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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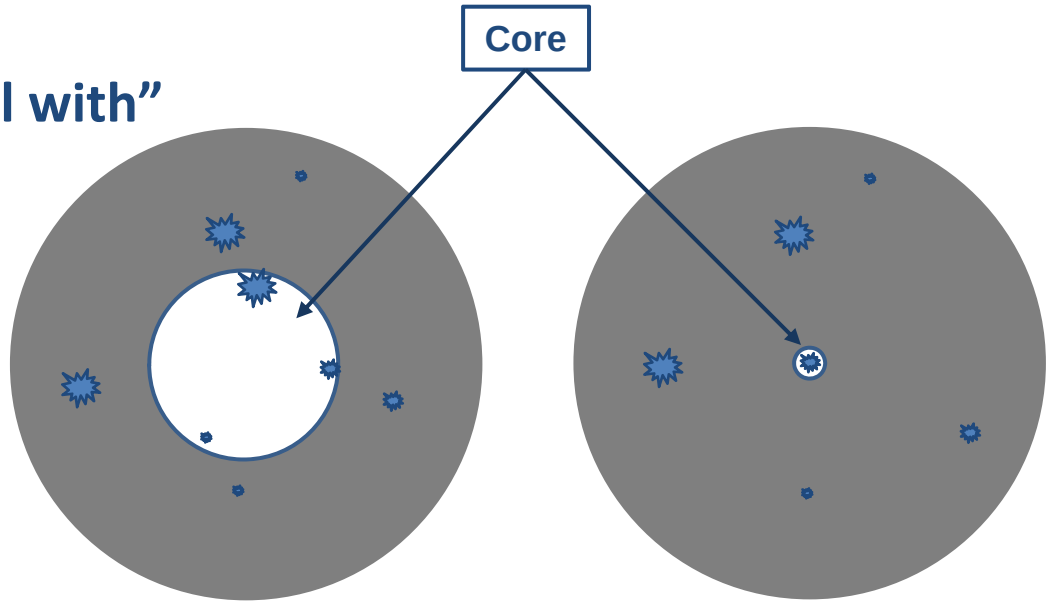
Traditional thoughts on single-mode

- **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

Multimode Cable Type	100GBASE-SR4
OM1	Not supported
OM2	Not supported
OM3	70 m
OM4	100 m
OM5	100 m

Single-Mode Cable Type	100GBASE-DR
OS1a	500 m
—	—
—	—
—	—
OS2	500 m

- If you installed OS1a back in 1999 or OS2 today in 2018, 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)

1 Gb/s	Distance (m)
1000BASE-LX	5,000
1000BASE-LX10	10,000
1000BASE-EX	40,000
1000BASE-ZX	70,000

10 Gb/s	Distance (m)
10GBASE-LR	10,000
10GBASE-LX4	10,000
10GBASE-ER	40,000
10GBASE-ZR	80,000

40 Gb/s	Distance (m)
40GBASE-LRL4	1,000
40GBASE-FR	2,000
40GBASE-LR4	10,000
40GBASE-ER4	40,000

100 Gb/s	Distance (m)
100GBASE-DR	500
100GBASE-CWDM4	2,000
100GBASE-LR4	10,000
100GBASE-ER4	40,000

200 Gb/s	Distance (m)
200GBASE-FR4	2,000
200GBASE-LR4	10,000

400 Gb/s	Distance (m)
400GBASE-FR8	2,000
400GBASE-LR8	10,000

Single-mode options to 400 Gb/s (Parallel)

