IEEE 802.3
10GE MM Study Group
PHY Submission

Optically Mode Filtered PHY Testing for 300m FDDI Fiber Transmission

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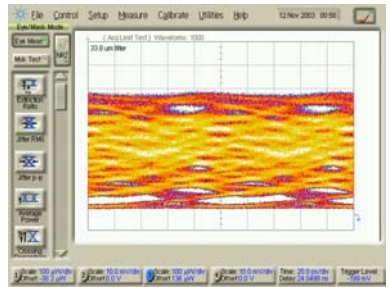
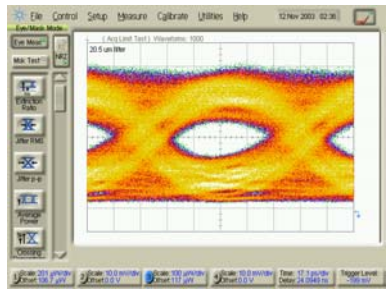
Optical Mode Filtering Approach

1. The ISI caused by DMD attributable to poor index profile limits link distance



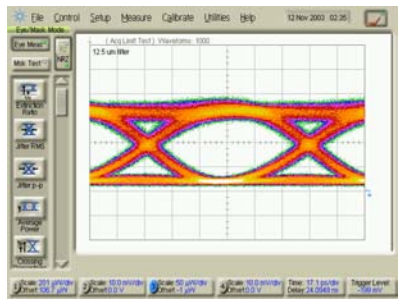
DMD Limited Eye

2. An output modal filter can be used to recover a small set of the modes; higher order mode groups are filtered out However, if Mode Selective Loss is present, MODAL NOISE will be present and must be compensated



Mode Filtered Receive Eye with Modal Noise

3. Proper Tx Design, Launch Profile and Output Mode Filter can reduce the Modal Noise and enable 300m transmission



Mode Filtered Receive Eye with Modal Noise Compensated

Modal Noise Considerations

- Mode Filtering was not studied during GBE activities, so this is new
- Modal Noise Generation is a Function of:
  1. Temporal Mode Amplitude Variations (Effective MSL Accumulation)
     - Connector Junction offsets or dirty connectors
     - Any other MSL points due to fiber defects
     - The Effective MSL will depend on the mode field at the MSL point
  2. Temporal Mode Propagation Variations
     - Environmental Effects: Mechanical, Thermal
     - Tx Source Spectral Dynamics
  3. Source Coherence
- MSL accumulation must be bounded for a given channel model and launch
- Tx Sources can be designed to provide immunity to propagation variations

Test Results

- 1296 TIA Fiber Spool -'FO2.2 12-96 BW MODAL Launch Test Cable' June '97

TIA Fiber Number	DetailedFiber Description	Modal BW	Link Length	Number of Connector Junctions in Link	Tx Launch	Rx B-B Sensitivity (1E-12)	Rx Receive power MM detector	Rx Receive Power at Rx	Temporal Variation at Output of Modal Filter	Link Margin (Inserted Attenuation for Link Failure at BER 1E-12)
					dBm	dBm	dBm	dBm	dB	dB
1	1/orange	0.6223	300m	2	-3	-17	-3.61	-5.4	0.80	**13.0**
2	1/green	0.347	300m	2	-3	-17	-3.33	-6.3	1.40	**12.0**
3	1/blue	0.6803	300m	2	-3	-17	-3.5	-5	0.80	**12.5**
4	2/orange	0.3153	300m	2	-3	-17	-3.35	-5.1	1.00	**12.7**
5	2/green	0.337	300m	2	-3	-17	-4.19	-6.73	1.80	**12.5**
6	2/blue	0.4963	300m	2	-3	-17	-3.7	-5.9	1.30	**12.5**
7	3/aqua	0.2837	300m	2	-3	-17	-3.76	-5	0.40	**13.6**
8	3/blue	0.2332	300m	2	-3	-17	-3.5	-5.22	0.60	**13.0**
9	3/violet	N/A	300m	2	-3	-17	-3.38	-5.69	1.50	**13.0**
10	4/orange	0.4558	300m	2	-3	-17	-3.4	-5.7	1.40	**12.5**
11	4/green	0.555	300m	2	-3	-17	-3.4	-6.4	0.50	**13.0**
12	4/blue	N/A	300m	2	-3	-17	-3.3	-6.1	1.20	**13.0**
13	5/orange	0.70395	300m	2	-3	-17	-3.35	-5.4	2.00	**11.0**
14	5/green	0.8175	300m	2	-3	-17	-4.2	-6.5	2.50	**7.0**
15	5/blue	0.7367	300m	2	-3	-17	-3.5	-5.33	1.70	**11.0**

