10GBASE-LX4:
Technical Feasibility Workshop

Workshop Dates: September 5-7, 2001

Molex Incorporated

Blaze Network Products

Pine Photonics

Participating Companies

- Molex Fiber Optics
  - Representative: John Dallesasse
- Blaze Network Products
  - Representative: Eric Grann
- Pine Photonics
  - Representative: Bor-Long Twu

Feasibility Endorsers

- Schelto van Doorn (Intel)
- Rich Taborek, Sr. (Intel)
- (In Process) (Intel)
- Caroline Larson (Intel)
- John Dallesasse (Molex)
- Tony Whitlow (Molex)
- Eric Grann (Blaze)
- Bill Wiedemann (Blaze)
- Ken Harrity (Blaze)
- Jeff Cody (OCLI)
- Jay Hoge (Demeter Technology)
- Kuen Chow (InChip)
- Jason Chen (Bitblitz)
- Bor-Long Twu (Pine Photonics)
- Others TBD

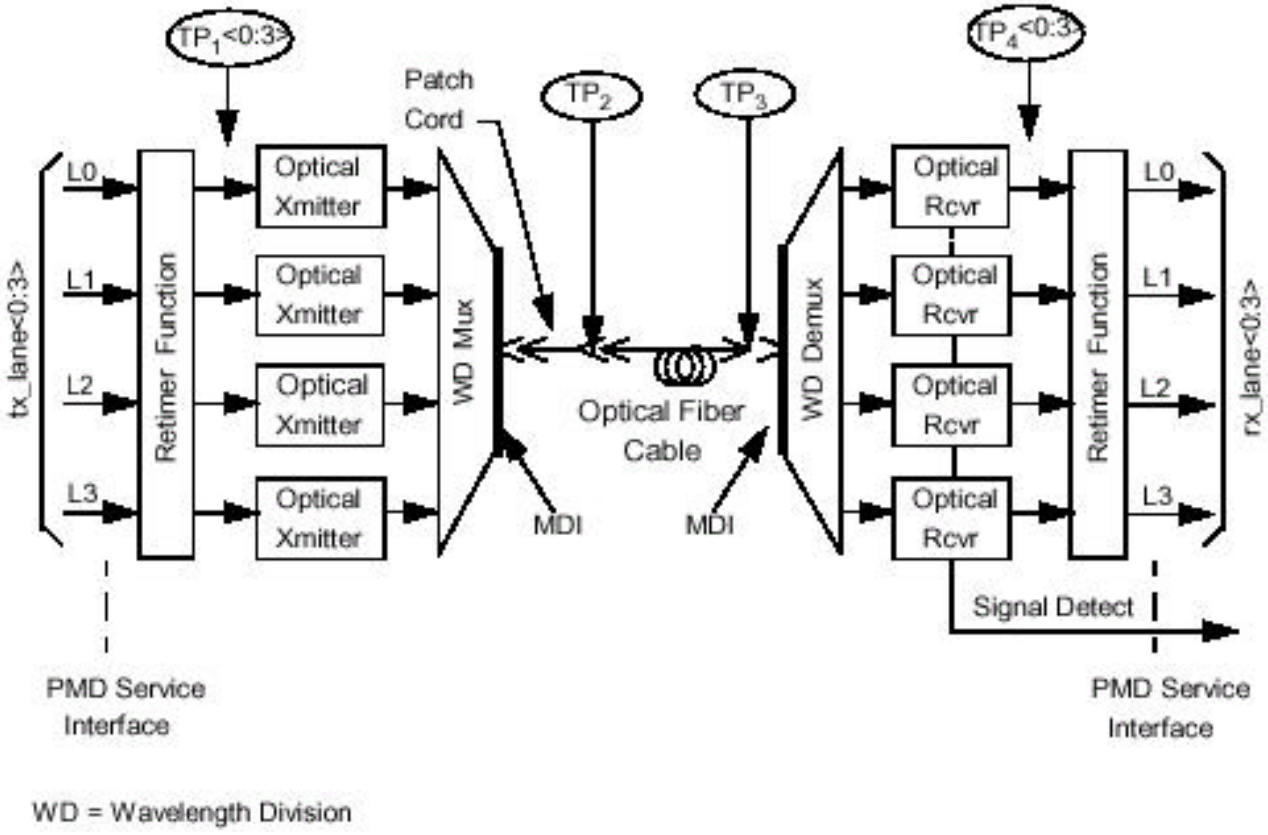
Presentation Outline

- Individual Vendor Data
  - Tx Operation
  - Link Data
- Inter-Vendor Operation Summary
  - BER < 10^{-12} At Rated Link Distances
- Path to Full Compliance

Summary

- Inter-Vendor Operation Has Been Demonstrated for All Link Distances and Fiber Types With a Less Than 10^{-12} Bit Error Rate
- Most Parameters Are Compliant, And On The Remaining Few, There Is A Clear Path To Full Compliance
- Technical Feasibility Has Been Demonstrated

Typical Link Under Test



WD = Wavelength Division

Our Tests: Drive at TP1,

Test at TP2 and TP4

Component Availability

- Retimer ICs (XAUI-XAUI or XAUI-Other): Available Soon From at Least 3 Vendors
- Laser Drivers, TIAs, Limiting Amplifiers: Currently Available from Multiple Vendors
- Lasers and Photodiodes: Currently Available from Multiple Vendors
- Optical Multiplexing: Multiple Technologies and Multiple Vendors
- Optical Demultiplexing: Multiple Technologies and Multiple Vendors
- Summary: There are multiple sources of components and multiple transceiver manufacturers – multi-vendor support is demonstrated.

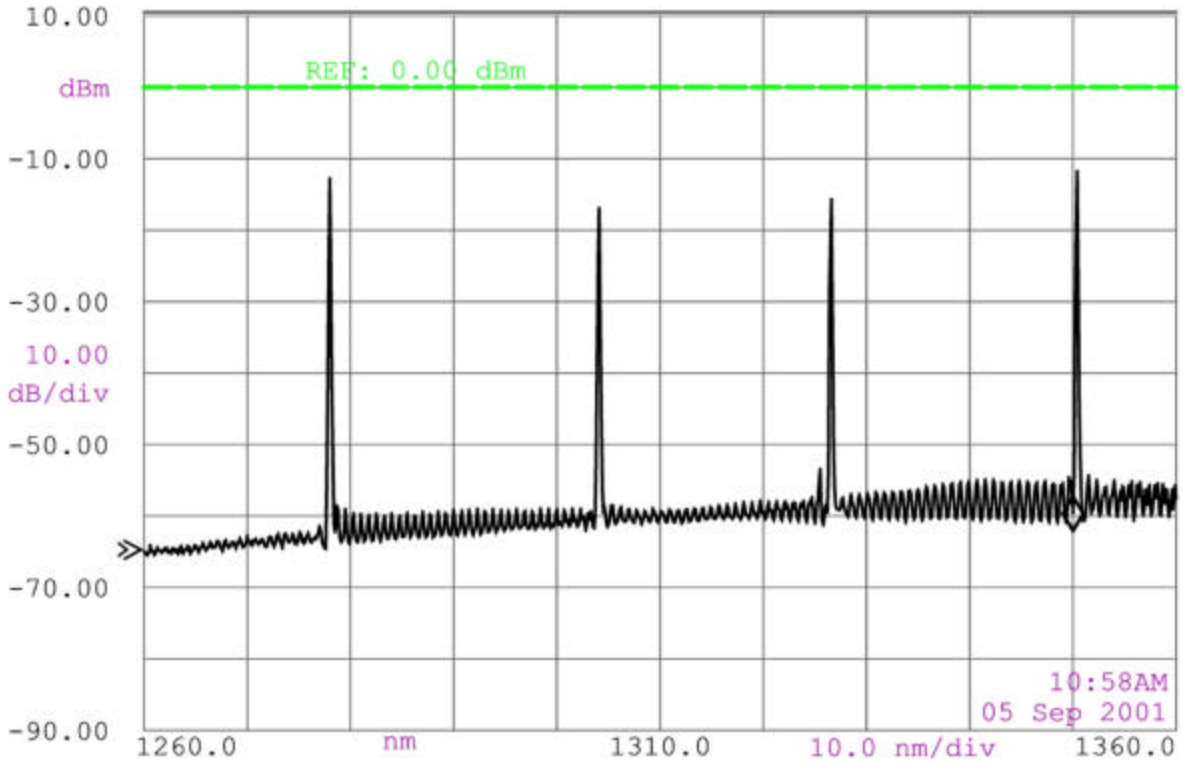
Individual Vendor Data

- Data From Three Companies
  - Presented as Vendors A, B, and C
- Data Presented
  - Tx TP2 Data
    - Optical Spectra, Rise/Fall Time, Optical Power, OMA
  - Link TP4 Eye Diagrams
  - Link BER Testing