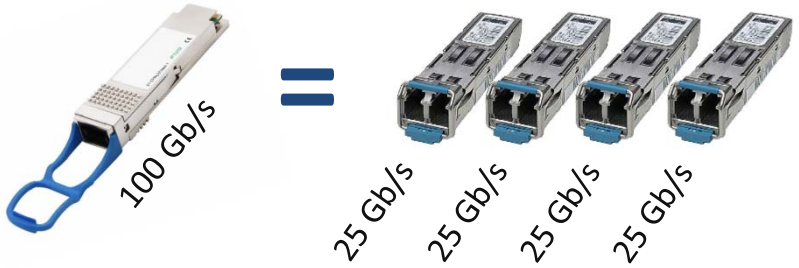
40 Gb/s	Distance (m)
40GBASE-PLR4	1,000

100 Gb/s	Distance (m)
100GBASE-PSM4	500

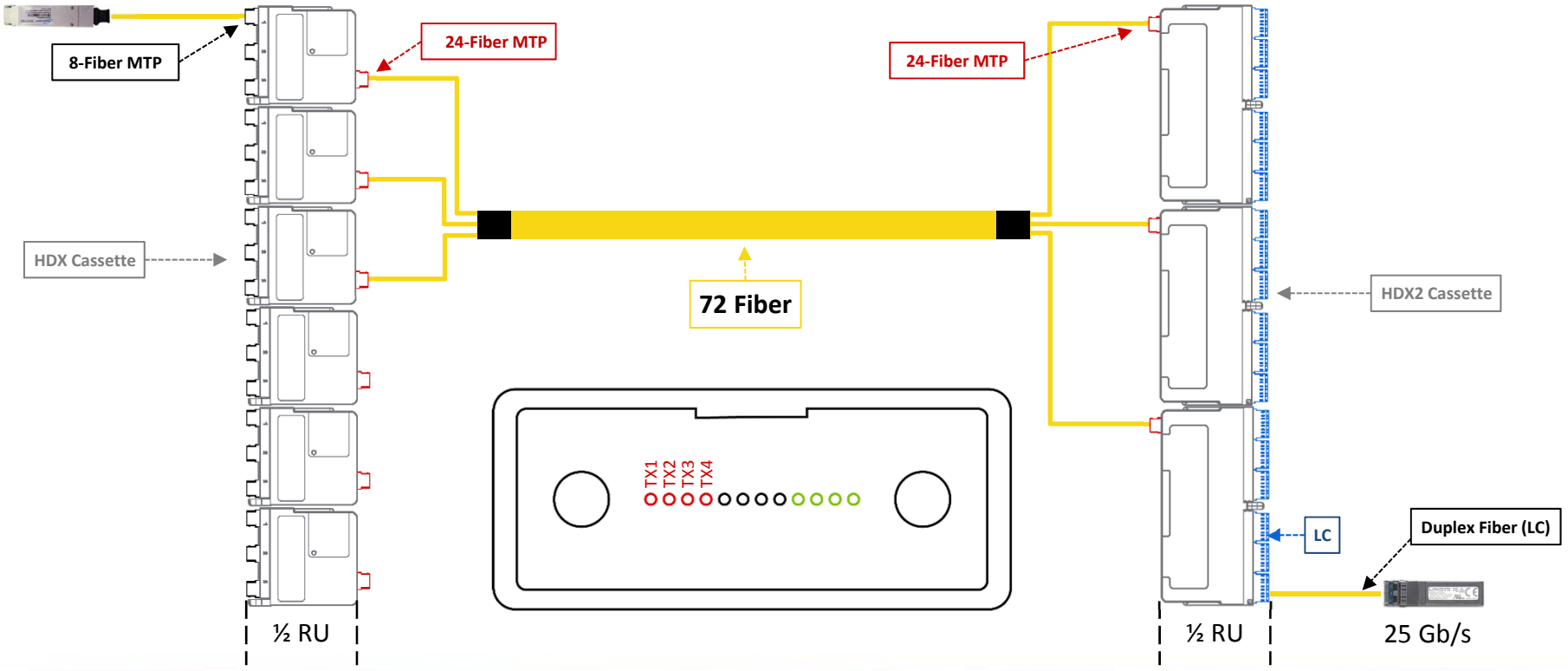
200 Gb/s	Distance (m)
200GBASE-DR4	500

400 Gb/s	Distance (m)
400GBASE-DR4	500

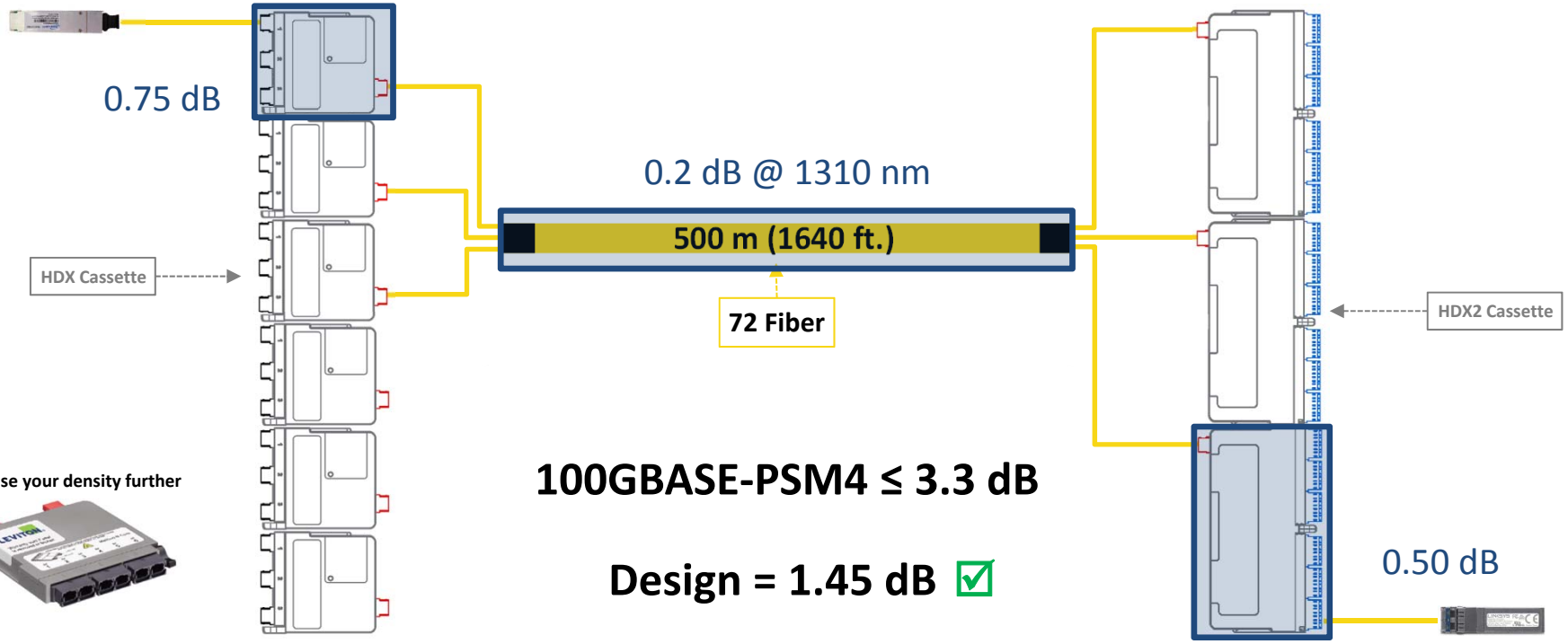
- Transceiver cost reduced
- These options allow breakout
  - Increases port density



100GBASE-PSM4 breakout



100GBASE-PSM4 by the numbers



Increase your density further

100GBASE-PSM4 ≤ 3.3 dB

Design = 1.45 dB ☑

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

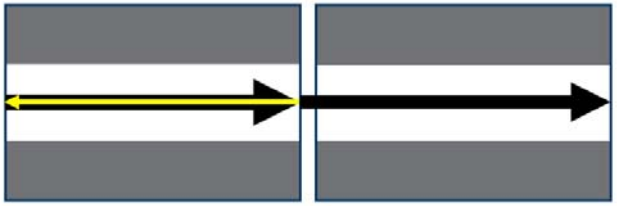
100 Gb/s Ethernet	Channel Loss
100GBASE-ER4	15.0 dB
100GBASE-LR4	6.3 dB
100GBASE-CWDM4	5.0 dB
100GBASE-PSM4	3.3 dB
100GBASE-DR	3.0 dB

- If your design has multiple connections, you can run into trouble

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



Physical Contact (PC)

Angled Physical Contact (APC)

- 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)
  - Call out reflective events as reflectance
- **Return loss or reflectance?**
  - Practically speaking, they're the same thing
  - Return loss is a positive number (45 dB)
  - Reflectance is a negative number (-45 dB)

Sensitive to reflectance (return loss)

100GBASE-DR

Maximum channel insertion loss (dB)

Number of connections where the reflectance is between -35 and -45 dB	Number of connections where the reflectance is between -45 and -55 dB								
	0	1	2	3	4	5	6	7	8
0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	**3.0**
1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
2	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9
3	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	—
4	2.8	2.8	2.8	2.8	2.7	2.7	2.7	—	—
5	2.8	2.8	2.7	2.7	2.7	2.6	—	—	—
6	2.6	2.6	—	—	—	—	—	—	—

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
- So our allowable loss will be **3.0 dB**

Sensitive to reflectance (return loss)

100GBASE-DR

Maximum channel insertion loss (dB)

Number of connections where the reflectance is between -35 and -45 dB	Number of connections where the reflectance is between -45 and -55 dB								
	0	1	2	3	4	5	6	7	8
0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
2	3.0	3.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9
3	2.9	2.9	2.9	2.9	2.9	2.8	2.8	2.8	—
4	2.8	2.8	2.8	2.8	**2.7**	2.7	2.7	—	—
5	2.8	2.8	2.7	2.7	2.7	2.6	—	—	—
6	2.6	2.6	—	—	—	—	—	—	—

Let's take another example of a 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
- So our allowable loss would be **2.7 dB**

Uses higher powered lasers

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

Fiber Scope
(Built in filter)

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

LASER RADIATION

DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 1M LASER PRODUCT

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 laser have a nominal output of 2.5 dBm
- IEEE typically specifies a minimum distance of 2.0 m (6.6 ft.)

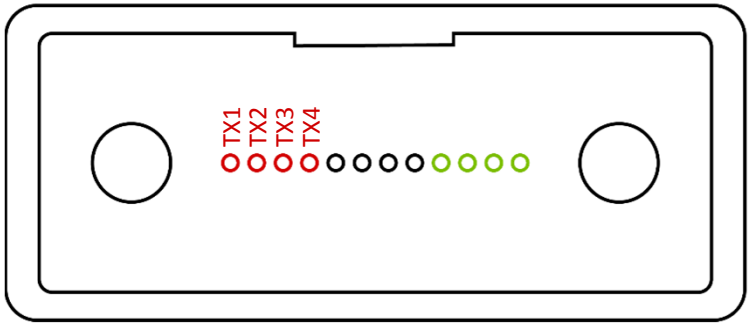
100GBASE-PSM4 in a switch to switch environment

Your Design

8, 12, or 24 fiber MPO?

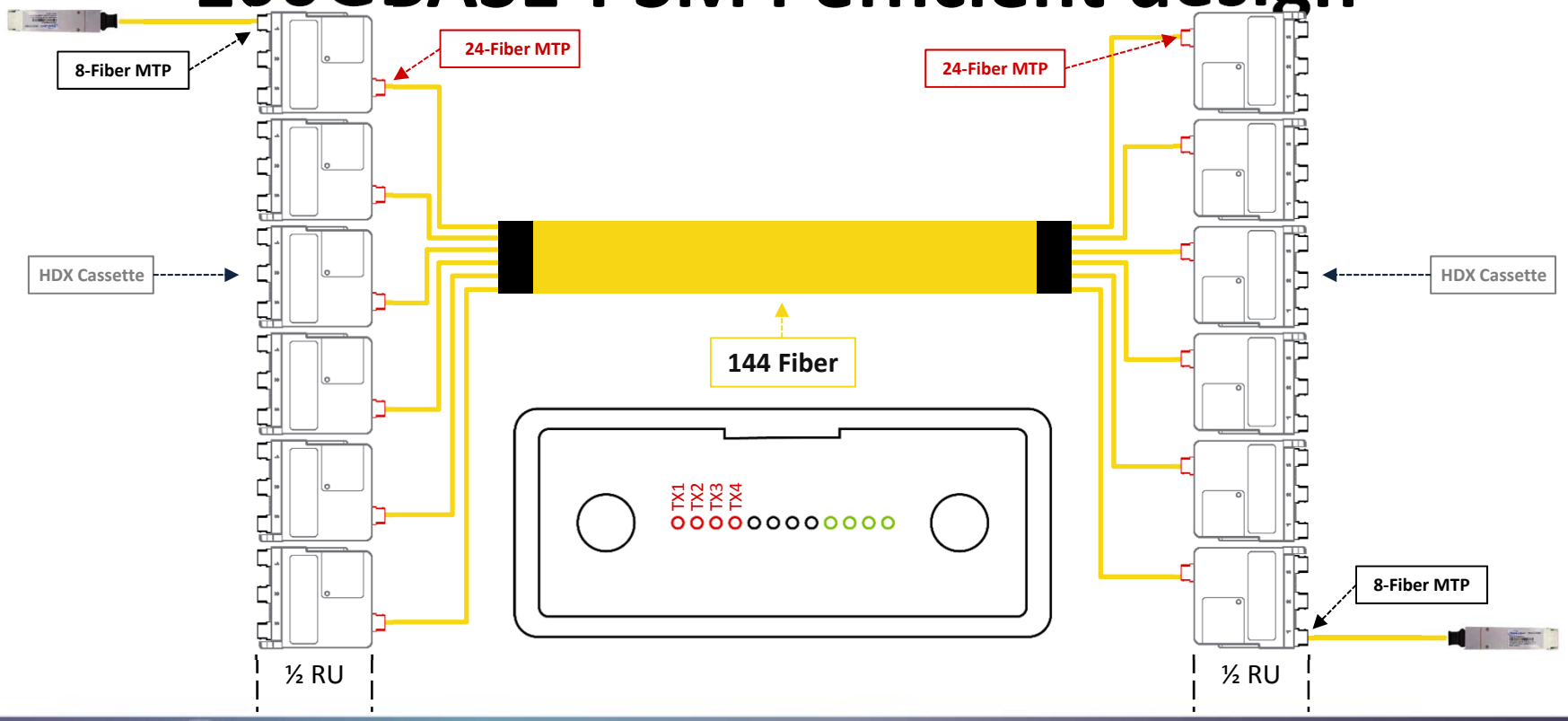
These applications use 8 fibers:

- 40GBASE-PLR4
- 100GBASE-PSM4
- 200GBASE-DR4
- 400GBASE-DR4

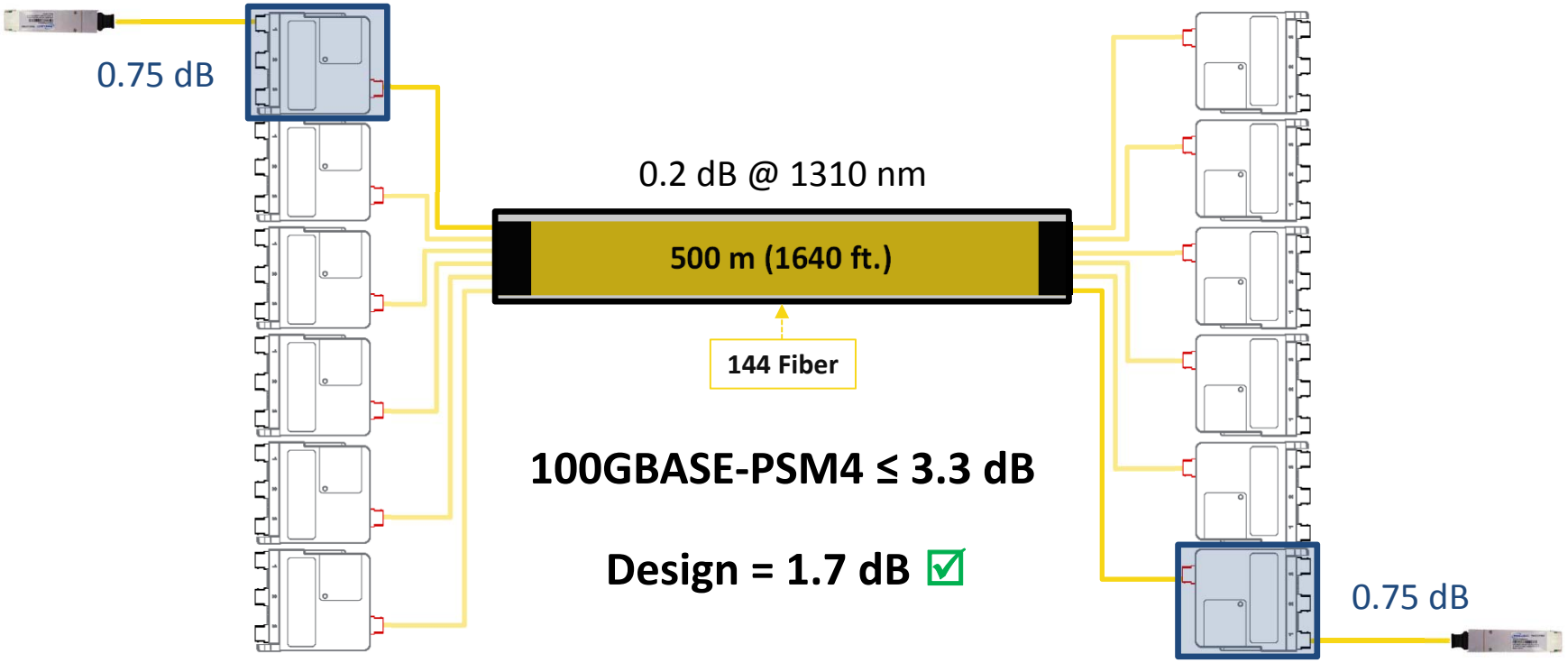


- There is no such thing as an 8 fiber MPO
- The transceiver vendors use a 12 fiber MPO
- The 4 fibers in the middle are left unused
- Can lead to an inefficient cabling system

100GBASE-PSM4 efficient design



100GBASE-PSM4 by the Numbers



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

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Single-Mode Testing

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Agenda

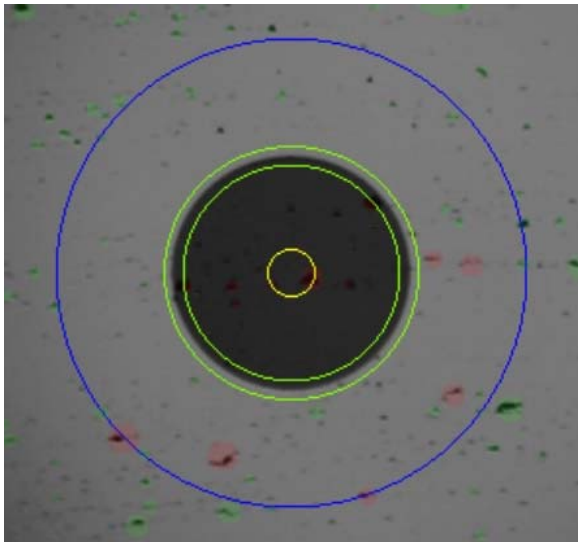
- **Inspection and Cleaning**
- **Loss Testing**
  - Set reference – find the difference
  - Options for MPO cables
    - Tester with MPO Port
    - Three jumper reference
- **How to Read Test Results**

