Optical Mode Filtering with EDC Standard Proposal For 10GBASE-LRM

Heider Ereifej, Pete Hallemeier

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Supporters of Future Optical Investigation

- **Jens Fiedler, Infineon**
- **Stefano Bottachi, Infineon**
- **Ali Ghiasi, Broadcom**
- **Jane Li, Eudyna (Fujitsu)**
- **Joe Calvitti, CyOptics**
- **E. Cornejo, OpNext**
- **M. Bennett, LBNL**
- **S. Inano, Sumitomo Electric**

PAR Criteria 1: Broad Market Potential

•10GBASE-LRM PAR description says it all!

•The proposed solution enables the adoption of 10GbE 300m serial solutions by the networking industry:

- Low cost
- Small form factor
- Serial transmission
- Low power

PAR Criteria 2: Compatibility with IEEE 802.3 Standard

- This Optical Mode Filtering with simplified EDC proposal will be fully compatible with the IEEE 802.3 standard.

- This proposal will affect the PMD only.

PAR Criteria 3: Technical Feasibility

Proposal Outline:

- Link Power Budget.
- Tx Specifications.
- Rx Specifications.
- Conformance Test Definitions.
- Supporting Technical Appendixes.

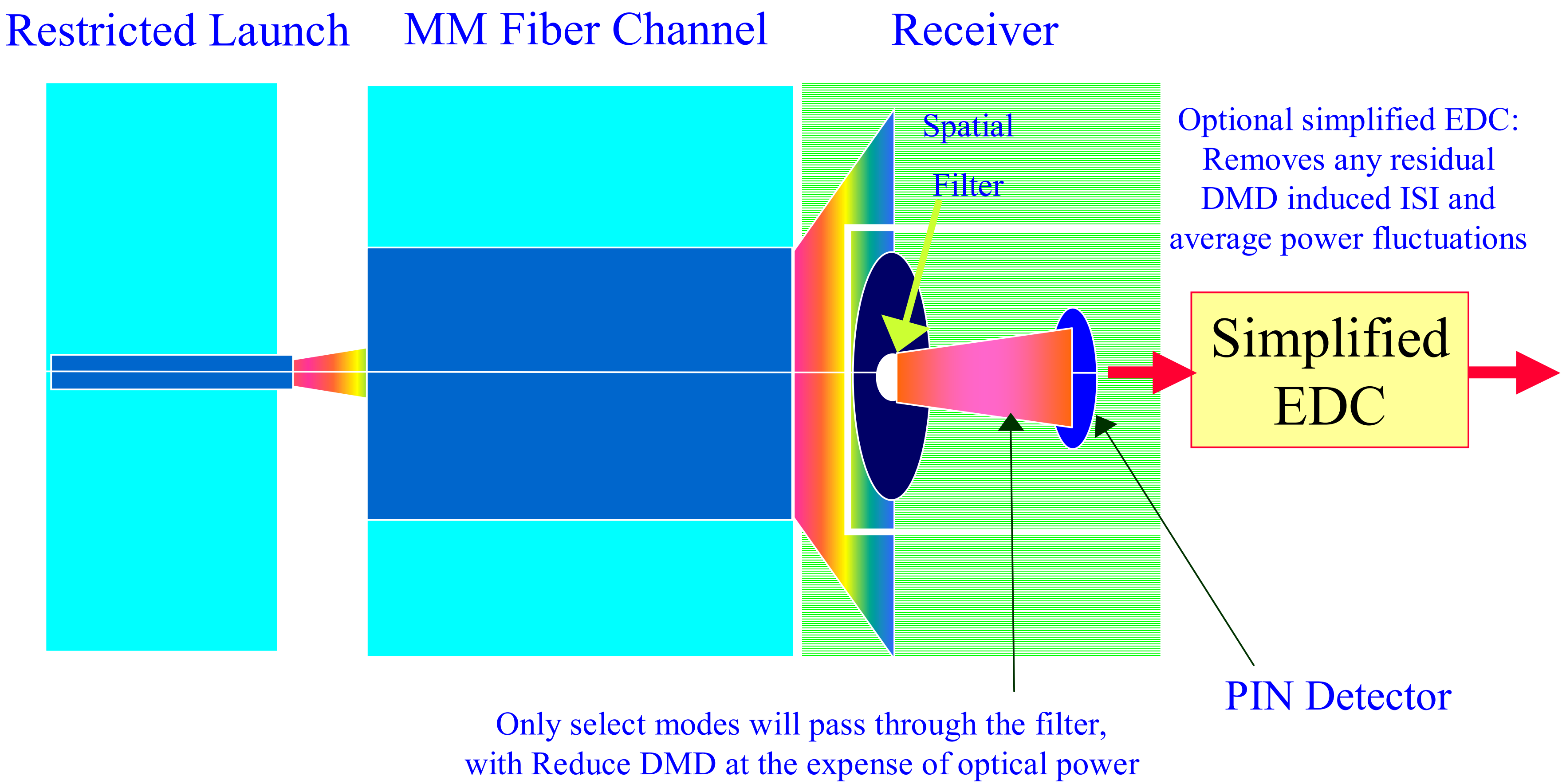
The following support data is included:

- Lab link transmission results.
- Simulation studies of the optical mode filtering approach
- Channel simulations utilizing 81 "Cambridge" index profiles

Link Budget

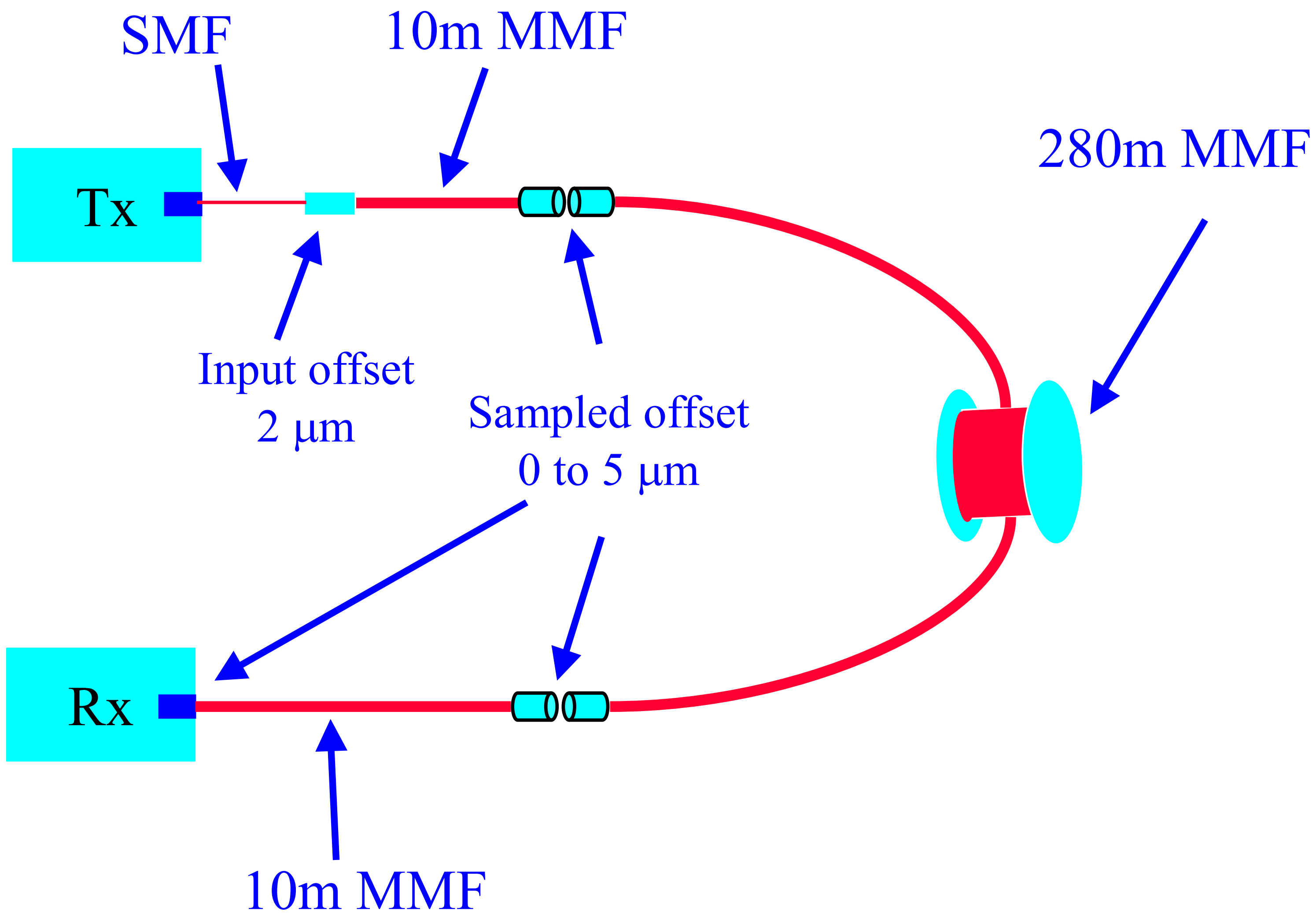
Parameter	10GBASE-LRM	Unit	Note
Center wavelength	1260 - 1355	nm	Related to MMF design
Multimode fiber BW	500	MHz.km	Minimum BW for 50µm and 62.5µm multimode fiber under OFL condition
OMA Power budget	-4.2-(-13.2) = 9	dB	Minimum transmitter OMA minus receiver sensitivity OMA
Average power budget	-3-(-12.0) = 9	dB	Difference of Minimum transmitter average launch power and Stressed Receiver (including penalties).
Fiber material loss	0.5	dB	0.3dB 220m scaled to 0.5dB for 300m
Excess Connector loss in Channel (total)	1	dB	4 connectors, corrected for restricted center launch beam profile
Mode Selective Loss	6	dB	Mode Selective Loss including Source Induced Modal Noise
EDC Insertion Penalty	1	dB	Equivalent optical power penalty to achieve 1E-12 BER
Unallocated	0.5	dB	

Overview Channel Schematic:



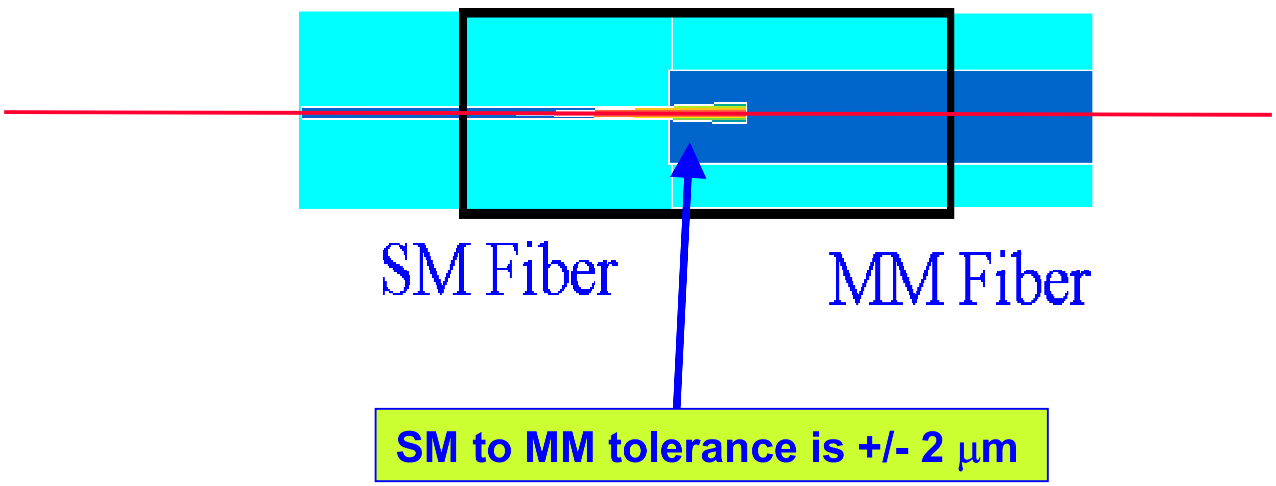
The tradeoff between launch conditions, mode filter design and EDC design implementation need to be optimized for the channel model.

300m Multimode Link Simulation Setup:



Center Launch Mode Conditioned Patchcord (CL-MCP):

- MSL can be greatly reduced with a Center Launch MCP
  - Higher quality restricted excitation into fundamentals.
- Ensures launch tolerance of +/- 2μm into multimode fiber.
- Generates resiliency to other MSL contributors in the link.
- Used to achieve 300m link distance in a poor fiber core alignment environment.

