10GBASE-LRM Interoperability Report

with Supplementary Material in Response to Questions and Comments

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Overview

- Recap October interoperability report with minor clarifications
- Provide additional information on channels tested
  - Extensive details on fiber characteristics with references
  - Rational for selection of specific fibers used in testing
  - Justification for fiber shaker design and location in link
- Review of 10GbE Interop precedents
- Directly address specific questions and concerns
- Summarize results

Recap of Interop Report from October Interim

Interoperability / Technical Feasibility Goals

- To confirm experimentally the feasibility of the 10GBASE-LRM 1310nm serial PMD using multiple vendor's implementations
- Demonstration of compliance / path to compliance to 10GBASE-LRM clause 68 specifications
  - Parameter measurements and limits based on IEEE P802.3aq D2.3 specification (unless otherwise noted)
- An interoperability test using 10GBASE-LRM implementations with 2^{31}-1 PRBS data
- Provide the Task Force data to support response to Motion #3 from November 2004 meeting:
  - *Move that IEEE 802.3aq demonstrate a 10^{-12} BER over the rated distance on a specified channel (TBD) and show interoperability between PMD's of at least three vendors for 10GBASE-LRM to support technical feasibility prior to sponsor ballot.*

Interoperability Test Description

- Four independent 10GBASE-LRM PMA/PMD implementations
- Vendor A, B, C and D MDI's connected over a range of 50um and 62.5um fiber types operating at the 10GBASE-R rate
  - LRM specification is 220m length with min. OFL BW = 500MHz·km for OM1 and OM2
  - The test fibers identified below are all 300m in length

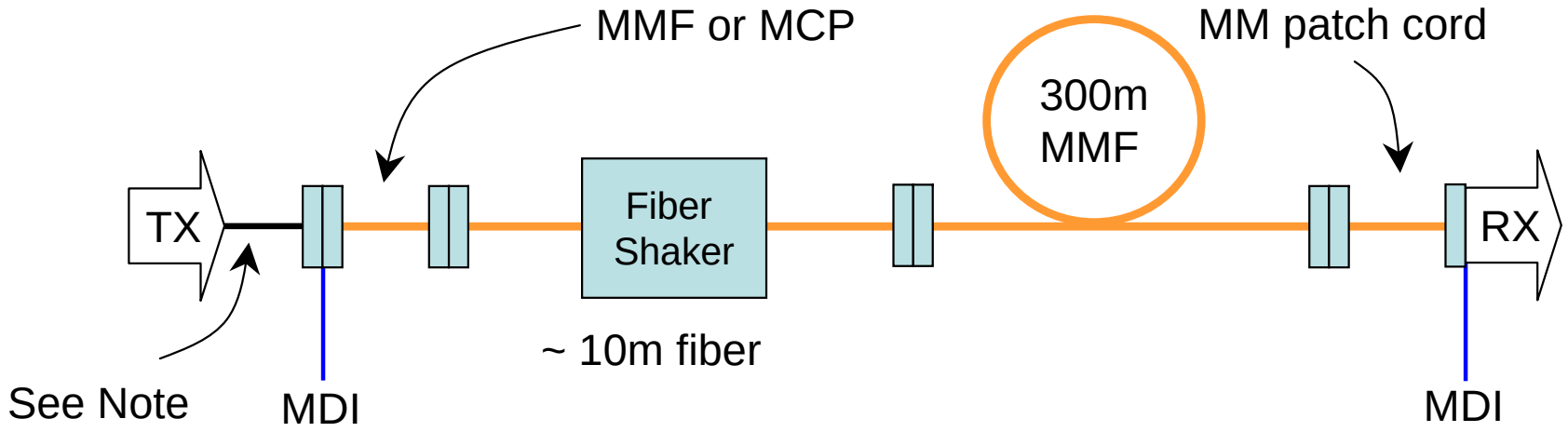
Fiber Type	Cable Name	Length Tested	OFL BW, MHz
OM1	1Green	300m	1950
OM1	2Orange	300m	1443
OM2	4Orange	300m	2180
OM3	Orange - Red	300m	1913

The rated OFL bandwidth of 500 MHz·km fiber at the 220m specification lengths is 2273 MHz. The selected fibers have less than this bandwidth.

More information on fiber characteristics and selection rational later in presentation

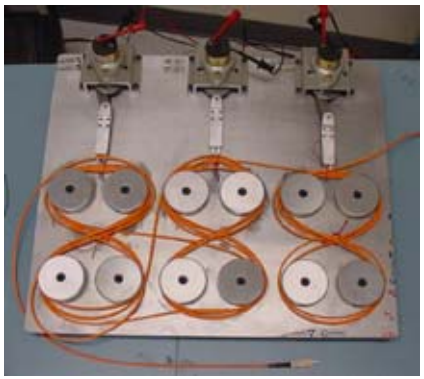
- OM1 & OM2 fibers from FO2-2 12/96 BW Modal Launch Test Cable
- OM3 fibers from TIA FO4.2.1 10GbE Demo Cables, provided courtesy of Corning, Inc.

Test Set-up Diagram



Note: At the request of some vendors, all vendors included a SMF and optionally an optical attenuator between their MDI and the MDI defined for these interoperation tests. This was to ensure that their receivers received a compliant optical power level but avoided receiver overload.

- Test Pattern: PRBS 2^{31}-1 (Rx under test looped back to Transmitter to verify PRBS)
- Fiber Shaker
  - 2 separate fiber shakers used for the test (50um & 62.5um)
  - 3 figure 8's coiled on the apparatus



Vendor Interoperability
TIA Round Robin Fibers

OM1 1-Green 300m				
	A RX	B RX	C RX	D RX
A TX		PASS	PASS	PASS
B TX	PASS		PASS	PASS
C TX	PASS	PASS		PASS
D TX	PASS	PASS	PASS	

OM1 2-Orange 300m				
	A RX	B RX	C RX	D RX
A TX		PASS	PASS	PASS
B TX	PASS		PASS	PASS
C TX	PASS	PASS		PASS
D TX	PASS	PASS	PASS	

OM2 4-Orange 300m				
	A RX	B RX	C RX	D RX
A TX		PASS	PASS	PASS
B TX	PASS		PASS	PASS
C TX	PASS	PASS		PASS
D TX	PASS	PASS	PASS	

