10GBASE-S Technical Feasibility

Picolight

Cielo

IEEE P802.3ae Los Angeles,

October 2001 Interim meeting

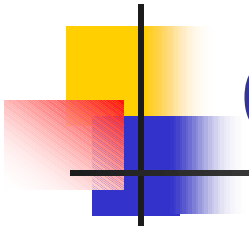
10GBASE-S

Feasibility Supporters

- Petar Pepeljugoski, IBM
- Tom Lindsay, Stratos Lightwave
- Bob Grow, Intel

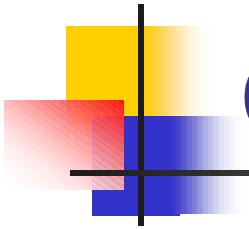
Interoperability Participants

- Picolight
- Cielo
- Corning
- CDT-Optical
- Lucent



Content

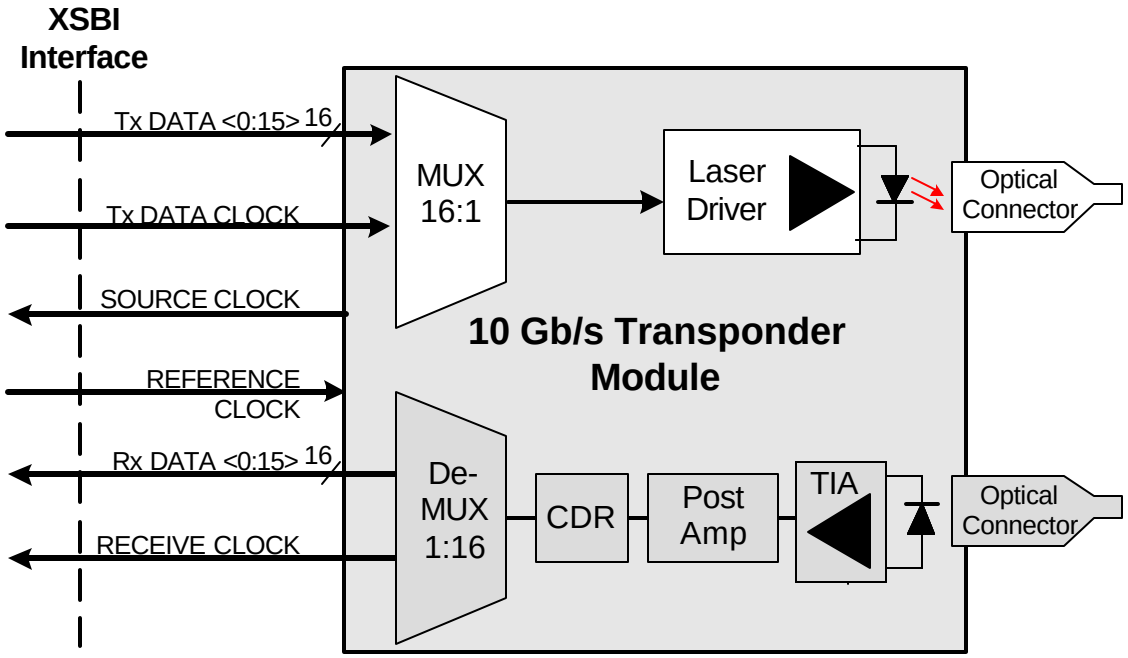
- Interoperability report (recap)
- Compliance report
- System interoperability demonstrations performed in public forums
- Results and summary



Overview

- Demonstration of compliance or credible path to compliance to 10GBASE-S D3.2 specifications
- Interoperability test using 10GBASE-SR transponders using 2^{23}-1 PRBS data
- Parameter measurements and performance testing based on IEEE P802.3ae D3.2 specification