Transmitter TP2 Testing

- Optical Spectra:
  - Measured with All Channels Operating
- Average Optical Power, OMA, Rise/Fall Time
  - Measured at TP2 With Channels Not Under Test Disabled

Vendor A Optical Spectra



RBW: 0.06 nm
VBW: 2.1 kHz
Sens: -60.00 dBm
ST: 1.01 s
Avg: Off
In Vacuum
User Cal

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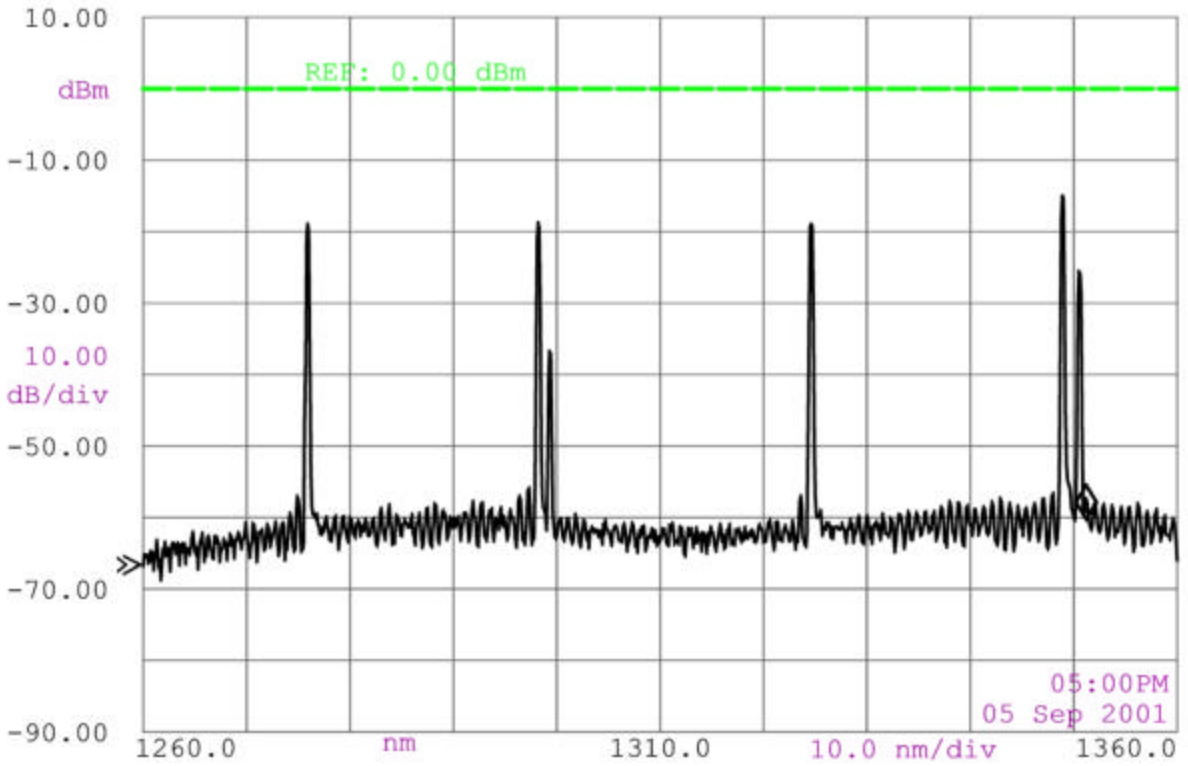
Vendor B Optical Spectra



RBW: 0.2 nm
VBW: 19.3 kHz
Sens: -60.00 dBm
ST: 76.0 ms
Avg: Off
In Vacuum
User Cal

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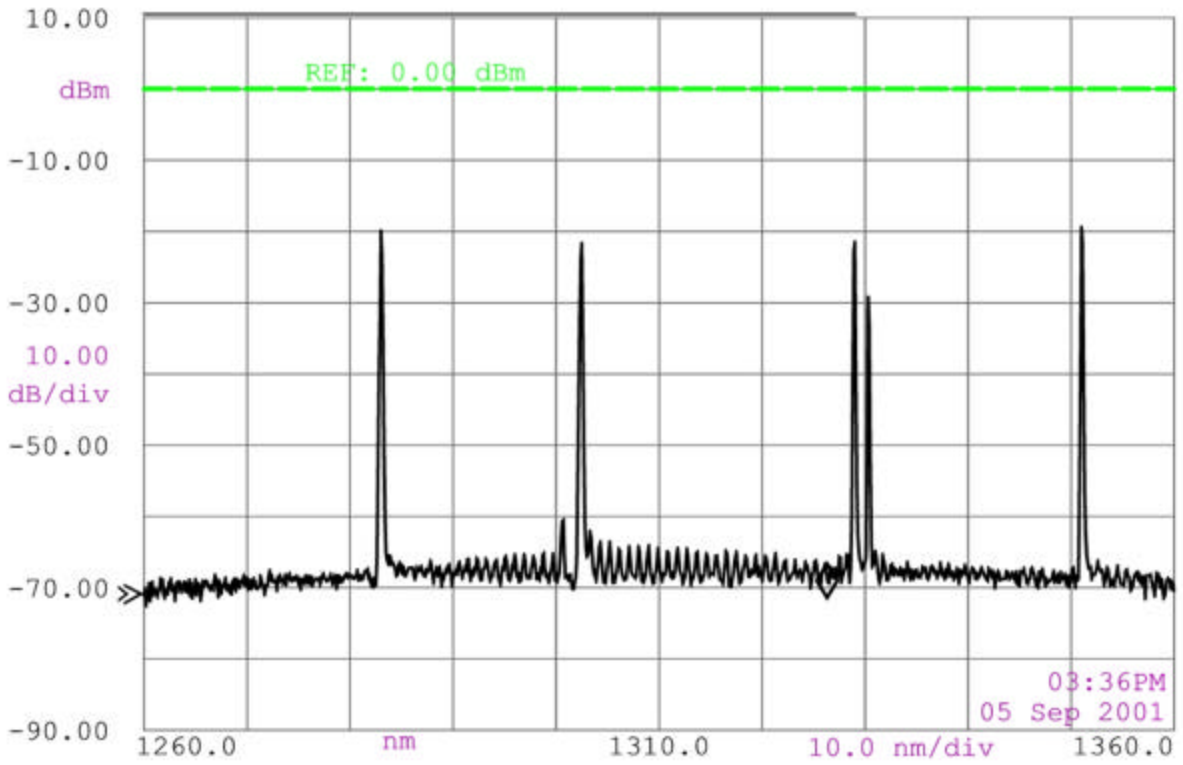
Vendor C Optical Spectra



RBW: 0.06 nm
VBW: 2.1 kHz
Sens: -60.00 dBm
ST: 1.01 s
Avg: Off
In Vacuum
User Cal

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Vendor A TP2 Data

	Channel 0 (1275)	Channel 1 (1300)	Channel 2 (1325)	Channel 3 (1350)
OMA	341 µW	580 µW	435 µW	749 µW
Average Power	-4.42 dBm	-2.8 dBm	-2.7 dBm	-0.5 dBm
Rise Time	145 ps	141 ps	153 ps	125 ps
Fall Time	177 ps	161 ps	167 ps	137 ps

Note: Subsequent Testing On Newer Transceivers
Has Shown Rise Times in the 89-109 ps Range
And Fall Times in the 122-136 ps Range

Vendor B TP2 Data

	Channel 0	Channel 1	Channel 2	Channel 3
OMA	290 µW	238 µW	260 µW	238 µW
Average Power	-6.34 dBm	-7.15 dBm	-6.35 dBm	-6.42 dBm
Rise Time	159 ps	124 ps	161 ps	139 ps
Fall Time	159 ps	138 ps	149 ps	125 ps

Vendor C TP2 Data

	Channel 0	Channel 1	Channel 2	Channel 3
OMA	478 µW	446 µW	405 µW	439 µW
Average Power	-4.56 dBm	-4.56 dBm	-5.30 dBm	-5.03 dBm
Rise Time	59 ps	48 ps	53 ps	96 ps
Fall Time	94 ps	87 ps	86 ps	96 ps

All Tested TP2 Parameters Compliant!