OM3 Orange/Red 300m				
	A RX	B RX	C RX	D RX
A TX		PASS	PASS	PASS
B TX	PASS		PASS	PASS
C TX	PASS	PASS		PASS
D TX	PASS	PASS	PASS	

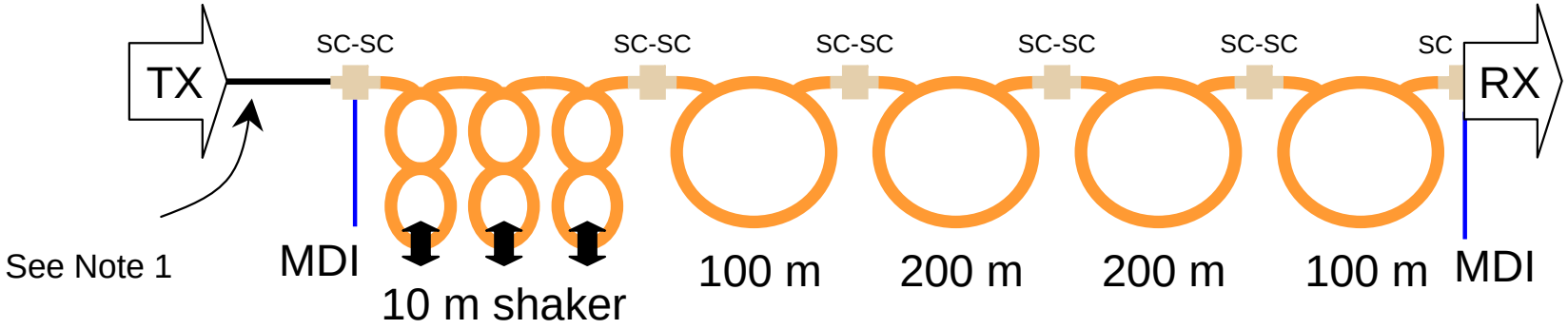
Pass = no errors in 5 minutes (>95%confidence of BER $<10^{-12}$)

Additional Test Results & Details

- **Link Tests Were Conducted With Both Launches for OM1 and OM2**
  - **Success on Either Launch Is Reported As a Pass**
  - **On Some Fibers the Preferred Launch Always Succeeded, On Others The Alternate Launch Always Succeeded**
- **Fiber Shaker Had Surprisingly Little Influence on Results**
- **Qualitative Link Performance Was Found to Be Sensitive to Connectors**
  - **Manipulation of Connectors Affected Performance in Marginal Cases**
- **Overload Considerations Were Found To Be Practical Issues With Some Present Implementations**

Vendor Interoperability
Nominal OM1 Fiber

OM1 Nominal 600 meters (100m, 200m, 200m, 100m)				
	A RX	B RX	C RX	D RX
A TX		not tested	not tested	not tested
B TX	not tested		**Pass**	**Pass**
C TX	not tested	**Pass**		**Pass**
D TX	not tested	**Pass**	**Pass**	



- To provide a data point for comparison to earlier 10GE interop testing, combined 4 segments of 'nominal' OM1 fiber totaling 600m. Nominal fiber = random purchase early 2004; did not specify any special characteristics.
- Testing was performed at the end of the interop period, and the matrix was not completed due to lack of time.
- Note 1: At the request of some vendors, all vendors included a SMF and optionally an optical attenuator between their MDI and the MDI defined for these interoperation tests. This was to ensure that their receivers received a compliant optical power level but avoided receiver overload.
- Note 2: This is not meant in any way to imply that LRM PMD's are suitable for 600m use, but that with nominal links, there is margin to the 220m distance specification.

Vendor Compliance Data
802.3aq Draft 2.3

Transmit Characteristics per Table 68-3

Pass Fail Not Tested

Description	Type	Value	Unit	A	B	C	D
Signaling speed	nom	10.3125	GBd				
Signaling speed variation from nominal	max	± 100	ppm				
Center wavelength	range	1260 to 1355	nm				
RMS spectral width at 1260 nm	max	2.4	nm				
RMS spectral width between 1260 nm and 1300 nm	max	See Figure 68-3	nm				
RMS spectral width between 1300 nm and 1355 nm	max	4	nm				
Launch power in OMA	max	1.5	dBm				
Launch power in OMA	min	-4.5	dBm				
Average launch power	max	0.5	dBm				
Average launch power	min	-6.5	dBm				
Average launch power of OFF transmitter	max	-30	dBm				
Extinction ratio	min	3.5	dB				
Peak launch power	max	3	dBm				
$RIN_{20}OMA$	max	-128	dB/Hz				
Eye mask parameters {X1, X2, X3, Y1, Y2, Y3}		{0.25, 0.40, 0.45, 0.25, 0.28, 0.80}					
Transmitter waveform and dispersion penalty (TWDP)	max	4.7	dB				
Uncorrelated jitter (rms)	max	0.033	UI				
Optical launch for OM1 and 160/500, 62.5 μm fiber:							
Preferred:		62.5 μm mode-conditioning patch cord, see 68.9.3					
Encircled flux for alternative launch per D2.2	min min	30 % in 5 μm radius 86 % in 11 μm radius					
Optical launch for OM2 and 400/400, 50 μm fiber:							
Preferred:		50 μm mode-conditioning patch cord, see 68.9.3					
Encircled flux for alternative launch per D2.2	min min	30 % in 5 μm radius 86 % in 11 μm radius					
Optical launch for OM3 50 μm fiber:							
Encircled flux per D2.2	min min	30 % in 5 μm radius 86 % in 11 μm radius					
Optical return loss tolerance	min	20	dB				
Transmitter reflectance	max	-12	dB				

