The Road to Single-Mode: Direction for Choosing, Installing and Testing Single-mode Fiber

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Single-mode Applications/Design

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Fluke Networks
Traditional Thoughts on Single-mode

- More challenging to keep clean
- Less generations of fiber to deal with
- Transceivers are more expensive
- Applications are duplex, no need for MPOs to achieve higher speeds
- Greater distance with single-mode transceivers
- Greater insertion loss allowed (≈ 6.7 dB) compared to multimode
- Reflectance (return loss/back reflection) concerns
- Uses high power lasers – safety concerns
- May have to use an attenuator on shorter links
Multimode vs. Single-mode

- Multimode is easier to deal with
- Dust in an office
  - 2.5 to 10 µm
- Human hair
  - ≈ 100 µm
- It is a great deal easier to block all the light in a single-mode end face

Multimode
OM2, OM3, OM4, OM5

Single-mode
OS1a, OS2
Less Generations of Fiber to Deal With

<table>
<thead>
<tr>
<th>Multimode Cable Type</th>
<th>100GBASE-SR4</th>
</tr>
</thead>
<tbody>
<tr>
<td>OM1</td>
<td>Not supported</td>
</tr>
<tr>
<td>OM2</td>
<td>Not supported</td>
</tr>
<tr>
<td>OM3</td>
<td>70 m</td>
</tr>
<tr>
<td>OM4</td>
<td>100 m</td>
</tr>
<tr>
<td>OM5</td>
<td>100 m</td>
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</table>

<table>
<thead>
<tr>
<th>Single-Mode Cable Type</th>
<th>100GBASE-DR</th>
</tr>
</thead>
<tbody>
<tr>
<td>OS1a</td>
<td>500 m</td>
</tr>
</tbody>
</table>

• If you installed OS1a back in 1999 or OS2 today in 2022, the distance reach is the same for 100GBASE-DR
• The connectors may need replacing, but no pulling new cable
• Decision to install multimode driven by transceiver cost
Transceivers Are More Expensive

• Single-mode transceivers have certainly come down in cost
• There was a time when you could say 7.5 x cost of multimode
• Large (hyper-scale) data centers driving the demand for low-cost single-mode transceivers have changed the enterprise and data center markets

100GBASE-SR4 (multimode) ≈ 100GBASE-PSM4 (single-mode)
## Single-mode Options to 400 Gb/s (Duplex)

<table>
<thead>
<tr>
<th>1 Gb/s</th>
<th>Distance (m)</th>
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</thead>
<tbody>
<tr>
<td>1000BASE-LX</td>
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<tr>
<td>1000BASE-LX10</td>
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<tr>
<td>1000BASE-EX</td>
<td>40,000</td>
</tr>
<tr>
<td>1000BASE-ZX</td>
<td>70,000</td>
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</table>

<table>
<thead>
<tr>
<th>10 Gb/s</th>
<th>Distance (m)</th>
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<td>10GBASE-LR</td>
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<tr>
<td>10GBASE-LX4</td>
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</tr>
<tr>
<td>10GBASE-ER</td>
<td>40,000</td>
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<tr>
<td>10GBASE-ZR</td>
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<table>
<thead>
<tr>
<th>40 Gb/s</th>
<th>Distance (m)</th>
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<tbody>
<tr>
<td>40GBASE-LRL4</td>
<td>1,000</td>
</tr>
<tr>
<td>40GBASE-FR</td>
<td>2,000</td>
</tr>
<tr>
<td>40GBASE-LR4</td>
<td>10,000</td>
</tr>
<tr>
<td>40GBASE-ER4</td>
<td>40,000</td>
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</table>

