CFI
10 Gb/s Ethernet on FDDI-grade MM Fiber

final

Bruce Tolley, Cisco Systems

Jeff Bisberg, Picolight

Chris Bryson, Phyworks

John Jaeger, Big Bear Networks

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Supporters

- Ali Abaye / Centillium
- Lew Aronson / Finisar
- Richard Brand / Nortel
- Dan Dove / HP
- Wayne Eng / Mysticom
- Ali Ghiasi / Broadcom
- David Law / 3Com
- Tom Lindsay / UI Technolgies
- Petre Popescu / Quake Technologies
- M. Leonard Riaziat / OEpic, Inc
- David Srodzinski /Elonics
- Norm Swenson / Clariphy
- Brian Taylor / OEpic, Inc.
- Shelto Vandoorn / Intel
- Paul Voois / Clariphy

And special thanks to Vipul Bhatt

Why We Are Here?

- To measure the **interest** in starting a study group to investigate
  - Using 10Gbs serial lasers to achieve 300 meters on legacy 62.5 micron MM fiber
    - 160/500 MHz·km, 200/500 MHz-km 62.5µm
    - 500/500 MHz·km 50µm
- Not to
  - Fully explore the problem
  - Debate strengths and weaknesses of solutions
  - Choose any one solution
  - Write PAR or five criteria
  - Write a standard or specification

Why Now?

- Lack of broad market availability from multiple vendors of 10GBASE-LX4, the port type specified to meet the 300 meter goal for installed MM fiber
- Other standards bodies were investigating solutions for MM fiber, EDC for extended reach
  - OIF
  - Fibre Channel ANSI T11.2
- Many companies privately investigating non-standards-based, proprietary 10 GbE MM fiber solutions

Scope of the Problem

- Specify a PHY that supports a full-duplex 802.3ae MAC across the target distance of multimode fiber
  - 300m of 'FDDI grade' fiber media types including:
  - TBD distance on additional fiber media types including:
    - 400/400 MHz·km 50μm
    - IEC 11801 OM3 50μm
- Leverage existing 10GbE PHY & PMD technologies to the extent possible
- Cost goal:
  - Solution to cost <= 10GBASE-LR. IMHO we cannot end up with a solution that costs more than -LR

Goal For Tonight: Measure Interest

- Presentations:
  - Distinct identity (Jeff Bisberg: Picolight), Market and economic issues (Chris Bryson: Phyworks), Technical feasibility (John Jaeger: Big Bear Networks)
- CFI Poll
- Polls
- Next steps, formation of ad hocs
- Short Q&A

10GbE on FDDI-grade MM Fiber
Call For Interest (CFI)

Distinct Identity & Compatibility

Jeff Bisberg, Picolight

Distinct Identity – Availability

- 10GBASE-SR, Shipping from multiple vendors
- 10GBASE-LR, Shipping from multiple vendors
- 10GBASE-LX4, Limited availability
- 10GBASE-ER, Shipping from multiple vendors

System vendors have not been able to secure sufficient quantities of 10GBASE-LX4 to establish a viable market.

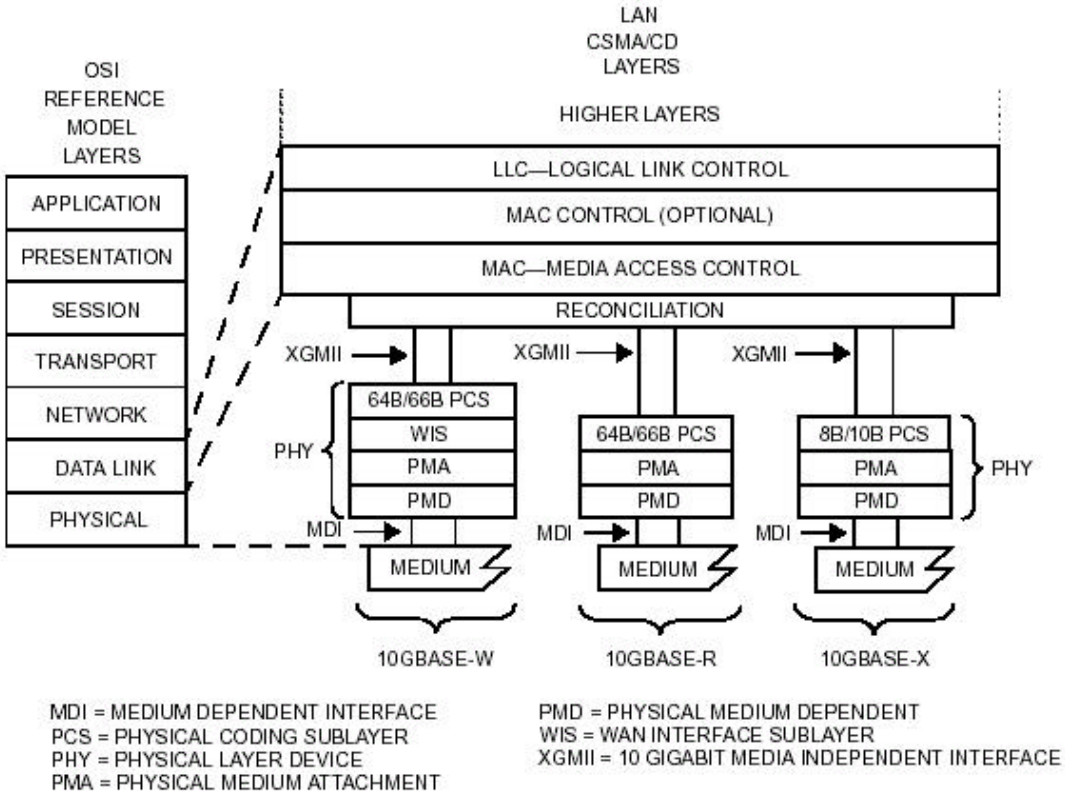
Distinct Identity

GOAL 300 meters on legacy fiber

	Fiber Type	Wavelength	Modal Bandwidth @ 850nm	Modal Bandwidth @ 1310nm	Operating Range
10GBASE-SR	62.5 um MMF	850	160	500	2 to 26
10GBASE-SR	62.5 um MMF	850	200	500	2 to 33
10GBASE-SR	50 um MMF	850	400	400	2 to 66
10GBASE-SR	50 um MMF	850	500	500	2 to 82
10GBASE-SR	50 um MMF	850	2000	500	2 to 300
Limited Availability					
10GBASE-LX4	62.5 um MMF	<1310>	160/200	500	2 to 300
10GBASE-LX4	50 um MMF	<1310>	400	400	2 to 240
10GBASE-LX4	50 um MMF	<1310>	500	500	2 to 300
10GBASE-LX4	10um SMF	<1310>	2000	n/a	2 to 10000
10GBASE-LR	10um SMF	1310	n/a	n/a	2 to 10000
10GBASE-ER	10um SMF	1550	n/a	n/a	2 to 30000
			n/a	n/a	2 to 40000
Proposed					
10GBASE-L*	62.5 um MMF	1310	160	500	2 to 300
10GBASE-L*	62.5 um MMF	1310	200	500	2 to 300
10GBASE-L*	50 um MMF	1310	400	400	2 to 240
10GBASE-L*	50 um MMF	1310	500	500	2 to 300
10GBASE-L*	50 um MMF	1310	2000	500	2 to 300

Conformance with 802.2

- Working group will draft PMD clause and possibly PHY clause.
- Will not touch MAC and therefore will maintain compatibility and conformance



Broad Market Potential & Economic Case for 10 Gb/s Ethernet on FDDI-grade MM Fiber