Repeat as needed

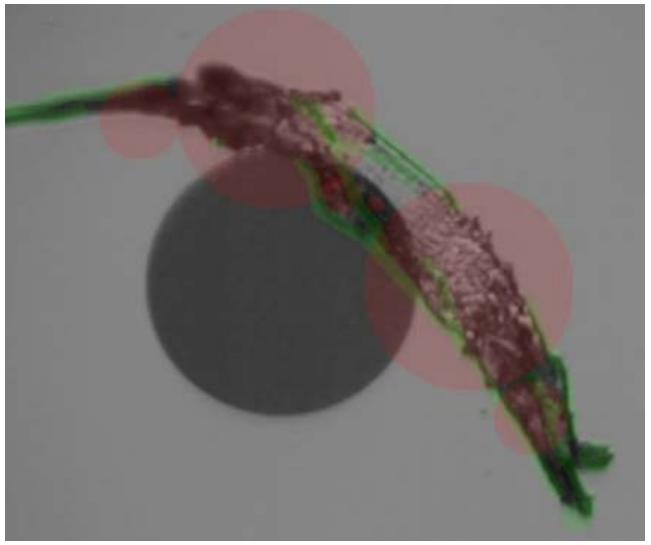
Inspection and Cleaning

Inspect, Clean, Repeat

Video Microscope



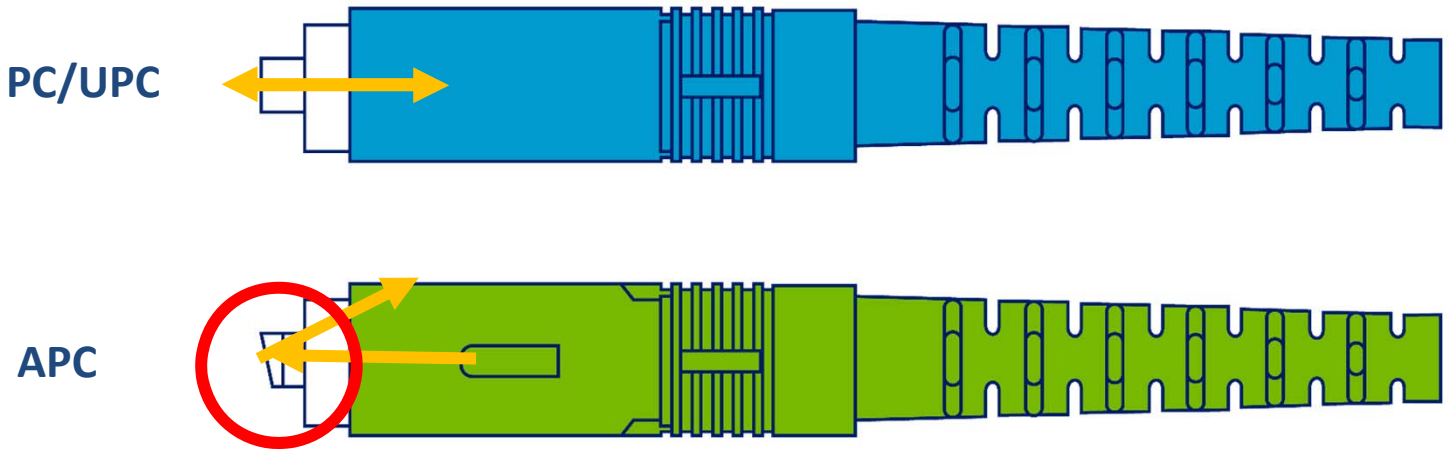
Brand new out of bag



After Cleaning 🙄

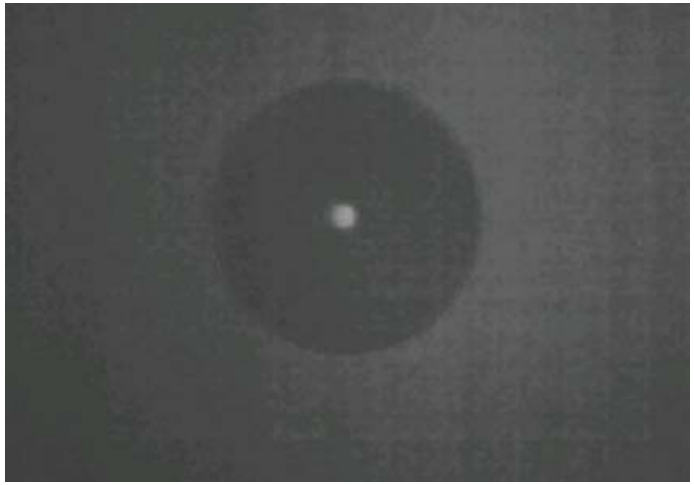
Inspecting APC Connectors — Compensate for Angle

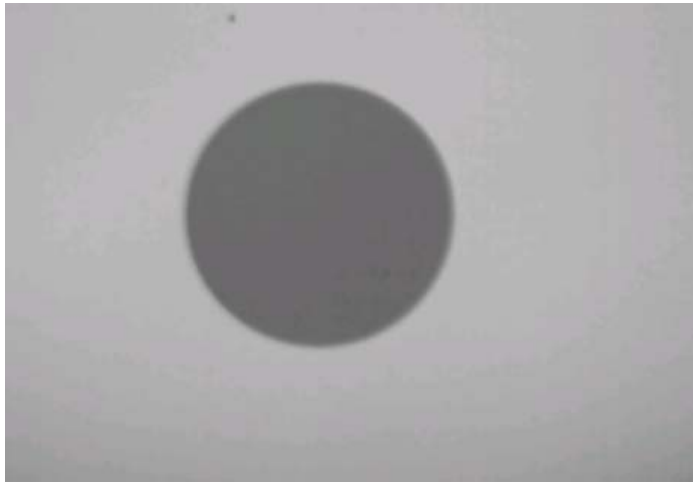
- Same cleaning equipment – new camera tips

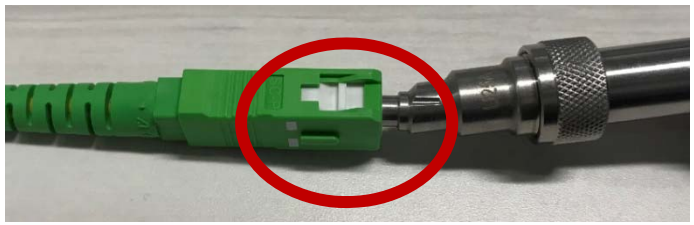


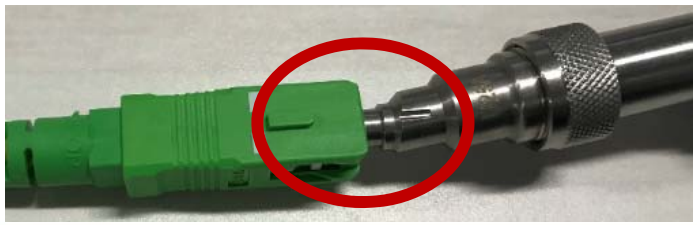
APC Tips Have a Slight Bend — These are SC

APC Connectors May Need a “Twist” to Show Up

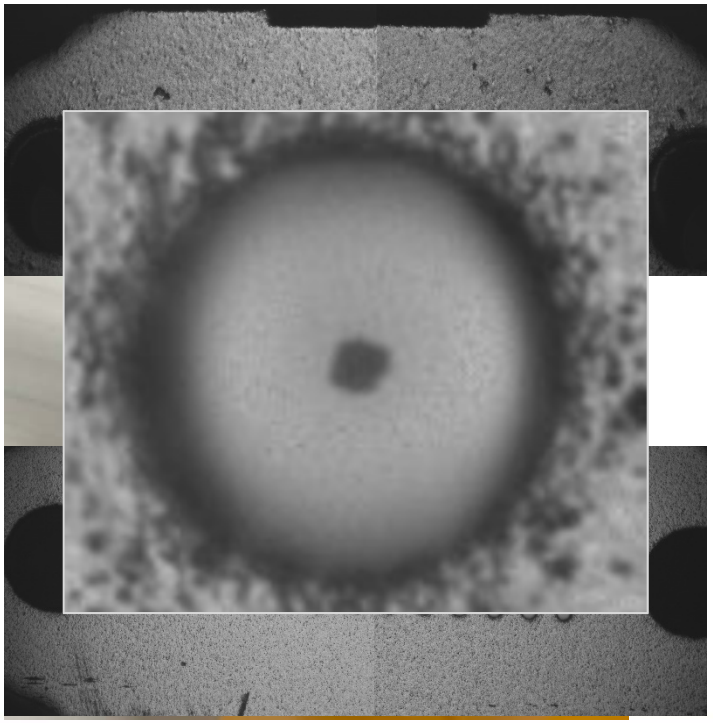






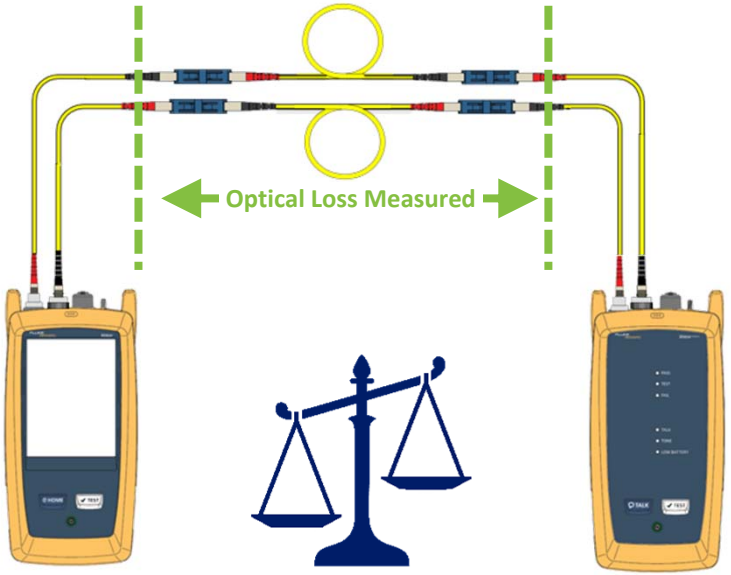


Single-mode MPO connectors also need an adapter



Loss Testing

First Set a Reference > Then Find the Difference



All connections are included in the loss measurement

Tier 1 (OLTS) Certification

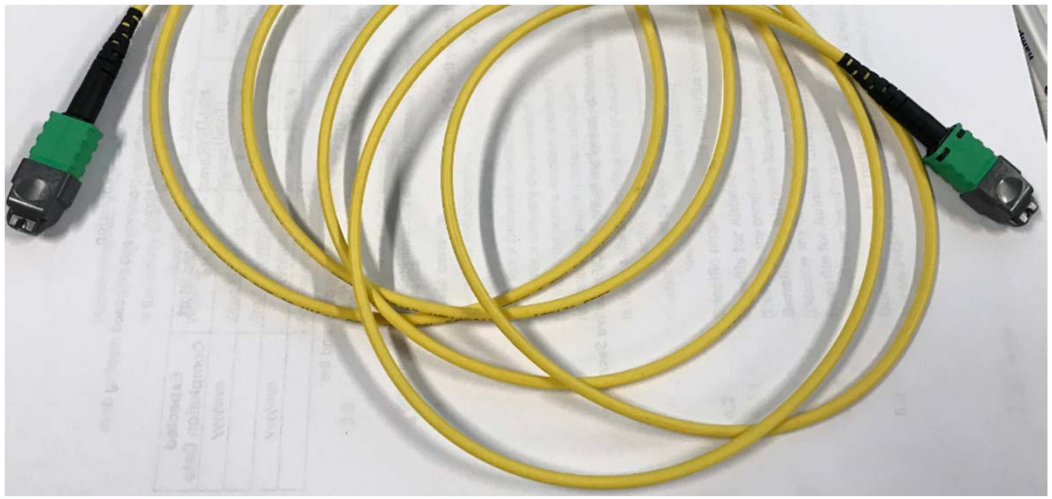
- Test Reference Cords (TRCs) are a requirement in ANSI/TIA and ISO/IEC
- Patch cords from a distributor are specified with a loss of up to 0.50 dB