<table>
<thead>
<tr>
<th>100 Gb/s</th>
<th>Distance (m)</th>
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<tbody>
<tr>
<td>100GBASE-DR</td>
<td>500</td>
</tr>
<tr>
<td>100GBASE-CWDM4</td>
<td>2,000</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>10,000</td>
</tr>
<tr>
<td>100GBASE-ER4</td>
<td>40,000</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>200 Gb/s</th>
<th>Distance (m)</th>
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</thead>
<tbody>
<tr>
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<td>2,000</td>
</tr>
<tr>
<td>200GBASE-LR4</td>
<td>10,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>400 Gb/s</th>
<th>Distance (m)</th>
</tr>
</thead>
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<tr>
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<td>2,000</td>
</tr>
<tr>
<td>400GBASE-LR8</td>
<td>10,000</td>
</tr>
</tbody>
</table>
Single-mode Options to 400 Gb/s (Parallel)

<table>
<thead>
<tr>
<th>Speed (Gb/s)</th>
<th>Distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 GBASE-PLR4</td>
<td>1,000</td>
</tr>
<tr>
<td>400 GBASE-DR4</td>
<td>500</td>
</tr>
<tr>
<td>100 GBASE-PSM4</td>
<td>500</td>
</tr>
<tr>
<td>200 GBASE-DR4</td>
<td>500</td>
</tr>
</tbody>
</table>

- Transceiver cost reduced
- These options allow breakout
  - Increases port density
100GBASE-PSM4 Breakout

- 8-Fiber MTP
- 24-Fiber MTP
- HDX Cassette
- 24-Fiber MTP
- HDX2 Cassette
- Duplex Fiber (LC)
- TX1, TX2, TX3, TX4
- RX1, RX2, RX3, RX4
- 72 Fiber
- ½ RU
- ½ RU
- 25 Gb/s
100GBASE-PSM4 by the Numbers

0.75 dB

HDX2 Cassette

0.2 dB @ 1310 nm

500 m (1640 ft.)

72 Fiber

0.75 + 0.75 + 0.2 + 0.5 = 1.45 dB

Increase your density further

Design = 1.45 dB

100GBASE-PSM4 ≤ 3.3 dB

0.50 dB

HDX2 Cassette

NECA • BICSI SUMMIT 2022
Greater Insertion Loss Allowed

• No longer a true statement
• With cheaper transceivers comes a reduced allowance for insertion loss
• Designers need to be aware of the reduced loss budget for the newer transceivers targeted at data centers
• If your design has multiple connections, you can run into trouble

<table>
<thead>
<tr>
<th>100 Gb/s Ethernet</th>
<th>Channel Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>100GBASE-ER4</td>
<td>15.0 dB</td>
</tr>
<tr>
<td>100GBASE-LR4</td>
<td>6.3 dB</td>
</tr>
<tr>
<td>100GBASE-CWDM4</td>
<td>5.0 dB</td>
</tr>
<tr>
<td>100GBASE-PSM4</td>
<td>3.3 dB</td>
</tr>
<tr>
<td>100GBASE-DR</td>
<td>3.0 dB</td>
</tr>
</tbody>
</table>
Return Loss (Reflectance)

• What is return loss?
  • It’s light reflected back into the transceiver
  • Caused by a change in refractive index (glass – air – glass)
  • At higher data rates, errors are generated if too much light is received back

• Putting an 8° angle on the end face results in the mode of light being forced back into the cladding rather than the transceiver
Return Loss (Reflectance) Concerns

• ANSI/TIA-568.3-D calls out connector return loss
• IEEE 802.3 (Ethernet) calls out reflectance for connections
• Measured using Optical Time Domain Reflectometers (OTDRs)
  • Calls out reflective events as reflectance
• Return loss or reflectance?
  • Practically speaking, they’re the same thing
  • Return loss is a positive number (e.g. 45 dB)
  • Reflectance is a negative number (e.g. -45 dB)
### Sensitive to Reflectance (Return Loss)

**100GBASE-DR**

Maximum channel insertion loss (dB)