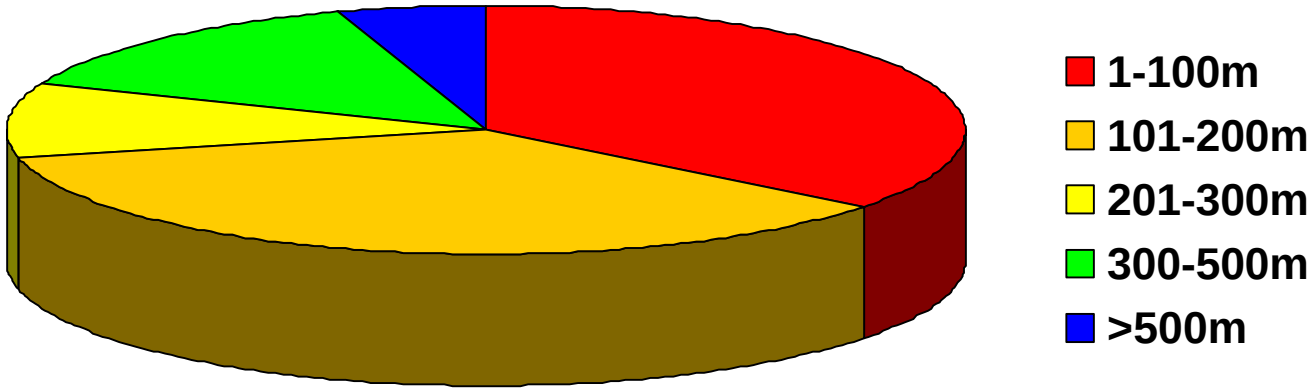
Bruce Tolley
Cisco Inc

Chris Bryson
Phyworks Ltd

Why 10GbE on Legacy MMF is Important

- Today: 80 to 90% of 1000BASE-X pluggables are –SX for MM fiber
- Enterprise customers do not want to be forced to pull new fiber to deploy 10 GbE. MMF is the installed fiber base in vertical riser
- Broad Market Potential has not been achieved with -LX4
  (Broad sets of applicability, multiple vendors and numerous users, balanced costs – LAN vs. attached stations).
- Without MM fiber support, 10 GbE market shrinks dramatically
- 10GbE on MM fiber is aimed specifically to extend core business of enterprise Ethernet switching, aggregation of 10/100/1000
  - –24 million ports
  - –$2.7 Billion market in Q1CY03 (Dell'Oro Group)

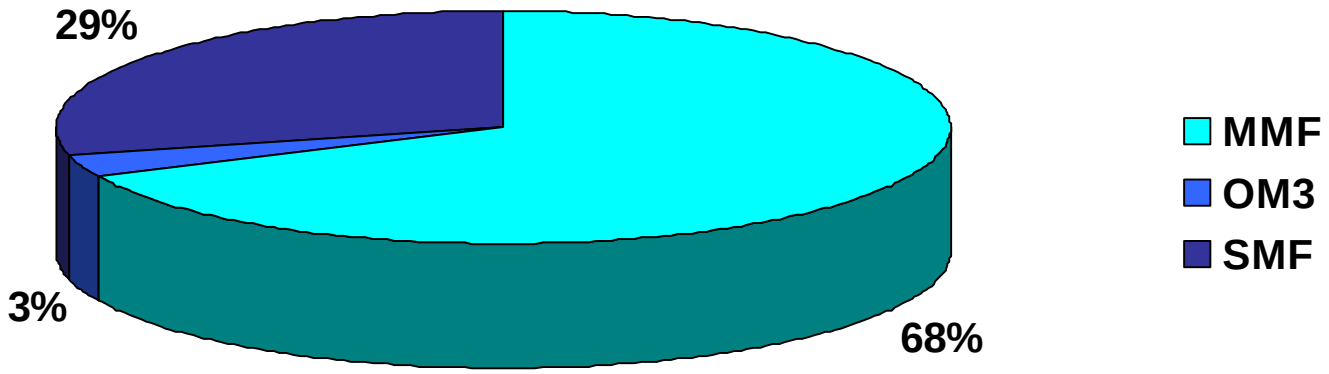
Intrabuilding Backbone Max. Distance



Chris Diminico, Fiber Optic Cabling Survey. IEEE 802.3, 1997

How would the above reaches be typically served at 10G?

Installed Base of Fiber



Systimax SCS™ Cabling Infrastructure Report, Avaya, 2002

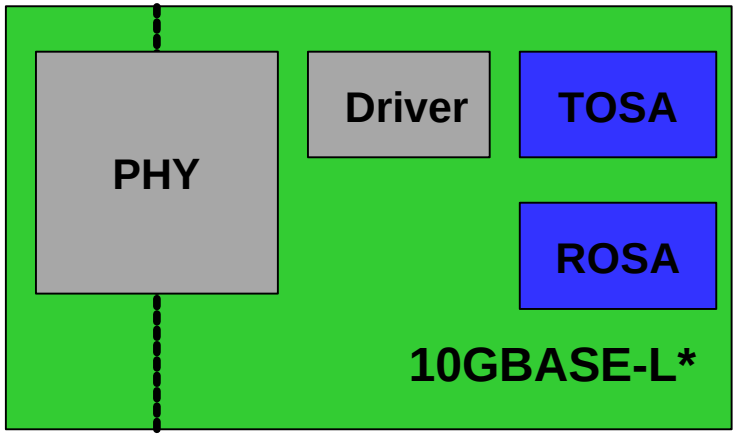
- Worldwide sample of over 2000 network & IT managers; intentions & priorities for upgrading LANs
- Mixed user types and industries (customers & non-customers)
- 59% expected to deploy 10GbE backbone in next 5 years
- Since this report, OM3 has started to be deployed in significant quantities in order to support upgrades to 10G

Economic Case - Unlocking the Market

- The 10GbE market still has huge potential (e.g. latest Dell'Oro market forecast)
- Customers demand a "plug and play" solution across all key reaches and installed media
- By supporting the installed media, we lower the cost of deployment (upgrading the fiber is significant extra cost)
- There is no cost effective solution for 300m over 62.5μm fiber available today
- Lack of support for the installed base of multimode fiber will continue to delay the entire market takeup

Module Economics

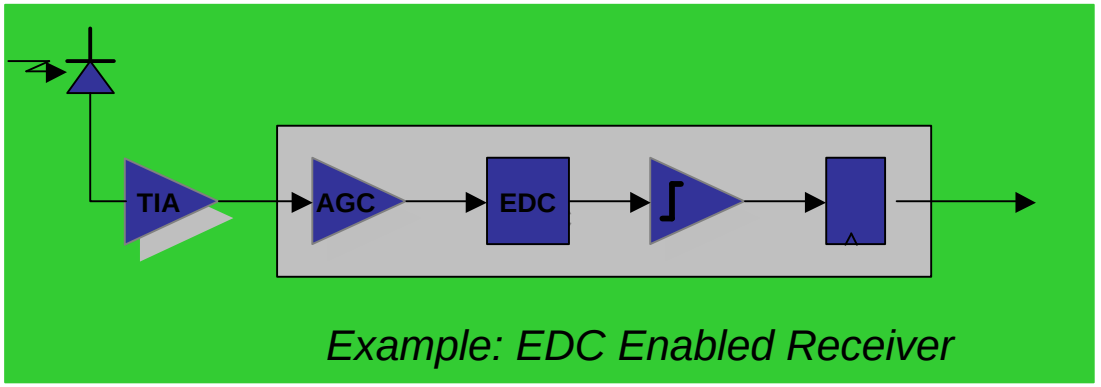
A common assertion is that for 10GbE to be deployed in volume, 10Gbps modules should cost (3x – 4x) 1GbE modules.



Example 10GBASE-L* Module Content

- 10GBASE-L* can be fundamentally a straightforward, low-cost architecture.
- Compared to 10GBASE-L, certain reach enhancing technologies may enable lower cost modules.

Component Level Economics



- Getting to 300m is likely to involve a combination of optical solutions and reach enhancing silicon ICs.
- These reach enhancing technologies are now becoming available from several vendors (broad market potential).
- Both electronic and optical technologies being developed for this application can be integrated into all of the module MSAs.
- It is likely that the technologies developed for this application will simply become a feature at marginal extra cost as the volume increases.

Summary

- Deploying 10G over the installed fiber base makes economic sense, and fulfils a real market need
- The original PMD chosen does not have broad market potential,
  hence the need to revisit this.
- The lack of a 300m MMF solution is a delaying factor to the whole 10GbE market
- Economically viable extended reach module solutions are being developed by multiple module & component vendors
- Potential implementations to extend the reach are predicted at the same or lower cost than 10GBASE-LR

Technical Feasibility of 10 Gb/s Ethernet on FDDI-grade MM Fiber

John Jaeger

Big Bear Networks

Contributors

- David Cunningham, Piers Dawe & Richard Dugan – Agilent Technologies
- Sudeep Bhoja & Jonathan King – Big Bear Networks
- Petar Pepeljugoski – IBM Research
- Scott Schube, Bob Zona – Intel
- John Ewen – JDSU
- Pete Hallemeier – Optium
- Abhijit Shanbhag – Scintera
- Vipul Bhatt – unaffiliated

Note: Please note that additional material relevant to the technical feasibility presentation is attached as back-up slides

Impairments & Technical Challenges

- 'Conventional' serial 10G transmission on installed base fiber exhibits differential mode delay (DMD) of the transmitted signal
- This modal dispersion leads to complex multi-path impulse responses resulting in ISI
  - The impulse responses can vary with time due to cable movement, temperature change, or other effects that result in a change of the optical power split across the mode groups
  - The effective bandwidth performance of the channel results in a significant dispersion link penalty
- Modal noise due to the coherent source on the multi-path link & variations of the speckle pattern at points of mode-selective loss
- Launch dependence on the 'effective modal bandwidth'
  - Specification of restricted/off-set launches to achieve required BW?
  - An "Modal Bandwidth Investigation Part 2" work item?