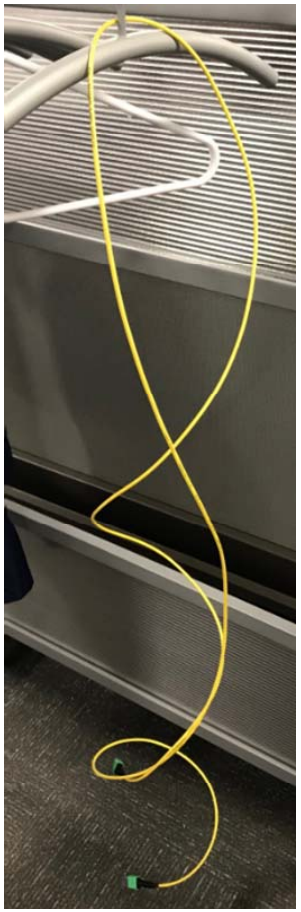
- Test Reference Cords per ANSI/TIA and ISO/IEC
  - Multimode Loss ≤ 0.10 dB
  - Single-mode Loss ≤ 0.20 dB

Tech Tip

Before setting a reference, allow cords to relax

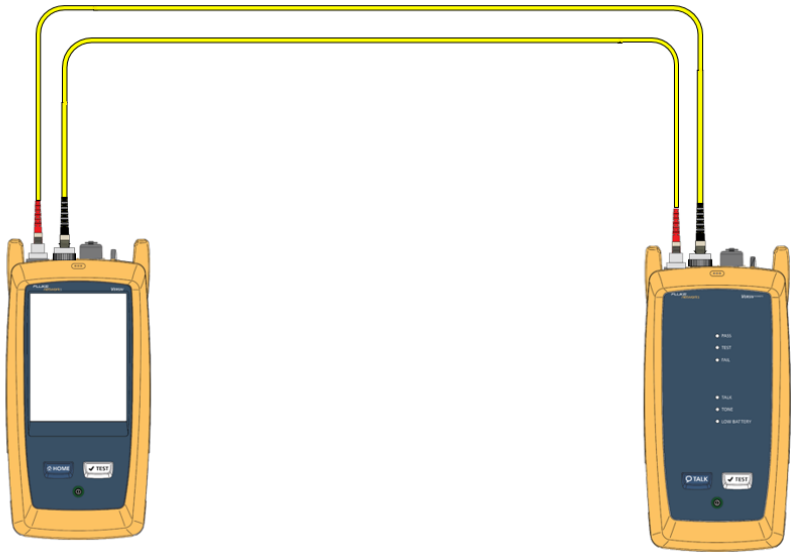
- Helps remove the bend from the cords



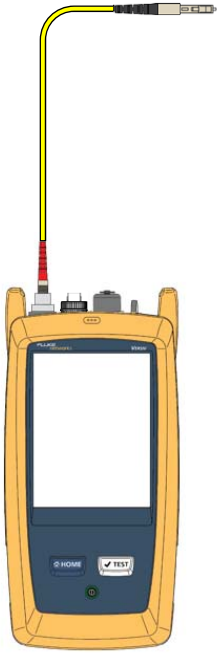


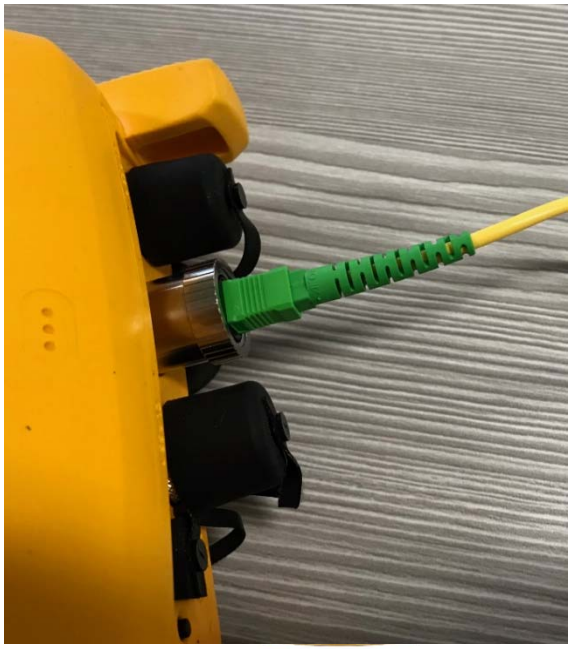
For Most Accurate Measurement, Use 1 Jumper Reference (This Provides the Least Uncertainty)

- Power meter requires a variable adapter to match port on fiber patch panel
- Check your manufacturers specification for valid reference values
- Reference Grade Test Reference Cords (TRC)



Then Remove Cords from Power Meter

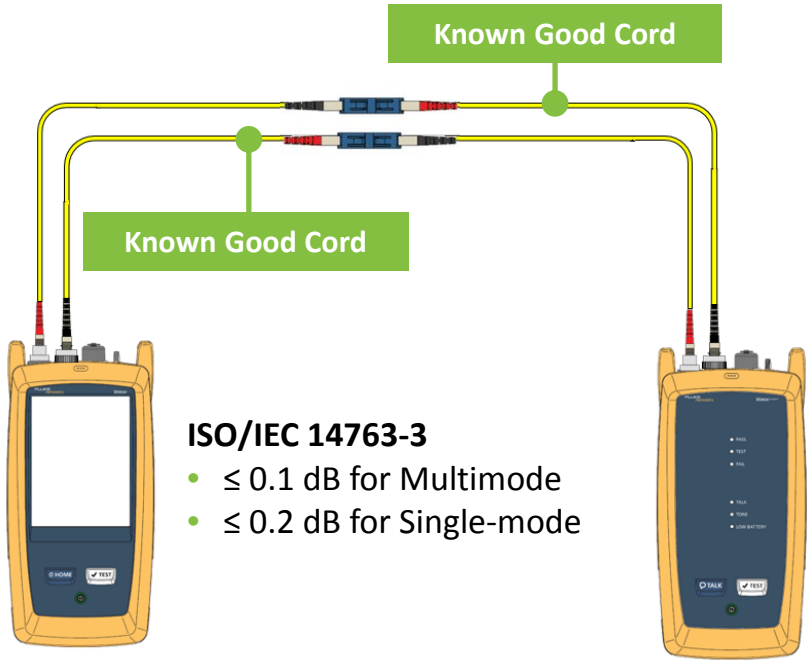




- There is no physical contact/ alignment at the power meter – APC Connector can also be used

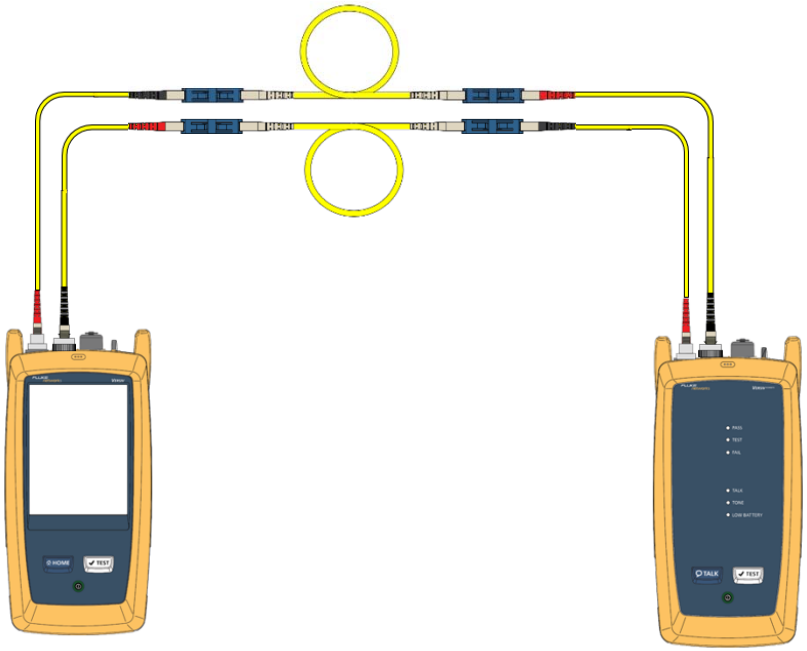
TRC Verification

- Connect the “Known Good” leg using a single-mode adapter and measure the loss
- Loss should be ≤ 0.25 dB
- **Save this test**