Receiver Characteristics per Table 68-5

Pass Fail Not Tested

Description	Type	Value	Unit	A	B	C	D
Signaling speed	nom	10.3125	GBd				
Signaling speed variation from nominal	max	± 100	ppm				
Center wavelength	range	1260 to 1355	nm				
Stressed sensitivity in OMA at BER 10^{-12}	-	-6.5	dBm				
Overload in OMA at BER 10^{-12}	-	1.5	dBm				
Conditions of comprehensive stressed receiver tests:							
Bandwidth of Gaussian white noise source	min	10	GHz				
Test transmitter signal to noise ratio, Q_{sq}							
For sensitivity tests	-	22.5					
For overload tests	-	28.8					
Tap Spacing, Δt, of ISI generator	-	0.75	UI				
Pre-cursor tap weights {A1,A2,A3,A4}		{0.158, 0.176, 0.499, 0.167}					
Symmetrical tap weights {A1,A2,A3,A4}		{0.00, 0,513, 0.00, 0.487}					
Post-cursor tap weights {A1,A2,A3,A4}		{0.254, 0.453, 0.155, 0.138}					
Conditions of simple stressed receiver test:							
Signal rise and fall times (20% to 80%)	-	115	ps				
Conditions of receiver jitter tolerance test:							
Jitter frequency and peak to peak amplitude	-	(40, 5)	KHz, UI				
Jitter frequency and peak to peak amplitude	-	(200, 1)	KHz, UI				
Received average power for damage	-	2.5	dBm				
Receiver reflectance	max	-12	dB				

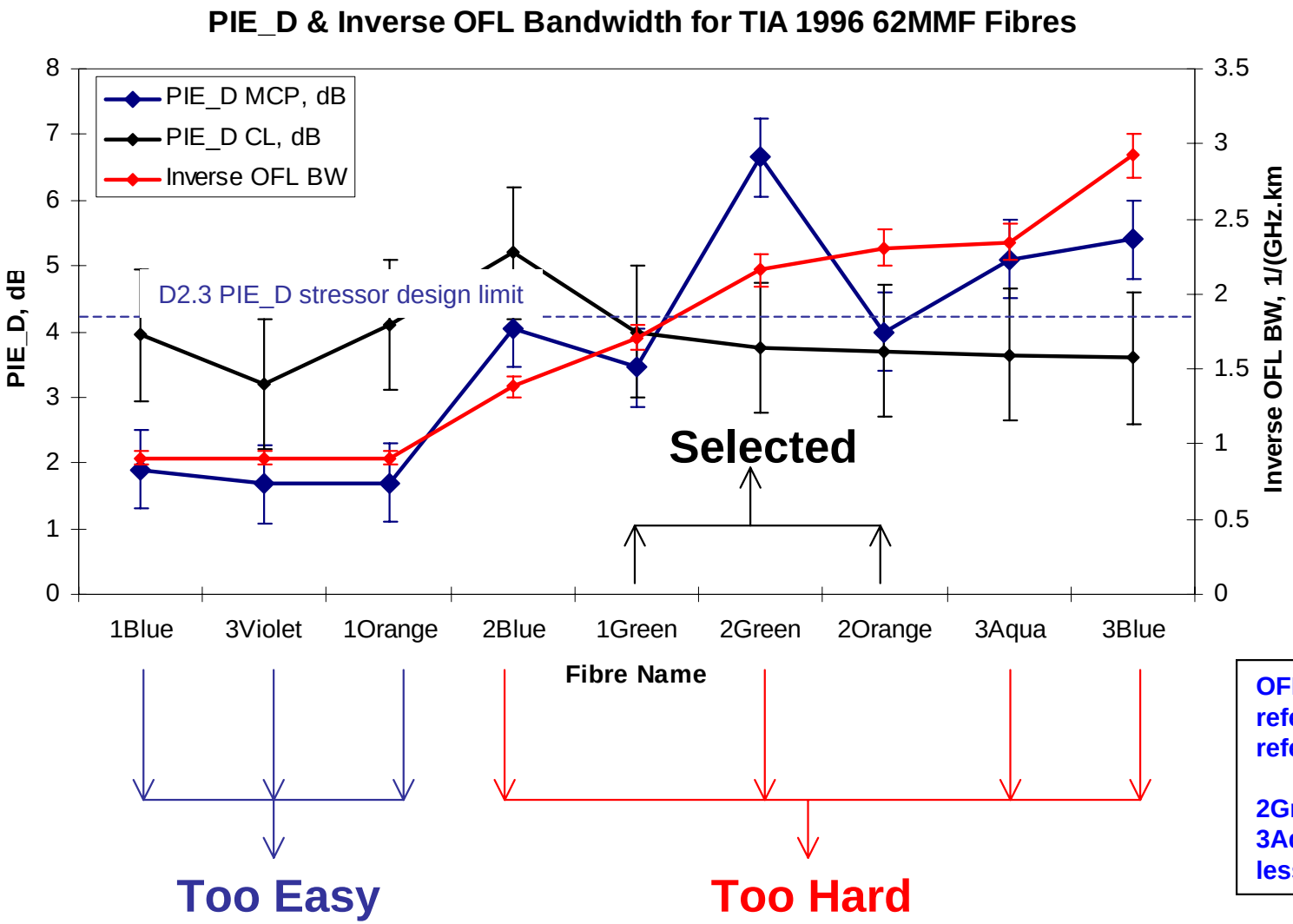
Additional Details on Channel Characteristics and Selection Rational

What are the TIA 1996 Fibers

(FO2-2 12/96 BW Modal Launch Test Cable)

- They are sets of 300 m length cabled fibers, nine 62MMF and six 50MMF.
- Produced as part of a TIA round robin for investigation of restricted mode launch.
- Extensively studied as part of IEEE 802.3z (Gigabit Ethernet) and in large part formed the basis of that standard, the 81 Fiber Model and the MCP specification.
- They are interesting fibers representative of the range of MMF available in 1996.
  - Cover range of easier to harder than 802.3aq stressor design limits
- These fibers are familiar to IEEE 802.3 and its channel experts.
- A lot of experience, experimental and theoretical data is available on these fibers: Refractive index profiles, DMD, Bandwidth and ISI measurements.
  - Most of this material has been presented to IEEE 802.3z, IEEE 802.3ae and IEEE 802.3aq and is archived on the IEEE 802.3 website.
- Multiple groups within IEEE802.3aq still have these well characterised cables enabling multiple labs to collaborate and correlate results.
- For the past two years these fibers have been extensively studied within IEEE 802.3aq within the Channel ad hoc. See references and our website.
- Parameters important to 802.3aq have been measured, simulated and reported.
  - PIE_D versus: launch, polarization state, SMF launch offset, MMF connector offset, number of MMF connectors with variable offset, fiber shaking, position of fiber shaker.

