR_2| = 1.457 \)

and: \( T = 391.2\mu s \) for 40km range

then \( \Delta d \) will be as follows:

<table>
<thead>
<tr>
<th>Distance</th>
<th>I.O.R.</th>
<th>1.477</th>
<th>1.468</th>
<th>2%</th>
<th>5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2km</td>
<td>13m</td>
<td>1.4m</td>
<td>39.6m</td>
<td>97m</td>
<td></td>
</tr>
<tr>
<td>20km</td>
<td>138m</td>
<td>14m</td>
<td>387m</td>
<td>950m</td>
<td></td>
</tr>
<tr>
<td>40km</td>
<td>271m</td>
<td>27m</td>
<td>775m</td>
<td>1.896km</td>
<td></td>
</tr>
</tbody>
</table>
Four ways to do the job

O.T.D.R. : Functions

- Fiber loss measurement:
  - 2PA = Two Point Approximation
Four ways to do the job

**O.T.D.R. : Functions**

- Connector/splice loss measurement:

**LSA = Least Squares Approximation**
Four ways to do the job

**O.T.D.R. : Functions**

- Connector Return Loss measurement:
  - Generates a substantial level of reflected signal power as compared to the backscatter level (Return Loss)
  - Typical Figures (Approx.)
    - Perfect (90°) Cleave, Glass/Air Interface.. -14dB
    - PC Connector -25 ~ -35dB
    - SPC Connector -40 ~ -45dB
    - UPC Connector -50 ~ -55dB
    - APC Connector -65dB
  - Higher value figure = Lower reflectance loss = Better connector
Four ways to do the job

O.T.D.R. : Specifications

Main OTDR Specifications

- Dynamic range
- Measurement range
- Attenuation dead zone
- Event dead zone
- Pulse widths

OTDR specification sheet
Four ways to do the job

**O.T.D.R. : Specifications**

- **Dynamic range (in dB)**
  - Difference between the initial backscattered level at the interface to the fiber under test and the sensitivity or noise floor level of the receiver
  - Will be different according to the **pulse width** and **wavelength**
Four ways to do the job

**O.T.D.R. : Specifications**

- Measurement range (in km)

Dynamic Range = 34dB (effective) at 1310nm
But if loss = 0.33dB/km, Measurement Range = \( \frac{34}{0.33} = 103\text{km} \)
Dead Zone (in m)
- Dead zones result from the huge amount of energy sent back to the detector by a **reflective event**
- The detector is temporary saturated; therefore, it needs some time to recover from the overload of energy
- As a consequence of this temporary blindness, a **part of the fiber located immediately after the event cannot be seen**
- It depends on pulse width, wavelength and the amount of reflectance
- A **Launch cable** is used to ‘see’ the loss off the first connector on the FUT
Four ways to do the job

**O.T.D.R. : Specifications**

Trade-Off:

- **Larger Pulse Widths:**
  - More power, more dynamic range, less averaging
  - Less noise, faster, less resolution, increase deadzone

- **Smaller Pulse Widths:**
  - Less power, dynamic range reduced, more averaging, more noise, slower, higher resolution, decreasing deadzone
Four ways to do the job

**O.T.D.R. : Specifications**

- Two connectors 3 meters apart
- End of link (patch panel)

**Connectors are measured for distance and marked as separate events**

**Long pulses will give a better dynamic range but less resolution:**

- Connectors are measured for distance and marked as separate events
- End of fiber is not reached due to low power of short pulses

- Connectors are merged and identified as one event
- End of fiber is reached and located when using a larger pulse

---

**5ns pulse**

**30ns pulse**
Four ways to do the job

**O.T.D.R. : Practical**

- Loss in Fiber is Wavelength-Dependent
  
  So: Optical fiber is normally tested at the same wavelength that the fiber system will be operated

  **OTDR wavelengths available:**
  - 850 nm (multimode)
  - 1300 nm (multimode)
  - 1310 nm (singlemode)
  - 1410 nm (singlemode)
  - 1550 nm (singlemode)
  - 1625 nm (singlemode)

---

**Spectral Attenuation (typical fiber)**

<table>
<thead>
<tr>
<th>nm</th>
<th>dB/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>850</td>
</tr>
<tr>
<td>b</td>
<td>1300</td>
</tr>
<tr>
<td>c</td>
<td>1310</td>
</tr>
<tr>
<td>d</td>
<td>1383</td>
</tr>
<tr>
<td>e</td>
<td>1550</td>
</tr>
</tbody>
</table>

---

**Corning SMF-28 SM Fiber**
Four ways to do the job

*O.T.D.R. : Practical*

- Loss in Fiber is Wavelength-Dependent
  
  So:

- Shorter wavelengths are more attenuated by the scattering of the fiber

- Longer wavelengths tend to leak out of the fiber more easily due to **bending**

![Graphs showing acquisition at 1310 nm and 1550 nm]
Four ways to do the job

O.T.D.R. : Practical

- Echo (Ghosts)

This phenomenon is common with multimode links due to short distances and high connector reflections.