Technical Issues - Study Group/Task Force

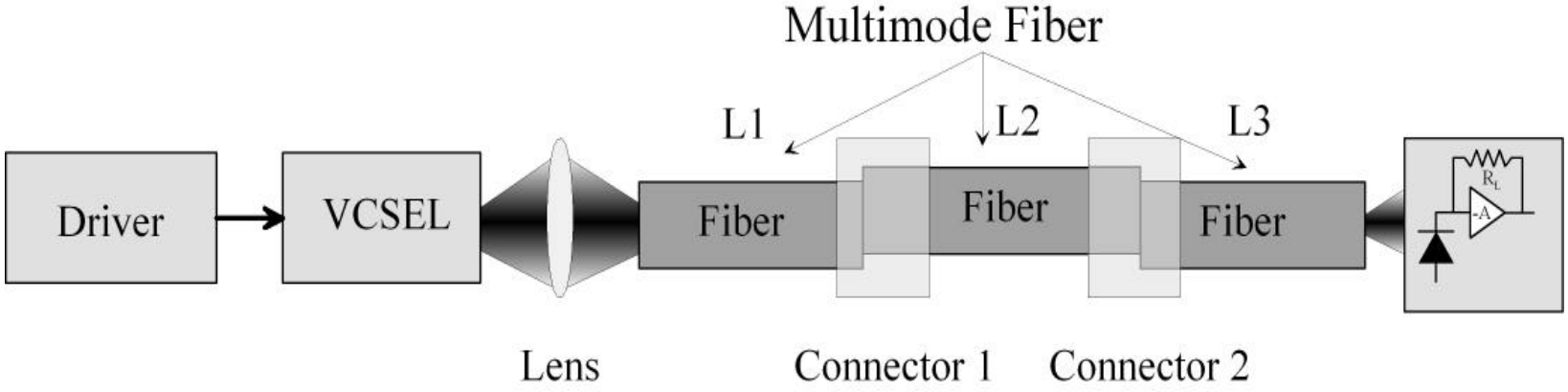
1) Channel Definition, Characterization & Model
   - Provide a framework for a channel model that can be used to benchmark technical solutions
     - Extensions off the 802.3.z worst case model
     - Complementary fiber model leveraging efforts of recent TIA activities
   - The model results are a likely input to the compliance test activities
2) Compliance / Conformance Test
   - Define a standardized test approach to provide a uniform compliance procedure to ensure link interoperability
3) Selection of a PHY / PMD solution
   - The detailed specification of a PHY/PMD is a work item for a Task Force, but the SG should start down the selection & specification path
     - Review proposed technical approaches and evaluate them for technical feasibility & ability to meet general requirements

(1) MMF Characterization & Feasibility

- Characterization: Leverage 802.3z MMF work as basis for statistical analysis of electronically equalized multimode fiber links
  - Publish full set of 81 fiber impulse responses for complete statistical analysis
    - Ref.: M.Webster, L. Raddatz, I.H. White, and D. G. Cunningham, "A Statistical Analysis of Conditioned Launch for Gigabit Ethernet Links Using Multimode Fiber," IEEE J. Lightwave Technol., vol. 17, No. 9, pp.1532-1541, 1999.
  - Create and publish a reduced set of impulse responses based upon data measured from legacy "worst-case" fibers
    - Corner cases used to establish viability and coverage of standard
- Feasibility: Provide implementation independent analytical equations for modeling electronically equalized multimode fiber links to:
  - Underpin power budget methodology
  - Enable a simple link spreadsheet for equalized MMF links similar to the 10GE
  - Challenges & Goals:
    - Prove that electronic equalization can support 300m operation over the installed base
    - Develop minimum set of conformance tests for electronically equalized PMD

(1) Multimode Fiber Link Model*

- Structure of MMF Link Model follows typical structure of Ethernet Links
- Fiber model based on solution of the scalar wave equation
  - Used by the TIA to aid the development of specifications for NG-MMF
  - Fiber mode delays can be calculated or used from statistical sample
- Laser launch conditions (offsets, tilt, mode structure, beam size) included in a statistical manner
- Degradations due to connector offset included
- Typical models for the driver, laser and Rx, user defined input pattern
- ISI penalty, DJ and retiming window are among model outputs



*Pepeljugoski et al: "Modeling and Simulation of Next Generation Multimode Fiber Links", IEEE JLT, May 2003

Feasibility Testing Results Summary

- 2 silicon vendors & 4 module/transponder vendors contributed data
- Since the 802.3ae EQ Ad-hoc, several vendors have reduced to practice implementations that begin to address the 10GE serial MMF requirements
  1) Electrical approach – Rx Equalization
  2) Optical approach – Spectrally Conditioned Tx with Mode Filtering

➢ NB: These are preliminary results from 2 simulations & a few point lab tests

Simulation / Analytical System Feasibility Results:

B0. A simulation model of the 802.3z MMF impulse responses, demonstrates >94% coverage of 300m links for a representative linear / DFE Equalizer

C0. A simulation of a linear EQ on a 'worst-case' fiber with off-set patch cord, yields a 300m equalized path penalty of ~5+ dB & ~4+ dB for a linear & linear/DFE EQ respectively

Experimental System Feasibility Results:

B1. 300m, 12 fibers from the TIA 10GbE Demo round robin cable (OFL BW 515MHz·km on up), consistent 10^{-12} BER performance with a linear Equalizer

B2. 800m 'off-the-shelf' fiber, equivalent to 290m 500MHz·km (w/ MCP) with linear equalizer

D1. 400m 621 MHz·km (OFL BW) w/ CL, 10^{-12} BER results w/ linear & feedback equalizer

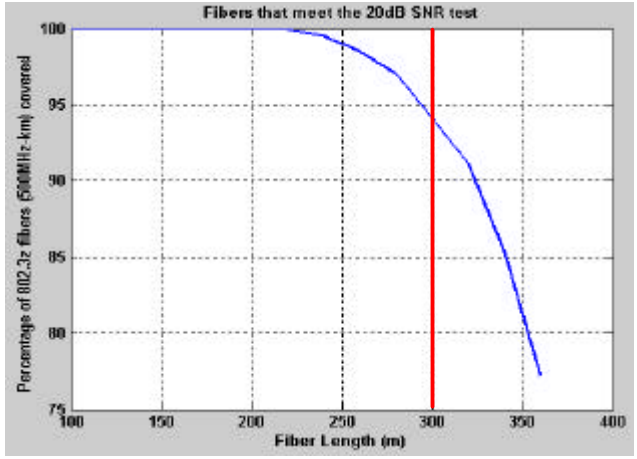
D2. 300m 576 MHz·km (OFL BW) w/ MCP, 10^{-12} BER results w/ linear & feedback equalizer

F1. 500m (8 sections, 200-600 MHz·km fiber) 10^{-12} BER results with optical mode filtering on Tx & Rx