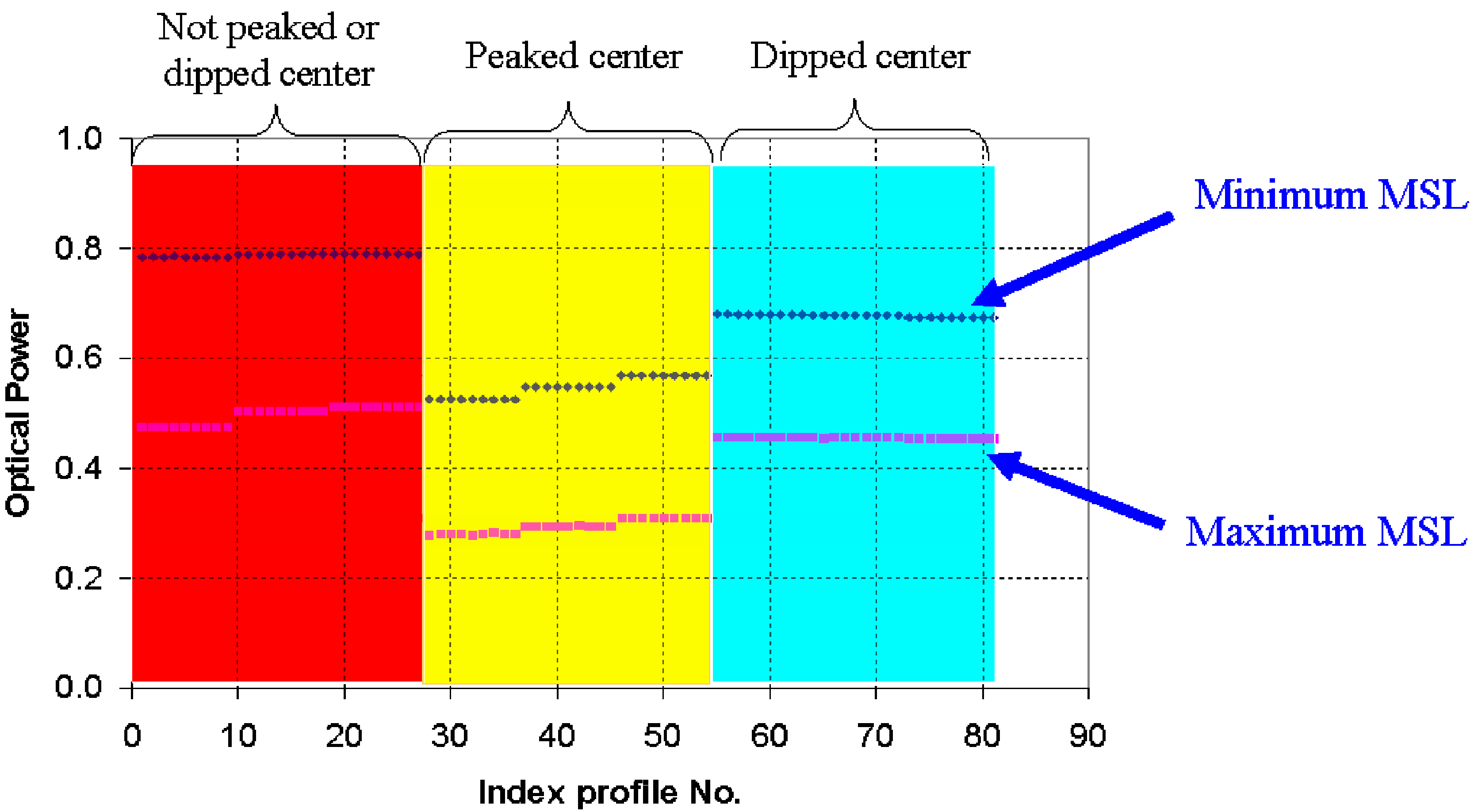


Channel Model Assumptions:

- **Cambridge 81 Index Profiles:**
  - Theoretically simulated index profiles.
  - Theoretical model has been independently verified.
  - On going, some initial results are presented.
- **TIA "1296" Round Robin Cable Index Profiles:**
  - Performed link experimental measurements.
  - Index profile for all 15 fiber links received.
  - Theoretical modeling is underway**.**
- **4 connector link, 0.5dB OFL Loss:**
  - Using the restricted launch approach 0.25 dB/connector is assumed.
- **Transmitter Alignment Tolerance :**
  - Use a Center Launch Mode Conditioned Patchcord (CL-MCP).
  - Increases the tolerance of the Tx launch to +/-5 um.
- **Receiver Alignment Tolerance of +/- 5μm.**
- **Thermally and Mechanically induced mode mixing.**

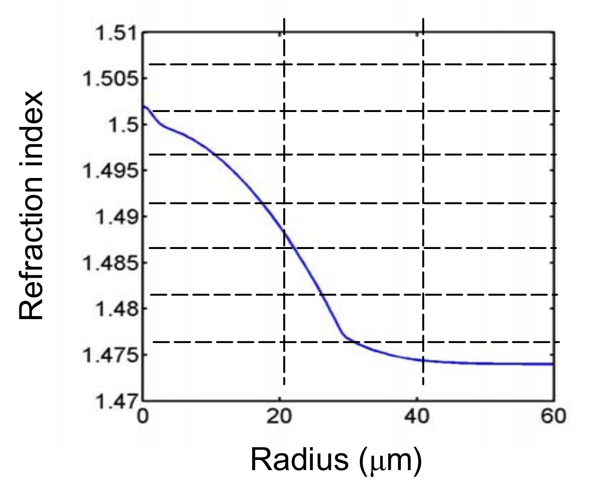
Mode Selective Loss (MSL) – 81 index profiles

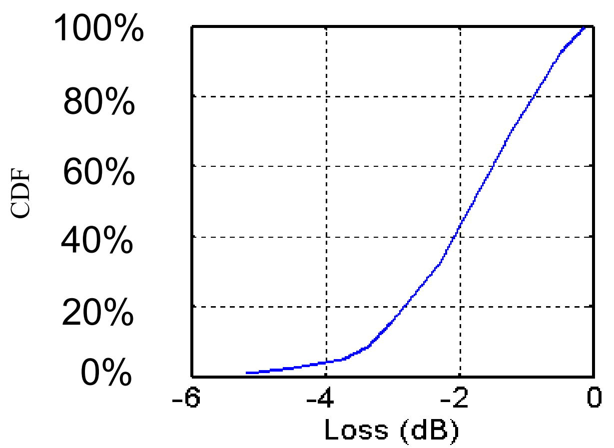
Two connectors with first connector at 2 µm and second connector scanned 3 to 5 µm

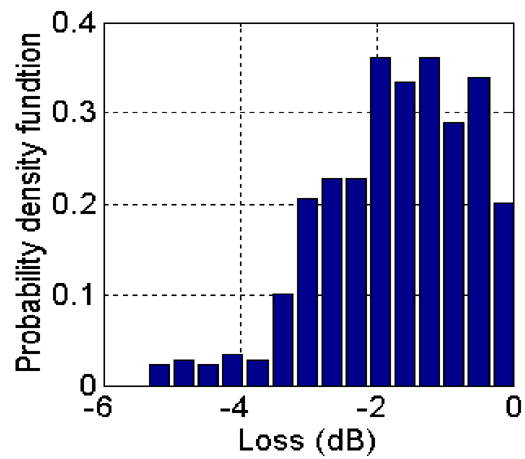


Mode Selective Loss (MSL) – (Fiber No. 30):

- 4 total connectors, launch connector at 0 to 2 μm, other three connectors 0 to 5 μm.
- MSL generated by: Connector Offsets.
- Simulated by calculating all mode mixing combinations that can occur in the link.