Insert the Link to be Tested

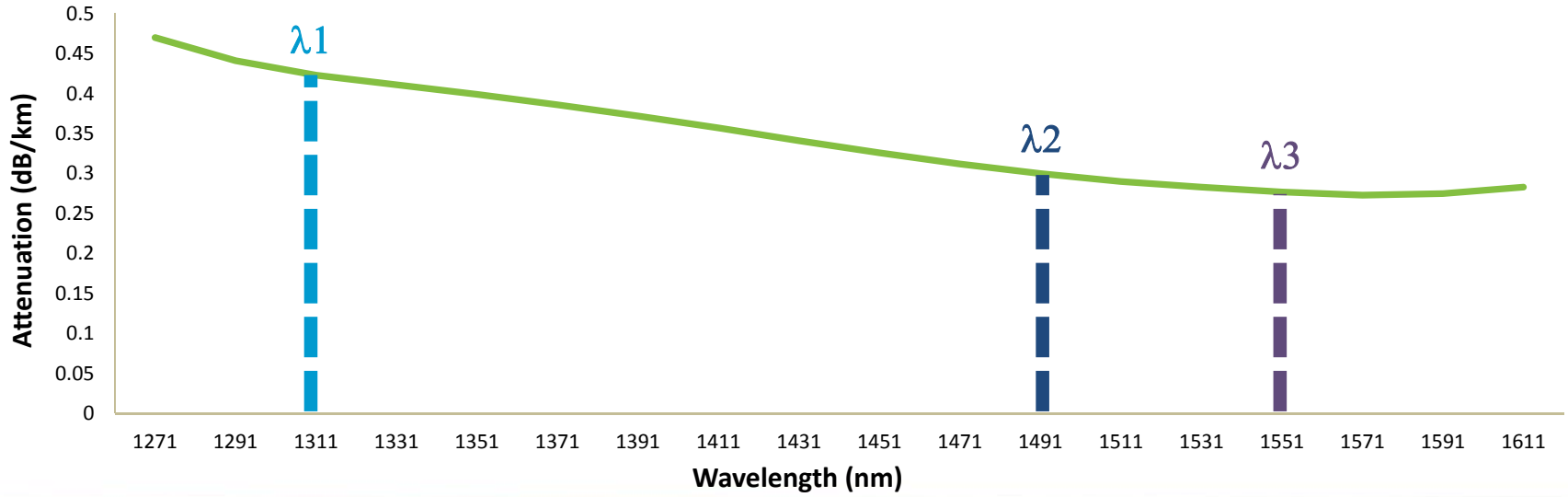
- Pass or Fail results depend on the limit selected
- Test at two wavelengths 1310 nm and 1550 nm



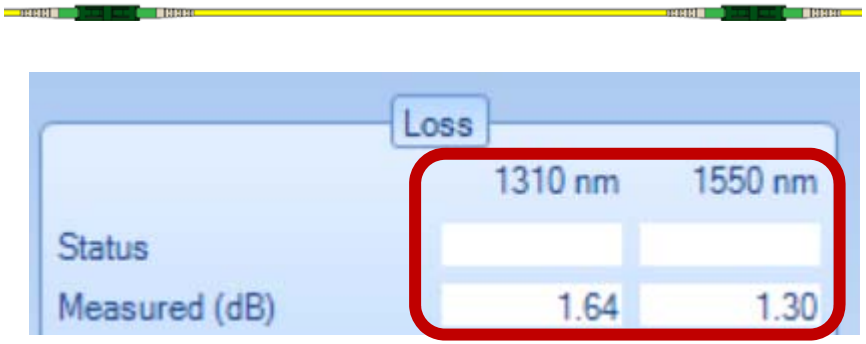
Bend Detection and Future Proofing

Wavelengths are “bound”

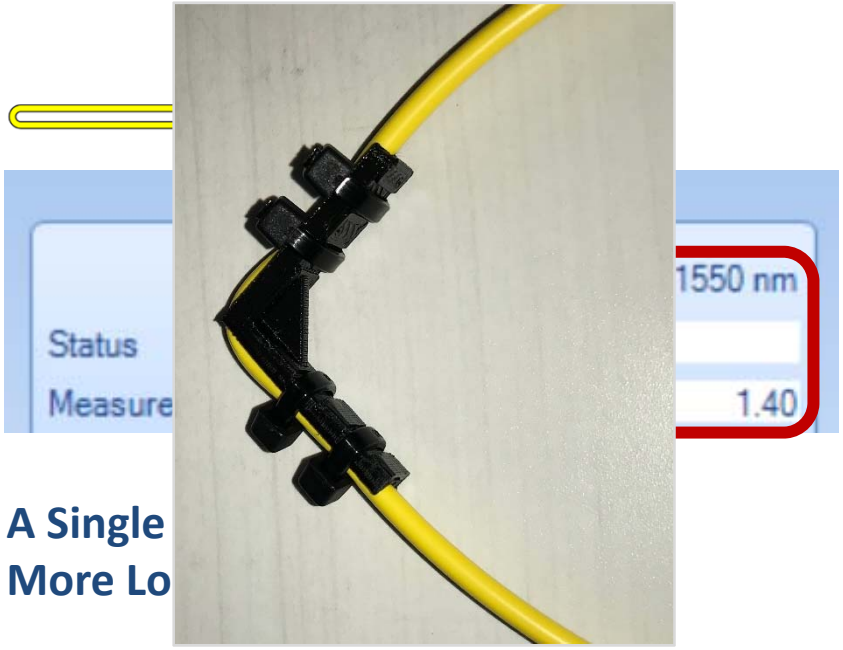
- If 1310 nm and 1550 nm pass, the others wavelengths will pass



A Quick Study of Testing at Two Wavelengths



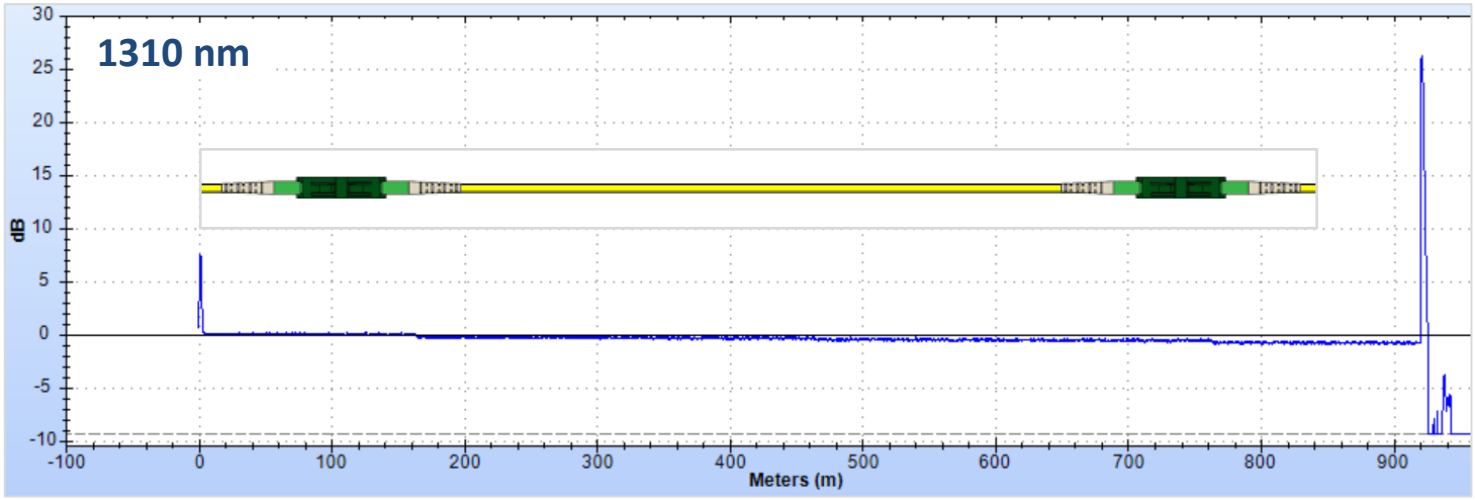
A Single Fiber Link
More Loss at 1310 than 1550