<table>
<thead>
<tr>
<th>Maximum channel insertion loss (dB)</th>
<th>Number of connections where the reflectance is between -45 and -55 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Number of connections where the reflectance is between -35 and -45 dB</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
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<tr>
<td></td>
<td>3</td>
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<td>6</td>
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</table>

- Let’s take an example link containing four LC/MTP cassettes
- Single-mode MTPs are APC, so there will be four of those (typically > -55 dB)
- The four LCs are factory polished (typically >= -50 dB)
- We have no connections between -35 dB and -45 dB
- Our allowable loss will be 3.0 dB
### Sensitive to Reflectance (Return Loss)

**100GBASE-DR**

Maximum channel insertion loss (dB)

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<thead>
<tr>
<th>Number of connections where the reflectance is between -35 and -45 dB</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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- Let’s take an example link containing four LC/MTP cassettes
- Single-mode MTPs are APC, so there will be four of those (typically > -55 dB)
- The four LCs are factory polished (typically >= -50 dB)
- Future performance could be less than -45 dB
- Our allowable loss will be 2.7 dB
Uses Higher Powered Lasers

• Long haul versions only
• Class 1M lasers for
  • 100GBASE-DR
  • 100GBASE-PSM4
  • 100GBASE-CWDM4

A Class 1M laser is safe for all conditions of use except when passed through magnifying optics such as microscopes and telescopes.
Attenuators

• If the link is too short, the transmitted light could saturate the receiver
  • This is typically an issue associated with high power lasers only
  • The sort of lasers you find in outside plant such as cable tv
  • If the link is short, the designer will add an attenuator
  • Alternatively, a quick fix is to put a bend in the fiber and tape it in the cabinet/tray

• In the Data Center, low power Fabry–Pérot (FP) lasers are used
  • These lasers have a nominal output of -3 dBm

• Distributed Feedback Lasers can be found in CWDM4 transceivers
  • These lasers have a nominal output of 2.5 dBm

• IEEE typically specifies a minimum distance of 2.0 m (6.6 ft.)
  • This avoids any concerns over saturation
Your Design

100GBASE-PSM4 in a Switch to Switch Environment
8, 12, or 24 Fiber MPO?

These applications use 8 fibers:
- 40GBASE-PLR4
- 100GBASE-PSM4
- 200GBASE-DR4
- 400GBASE-DR4

- There is no such thing as an 8 fiber MPO
- The transceiver vendors typically use a 12 fiber MPO
- The 4 fibers in the middle are left unused
- Can lead to an inefficient cabling system
100GBASE-PSM4 Efficient Design

- 8-Fiber MTP
- 24-Fiber MTP
- HDX Cassette
- 144 Fiber
100GBASE-PSM4 Efficient Design

0.75 dB

0.2 dB @ 1310 nm

500 m (1640 ft.)

144 Fiber

0.75 dB + 0.2 dB + 0.75 dB = 1.7 dB

100GBASE-PSM4 ≤ 3.3 dB

Design = 1.7 dB ✓
Take-aways

• Cost of data center single-mode transceivers are being driven down
• PSM4 over MPO links allows breakout to LCs for increased density
• Conversion cassettes provide an efficient design
• Single-mode distances low as 500 m, transceiver dependent
• Loss budgets on single-mode have been reduced
• Return loss (reflectance) can impact your loss budget further
Agenda – Plan Ahead for Greater Efficiency

• Inspection and Cleaning
  • What Camera tips will you need?

• Loss Testing
  • What limit will you use?
  • What are your Cable Identification numbers/sequence
  • Set reference – Process for reliable results

• Troubleshooting with OTDR (briefly!)

• Results Management
Inspection and Cleaning

Repeat as Needed
Inspect, Clean, Repeat

Video Microscope

Multimode has a larger core

Single Mode has a smaller Core
Inspecting APC Connectors - Compensate for the Angle

- Same cleaning equipment – new camera tips

APC – Angled Physical Contact
Tips Have a Slight Angle - These are SC
APC Connectors May Need a “Twist” to Show Up
Single-mode MPO Connectors Also Need an Adapter
Loss Testing

Tier I Testing: Loss, Length and Polarity is Used to Confirm What Applications Will be Supported on a Fiber Link
What Limits and Cable IDs Will You Use?