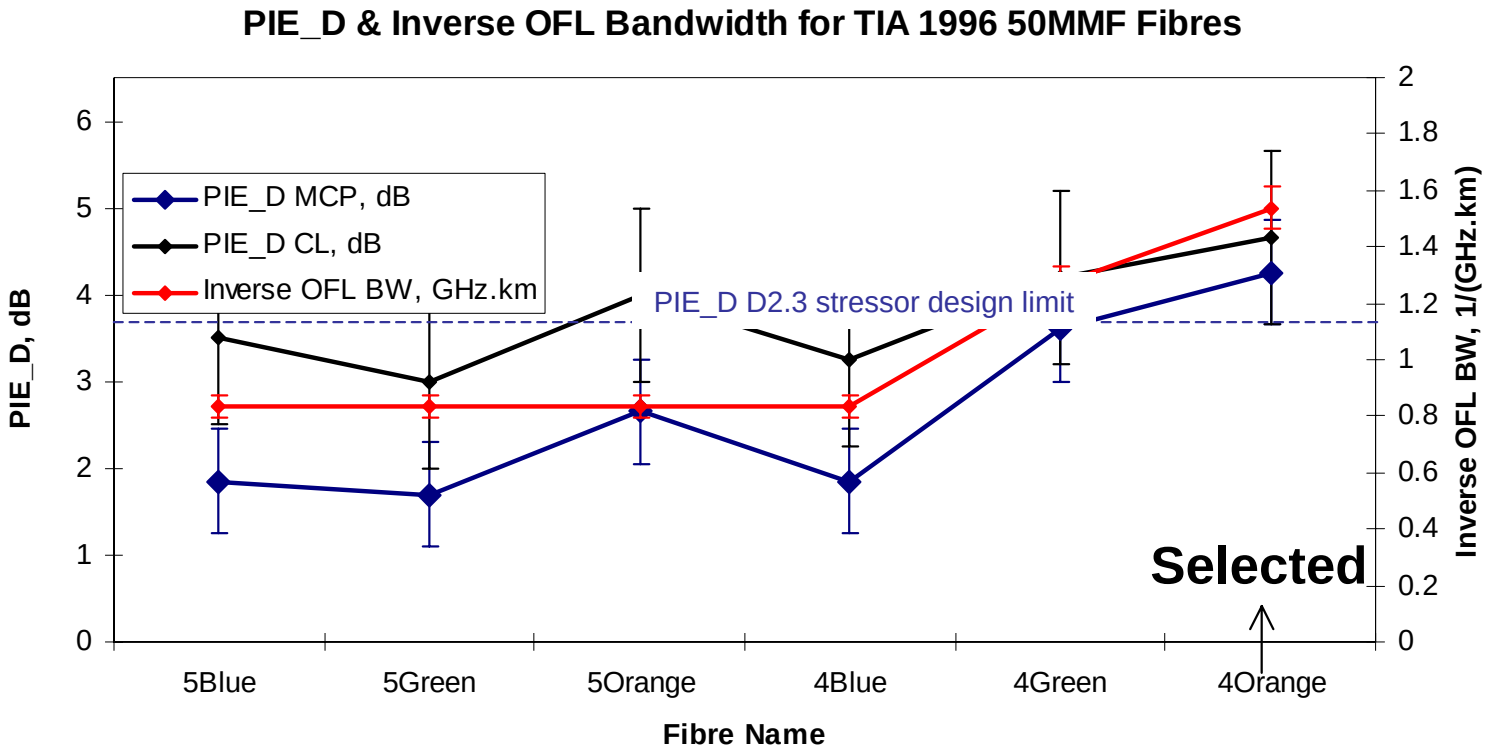
OM1/FDDI Grade Fiber Selection

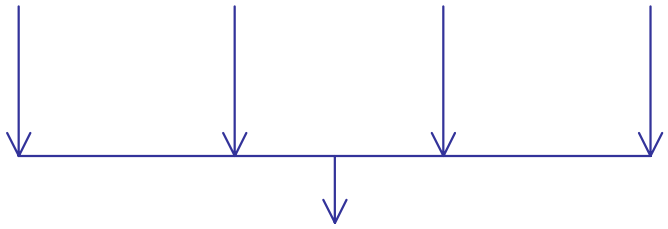


OFL bandwidth from reference 1, PIE_D from reference 2

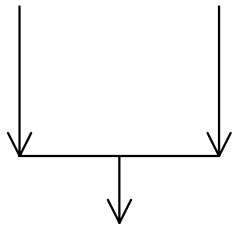
2Green, 2Oramge, 3Aqua & 3Blue have less than 500 MHz.km