An example of an echo located at twice the distance of the reflection2 connector.
Four ways to do the job

**O.T.D.R. : Practical**

- Echo (Ghosts)

---

<table>
<thead>
<tr>
<th>Type</th>
<th>No.</th>
<th>Loc.</th>
<th>Loss</th>
<th>Refl.</th>
<th>Att. @ 24.2 dB</th>
<th>Cumul.</th>
</tr>
</thead>
<tbody>
<tr>
<td>↓</td>
<td>1</td>
<td>0.000</td>
<td>-</td>
<td>-33.7</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>↓</td>
<td>(1.2430)</td>
<td>0.242</td>
<td>0.195</td>
<td>-30.4</td>
<td>0.242</td>
<td>0.437</td>
</tr>
<tr>
<td>↓</td>
<td>2</td>
<td>1.2430</td>
<td>0.236</td>
<td>0.139</td>
<td>0.673</td>
<td>0.855</td>
</tr>
<tr>
<td>↓</td>
<td>(1.2443)</td>
<td>0.183</td>
<td>-34.3</td>
<td>0.139</td>
<td>0.673</td>
<td>0.855</td>
</tr>
</tbody>
</table>

Comment: 

---

Image of a graph showing a trace with markers indicating different points. The graph is labeled with various parameters and units, including distance in kilometers. The software interface shows data points and their corresponding values in a table format.
Four ways to do the job

*O.T.D.R. : Practical*

- Splice gain and two-way measurements (SM only)

\[
\text{True loss} = \frac{(0.5-0.1)}{2} = 0.2\text{dB}
\]
Four ways to do the job

**O.T.D.R. : Practical**

- Splice gain and two-way measurements (SM only)
Four ways to do the job

*O.T.D.R. : Practical*

- Continuous Trace
Four ways to do the job

O.T.D.R. : Practical

- Loopback

Starting LC

OTDR

Ending LC

Loopback LC

FUT
Four ways to do the job

Virtual Hands-on: O.T.D.R using FTB200
Four ways to do the job

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Four ways to do the job

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Four ways to do the job

Virtual Hands-on: O.T.D.R using FTB200
Four ways to do the job

Virtual Hands-on: O.T.D.R using FTB200
Four ways to do the job

Virtual Hands-on : Loss Budget Certification

Calculation for 10GBASE-S certification (850nm – 50um MM)

- Length of the fiber : 50 m  $0.050 \times 3.5\text{dB} = 0.175\text{dB}$ (TIA 568-B / ISO11801)
- Number of connector pairs : 2  $0.75\text{dB} \times 2 = 1.5\text{dB}$ (TIA 568-B / ISO11801)
- Number of splices : 0  $0 \times 0.30\text{dB} = 0\text{dB}$ (TIA 568-B / ISO11801)

Max loss for 10GBase-S ($\text{IEEE802.3ae}$) : 2.6 dB
Max fiber length : 300 m

Link loss 2.395 dB  **FAIL**

OTDR identify that the second connector is faulty.
Four ways to do the job

Virtual Hands-on : IEEE 802.3z up to 2 km

Application Note (Cisco)

LONG REACH SUPPORT ON MULTIMODE FIBERS
(Up to 2 km)

- The maximum distance guaranteed by the IEEE 802.3z standard for 1000BASE-LX optics on multimode fiber is 550 m, provided the signal is launched with a mode conditioning patch cord.
Four ways to do the job

Virtual Hands-on: IEEE 802.3z up to 2 km

### Table GBIC and SFP Module Port Cabling Specifications

<table>
<thead>
<tr>
<th>GBIC Module</th>
<th>SFP Modules</th>
<th>Wavelength (nm)</th>
<th>Fiber Type</th>
<th>Core Size (micron)</th>
<th>Modal Bandwidth (MHz-km)</th>
<th>Maximum Cable Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS-G5484 or GLC-SX-MM</td>
<td>SFP-GE-S or GLC-SX-MM</td>
<td>850</td>
<td>MMF&lt;sup&gt;1&lt;/sup&gt;</td>
<td>62.5</td>
<td>160</td>
<td>722 ft (220 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>62.5</td>
<td>200</td>
<td>902 ft (275 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
<td>400</td>
<td>1640 ft (500 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
<td>500</td>
<td>1804 ft (550 m)</td>
</tr>
<tr>
<td>WS-G5486 or GLC-LH-SM</td>
<td>SFP-GE-L or GLC-LH-SM</td>
<td>1300</td>
<td>MMF&lt;sup&gt;1&lt;/sup&gt; and SMF</td>
<td>62.5</td>
<td>500</td>
<td>1804 ft (550 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
<td>400</td>
<td>1804 ft (550 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>50.0</td>
<td>500</td>
<td>1804 ft (550 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9/10</td>
<td>—</td>
<td>6.2 miles (10 km)</td>
</tr>
<tr>
<td>WS-G5487&lt;sup&gt;2&lt;/sup&gt; or GLC-ZX-SM</td>
<td>SFP-GE-Z or GLC-ZX-SM</td>
<td>1550</td>
<td>SMF</td>
<td>9/10</td>
<td>—</td>
<td>43.5 miles (70 km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>—</td>
<td>62.1 miles (100 km)</td>
</tr>
</tbody>
</table>