TP2 Test Result Comments

- At Least One Vendor Fully Compliant With All Tested Parameters
- Rise/Fall Time Metrology Issues
  - Removal of Parasitic Effects
  - Overshoot/Undershoot
  - Filter Characteristics
- Not Considered a Major Problem Area
- Further Work Needed for Full Compliance By Some Vendors (Not for Technical Feasibility)

Transmitter Intra-Vendor TP4 Testing

- Goal: Demonstrate Data Transmission for All Fiber Types at Rated Distance
  - 10,000 meters SMF
  - 300 meters, 62.5 μm Core, 500 MHz•km MMF
  - 240 meters, 50 μm Core, 400 MHz•km MMF
  - 300 meters, 50 μm Core, 500 MHz•km MMF
- Summary: This Goal Achieved

Vendor A Link Testing

- 10,000 meters SMF
  - < 10^{-12} BER for > 1 Hour With Up To 2.5 dB Attenuation
  - < 10^{-12} BER for 20,000 meters SMF
- 330 meters, 62.5 µm Core, 500 MHz•km MMF
  - < 10^{-12} BER for > 1 Hour With Up To 5 dB Attenution
- 263 meters, 50 µm Core, 400 MHz•km MMF
  - < 10^{-12} BER for > 1 Hour With Up To 2.6 dB Attenuation
- 300 meters, 50 µm Core, 500 MHz•km MMF
  - < 10^{-12} BER for > 1 Hour With Up To 5.5 dB Attenuation

Rated Distance for All Fiber Types!

Vendor B Link Testing

- All Link Distances and Fiber Types Tested with < 10^{-12} BER
- Data Not Available with Attenuation

Rated Distance for All Fiber Types!

Vendor C Link Testing

- All Link Distances and Fiber Types Tested with < 10^{-12} BER
- 10,000 meters SMF
  - < 10^{-12} BER With Attenuation (per Channel) of Up to 7.3, 7.6, 5.3, and 4.7 dB
- 300 meters, 62.5 µm Core, 500 MHz•km
  - < 10^{-12} BER With Attenuation (per Channel) of Up to 6.3, 6.7, 4.5, and 1.7 dB

Rated Distance for All Fiber Types!

Intra-Vendor Link Testing Comments

- Required Bit Error Rates (< 10^{-12} BER) Demonstrated Under “Stressed” Conditions
  - Excessive Rise/Fall Times
  - Extra Fiber Length
  - Added Attenuation
- These Results are Very Good

Inter-Vendor Testing Goals

- Vendor A Tx – Vendor B Rx
  - Rated Distances, All Fiber Types
    - 10,000 (10,400) meters SMF
    - 300 (330) meters, 62.5 µm Core, 500 MHz•km MMF
    - 240 (263) meters, 50 µm Core, 400 MHz•km MMF
    - 300 meters, 50 µm Core, 500 MHz•km MMF
- Vendor A Tx – Vendor C Rx
  - Rated Distance, All Fiber Types
- Vendor B Tx – Vendor A, C Rx
  - Rated Distance, All Fiber Types
- Vendor C Tx – Vendor A, B Rx
  - Rated Distance, All Fiber Types

Test Details

- Data Source at TP1:
  - BERT Pattern Generators, 2^7-1 PRBS
  - All Channels Independently Driven
- Multiple Connections:
  - SC Optical Interface on Transmitters
  - 2 Patch Cords Prior to Fiber Under Test
  - 2 Patch Cords After Fiber Under Test
- CDR at TP4 for BER Testing Only (Needed Clock)
- Test For Minimum of 5 Minutes Per Channel
- Vendor B Tx to Vendor C Rx 10 km SMF Test With Additional 2 dB of Attenuation ⇒ No Problem!

Data Summary: Vendor A to Vendor C

	62.5 [redacted] m Core MMF 500 MHz-km, 330 m	50 [redacted] m Core MMF 400 MHz-km, 263 m	50 [redacted] m Core MMF 500 MHz-km, 300 m	10 [redacted] m Core SMF 10,400 m
Vendor A Tx - Vendor C Rx				
Channel 0	X	X	X	X
Channel 1	X	X	X	X
Channel 2	X	X	X	X
Channel 3	X	X	X	X
Vendor C Tx - Vendor A Rx				
Channel 0	X	X	X	X
Channel 1	X	X	X	X
Channel 2	X	X	X	X
Channel 3	X	X	X	X

"X" Indicates < 10^{-12} Bit Error Rate

Rated Distance for All Fiber Types!
Full Demonstration of Inter-Vendor Operation

Data Summary: Vendor A to Vendor B

	62.5 [redacted] m Core MMF 500 MHz-km, 330 m	50 [redacted] m Core MMF 400 MHz-km, 263 m	50 [redacted] m Core MMF 500 MHz-km, 300 m	10 [redacted] m Core SMF 10,400 m
Vendor A Tx - Vendor B Rx				
Channel 0	X	X	X	X
Channel 1	X	X	X	X
Channel 2	X	I	X	X
Channel 3	X	X	X	X
Vendor B Tx - Vendor A Rx				
Channel 0	X	X	X	X
Channel 1	X	X	X	X
Channel 2	X	X	X	X
Channel 3	X	X	X	X

"X" Indicates < 10^{-12} Bit Error Rate

"I" Indicates Incomplete Test

Data Summary: Vendor B to Vendor C

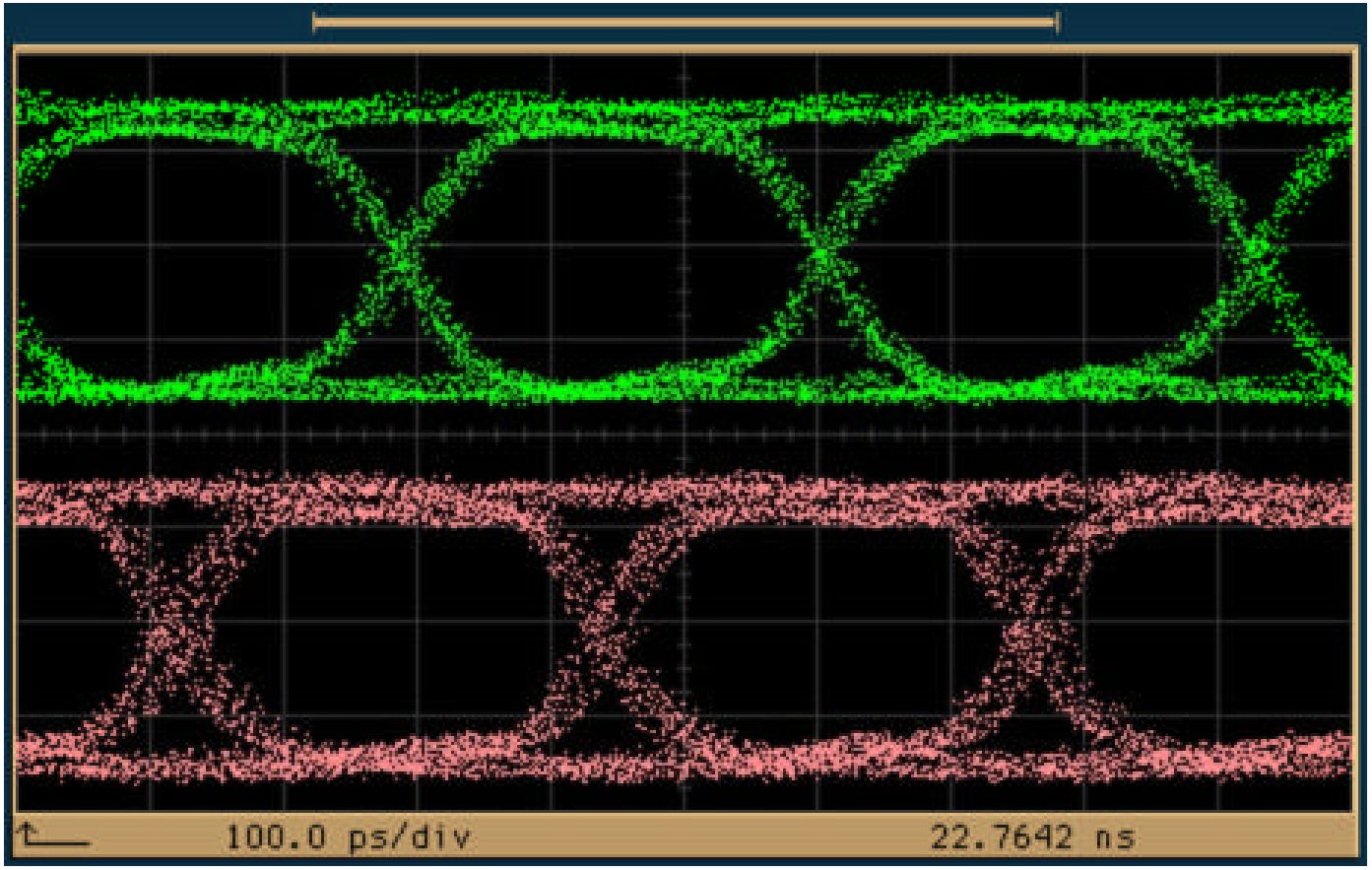
	62.5 µm Core MMF 500 MHz-km, 330 m	50 µm Core MMF 400 MHz-km, 263 m	50 µm Core MMF 500 MHz-km, 300 m	10 µm Core SMF 10,400 m
Vendor B Tx - Vendor C Rx				
Channel 0	X	*	X	X
Channel 1	X	*	X	X
Channel 2	X	*	X	X
Channel 3	X	*	X	X
Vendor C Tx - Vendor B Rx				
Channel 0	X	X	X	X
Channel 1	X	X	X	X
Channel 2	X	I	X	X
Channel 3	X	X	X	X