OM2/FDDI Grade Fiber Selection





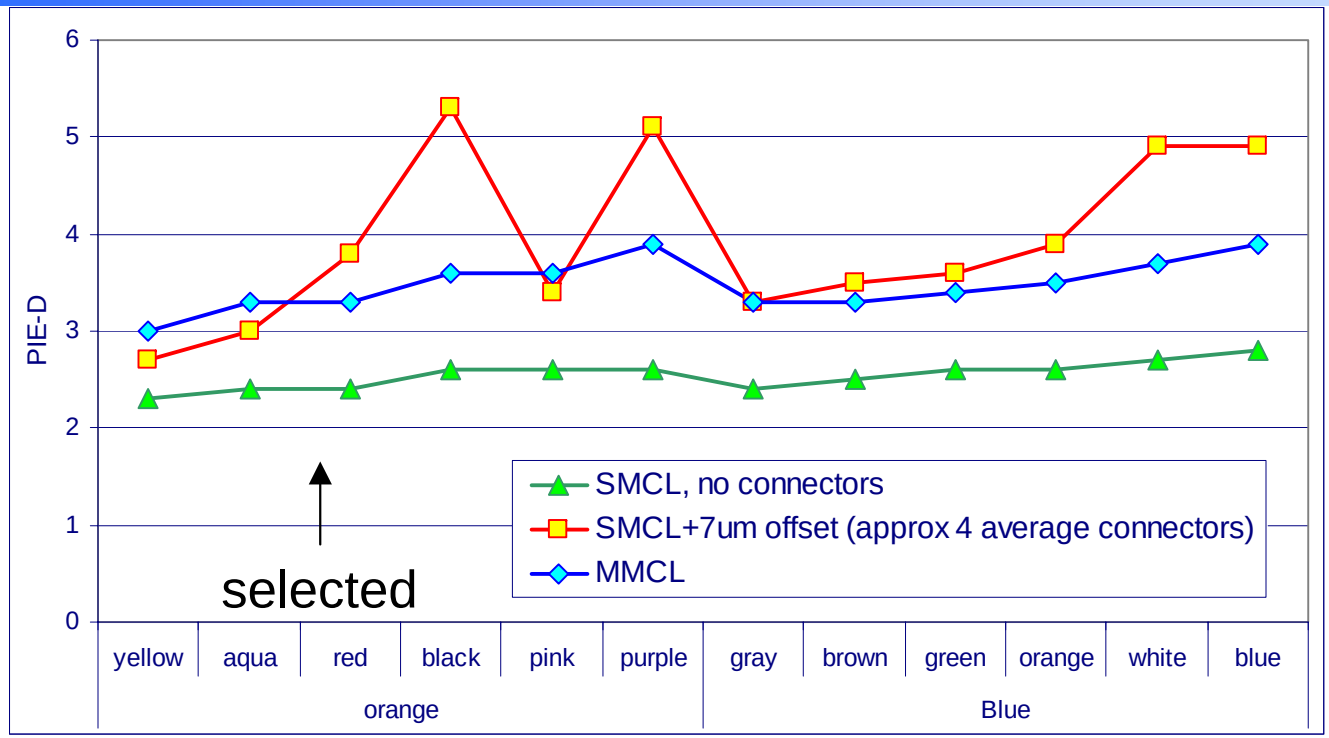
Too Easy



Choose one of these.

OFL bandwidth from reference 1, PIE_D from reference 2

OM3 selection



- OM3 fibers have similar centre launch characteristics and tend to have a Post-cursor IPR.
- OM3 Interoperation tests had 4 connections before the main fiber:
  - (1)MDI-MMF jumper, (2)MMF jumper-shaker, (3)shaker-MMF jumper (not shown in slide 6), (4) MMF jumper-main fiber
  - 4 typ. connections (rms of four 3.58um avg offsets) approx. equivalent to ~7um offset (red) [3].
  - PIE-D of orange red with this launch is ~4dB.

IPR States & Mean PIE_D of Interoperation Fibers

Fiber Name	Fiber Type	CL IPR States Mean PIE_D	MCP IPR States Mean PIE_D
1Green	OM1/FDDI	Symmetric Post-cursor 4 dB	Precursor Symmetric 3.5 dB
2Orange	OM1/FDDI	Precursor Symmetric 3.7 dB	Precursor Symmetric Post-cursor 4 dB
4Orange	OM2/FDDI	Symmetric Post-cursor 4.6 dB	Precursor Symmetric 4.3 dB
Orange-Red	OM3	Post-cursor 3.8 dB	Not applicable

Shaker causes:

- **PIE_D to vary by ~ 1 dB**
- **IPR states to cycle between extremes via intermediate states.**

The fibers chosen are at or beyond the extreme of the IEEE 802.3aq specification.

The combination of the fibers and launches exhibit all three ISI stressor types.

Fiber Shaker For 10GBASE-LRM Testing

- The Modal Noise Test Methodology Group of TIA 2.2 and IEEE 802.3 investigated the best shaker for producing and testing for modal noise.
  - A wide range of shakers were investigated.
  - Design that produced the max. modal noise without causing mode selective loss chosen.
- Due to the physics of light propagation within a multimode fiber, shakers designed to maximise modal noise must cause maximum change in the IPR too.
- Shaker design was adopted and standardised by TIA for its Encircled Flux standard.
- This is the only standardised fiber shaker: it has been proven to generate the maximum modal noise.
- It was used to verify the modal noise power penalty of IEEE 802.3z, IEEE 802.3ae, FC, IB, …….

The shakers used for interoperation testing comply with TIA standard.
There is no other reasonable, proven, standardised shaker to use.

- Positioning the fiber shaker within the first portions of the link will result in the largest variations in impulse response.

Review of 10GbE Interop Precedents

10GbE Interop Precedents

PMD	Number of vendors	Full compl. to PMD spec?	Interop w/ margin?	Tested w/ worst-case PMD specs?	Tested w/ worst-case fiber?
10GBASE-S	2	no	yes[1]	no	no
10GBASE-L	2	no	yes[2]	no	no
10GBASE-E	3	no	yes[3]	no	no
10GBASE-LX4	3	no	yes[4]	no	no
10GBASE-LRM	4	no	yes[5]	no	no[6]

1. 450m for 2000MHz fiber
2. 15 km SMF
3. 50 km SMF
4. 330m MMF 62.5um, 263m MMF 50um/400MHz
5. 300m MMF for all tests, 600m MMF shown
6. Efforts made to test with “reasonably bad” fiber

Usual Caveats and Expectations of Previous IEEE 802.3 Optical Interoperation Tests

- Validated a path to full compliance.
- Not parametric worst-case corner testing.
- Attempt to indicate margin by including some reasonable stresses (usually not all together):
  - Length of nominal cable greater specified
  - More nominal connectors than specified
  - More attenuation than specified
- If incomplete, typically promised better subcomponents from more vendors enabling a more complete PMD soon.
- Often did not attempt to demonstrate practical form factors.

Interoperation Links

- 10GBASE-S
  - http://www.ieee802.org/3/ae/public/nov01/kabal_1_1101.pdf
- 10GBASE-L
  - http://www.ieee802.org/3/ae/public/oct01/bhatt_1_1001.pdf
- 10GBASE-E
  - http://www.ieee802.org/3/ae/public/oct01/tipper_1_1001.pdf
- 10GBASE-LX4
  - http://www.ieee802.org/3/ae/public/nov01/dallesasse_1_1101.pdf

Responses to Specific Questions and Concerns

Issue 1: Interop Test Did Not Use A Specified Channel As Called For By the Nov 04 Motion

- The Nov 04 motion did not require the task force to decide which channels would be used, but that they be specified.
- The channels used in the interop testing have been fully specified in the interop report
- The rational for the selection of these fibers as representative of the standards limits has been given.
- Extensive additional data on the fiber characteristics, provided by many experts, has been provided directly or by reference.

Issue 2: Only 2 EDC Chip Vendors' Products Were Included in Modules Tested

- The Nov 04 motion required 3 or more PMD vendors.