Now for a quick overview

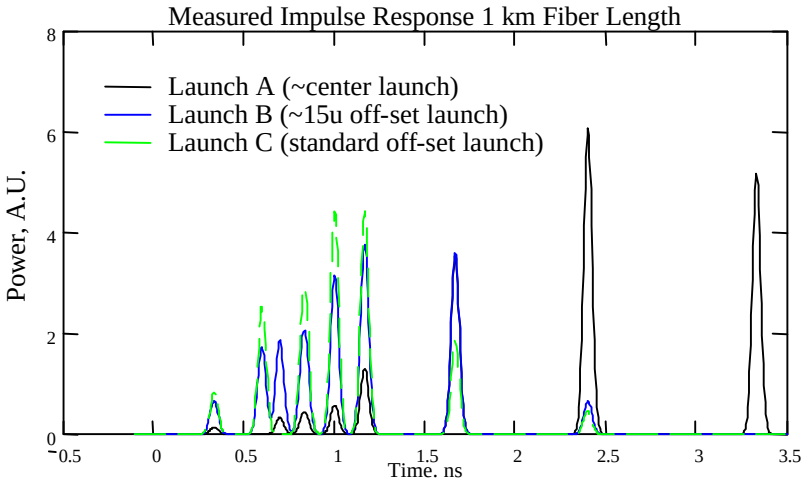
Vendor B & C – Analytical Results

Vendor B

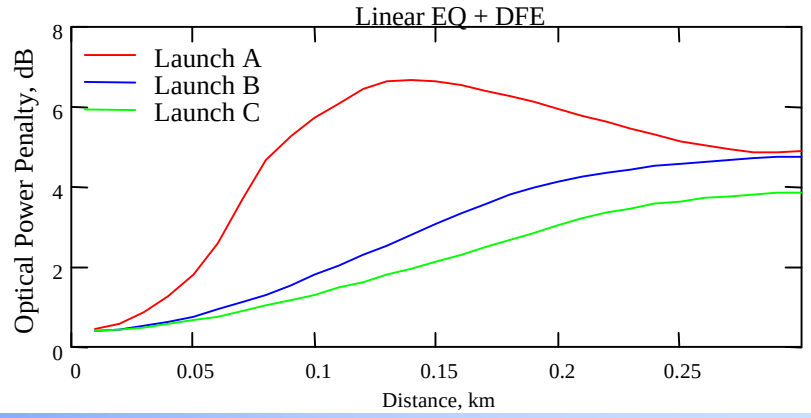


- Vendor B: Link Model:
  - Assumed Channel SNR is 31dBe
  - Target SNR at slicer is 20dBe
- All 802.3z measured fiber impulse responses that meet 500MHz·km test included
- A representative transversal Filter / DFE Equalizer architecture provides >94% fiber coverage @ 300m

Vendor C

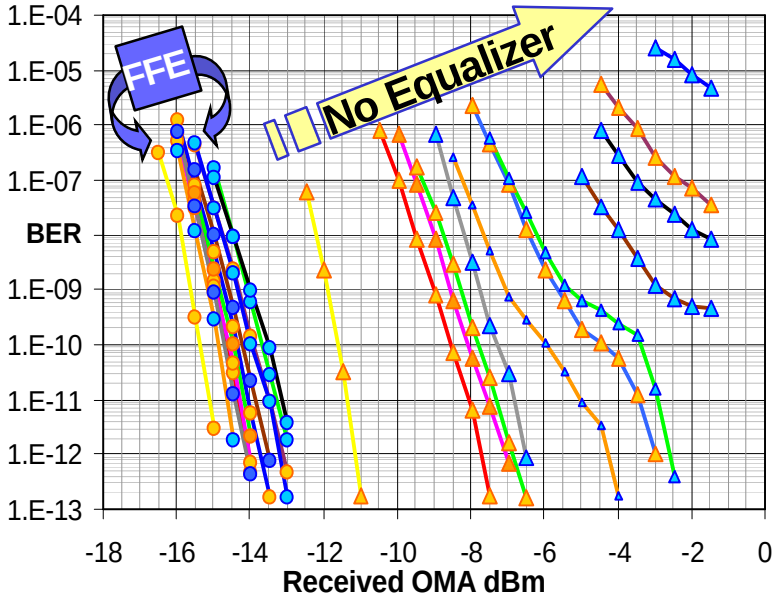


- Vendor C: Measured impulse response from fiber used in .z model establishment (a very poor fiber)
- 4 – 5 dB optical path penalty for modeled linear EQ w/ DFE for the 3 launch conditions
  - Clearly observe the benefits of the off-set launch



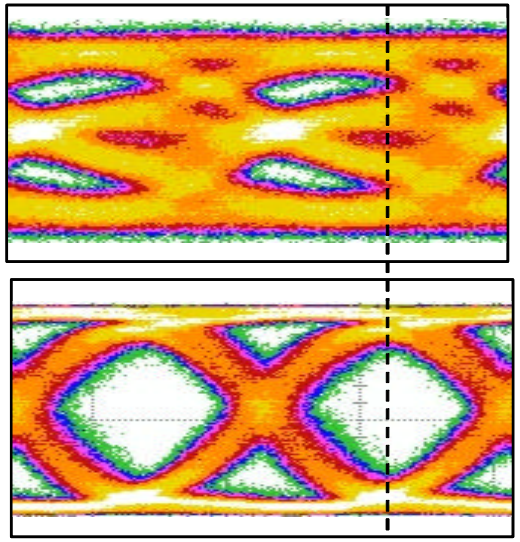
Vendor B - Various Test Fibre Results

TIA 10Gbe Demo Fibers – 300 meters



- 1310nm uncooled DML, MM Rx, 2^{31}-1 PRBS, MCP
- OFL bandwidths 515 – 1105 MHz·km
  - RML: 673 – 2196 MHz·km, MCP: 1600 – 5200 MHz·km
- Without equalization:
  - 8 fibres have path penalties 2-10dB, 4 have error floors
- With FFE Equalizer:
  - All fibres have <2dB path penalty
- Fibers provided courtesy of Corning, Inc.

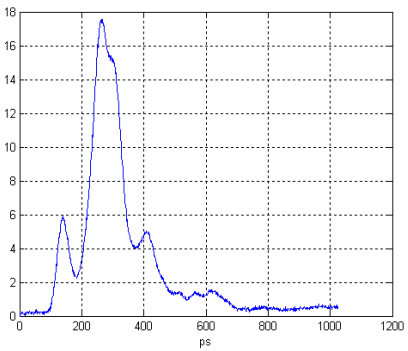
800m 1.3GHz·km Fiber



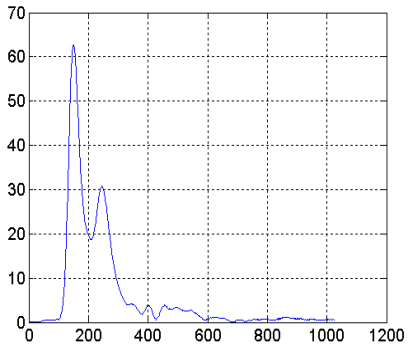
- 800m of "off-the-shelf" MMF
  - Measured 1.3GHz·km w/ MCP
- Scales ~290m @ 500MHz·km
- Completely closed eye
- BER at 10^{-12} limit at this distance with FFE Equalizer

Vendor D - Experimental Link Results

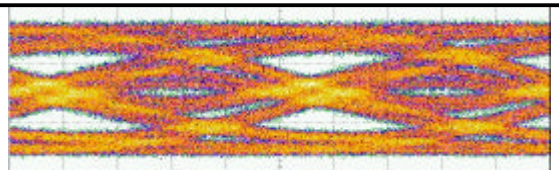
Link Parameter	Value
Data Rate	10.3125 Gb/s
Fiber/ Wavelength	62.5u / 1310nm
Link Attenuation	1.1 dB (measured)
Extinction Ratio	6 dB
ROSA Responsivity (A/W)	0.75
TIA differential Impedance (Ω)	1500
TIA bandwidth	7 GHz
RIN (dB/Hz)	-125
TIA induced noise (pA/sqrt Hz)	12
Transmit power range (dBm)	-4 to 0
EDC Architecture: linear & non-linear, feed-forward & feed-back signal processing	



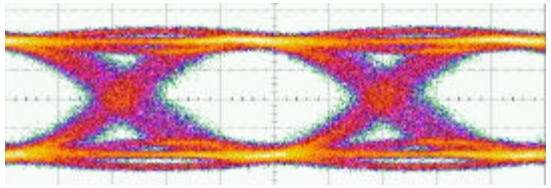
Center Launch F1
OFL BW: 621 MHz·km



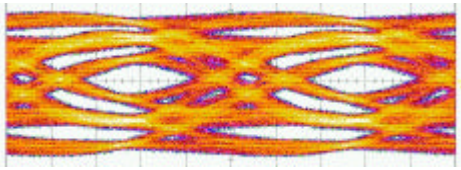
Offset Launch F2
OFL BW: 576 MHz·km



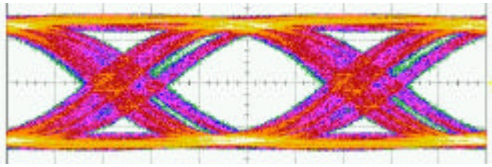
Uncompensated F1: 400m,
Error Floor at 1e-3 (Center launch)



Compensated F1: 400m, BER < 1e-12
for Tx power >-3dBm (Center launch)