1. Multimode fiber (MMF) only.
2. A mode-conditioning patch cord is required.

**1000BASE-SX SFP FOR MULTIMODE FIBER ONLY**
The 1000BASE-SX SFP, compatible with the IEEE 802.3z 1000BASE-SX standard, operates on 50 µm multimode fiber links up to 550 m and on 62.5 µm FDDI-grade multimode fibers up to 220 m.

**1000BASE-LX/LH SFP FOR BOTH MULTIMODE AND SINGLE-MODE FIBERS**
The 100BASE-LX/LH SFP, compatible with the IEEE 802.3z 1000BASE-LX standard, operates on standard single-mode fiber-optic link spans of up to 10 km and up to 550 m on any multimode fibers.
A Mode Conditioning Patchcord (MCP) is a duplex multimode cord that has a small length of singlemode fiber at the start of the transmission length. The basic principle behind the cord is that you launch your laser into the small section of single mode fiber. The other end of the singlemode fiber is coupled to the multimode section of the cable with the core offset from the center of the multimode fiber.

Gigabit Ethernet (GbE) requires a laser light source instead of an LED source to power the network, due to the lasers faster rise and fall times, the pulses of light injected into the fiber are more tightly packed together thus greater bandwidth. Without the use of a MCP, multiple signals are generated when a singlemode laser launch into the center of a multimode fiber. Multiple signals can be generated that overlap each other and make it difficult for the receiver to interpret. This condition is known as Differential Modal Delay (DMD). MCP provided the offset between the singlemode and multimode fiber that eliminates the DMD effect.
On average, customers will experience much longer transmission reaches than reported in the IEEE specifications given better than worst-case optics and better than worst-case multimode fiber characteristics.

Support for installations greater than 550 m with Gigabit Ethernet transceivers granted if following conditions are met:

- The customer uses high quality transceivers
- The Gigabit Ethernet signal is launched with a mode conditioning patch cord.
- Measure and document error-free full-duplex transmission for 8000 seconds on each specific link greater than 550 m. (The "8000" number of seconds is chosen to yield a bit error rate (BER) of at least 10e-12 with 99 % confidence.)
- Suggested setup: two Gigabit Ethernet traffic generators (Exfo Packetblazer or equivalent Gigabit Ethernet traffic generators) connected to two Ethernet switches/routers at each end of the link. The switches/routers are in turn connected to the multimode fiber with mode conditioning patch cords. Line-rate traffic is flowing in both directions.
Case Study: Upgrade 100 Mbit to 1Gb on MM up to 2 km (based on Cisco Appl. Note)

Four ways to do the job
Virtual Hands-on: IEEE 802.3z up to 2 km

Test Name: TESTL
Application Type: BERT
Topology: Single Port

Port Configuration:
- Port: 1
  - Transceiver mode: Optical
  - Speed: 10Gbps
  - Duplex mode: Full
  - Auto-negotiation: Enabled
  - VLAN: None
  - IP Source Address: 10.10.10.2
  - MAC Source Address: 00:0c:02:01:08:30:00

BERT:
- Framing Layer: Framed L2
- TX Rate: 100
- Ethernet Frame size: 84
- Pattern RX: PRE5 2A31-1

Test Results:
- Start Time: 2006-02-20 11:52:21
- Duration: 13:03:08

Verdict:
- Bit Error: 784
- Pattern Loss: 10236
- No Traffic: 0

Port
Alarms
- Seconds
- Los: 3.000
- Frequency: 12

Ethernet
Alarms
- Seconds
Four ways to do the job
Virtual Hands-on: IEEE 802.3z up to 2 km
Four ways to do the job
Virtual Hands-on: IEEE 802.3z up to 2 km
Four ways to do the job
Virtual Hands-on: IEEE 802.3z up to 2 km
Four ways to do the job

**O.T.D.R and the standards**

- What is new in ISO/IEC 14763-3?
  - OTDR **accepted as an alternative to light source and power meter**
    - **Opens the door to the possibility that sometime in the future, OTDR testing will be 100% required, which is very likely tied to today’s falling OTDR prices**
  - OTDR is a better instrument for comprehensive information on the fiber installation, such as fiber section attenuation, individual connector and splice losses, ORL and fiber length
  - To obtain good results, a good test setup is needed with **launch and tail cords** or the use of **bi-directional OTDR testing**

![Diagram of OTDR measurement of installed cabling](figure)
Testing Fiber Optic Cables

Thank You!

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