  4 PMD vendors were represented in the testing.

- The number of EDC vendors is not specified in the motion,

  nor in the interop report.

- The EDC is not the PMD any more than the XAUI IC is the PMD

Issue 3: The demonstration failed to provide sufficient evidence of technical feasibility

- The interoperation results showed successful interoperability of 4 PMD vendors over 4 lengths of 300m fiber of different types.
- This exceeds both the distance and number of channels required by the motion (which states 1 channel at rated distance).
- All TP2 and virtually all TP3 specifications demonstrated
  - Vendors have stated that they see no problem with remaining specifications.
  - No requests from vendors for related specification relaxations are pending
  - At least one vendor has subsequently reported meeting ALL TP3 specs
- These results exceed earlier interop testing precedents

Issue 4: The center launch condition used was through SMF and not representative of ‘native’ center launch

- The center launch condition tested was compliant with the 802.3aq specifications.

Issue 5: The technology is not proven as only one vendor has shown data to demonstrate specifications can be met, and this is the first demonstration of EDC for MMF

- This was not a requirement of the Nov 04 Motion which called for a demonstration of interoperability to support technical feasibility

Issue 6: The demonstration lacked a sufficient number of channels. Demonstration was equivalent of one duplex 62.5um channel, one half duplex 50um channel and one half duplex OM3 channel

- Motion only called for a single specified channel, this work demonstrated 4 channels.
- Previous interops did not require demonstration of duplex links, and no suggestion has been made as to why these results would not indicate successful duplex performance.
- Testing more than 4 channels among 4 PMDs would represent an impractical number of tests and total test time
  - 4 TXs * 4 fiber types * 3 RXs * 1 or 2 launches = 48 – 96 tests
  - Ensuring < 1e-12 BER requires 5 – 10 minutes
  - Total test time as reported could range from 4 – 16 test hours not including change-over and other setup time.

Summary Statement Based on This Report

- Shown Interoperation of 4 prototype PMD's from 4 different PMD vendors.
- Multiple PMD subcomponents from multiple vendors and more available soon.
- All prototype PMD's compliant to majority of D2.3 & now D2.4 specifications.
- Each PMD vendor states they have a clear path to full compliance.
- Each test link was longer than 220m in length.
- Fibers chosen with PIE_D levels representative of specification limits.
- In combination, the fibers chosen exhibit all three ISI types important to 10GBASE-LRM.

- **This interoperability demonstration meets or exceeds all of the requirements of the Nov 04 motion**
- **This interoperability demonstration meets or exceeds the precedents of previous 10G interoperability demonstrations**

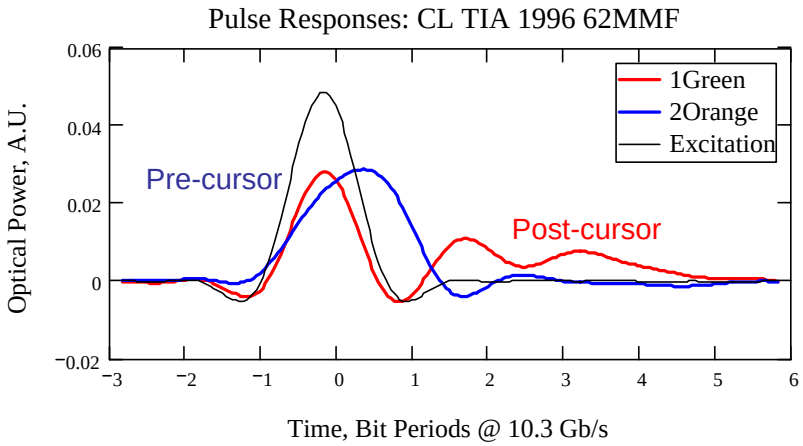
References

1. Round Robin Results of the Multimode Restricted-Launch Bandwidth Task Group, FO-2.2 Subcommittee on Digital Multimode Systems, 23 June 1997.
2. Variation of PIE_D in multimode fiber: Julia Shaw, David Cunningham, Simon Meadowcroft: http://ieee802.org/3/aq/public/jan05/meadowcroft_1_0105.pdf
3. Background of Connector Scenario for Worst Case proposal:J.-R. Kropp, S. Bottacchi, J. Fiedler, August 2004, IEEE 802.3aq Reflector archive.

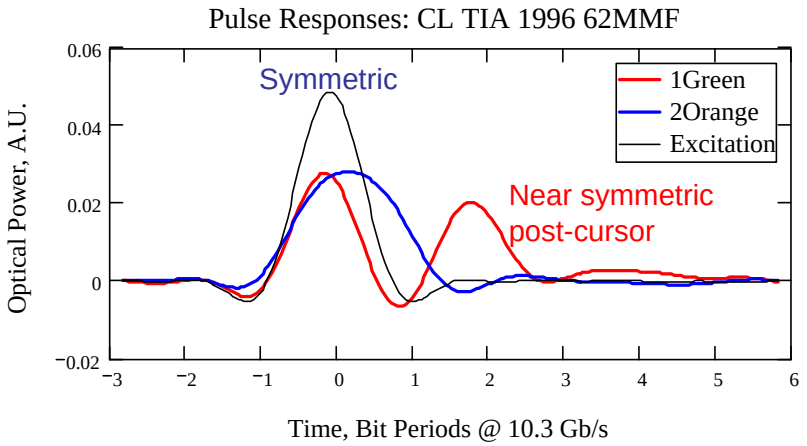
Backup Material – Fiber Impulse Response Measurements