"*" Indicates Fiber Not Available at Time of Test

"X" Indicates < 10^{-12} Bit Error Rate

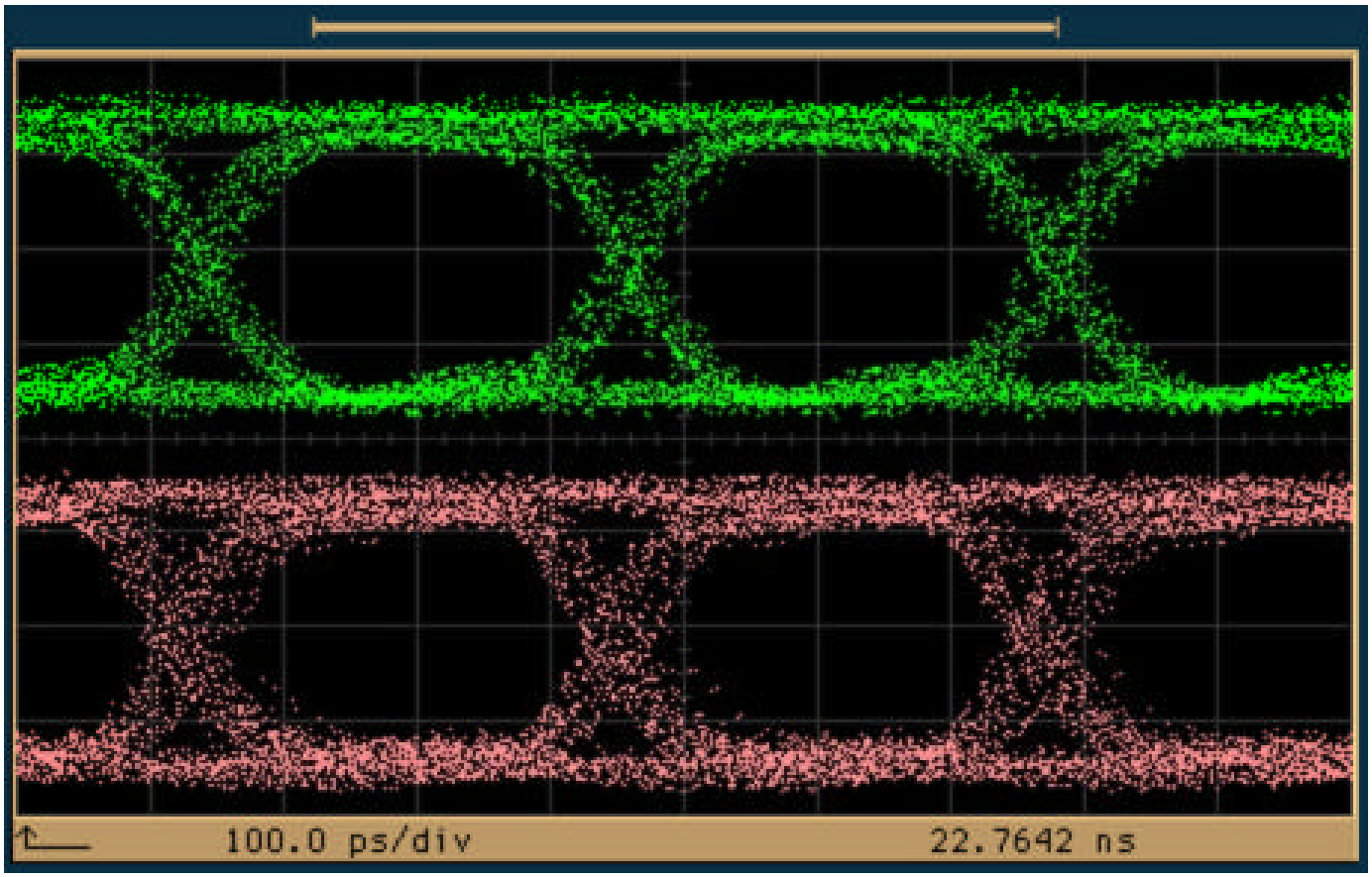
Representative Eye Diagrams

Vendor A Tx – Vendor C Rx
10.4 km SMF



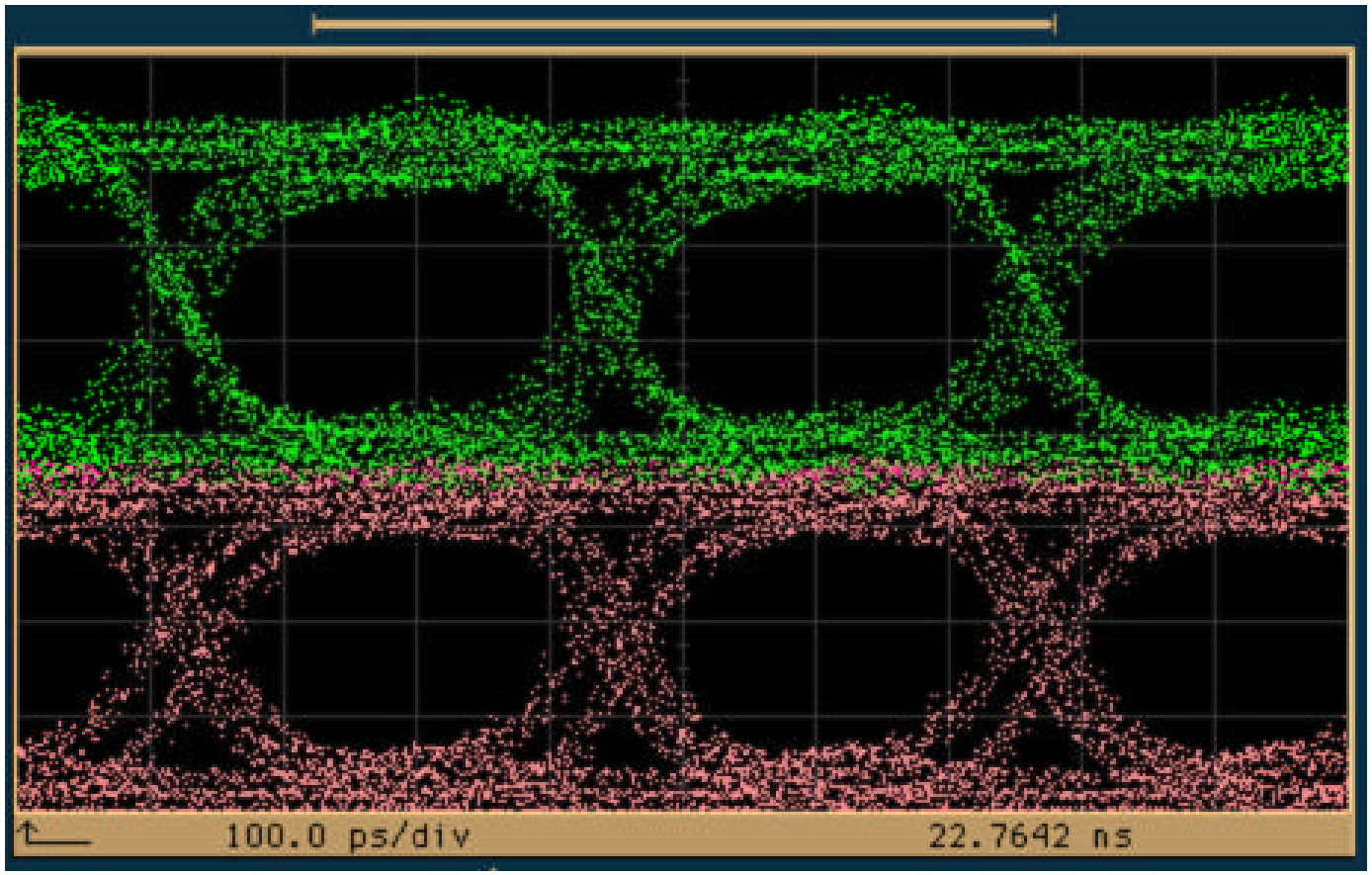
Note: Two Representative Channels Shown