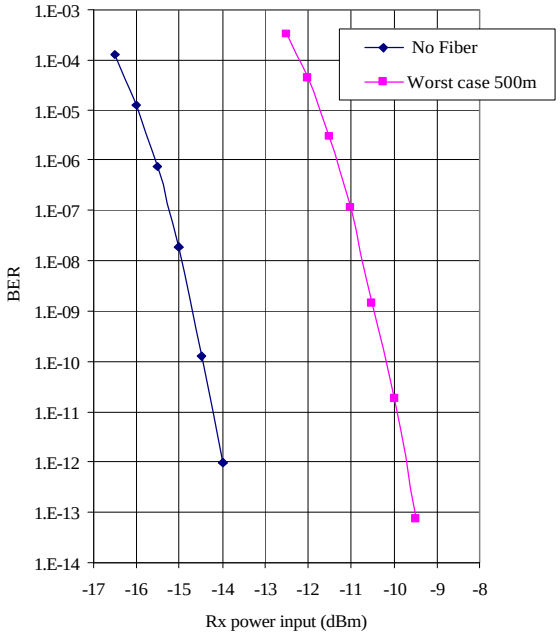
Uncompensated F2: 300m, BER varying
between 1e-5 to 1e-9 (Offset launch)

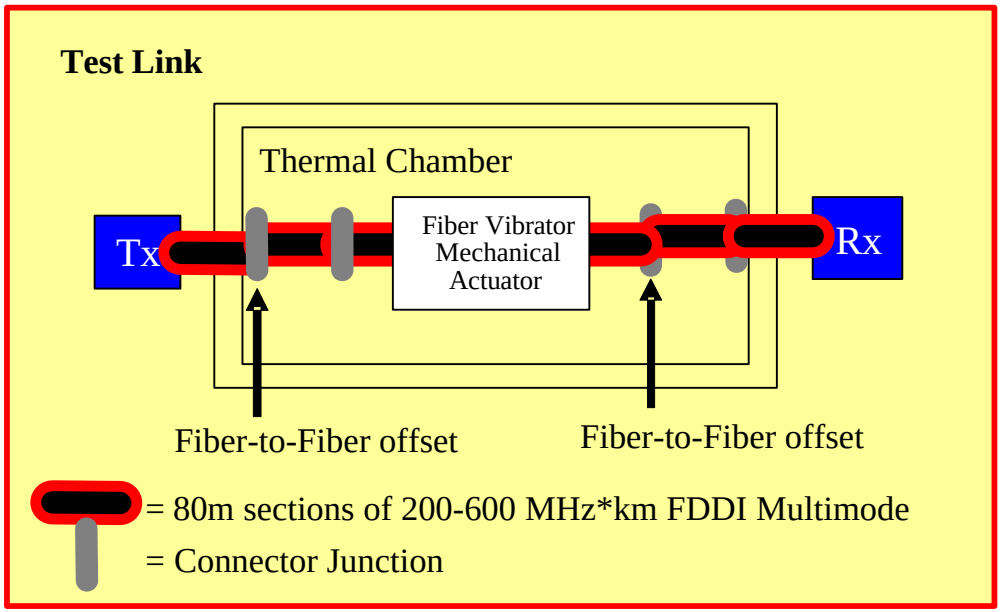


Compensated F2: 300m, BER < 1e-12
for Tx power >-3.5dBm (Offset launch)

Vendor F 10Gb/s Multimode Work

- Approach based on all-optical methods*
  - Utilizes a unique 1310nm modulated source transmitter w/ mode filtering techniques
  - Lab results demonstrate >500m performance through poor FDDI Fiber with >5um offset connector junctions, index profile variations, rapid thermal variations, vibration effects, i.e. varying modal bandwidths.
  - Very Low Cost





** Patents Pending*

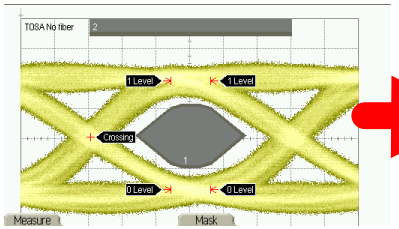
Vendor F Testing Summary

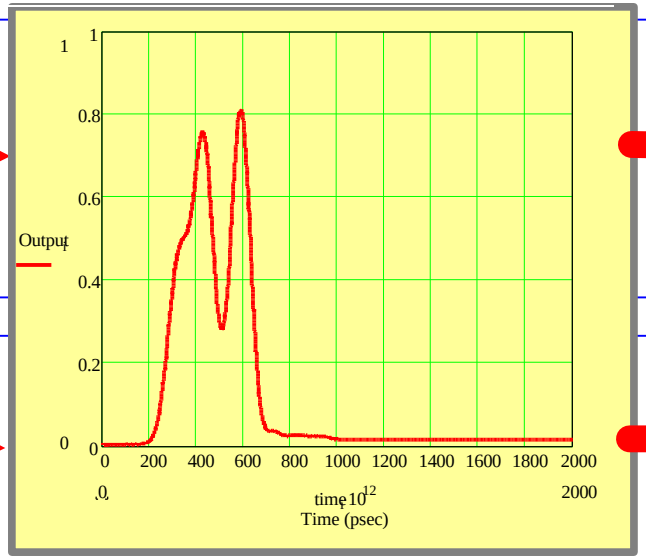
Transmitters

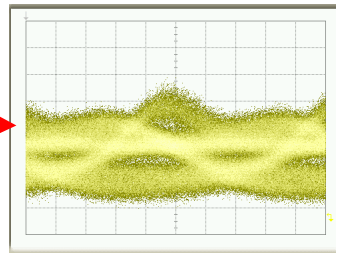
Impulse Response (OFL)

Receivers

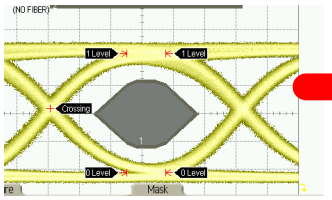
Industry Standard DML

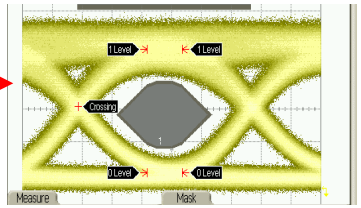






Vendor F Approach





1310nm Mode Filtered 10Gb/s Serial Tx*

500m Multimode Test Link with Fiber Defects, 6 Connector Pairs, Severe Connector Misalignments and Environmental Stress Effects

Mode Filtered Adaptive Rx* (no EDC)

Technical Feasibility Summary

- Multiple companies have contributed to this presentation, demonstrating that there is critical support of industry expertise & resources that will be committed to working to a completed specification
- The contributors feel there is a comprehensive understanding of the technical challenges in meeting the stated requirements
  - Reviewed several areas which require significant technical efforts to assist in the identification & selection of a preferred approach
- Have shown both analytical & experimental data that reveal recent technological advances have placed a feasible solution in-reach

Q&A

Call for Interest

- Should we request 802.3 at this meeting to authorize the formation of a Study Group to develop a standards project proposal (PAR and Five Criteria) for 10GBASE- serial optics to reach 300 meters on installed, FDDI-grade MM fiber?

Y: 116 N: 12 A:28

Poll 1

- How many people in the room?
  - Total 802.3 voters:_75__

Poll 2

- Study group to investigate the use of 10GBASE- serial optics to reach 300 meters on installed, FDDI-grade MM fiber
- I would support and participate in this study group
  - Total individuals
    - Yes: 56
  - Total 802.3 voters
    - Yes: 20

Poll 3

- Study group to investigate the use of 10GBASE- serial optics to reach 300 meters on installed, FDDI-grade MM fiber
- My company would support and participate in this study group
  - Companies
    - Yes 40

Poll 4: Room Planning

- I will attend the 10BASE- on FDDI grade MM fiber SG interim meeting in January
  - Yes: 52

More Q&A

Next Steps

- Ask 802.3 to authorize formation of a SG on Thursday
- Ask 802.3 to set up SG reflector
- Inform 802 SEC of SG on Thursday
- Find volunteer to lead PHY ad hoc
- Find volunteer to lead channel model ad hoc
- Advertise ad hocs on the reflector
- Schedule meeting that will co-locate at Vancouver interim: Week of January 12th

Back-up Material

NOTE: Will not be discussed during the CFI

Some History: 802.3ae Detailed Objectives

- Define two families of PHYs
  - A LAN PHY, operating at a data rate of 10.000 Gb/s
  - A WAN PHY, operating at a data rate compatible with the payload rate of OC-192c/SDH VC-4-64c
- Define a mechanism to adapt the MAC/PLS data rate to the data rate of the WAN PHY
- Provide Physical Layer specifications which support link distances of:
  - At least 65 m over MMF
  - At least 300 m over installed MMF
  - At least 2, 10, and 40 km over SMF
- Support fiber media selected from the second edition of ISO/IEC 11801