Example Pulse Responses TIA 1996 62MMF

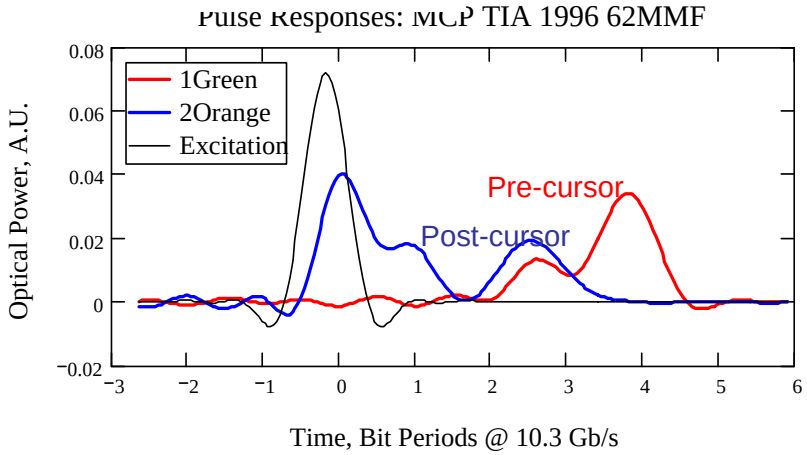
Zero connector offset



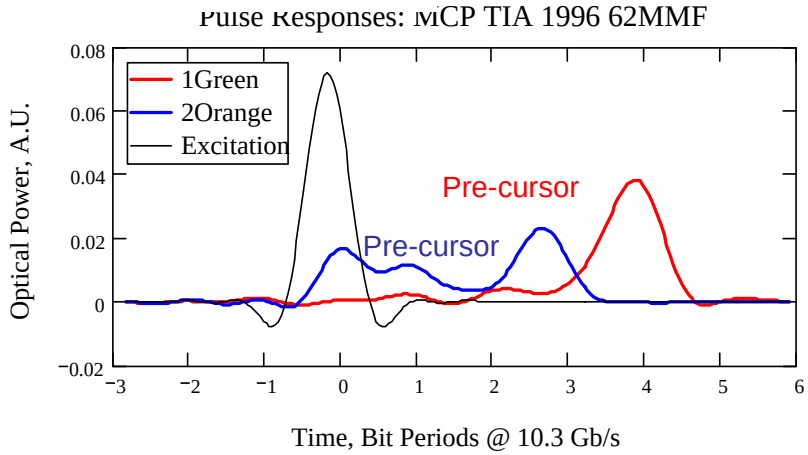
7 um connector offset



Zero connector offset

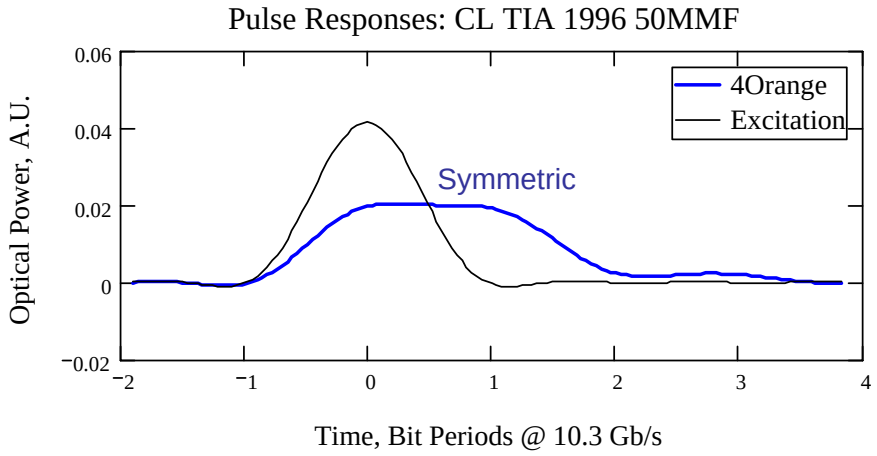


7 um connector offset

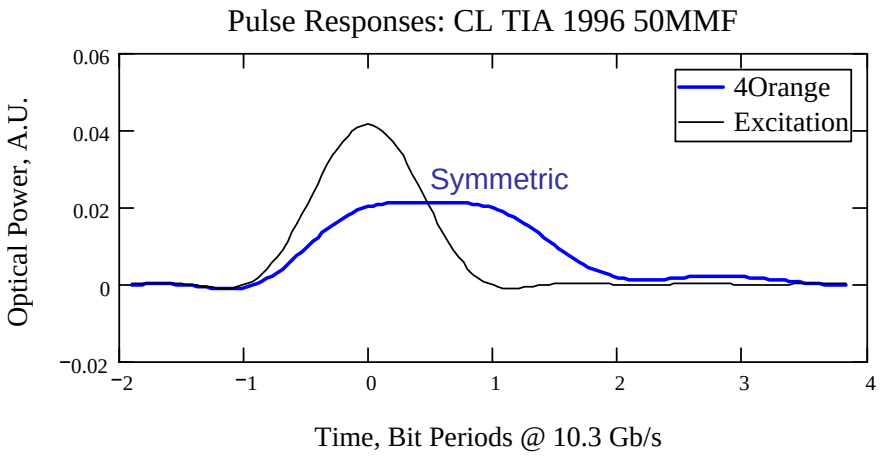


Example Pulse Responses TIA 1996 50MMF

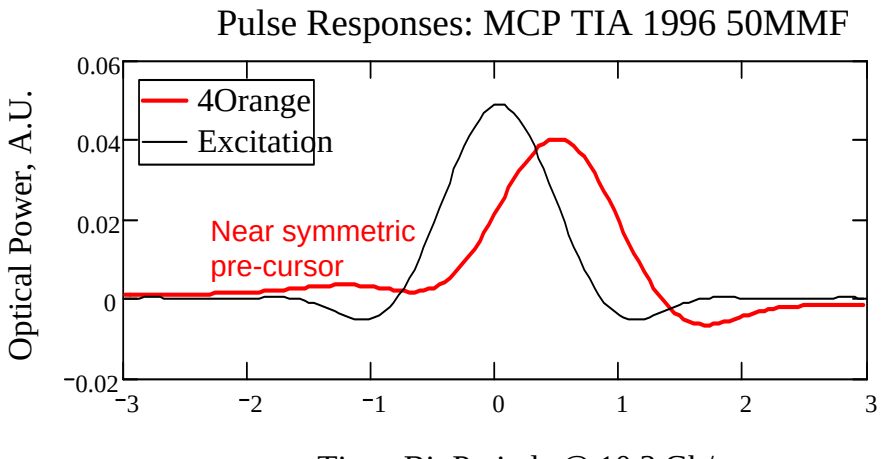
Zero connector offset



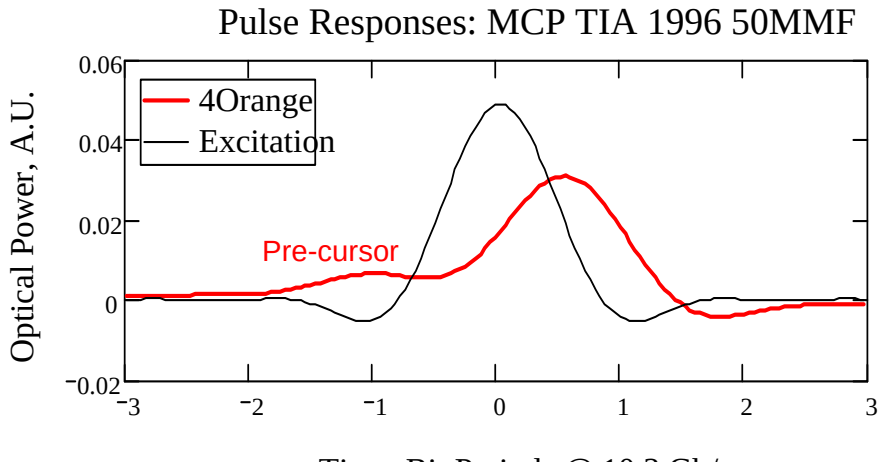
7 um connector offset



Zero connector offset



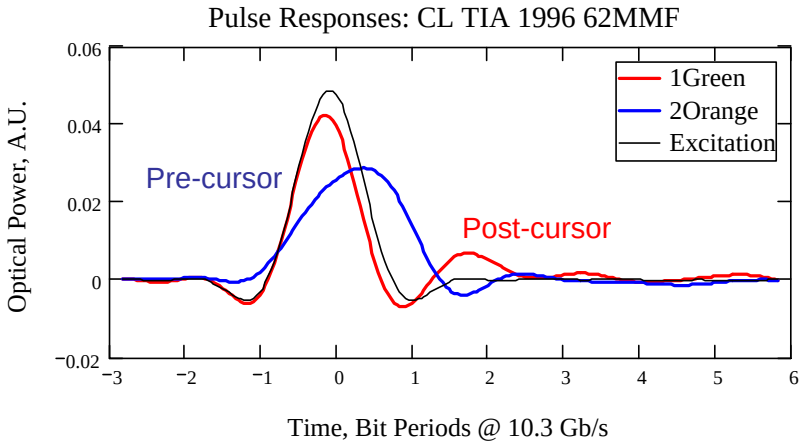