- >10dB Margin on 14/15 fibers, 7db on 1/15
- Mechanical stress applied during measurement
- Small MSL introduced

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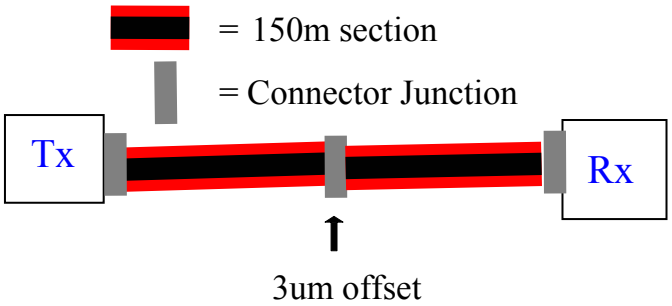
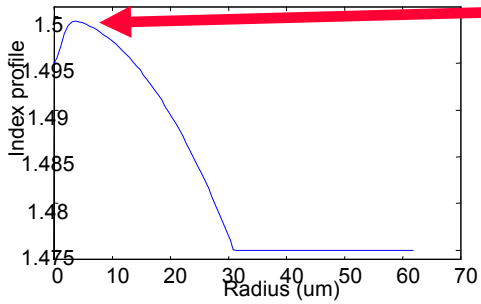
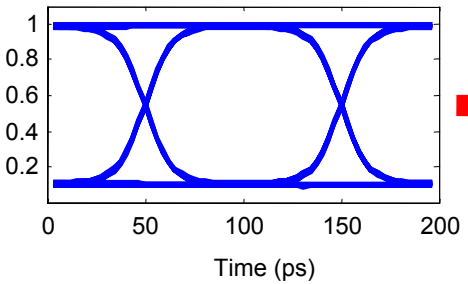
Link Simulation Showing Principle