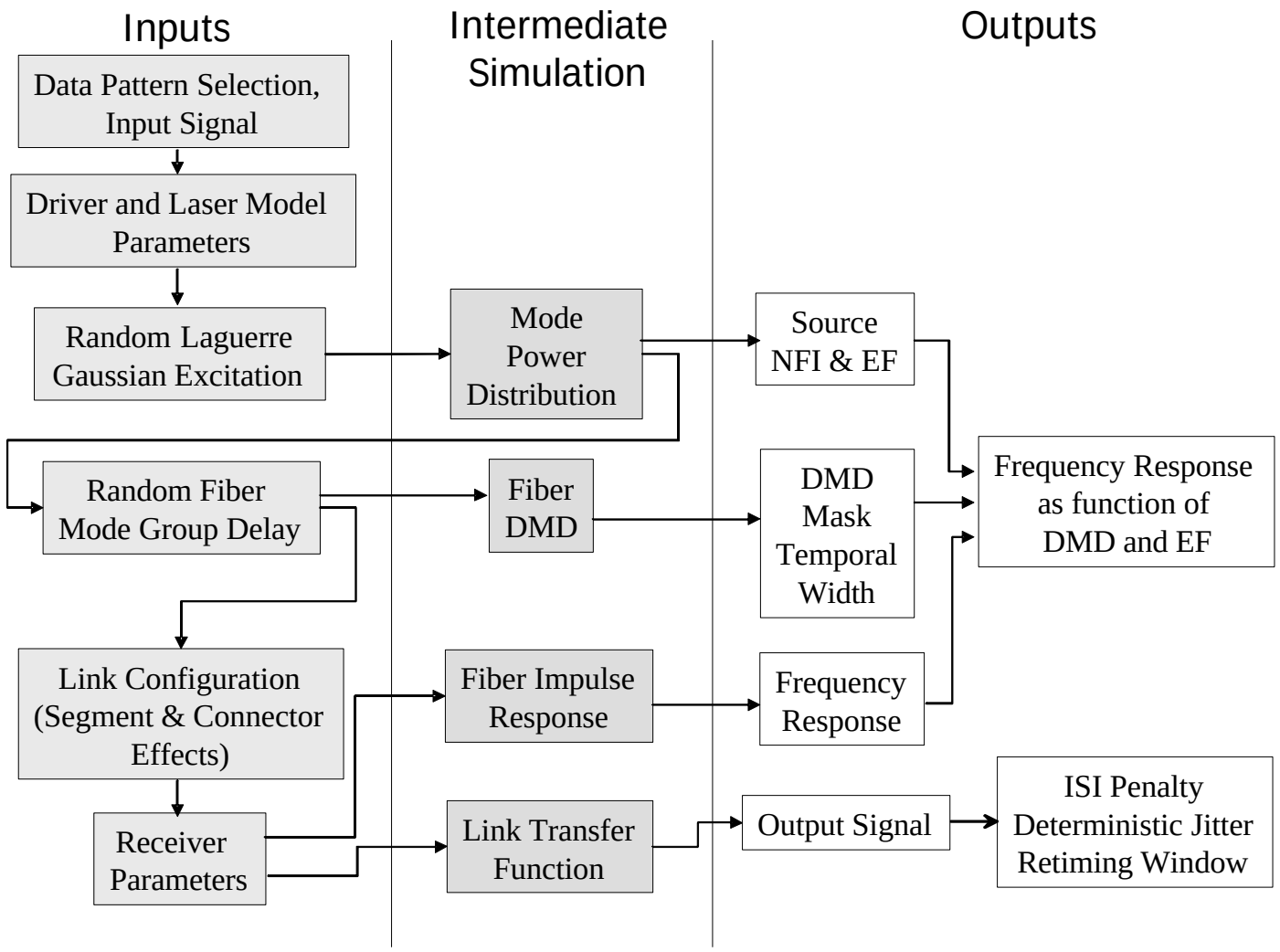
Technical Feasibility Presentation Back-up & Supporting Material

- Original Technical Feasibility material assembled assuming a 90+ minute CFI allocation
  - With the shortened time available, the current front matter is an abridged presentation
  - The remainder of a ‘more complete’ Technical Feasibility review follows this slide
- Appreciate the support & understanding of the contributors who prepared this appended material

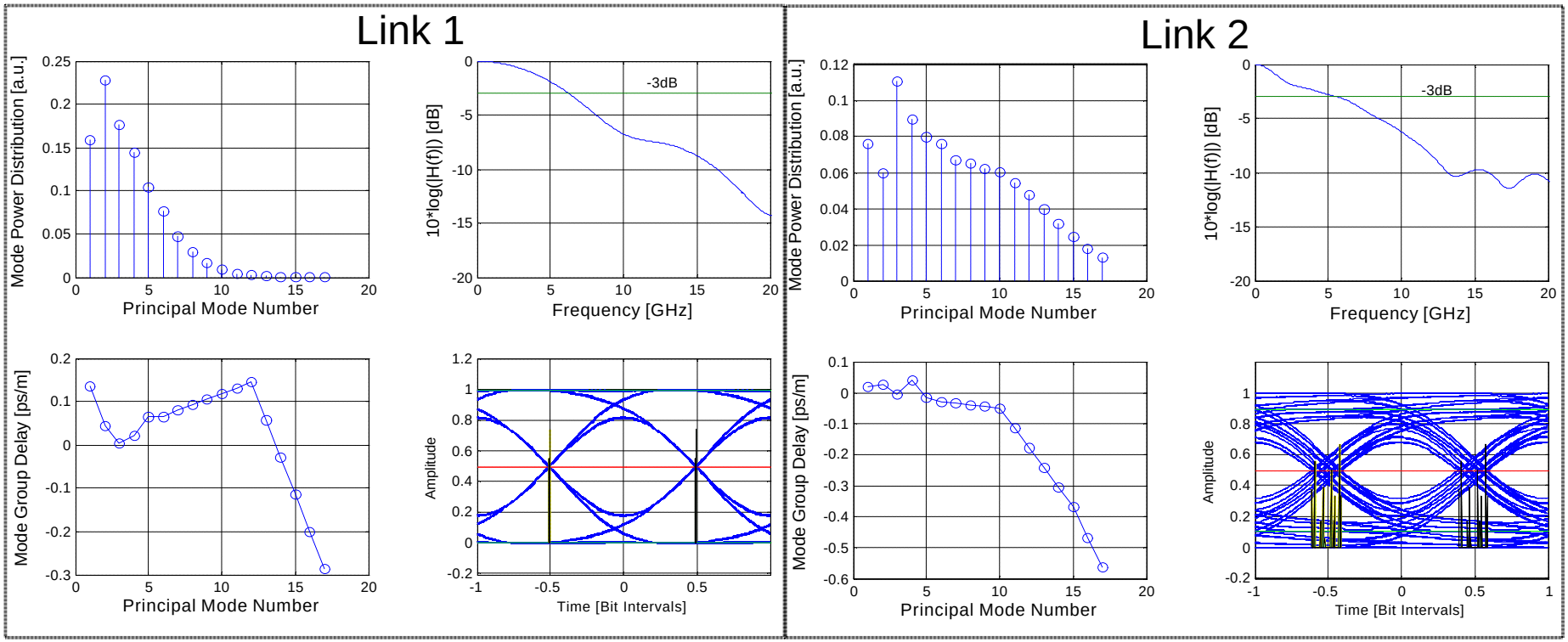
Top-level Requirements / Objectives

- Specify a PHY that supports a full-duplex 802.3ae MAC across the target distance of multimode fiber
  - 300m of 'FDDI grade' fiber media types including:
    - 160/500 MHz·km, 200/500 MHz-km 62.5µm
    - 500/500 MHz·km 50µm
  - TBD distance on additional fiber media types including:
    - 400/400 MHz·km 50µm
    - IEC 11801 OM3 50µm
- Meet general solution requirements commensurate with achieving broad market potential & economic feasibility
  - Power, cost, availability, …
  - Required real estate appropriate for industry defined form factors
- Desire to leverage existing 10GbE PHY & PMD technologies to the extent possible

(1) MMF Model Simulation Block Diagram



ISI Penalty More Relevant Than Bandwidth



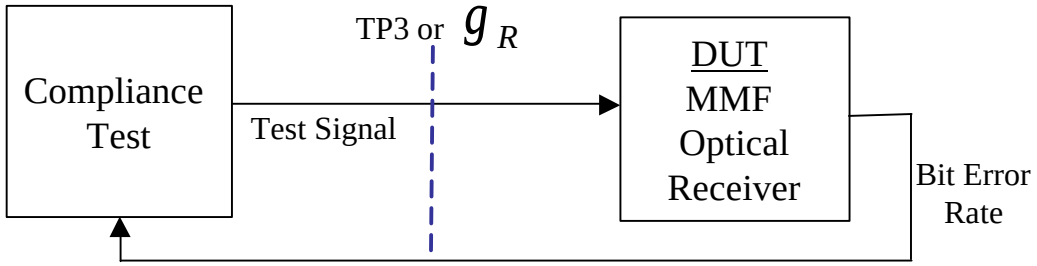
- Bandwidth is approximately the same; ISI penalty and DJ very different
- Fiber transfer function shape important for ISI penalty, not just the fiber bandwidth (Nyquist theory)