7 um connector offset



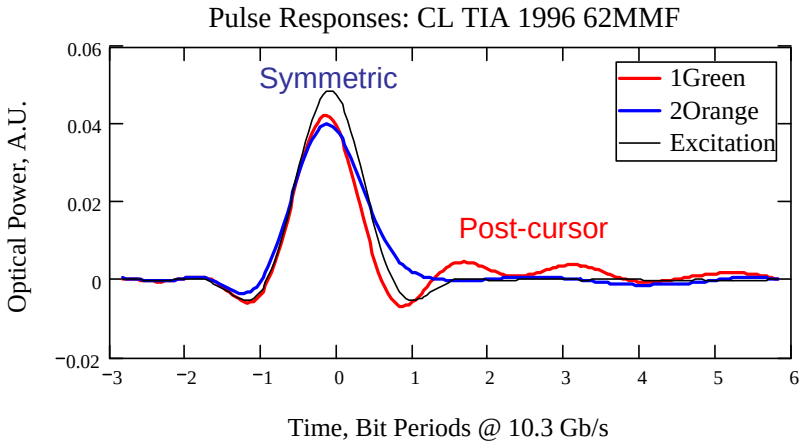
Note: OT4 = 4Orange

Example Pulse Responses TIA 1996 62MMF

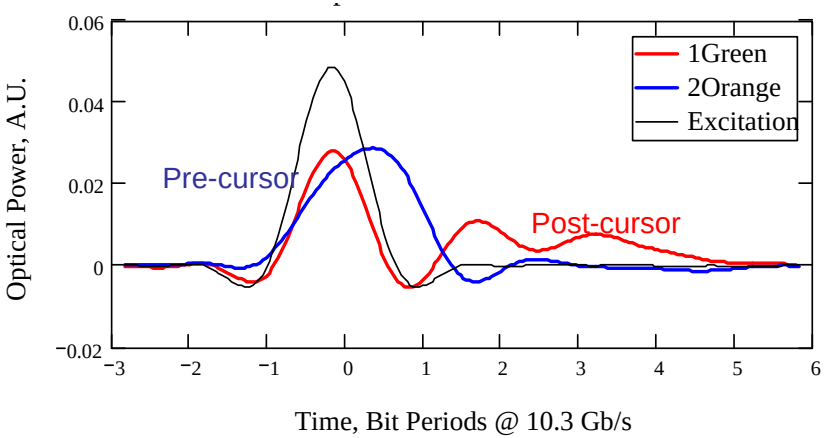
Zero connector offset Polarization 1



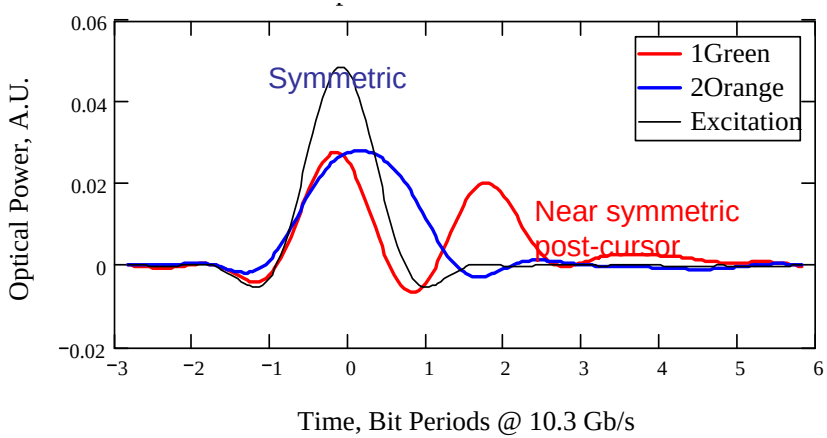
7 um connector offset Polarization 1



Zero connector offset Polarization 2



7 um connector offset Polarization 2



- **Largest changes occur with CL.**
- **Changing SOP, connector offset or shaking the fiber cycle the IPR through the same states.**