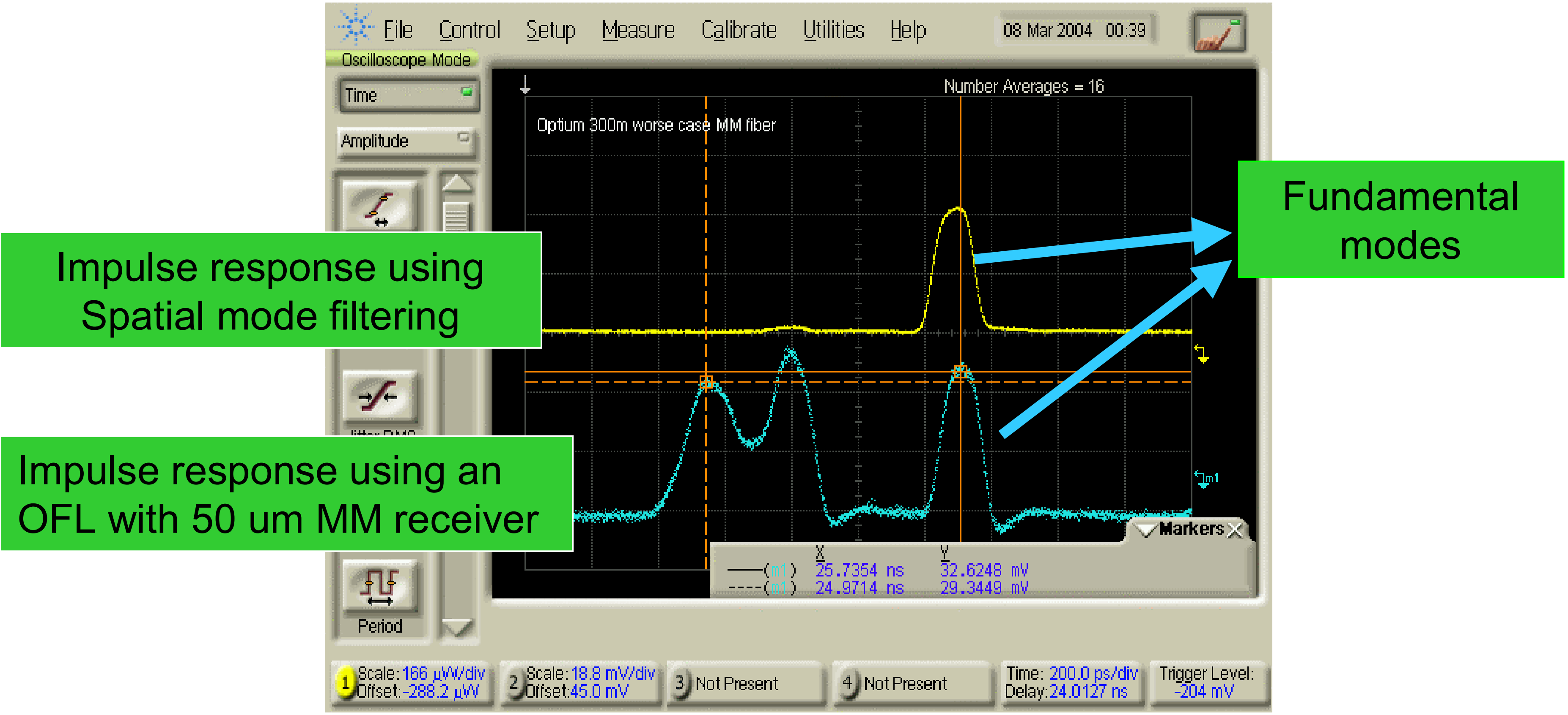




ISI Improvement of Mode Filtering:

Fiber length : 300 m

Note: For more details please refer to the IEEE march study group presentation, by P. Hallemeier.



Transmitter Specifications

Parameter	10GBASE-L	10GBASE-LRM	Unit	Note
Center wavelength	1260 - 1355	1260 - 1355	nm	Related to MMF design
Laser cavity	SLM	SLM	-	
Max. RMS spectral width (PRBS)	NA	0.5	nm	Based on DFB
Min. SMSR	30	30	dB	Almost standard for SLM laser
Min. average launch power	-8.2 (-4.2) →	-3.0	dBm	Guarantees OMA_{min} with ER_{min}
Max. average launch power	+0.5	+0.5	dBm	Maximum receiver overload or safety requirements
Min. OMA	-5.2	-4.2	dBm	link sensitivity at 10^{-12} BER
Max. OMA	NA	+3.5	dBm	Related to maximum average launch power with $ER \rightarrow \infty$
Min. ext. ratio	3.5 (2.24) →	3.5	dB	3.5dB for 220m, 7dB for 300m
RIN	-128	-128	dB/Hz	
Optical return loss	12	12	dB	Low cost LC connector
Modal Noise Generation	N/A	TBD	?	Reference MSL Test as proposed by 1GE work, need metric
Launch Beam Conformance	N/A	0.5	dB	Coupled power test into self stripping SM