Model Extension to Legacy Fiber

- Validate model against FDDI-grade fiber
  - DMD measurements
  - Impulse response vs. launch conditions? (e.g. MCP, OFL, ROFL, etc.)
- May need to consider higher limit for maximum DMD in simulations (e.g. > 2 ns/km)
  - But Legacy fiber installations after 1997 Gigabit Ethernet adoption greatly outnumber earlier legacy installed fiber
  - New legacy fiber is supposed to be better
    - DMD awareness after Gigabit Ethernet investigations

(2) Motivation for Compliance Test

- For a given launch condition, bandwidth of a multimode link varies widely with fiber process & manufacture date
- Performance of a compensated Rx varies w/ implementation & noise
- Other than extensive field testing, there is currently no available mechanism to test worst-case DMD
- These factors lead to a high degree of unpredictability regarding the distance improvement that can be achieved
- A standardized test will enforce a uniform and worst-case compliance condition on all EDC-enabled receivers
  - A high confidence level by users is essential for broad market potential
- Compliance Test: a test to verify that Tx/Rx is able to operate with target error rate in the presence of a severely bandwidth limited signal



Compliance Test Guiding Principles

- Define a worst-case optical test signal at TP3 for extended-distance links
  - Be conservative, without trying to emulate the worst fiber ever made
- Emulate key elements of multimode channel that guide Rx implementation – impulse response, noise, jitter & SNR
- Emulate the irregular & possibly time-varying impulse response resulting from the combination of launch condition & DMD
- Take into account RIN, Modal Noise, Interferometric Noise, and Mode Partition Noise
- Ensure sufficient SNR at TP3 to make it feasible for the receiver to meet the objective of BER = 10^{-12} cost-effectively

Compliance Test Material References

1. V. Bhatt, T. Lindsay and J. Gimlett, "Design Considerations for EDC Compliance Test", 03-359v0.pdf, T11.2 Plenary, Bloomington MN, June 2003
2. E.A. Lee and D.G. Messerschmitt, "Digital Communication", Second Edition, Kluwer Academic Publishers, 1994
3. J. G. Proakis and M. Salehi, "Communication System Engineering", Prentice Hall, 1994
4. Online: http://www.ieee802.org/3/ae/public/adhoc/equal/

(3) PHY / PMD Selection

- Will evaluate submitted architectural proposals on the ability to meet the stated objectives
- Depending on the alternatives, may or may not require the definition of a new PHY
- Expect the channel definition to include allocation of channel penalties & attenuation
  - Detailed treatment of the various link penalties (e.g. MPN, RIN, …)
  - Results in a straw-man optical link budget allocation
- All current suggested approaches require a specification of an MMF-specific PMD
  - E.g., Tx Optical parameters, Rx optical parameters, jitter specifications, …

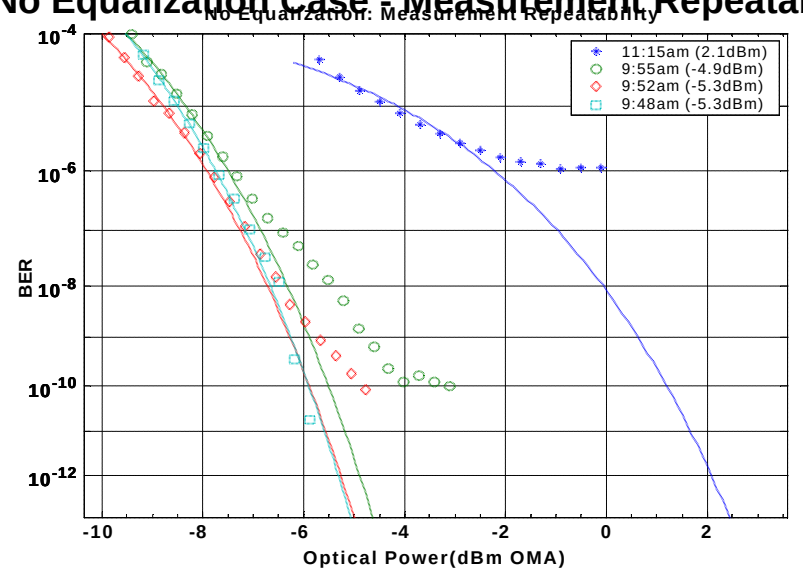
Demonstrated System Feasibility

- "Blind" set of summary analytical & experimental results that begin to address the requirements stated above
  - 2 silicon vendors & 4 module/transponder vendors contributed
    - Includes two alternative approaches:
      1) Electrical (Rx Equalization)
      2) Optical (Spectrally Conditioned Tx with Mode Filtering)
- As suitable for a CFI presentation, material touches-on & conveys several areas of technical feasibility & SG/TF work items:

1) System Feasibility Results that highlight the SG/TF work items
   - Consistency of measurements, temporal aspects of the channel, …
2) Simulation / Analytical System Feasibility Results
   - Base model assumptions
   - Channel specifics (e.g. impulse response, bandwidth, DMD, …)
   - Results & conclusions
3) Experimental System Feasibility Results
   - Set-up description (Tx, Rx, …)
   - Channel definition / specifics (e.g. impulse response, bandwidth, …)
   - BER, eye-mask, … summary results

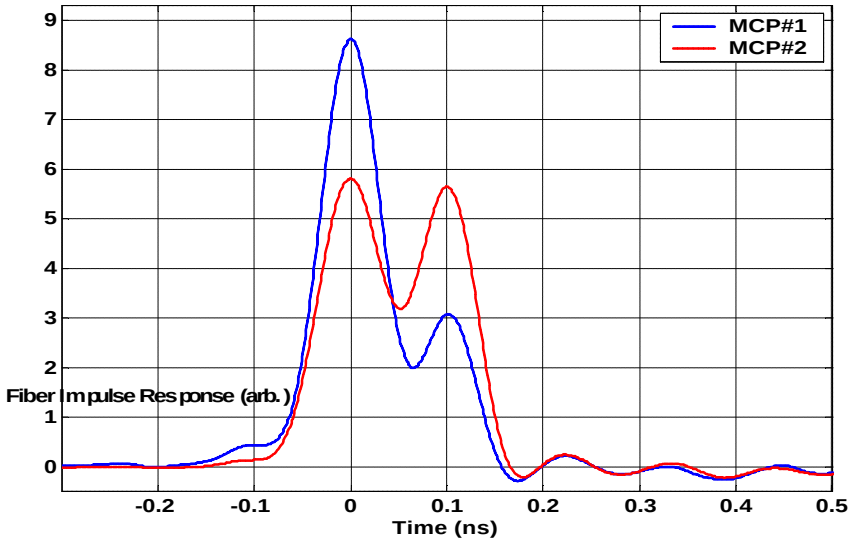
Vendor A - Channel Response Issues

No Equalization Case - Measurement Repeatability



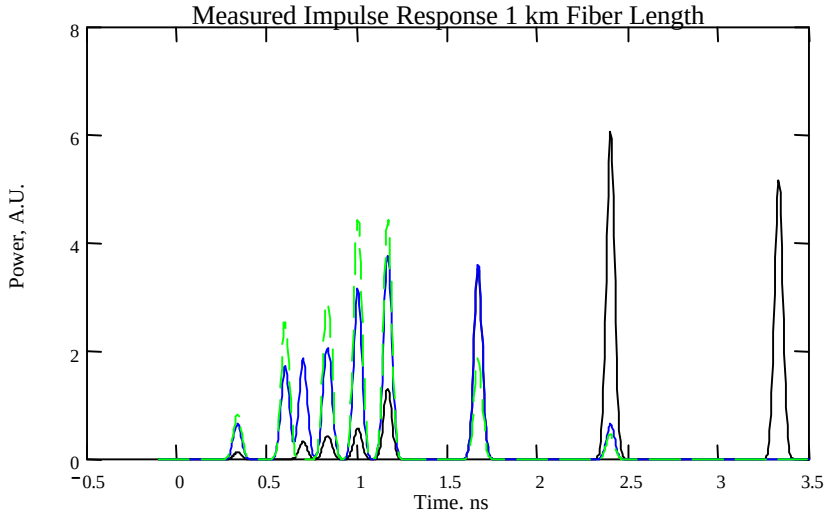
- ~750m, 62.5mm MMF
- ~7dB ISI penalty (best case)
- Poor measurement repeatability
  - Small variations in channel response?
- No EQ case provides unreliable metric
  - Comparison with B2B performance preferable
  - EQ improves measurement repeatability