Vendor A Tx – Vendor C Rx
330 m, 62.5 µm Core MMF



Vendor A Tx – Vendor C Rx

263 m, 50 μm Core, 400 MHz•km MMF



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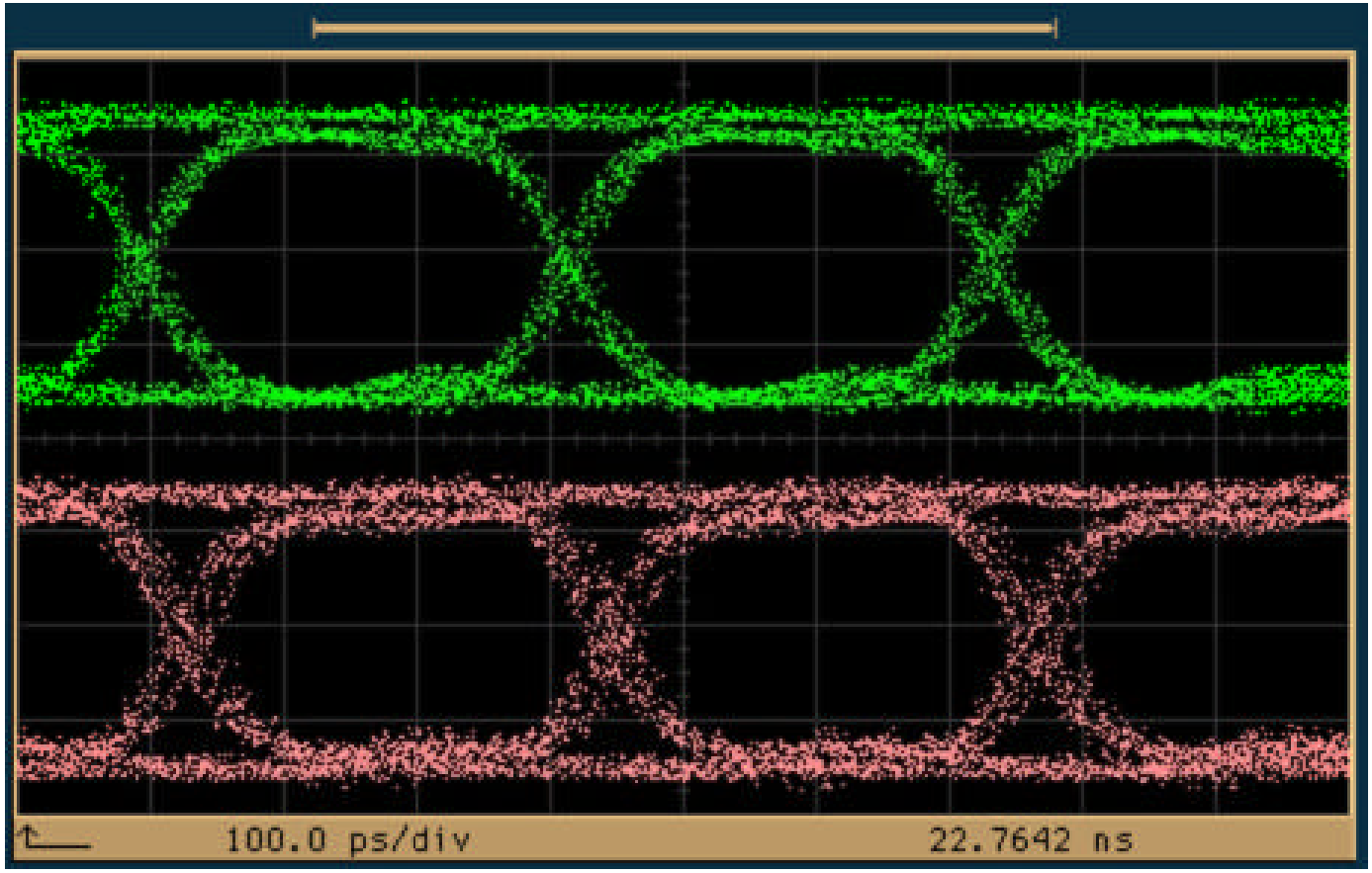
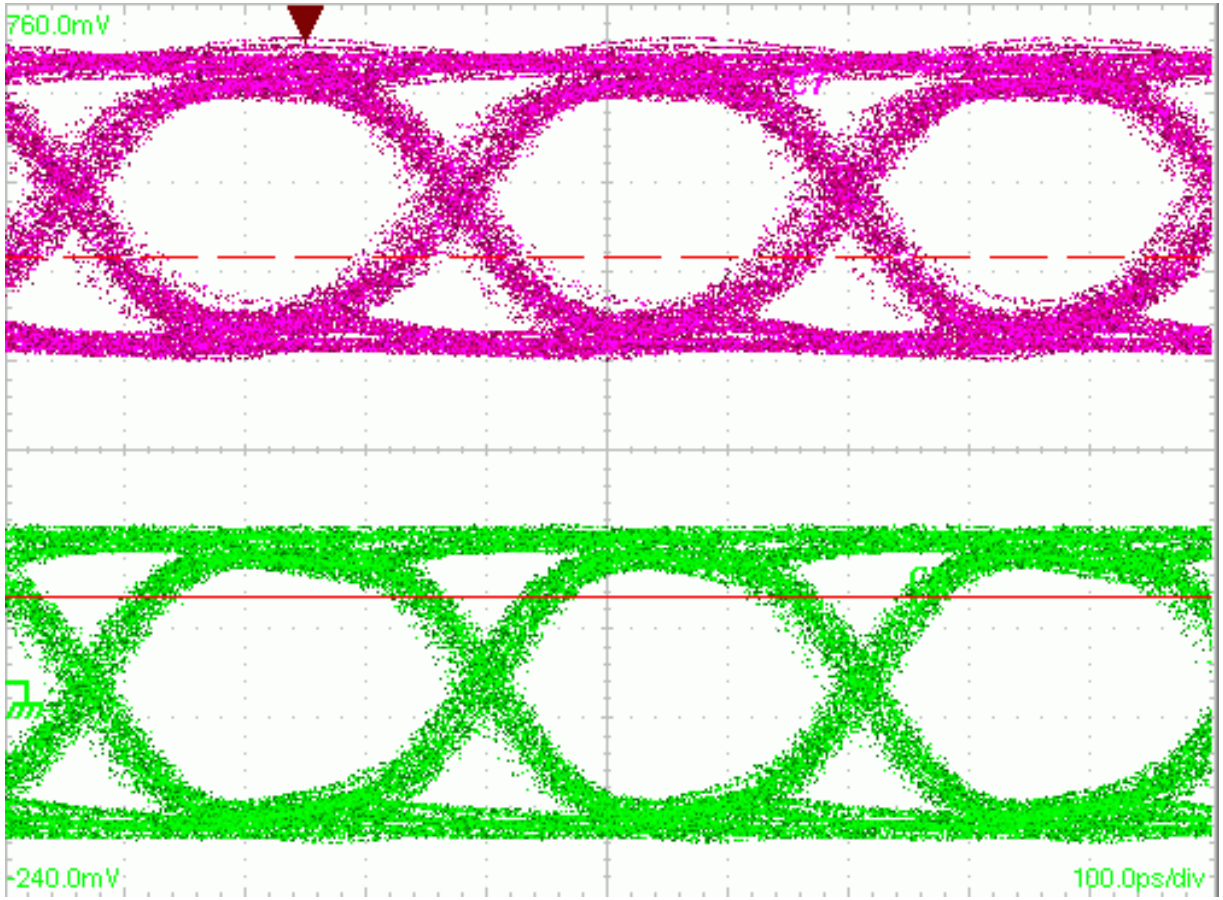
Vendor A Tx – Vendor C Rx