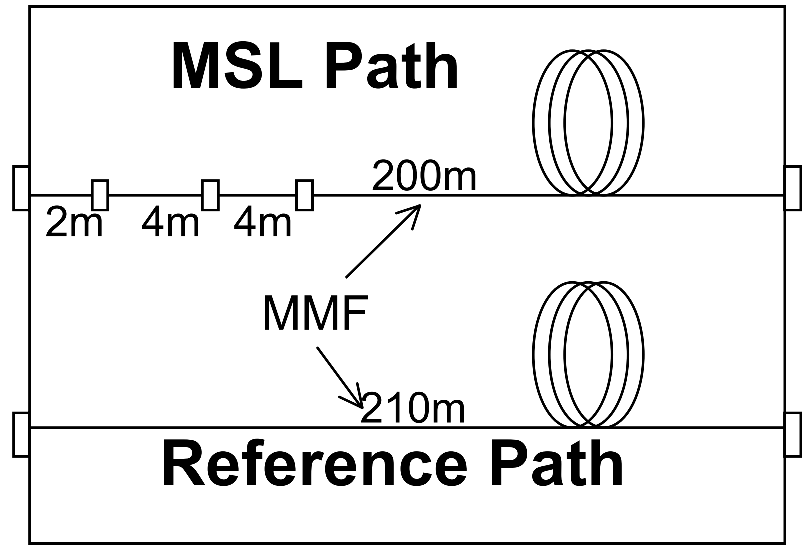
Transmitter Conformance Tests

Parameter	10GBASE-LRM Method
Center wavelength	**Same as 10GBASE-LR**
Laser cavity	**Same as 10GBASE-LR**
RMS spectral width	**Same as 10GBASE-LR**
Min. SMSR	**Same as 10GBASE-LR**
Min. average launch power (mod.)	**Same as 10GBASE-LR**
Max. average launch power (mod.)	**Same as 10GBASE-LR**
Min. OMA	**Same as 10GBASE-LR**
Max. OMA	**Same as 10GBASE-LR**
Min. extinction ratio	**Same as 10GBASE-LR**
RIN	**Same as 10GBASE-LR**
Optical return loss	**Same as 10GBASE-LR**
Modal Noise Generation	NEW – Reference MSL Test from 1GE work
Restricted Launch Conformance	NEW – Coupled power measurement into SM fiber

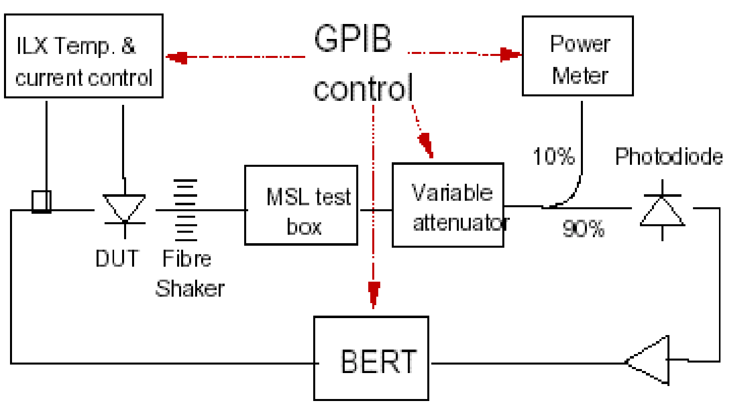
The proposed standard only have incremental changes from the Standard 10GBase-LR spec

Tx Modal Noise Measurement

- Same Modal Noise measurement used in FC and 1GE work
- Compare Modal Noise Generation between 2 paths
- Restricted Launch Conformance would be included
- Material from D.Cunningham, “Lessons from GbE”, Jan 2004.