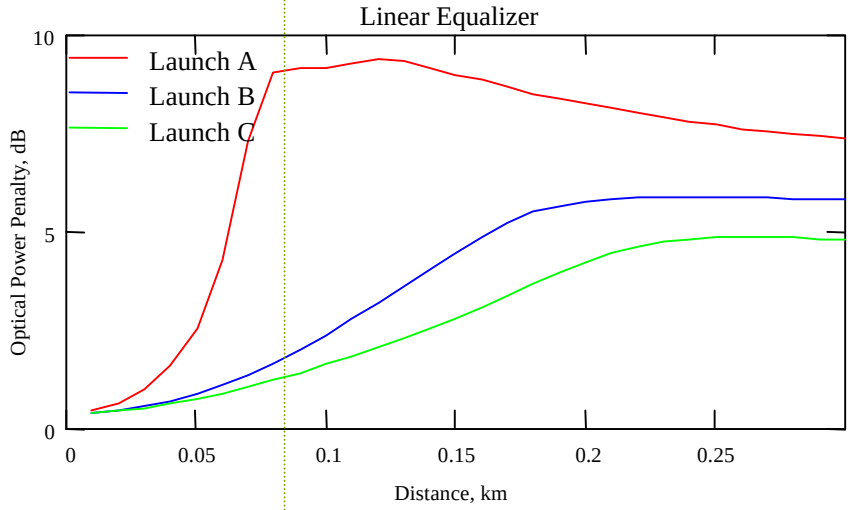
Impulse Response Repeatability

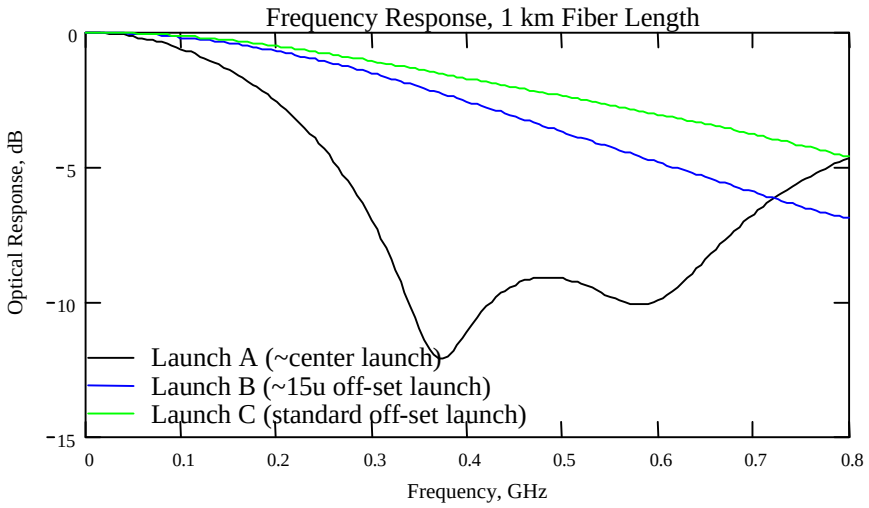


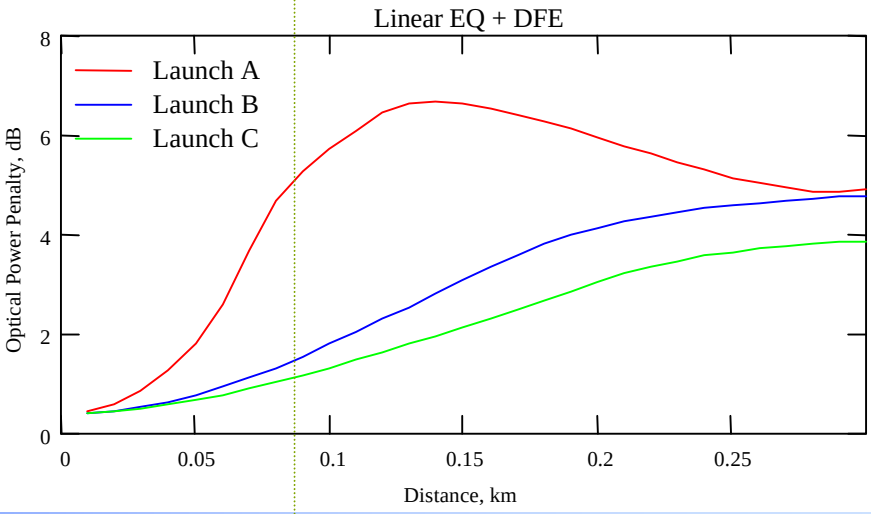
- Dramatic difference in channel response vs. mode conditioning patch cord
- Multiple-peak response
  - Easy to generate with preferred launch (e.g. MCP)
  - Also occurs with ROFL & center launch
- Cannot control channel response
  - EQ architecture must be robust to worst case

Vendor C: Analytical Results - 1310nm, Poor MMF Resulting Power Penalties for LE & DFE

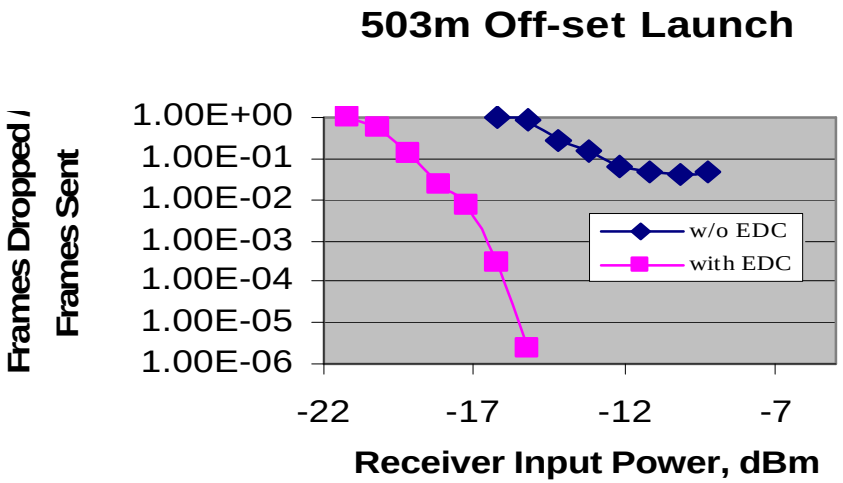


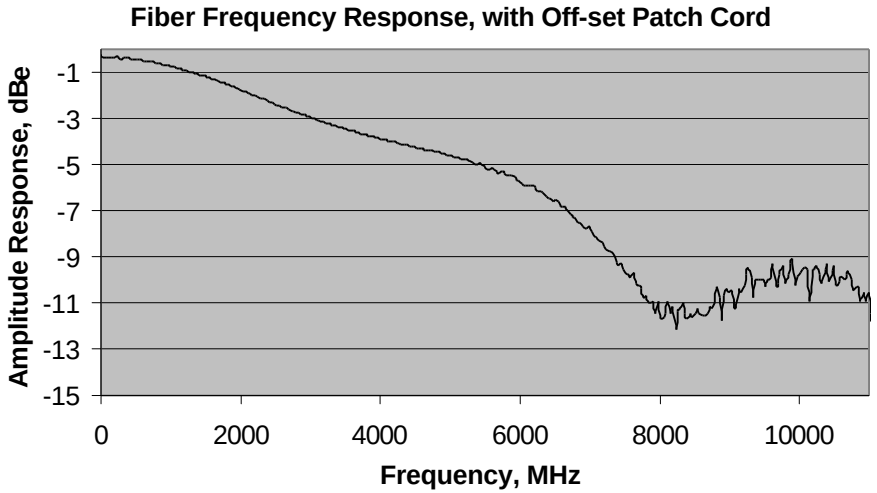






Vendor E - Quantitative Improvement





- EDC chip and linear multi-mode Rx; 1310nm direct modulated DFB; plumbed into XENPAK transceiver
- Measure of number of frames dropped vs. frames sent is an indirect BER measure
  - Random packet lengths between 64B and 1518B
- Fiber bandwidth & length normalized to 500 MHz·km OFL bandwidth, (actual OFL BW ~800 MHz·km); 3.1 GHz·km MCP bandwidth, 62.5/125u MMF
  - Utilized an off-set patch cord for these tests