A Single
More Lo

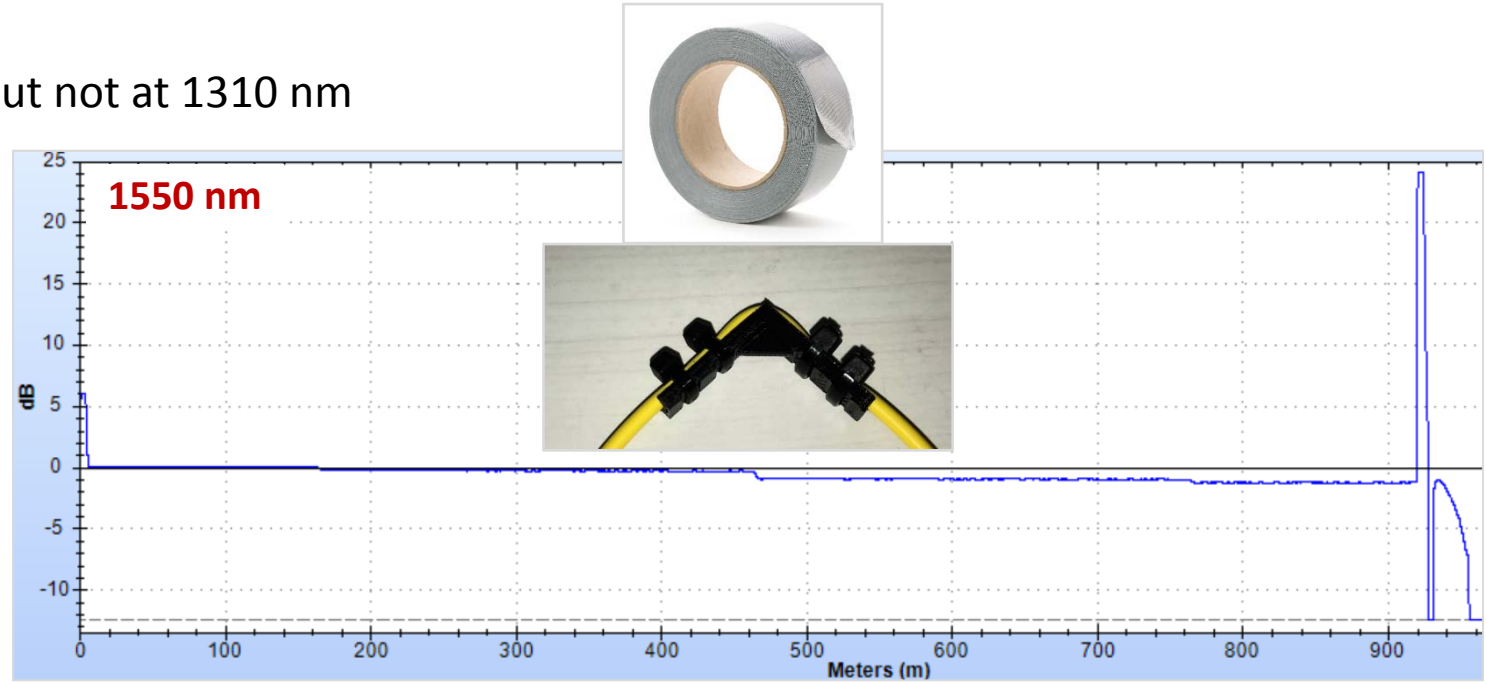
OTDR Trace Shows Location of Bend

- But not at 1310 nm

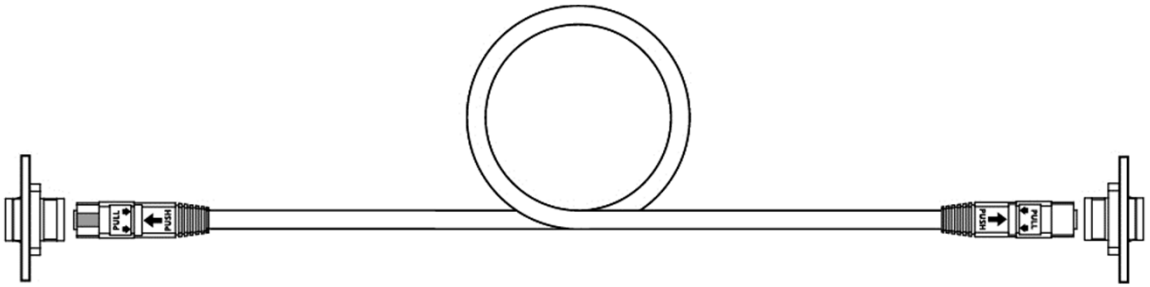


OTDR Trace Shows Location of Bend

- But not at 1310 nm



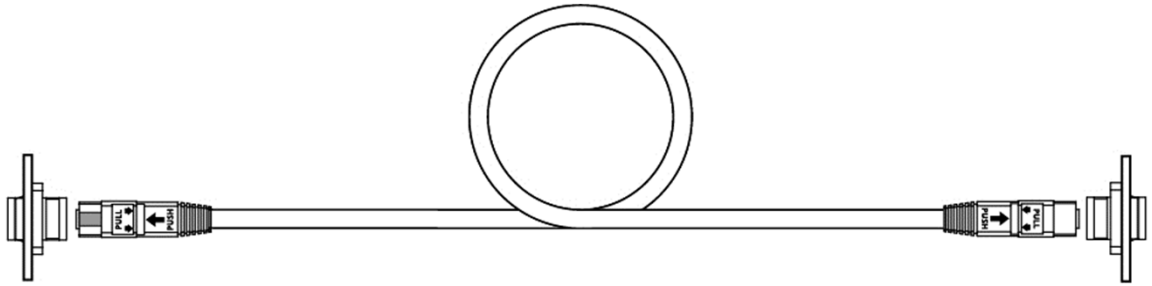
MPO/MTP Testing with OLTS

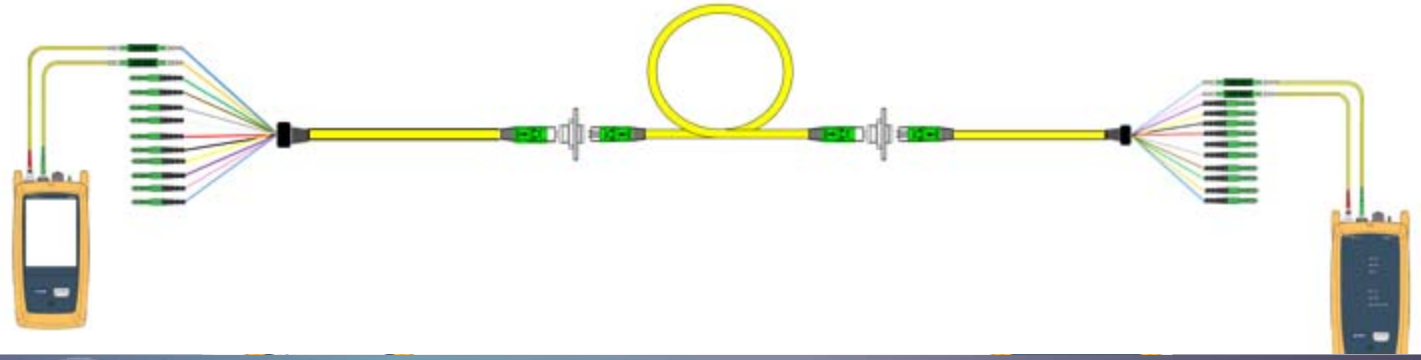


Two Options for Testing MPO to MPO Cables

MPO/MTP Testing with OLTS

3 Jumper Reference



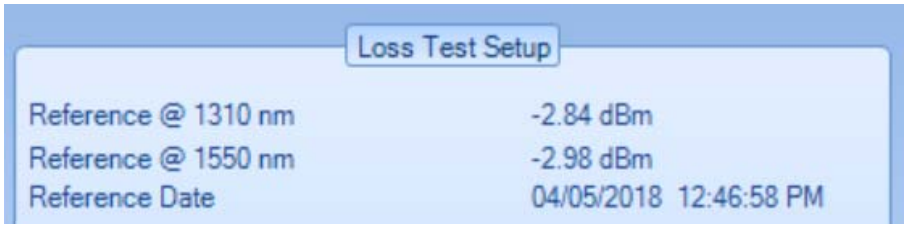


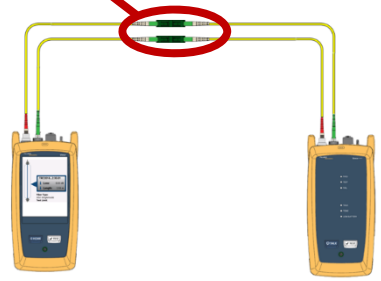
How to Tell 3 Jumper Reference is Set Properly