MSL test box



Shake fibre

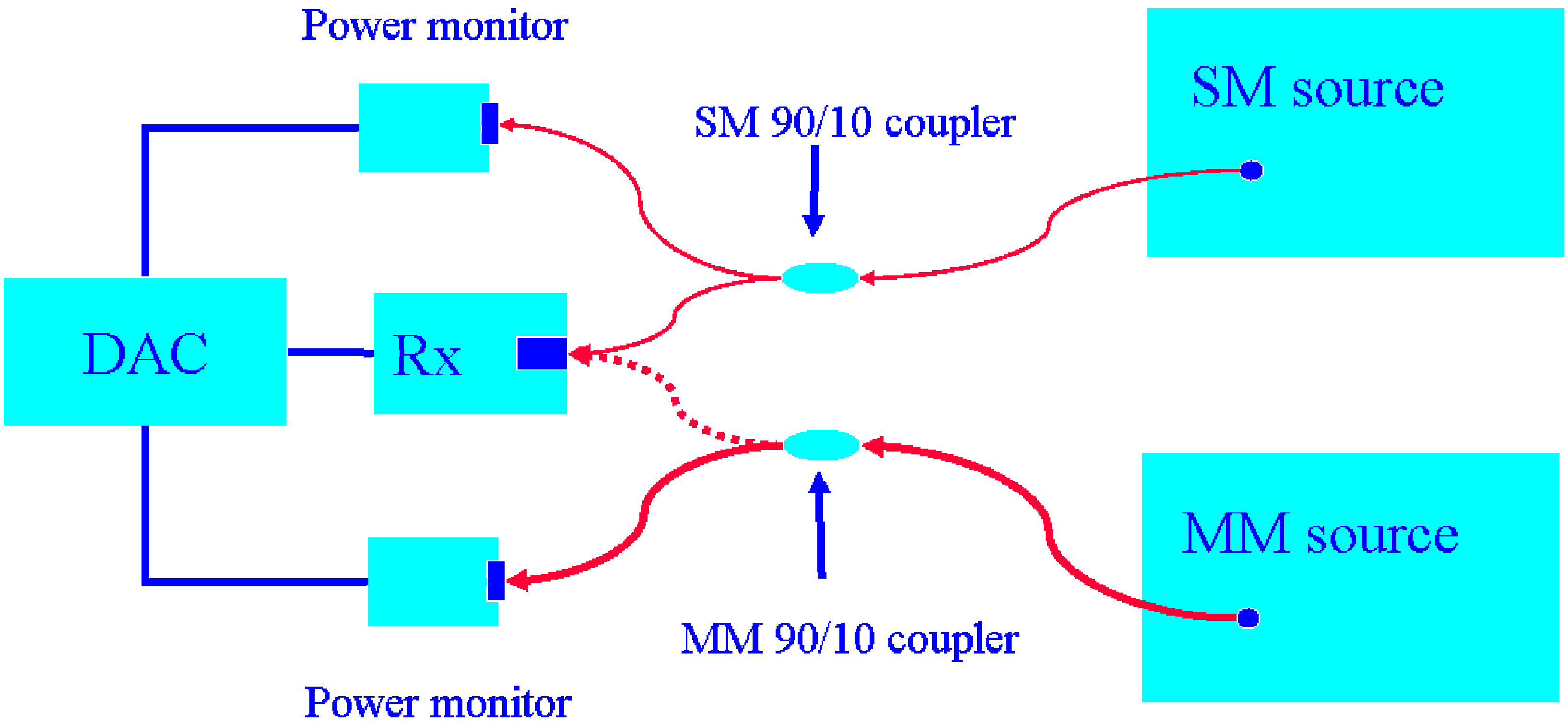
Ramp laser temperature

Computer controlled modal noise power penalty measurement setup.

Receiver Specifications

Parameter	10GBASE-L	10GBASE-LRM	Unit	Note
Center wavelength	1260 - 1355	1260 – 1355	nm	Related to MMF design
Min. average receive power sensitivity	-14.4	-12.0	dBm	Assuming OMA sensitivity at BER=10^{-12} with ER=3.5dB
Max. average receive power overload	+0.5	+0.5	dBm	Overload or safety
Sensitivity OMA_{sens}	-13.2	-12.6	dBm	Sensitivity at BER=10^{-12} and back-to-back connection with reference transmitter
Overload OMA_{max}	NA	+3.5	dBm	Overload with ER$\rightarrow\infty$
Max. reflectance	-12	-12	dB	Standard for low cost LC
Low frequency cut-off	NA	100	kHz	Max. low frequency cutoff
High frequency cut-off	12.3	7.8	GHz	High frequency cutoff for maximizing SNR
Receiver Mode Selective Loss	N/A	TBD	dB	Coupled Power Test to be developed by Task Force

Rx Conformance Test



Conformance test: Ratio between Rx Responsivity using SM source to MM source.

Receiver Conformance Test

Parameter	Unit	Test
Center wavelength	nm	**Same as 10GBASE-LR**
Min. average receive power sensitivity	dBm	**Same as 10GBASE-LR**
Max. average receive power overload	dBm	**Same as 10GBASE-LR**
Sensitivity OMA_{sens}	dBm	**Same as 10GBASE-LR**
Overload OMA_{max}	dBm	**Same as 10GBASE-LR**
Max. reflectance	dB	**Same as 10GBASE-LR**
Low frequency cut-off	kHz	**Same as 10GBASE-LR**
High frequency cut-off	GHz	**Same as 10GBASE-LR**
Mode Selective Loss	dB	**New – Coupled Power Test**

The proposed standard only have incremental changes from the Standard 10GBase-LR spec

PAR Criteria 4: Economic Feasibility

The proposal is designed to reduce the cost of the components Used in the 10GBASE-LR single mode Standard:

1. Addition of a Mode Filter at the receiver (negligible cost impact).
2. Minimize complexity of EDC function ("make it free")
3. Use minimum complexity source types to reach 220 and 300m

Relative Cost*	DFB	EAM
10,000/month	2	4
50,000/month	1.3	1.7
100,000/month	**1.0**	1.2

*** Prices are relative to DFB at 100kunits/month**

*** Assumes uncooled devices**

*** Devices are packaged using same TOSA type**

PAR Criteria 5: Distinct Identity

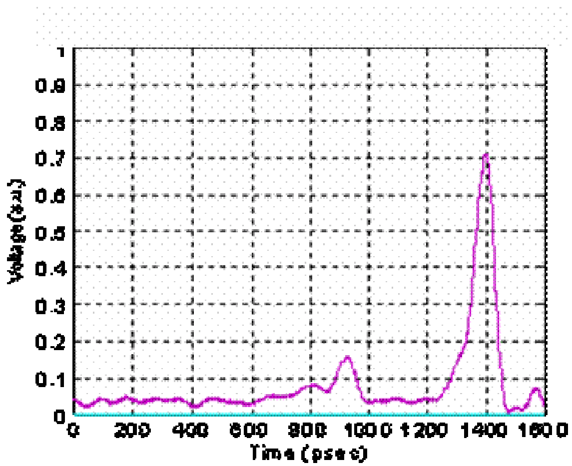
- Proposed technology has been shown to meet the power, cost, and form factor requirements of 10GBASE-LRM.
  - Supports all pluggable form factors including XFP
- This proposal addresses a distinct solution to this challenge.