• What does your contract/end-user require?
  • Length based limits (TIA-568.3-D) or Application or a fixed value?

• Preload test limit
  • How many adapters? How many splices? What values?

• Preload cable IDs
  • D3.DK110.43/E5.AM564.20.032 takes time to type into a tester
    • And more time to correct it after words

• Both on tester and remotely
  • Cloud service to update tester in the field?
Tier 1 (OLTS) Certification

• Test Reference Cords (TRCs) are recommended in ANSI/TIA and ISO/IEC
• Patch cords from a distributor are specified with a loss of up to 0.50 dB

ANSI/TIA-526-14-C & IEC 61280-4-1
≤ 0.10 dB

ANSI/TIA-526-7-A & IEC 61280-4-2
≤ 0.20 dB
Tech Tip

• Before setting a reference, allow cords to relax
• Helps remove the bend from the cords
For the Most Accurate Measurement

- Use a 1 Jumper Reference
  - This provides the least measurement uncertainty
  - Do you have the right adapter for the power port?
- Do you bring the right cords?
- Are they in good condition?

Direct connection (No bulkhead adapter!)
First Set a Reference.. Then Find the Difference

Direct connection
(No bulkhead adapter!)

The difference is what we want to know

Loss (dB)
After Setting the Reference

- Remove the cords from the power meter port - this is allowed
- There is no physical contact/alignment at the power meter

APC Connector can also be used
Insert Known Good Test Reference Cords

• But how do you know they are good?
• You can start by inspecting them........
Tester Reference Cord Verification

- Connect the testers together
- Run an optical loss test

**Tip:** Save the result as proof of good test reference cords

For single-mode $\leq 0.25$ dB
For multimode $\leq 0.15$ dB
Connect to Link to be Tested

- Measure at both wavelengths
  - Multimode – 850 nm & 1300 nm
  - Single-mode – 1310 nm and 1550 nm
Testing at Two Wavelengths? Why?

Typically, more loss @ 1310 nm

But can be more at 1550 nm?

When there is a bend or crack in the fiber......
Troubleshooting

• Optical Time Domain Reflectometer (OTDR)
• Are you an expert with traces?
• Leverage the expert in the tester
  • Here we can see the Bend or Crack in the fiber
  • And here is the distance to the end of the fiber

Tip: Make sure you have the correct launch fiber
Testing MPO Trunk Cables

• Most links will be terminated with a cassette
• But if you have to test MPO trunk cables………
• Option 1:

Traditional duplex field tester
Testing MPO Trunk Cables

• Most links will be terminated with a cassette
• But if you have to test MPO trunk cables………
• Option 2:

Dedicated MPO field tester
Results Management
Leverage a Cloud Service
Check the Results Every Day - While Your Team is Still at the Job Site

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Protect Your Results

• Ways to lose results:
  • Accidental deletion of results
  • Damage to tester
  • Theft of tester
  • Returned to rental company before downloading results
  • ...........
Manage Your Project

- **Project Manager** can track job progress anytime.
- **Technician** can download test setups and cable IDs on the tester in the field.
- **Technician** can upload test results from the job site.
- **Asset Manager** can track last used location, software version, and calibration status.
- **Project Manager** can setup the tester remotely.
- **Reports Administrator** can download test results.

Cloud Based Storage Site
Conclusions for Single-mode Testing

• Testing is time well spent
• Plan ahead, do it correctly the first time
• Inspect and clean if necessary – repeat as needed
• Know the test limit you are required to pass
• Know which connector types you will be working with
• Use a one jumper reference and check the TRCs
• Use an OTDR for troubleshooting
• Leverage Cloud Based Tester Configuration and Results management - check your teams work every day
Thank you

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