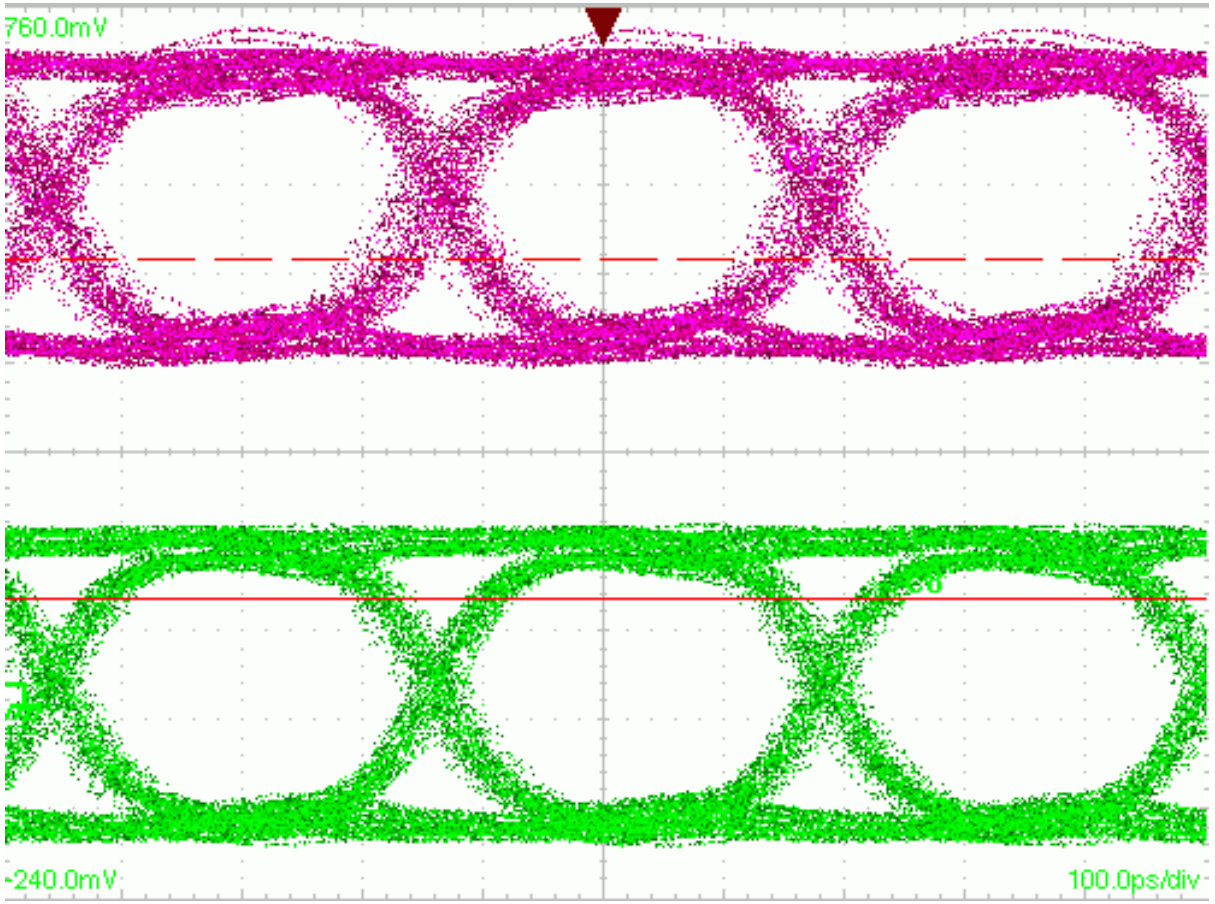
300 m, 50 µm Core, 500 MHz•km MMF



Vendor B Tx – Vendor C Rx
10 km SMF

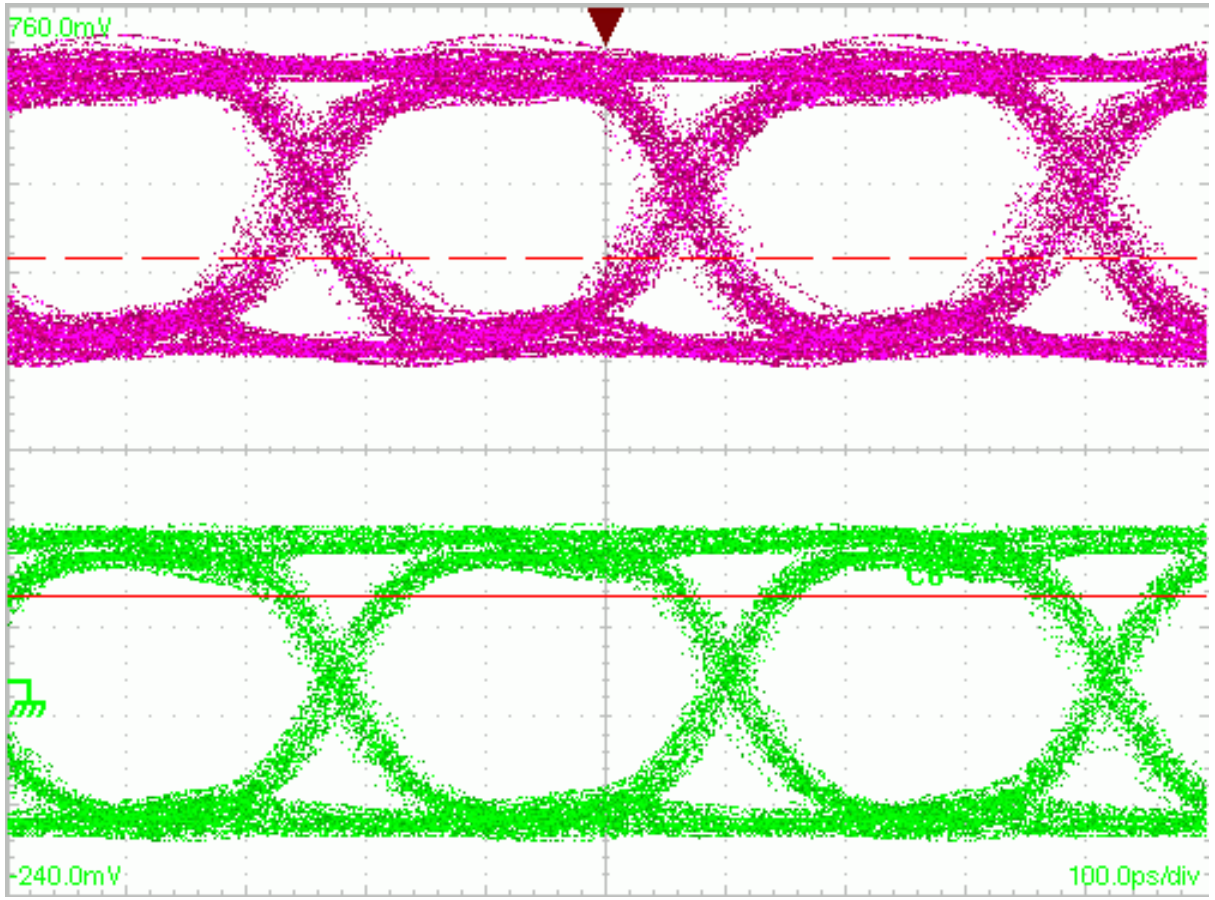


Vendor B Tx – Vendor C Rx
300 m, 62.5 µm Core MMF

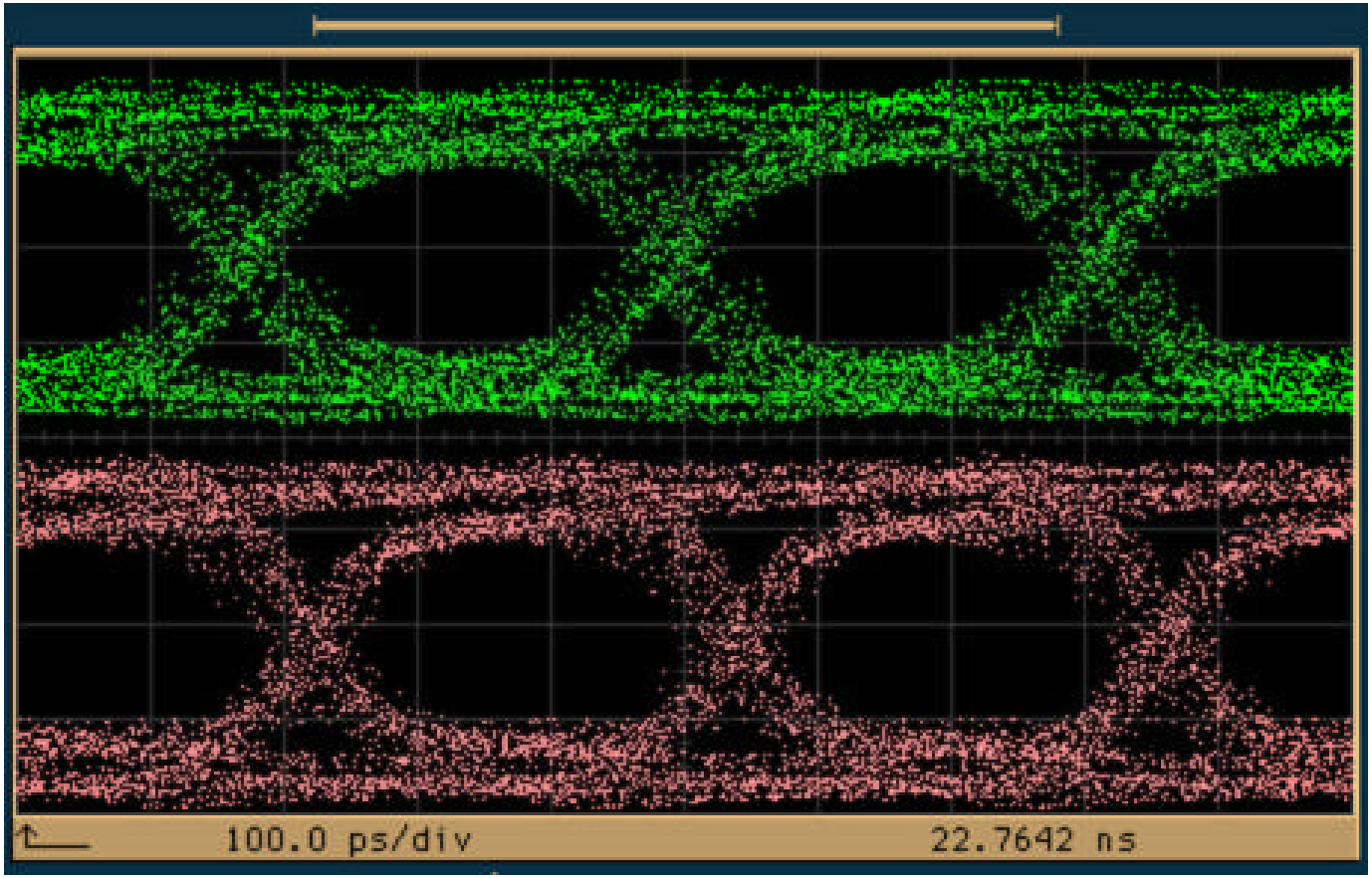


Vendor B Tx – Vendor C Rx

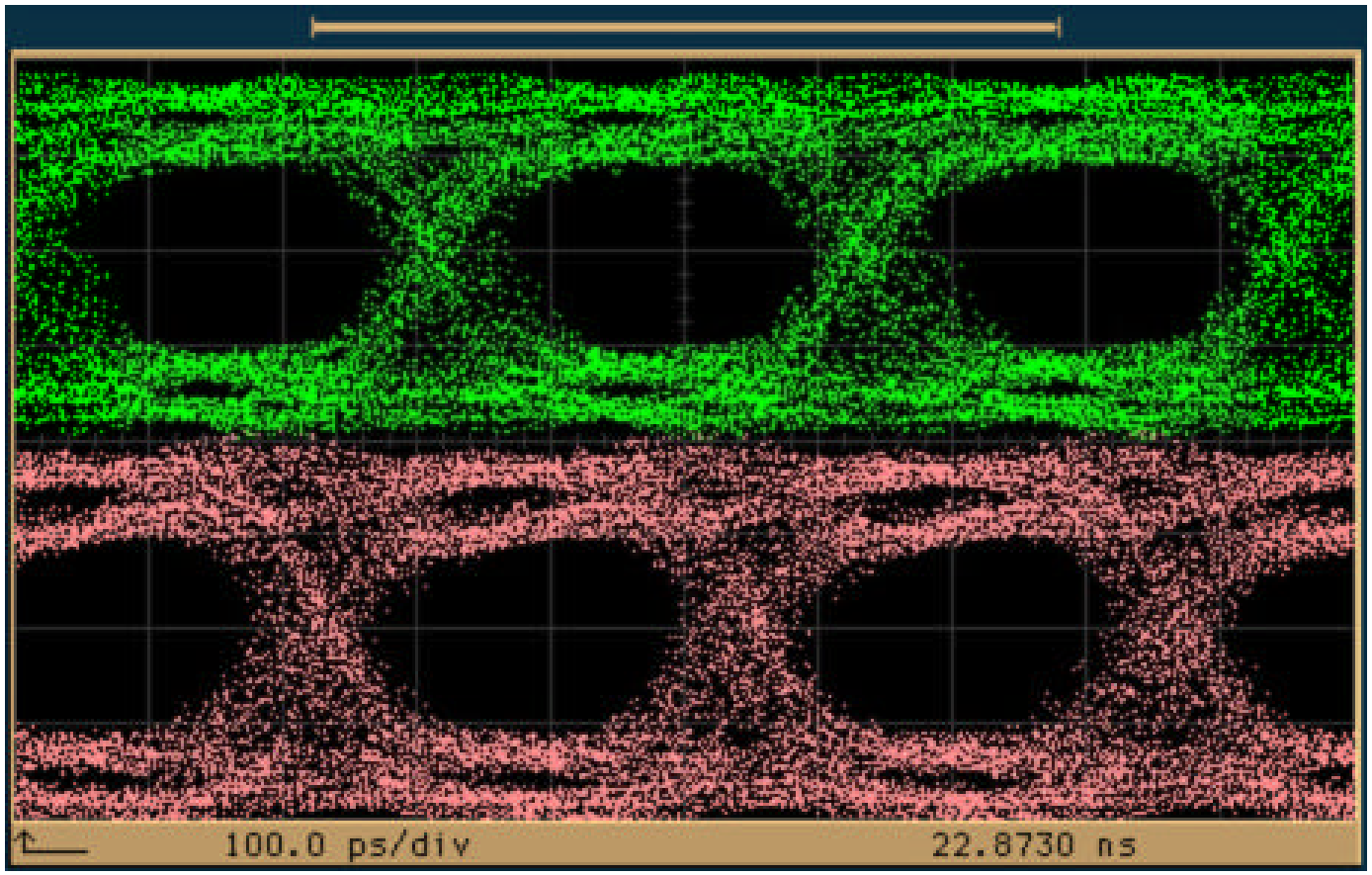
300 m, 50 μm Core, 500 MHz•km MMF



Vendor B Tx – Vendor A Rx
10.4 km SMF

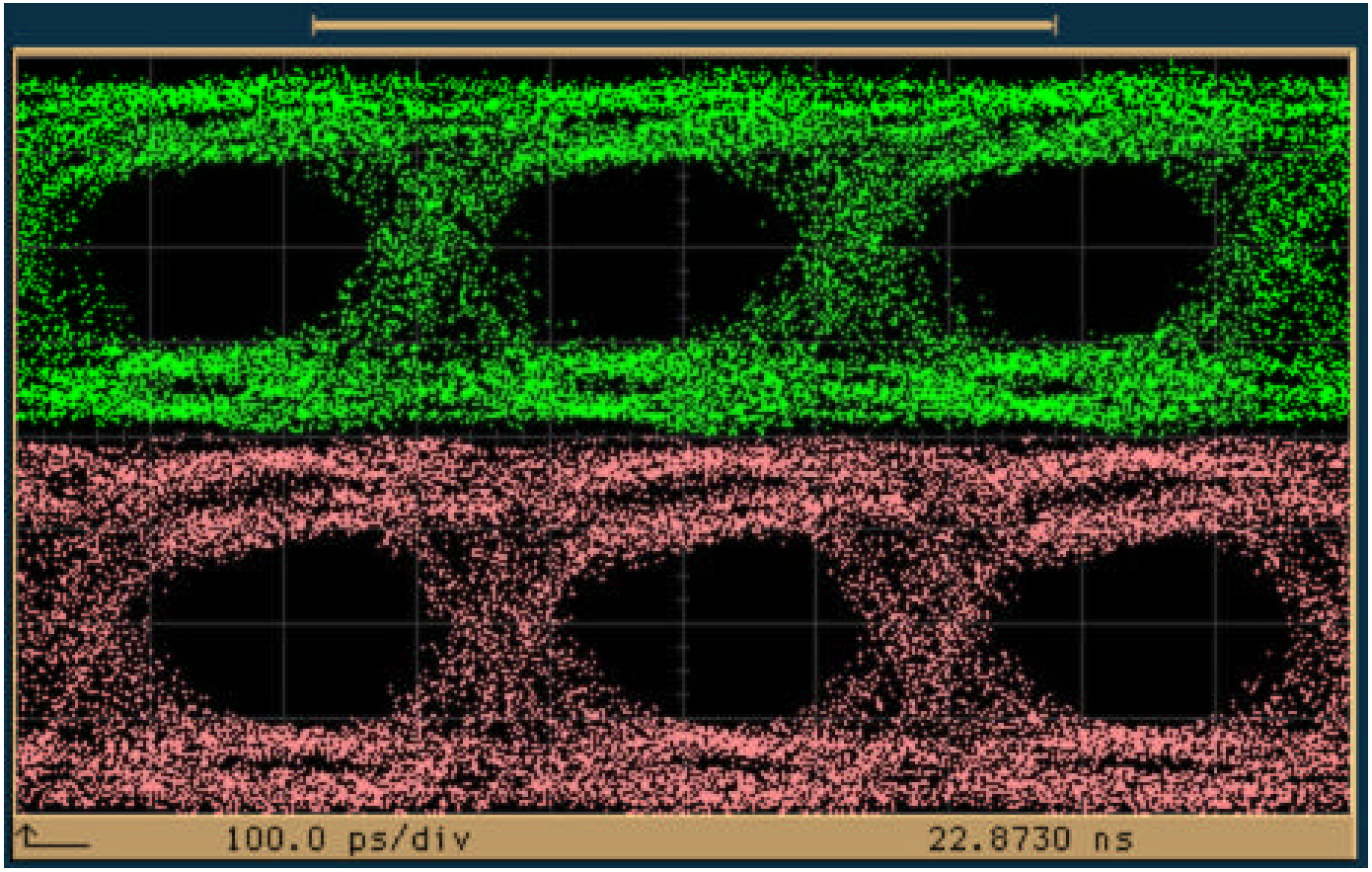


Vendor B Tx – Vendor A Rx
330 m, 62.5 µm Core MMF



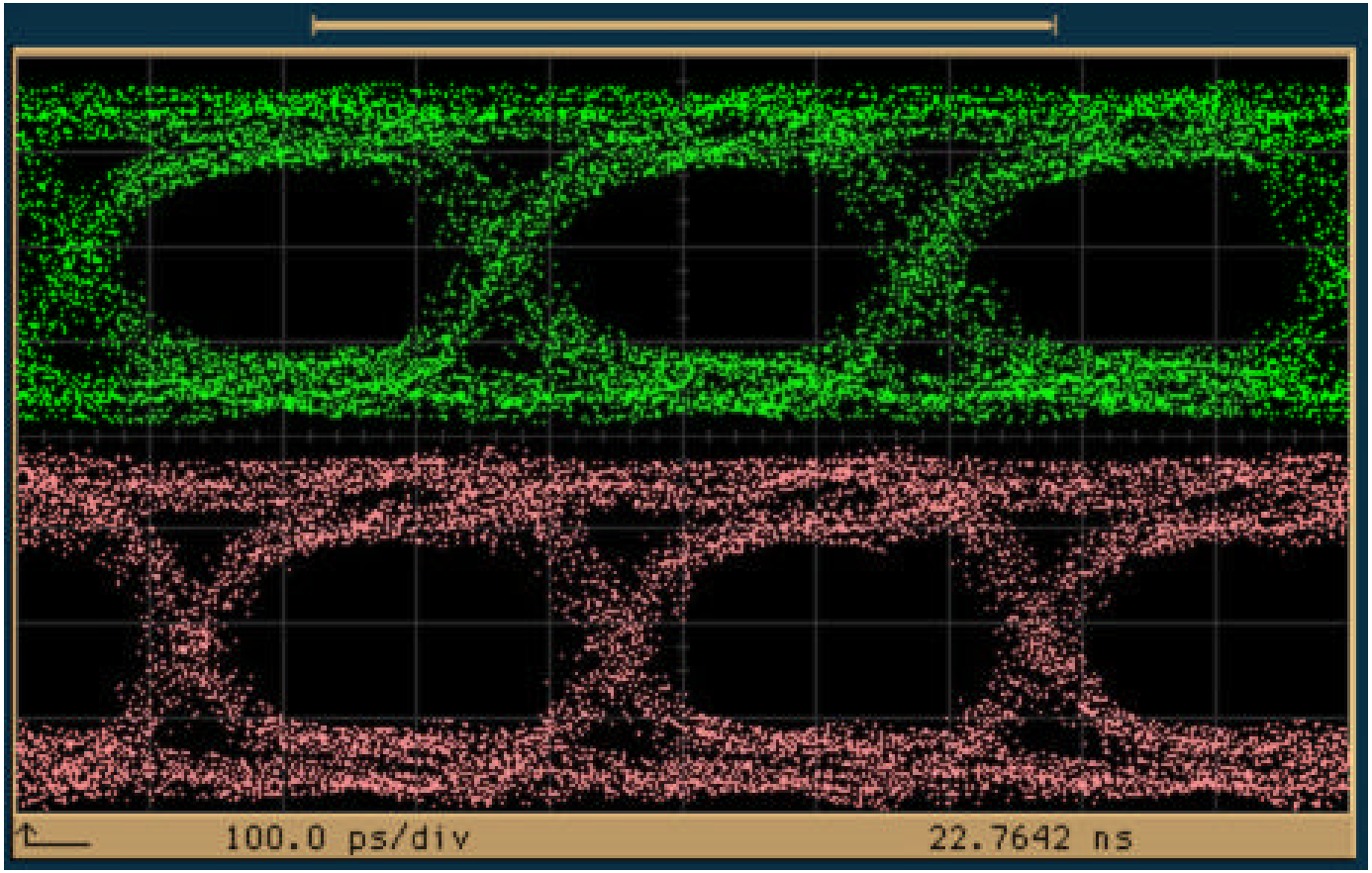
Vendor B Tx – Vendor A Rx

263 m, 50 µm Core, 400 MHz•km MMF



Vendor B Tx – Vendor A Rx

300 m, 50 µm Core, 500 MHz•km MMF



Inter-Vendor Operation Testing Comments

- Required Bit Error Rates Demonstrated During Extensive 3-Way Testing
  - All Distances and Fiber Types Demonstrated for At Least Two Vendors
- Some Testing Under “Stressed” Conditions
  - Additional Fiber Length
  - Multiple Connections
  - Attenuation
- These Tests Were A Success in Demonstrating Inter-Vendor Operation

Future Testing

- Additional Testing Will be Done by Individual Vendors to Verify:
  - Receiver Sensitivity
  - Stressed Receiver Sensitivity
  - Jitter Methodology and Performance
- This Testing Was Not Considered Necessary for Demonstration of Technical Feasibility

Conclusions

- Intra-Vendor Link Operation Has Been Demonstrated for All Link Distances and Fiber Types
- Inter-Vendor Link Operation Has Been Demonstrated for All Link Distances and Fiber Types
- A Viable Path to Full Compliance Exists
- Technical Feasibility Has Been Demonstrated

Motion

- Appropriate text may be added.