Summary:

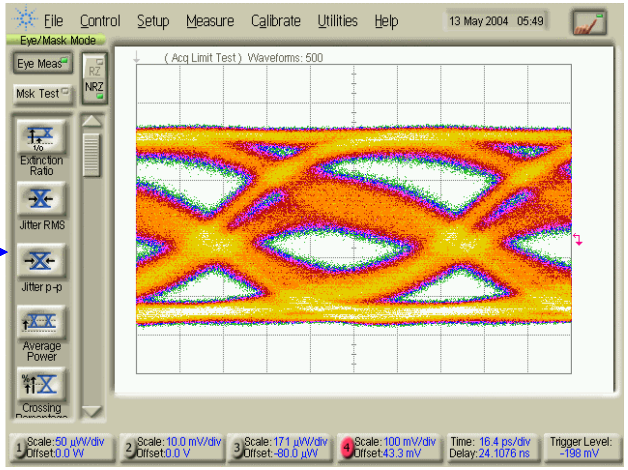
- New Optical filtering approach shows promising results for solving the 300m FDDI grade MM fiber problem.
- Performance improvements from using different optical transmitters and receivers is not cost prohibitive.
- The proposed solution only is an incremental change to the standard 10GBASE-LR specification.
- Depending on the channel model definitions the combination of an EDC with the optical filtering approach can provide the best design tradeoff between cost, power dissipation and performance.

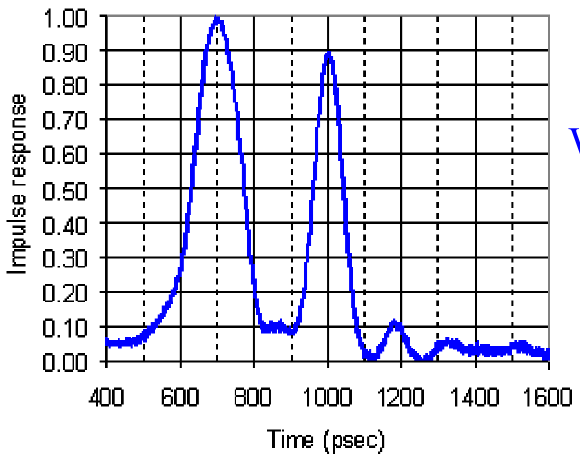
Appendix A: Impulse response improvement with mode filtering:

3 µm offset at launch and +5 µm offset in the middle – link is 300 m

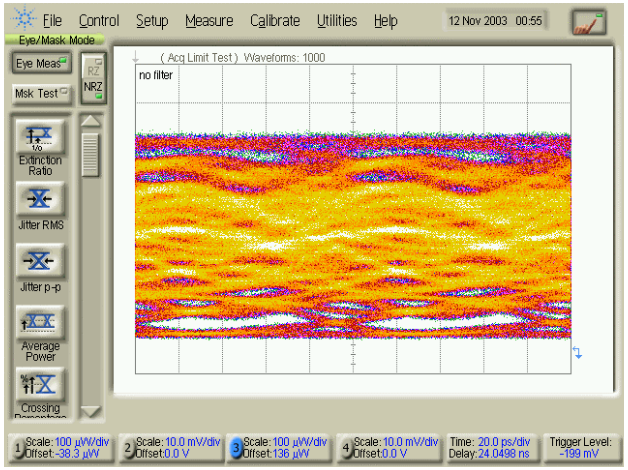


With Spatial Filter

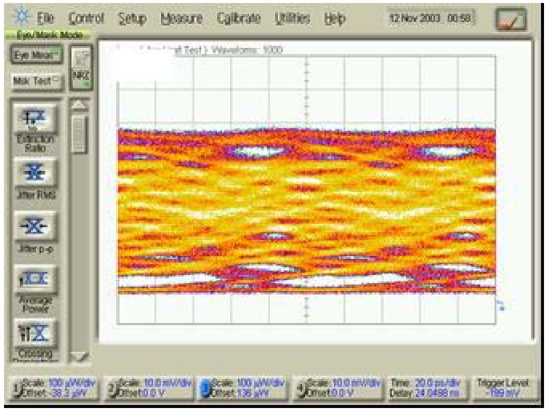
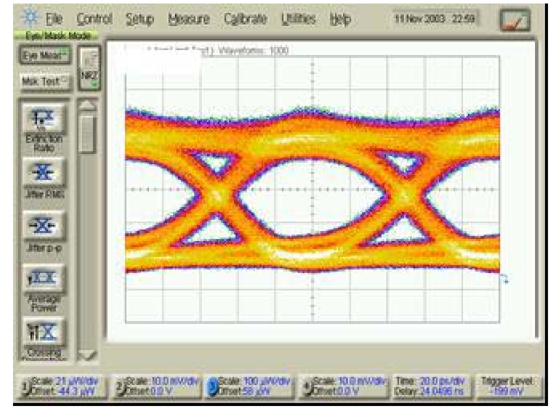




Without Spatial Filter



Appendix B: Longer reach link experiments

	Without Spatial Mode filtering	With Spatial Mode filtering
450 m		
600 m