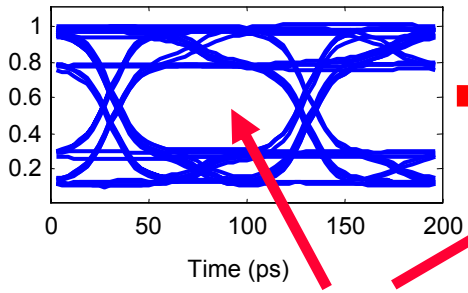
Dipped Index Profile



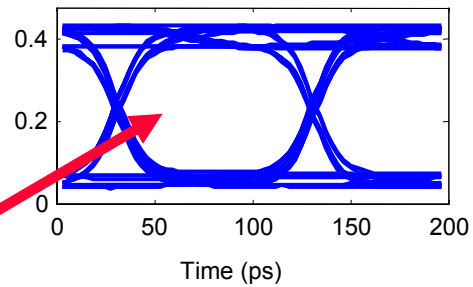
Launch Eye



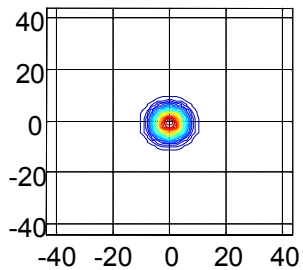
Pre Mode Filter Eye

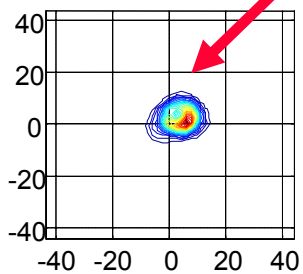


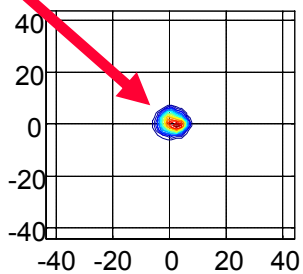
Post Mode Filter Eye



Modal Filtering







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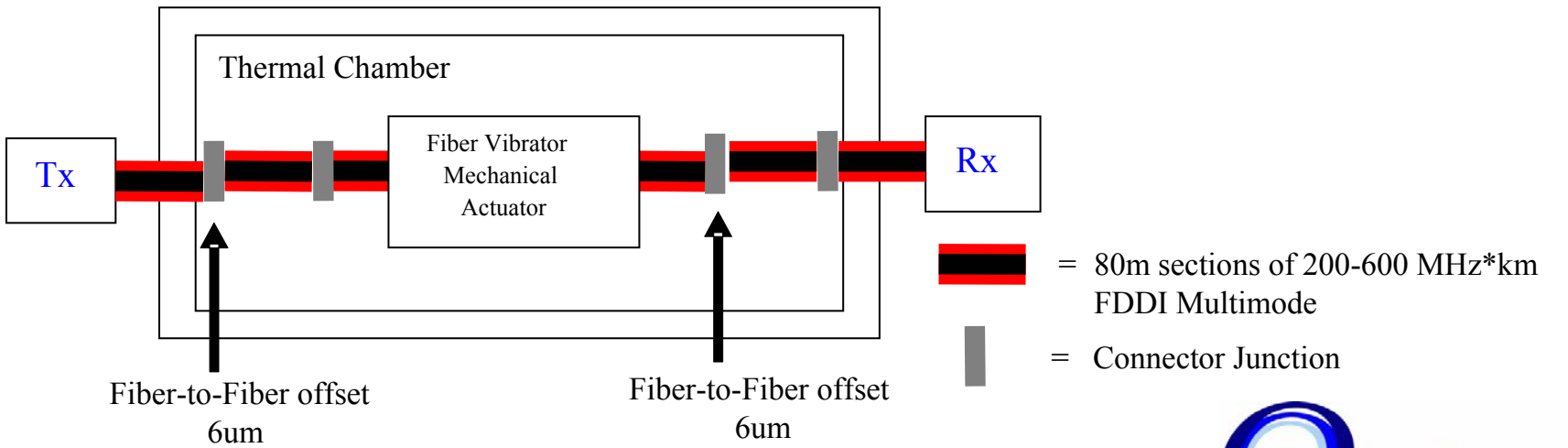
Environmental Testing (1)

- Extreme environmental testing was performed to understand the boundaries of the optical approach:
  - OFL Modal BW's – Tested in the range of 200 - 800MHz*km
  - Impulse Responses – Many fibers tested with Impulse responses to 1 ns/km delays, multiple launch offsets
  - Connector misalignment testing – Introduced 0-6um offsets into the links to test resiliency to MSL and cross coupling



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Environmental Testing (2)

- Thermal ramp testing – Cycled 6 span links (with connector offsets) at rates of 2C/min , -5 to 70C
- Mechanical testing – Introduced mechanical perturbations through fiber benders to generate modal noise
- Multiple connectors in link – added 6 connector junctions in link (with and without offsets)
- Preliminary data looks promising for an optical approach based on modal noise reduction and mode filtering
  - The channel model definition is critical to this approach's feasibility

Environmental Testing (3)

- Preliminary Extreme Environmental Testing exhibited the following modal noise penalties:
- Worst Case Equivalent Power Penalties
  - Nominal Modal Noise 300m FDDI grade fiber with 4 offset connectors (4um) = 2dB
  - Modal Noise Mode increase during thermal and mechanical agitation with same offsets = 4dB
  - Total Worst Case Modal Noise Penalties = 6dB
- With Back to Back Sensitivity of -14dBm there is still plenty of margin for other power penalties

This type of characterization needs much more detailed study by the Group

Compliance Testing Considerations

- Need to choose Modal Noise Parameter and Method
  - Eye quality? Q factor? Sigma?
  - Equivalent Power Penalty?
- Transmitter Compliance Test:
  - Max Modal Noise Generation through known channel
- Receiver Compliance Test
  - “Dirty-Eye” receiver tolerance test with modal noise loaded Signal

Interoperability with EDC

- EDC could be used to increase link distance of Optical technique alone
- Study Group needs to understand tradeoffs of ISI compensation (EDC) and Optical Filtering with Modal Noise compensation
  - Intermediate solution that's most cost effective?
- Proper mode filter design could accommodate EDC and/or all optical approach

Module Economics

- Mode filters can be made inexpensively
  - The use of a fiber stubs or equivalent will meet the requirements of 300m transmission, farther distances with more sophisticated designs
- We have demonstrated 300m transmission with a transmit device made with same processing capability used for a making Directly Modulated DFB's
- Source can be un-cooled for cost and power reductions
- Fits in all pluggable form factors

Summary of All Optical Approach

- Test results look promising for exceeding the 300m requirement in a field system environment
- The previous limitations resulting from Modal Noise during mode filtering can be overcome with new optical techniques
- The channel model will need to consider parameters which contribute to modal noise
- The approach can be implemented to interop with EDC
- The approach has been tested successfully on known poor fibers
  - TIA Round Robin Fiber
  - Industry participants who gave access to their test beds (thank you!)