Very important for end user

- Look for **two** TRC Verifications in test results

	Cable ID	Date / Time:	Status	Length(m)	Headroom	Info	Test Limit
1	TRC20180405:12:46:10.01	04/05/2018 12:46:09 PM	N/A	2.6	0.09 (Loss Value)		TRC Limit
2	TRC20180405:12:46:10.02	04/05/2018 12:46:09 PM	N/A	2.6	0.15 (Loss Value)		TRC Limit
3	TRC20180405:12:52:30.01	04/05/2018 12:52:30 PM	N/A	2.5	0.03 (Loss Value)		TRC Limit
4	TRC20180405:12:52:30.02	04/05/2018 12:52:30 PM	N/A	2.5	0.04 (Loss Value)		TRC Limit
5	MPO OLTS DEMO 1a	04/05/2018 01:07:17 PM	PASS	104.8	0.35 (Loss Value)		TIA-568.3-D Singlemode ISP (STD Grade)
6	MPO OLTS DEMO 1b	04/05/2018 01:07:17 PM	PASS	104.8	0.64 (Loss Value)		TIA-568.3-D Singlemode ISP (STD Grade)



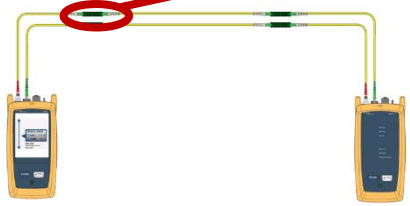


How to Tell 3 Jumper Reference is Set Properly

Very important for end user

- Second step – check 2nd TRC and reset reference

	Cable ID	Date / Time:	Status	Length(m)	Headroom	Info	Test Limit
1	TRC20180405:12:46:10.01	04/05/2018 12:46:09 PM	N/A	2.6	0.09 (Loss Value)		TRC Limit
2	TRC20180405:12:46:10.02	04/05/2018 12:46:09 PM	N/A	2.6	0.15 (Loss Value)		TRC Limit
3	TRC20180405:12:52:30.01	04/05/2018 12:52:30 PM	N/A	2.5	0.03 (Loss Value)		TRC Limit
4	TRC20180405:12:52:30.02	04/05/2018 12:52:30 PM	N/A	2.5	0.04 (Loss Value)		TRC Limit
5	MPO OLTS DEMO 1a	04/05/2018 01:07:17 PM	PASS	104.8	0.35 (Loss Value)		TIA-568.3-D Singlemode ISP (STD Grade)
6	MPO OLTS DEMO 1b	04/05/2018 01:07:17 PM	PASS	104.8	0.64 (Loss Value)		TIA-568.3-D Singlemode ISP (STD Grade)



Loss Test Setup

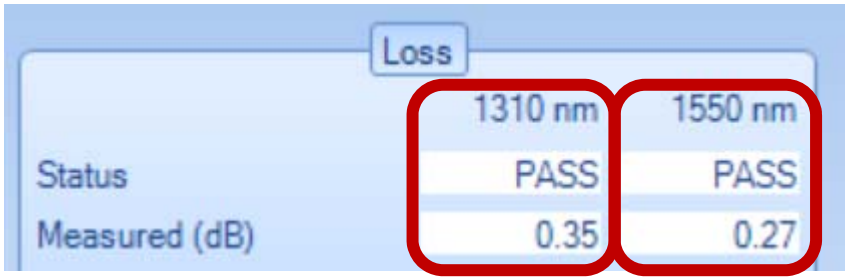
Reference @ 1310 nm	-2.84 dBm
Reference @ 1550 nm	-2.98 dBm
Reference Date	04/05/2018 12:46:58 PM

Testing MPO to MPO Cables

	Cable ID	Date / Time:	Status	Length(m)	Headroom	Info	Test Limit
	TRC20180405:12:46:10.01	04/05/2018 12:46:09 PM	N/A	2.6	0.09 (Loss Value)		TRC Limit
	TRC20180405:12:46:10.02	04/05/2018 12:46:09 PM	N/A	2.6	0.15 (Loss Value)		TRC Limit
	TRC20180405:12:52:30.01	04/05/2018 12:52:30 PM	N/A	2.5	0.03 (Loss Value)		TRC Limit
	TRC20180405:12:52:30.02	04/05/2018 12:52:30 PM	N/A	2.5	0.04 (Loss Value)		TRC Limit
	MPO OLTS DEMO 1a	04/05/2018 01:07:17 PM	PASS	104.8	0.35 (Loss Value)		TIA-568.3-D Singlemode ISP (STD
	MPO OLTS DEMO 1b	04/05/2018 01:07:17 PM	PASS	104.8	0.64 (Loss Value)		TIA-568.3-D Singlemode ISP (STD

A Closer Look at the Results

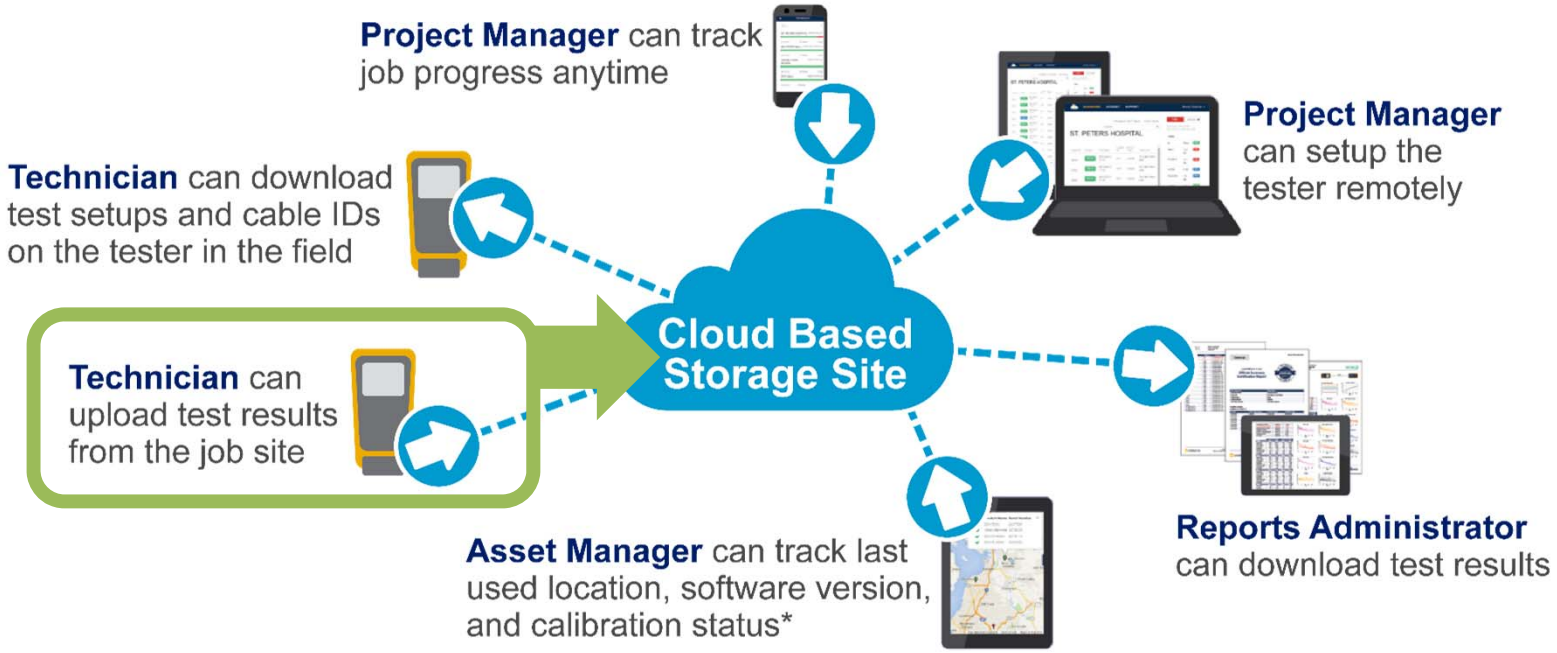
Here we see the drill down of the loss for this specific fiber in the MPO connection



- At 1310 nm we have 0.35 dB
- At 1550 nm we have 0.27 dB
- We expect more loss at 1310 than 1550 as 1310 has more loss per KM than 1550

Results Management

Send Test Results to the Cloud the Same Day You Test



Conclusions for Single-Mode Testing

Inspect and clean if necessary – repeat as needed

Loss testing assures the amount of light coming out of the fiber

- Consider TIA or a custom limit based on application
- Measure two wavelengths for bend detection
- Set a one jumper reference
- Three jumper reference for MPO testing with OLTS
- Look for results of “known good” TRC

Consider Cloud based results management

Thank you