Transponder Functional Block Diagram



- XSBI interface
- Directly Modulated 850 nm VCSEL

Interoperability Test Description

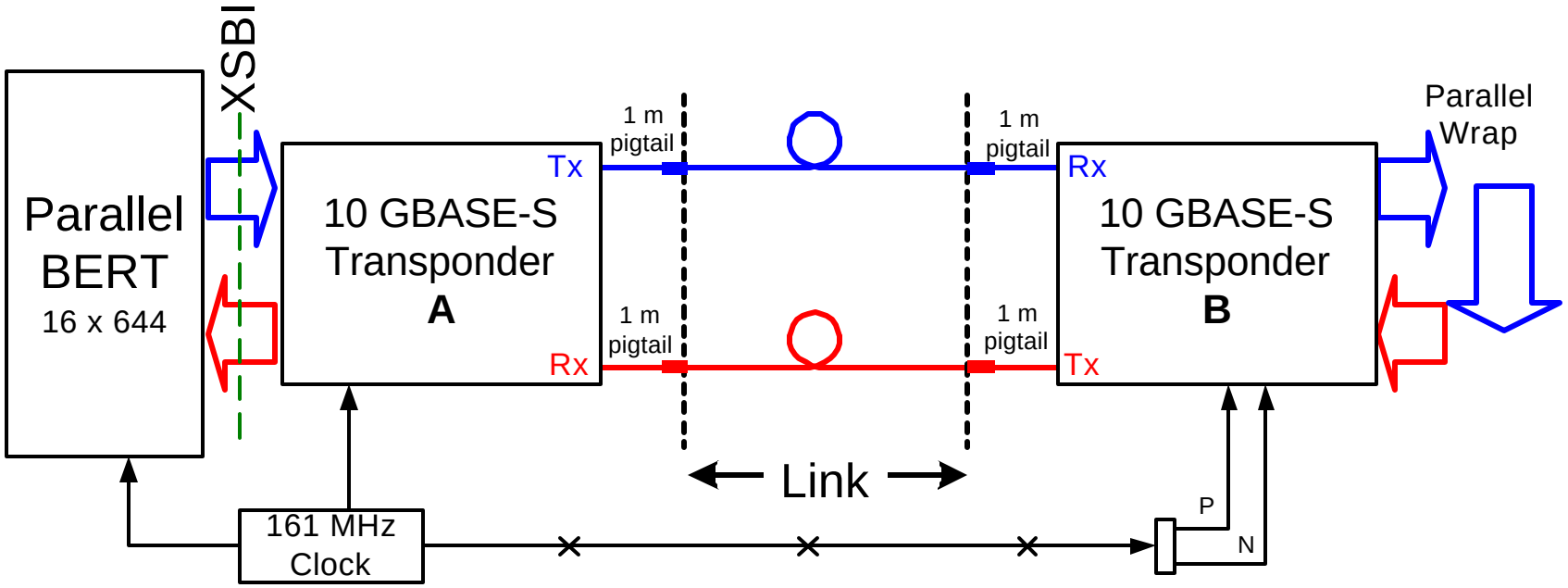
- Two 10GBASE-S PMA/PMD modules (Vendor A & B) connected over complete set of 50µm and 62.5µm fiber types operating at 10GBASE-R rate
- Module electrical interfaces defined by XSBI specifications (clause 51)
- Optical link stressed using excess optical fiber length

Target Link Distances and Fiber Types

Core Diameter	Modal Bandwidth (MHz-km)	Target Distance
62.5 m	160	26 meters
62.5 m	200	33 meters
50 m	400	66 meters
50 m	500	82 meters
50 m	2000	300 meters

Link distance based on fiber types as specified in IEEE 802.3ae draft document

Block Diagram of Test Setup



Test Pattern: PRBS 2^{23}-1 Signal Speed 10.3125Gbps

Interoperability Testing Results

Cable label	Fiber type	Length	Connector	# ofmFibers	Jumpers	Results	Comments
A	2000 MHz-km	300	SC	2		8.00E-13	
	2000 MHz-km	300				0	
B	2000 MHz-km	300	SC	2		0	
	2000 MHz-km	300				0	
D	2000 MHz-km	300	LC	2	2 x FC to LC 1 m jumper (62.5 um receive, 50 um transmit)	0	
	2000 MHz-km	300			2 x FC to LC 1 m jumper (62.5 um receive, 50 um transmit)	3.00E-13	
F	50 um - 400 MHz-km	66	SC	1		0	Near worst case (+/- 50 MHz)
G	62.5 um - 160 MHz-km	26	SC	1	2 m SC-SC jumper added (tension relief)	0	Near worst case (+/- 50 MHz)
H	50 um - 500 MHz-km	82	SC	1	2 m SC-SC jumper added (tension relief)	0	Near worst case (+/- 50 MHz)
I	62.5 um - 200 MHz-km	33	SC	1	2 m SC-SC jumper added (tension relief)	0	Near worst case (+/- 50 MHz)
J	50 um	66	SC	2		0	
	50 um	66				0	
K	62.5 um	35	SC	2	2 m SC-SC jumper added (tension relief)	4.90E-13	
	62.5 um	35			2 m SC-SC jumper added (tension relief)	0	
L	2000 MHz-km	360	SC	2	DMD 0.118 (0-23 um)	4.00E-13	
	2000 MHz-km	360			DMD 0.282 (0-23 um)	<1E-12	
M	2000 MHz-km	450	SC	2	DMD 0.119 (0-23 um)	<1E-12	
	2000 MHz-km	450			DMD 0.145 (0-23 um)	<1E-12	

Testing Summary

Fiber Type/ Bandwidth	Distance	% of link length	BER
62.5 μm MMF 160 MHz·km	26	100%	$<10^{-12}$
62.5 μm MMF 200 MHz·km	33	100%	$<10^{-12}$
50 μm MMF 400 MHz·km	66	100%	$<10^{-12}$
50 μm MMF 500 MHz·km	82	100%	$<10^{-12}$
50 μm MMF 2000 MHz·km	**450 m**	**150%**	**$<10^{-12}$**

Vendor A performance data

Link Parameters (Vendor A)

Transmit Characteristics

Description	Value Part 1	Value Part 2	Measured	Compliance with 802.3ae	Notes
Data Rate	10.3125 Gbps	10.3125 Gbps	Yes	Yes	
Clock Tolerance	< +/-100 ppm	< +/-100 ppm	No	Yes	Note 1
Wavelength	853.1 nm	852.2 nm	Yes	Yes	Note 2
RMS Spectral Width	0.2 nm	0.2 nm	Yes	Yes	Note 2, 4
Ave Optical Power	-5.6 dBm	-3.6 dBm	Yes	Yes	
Trise/Tfall	29 psec	33.2 psec	Yes	Yes	20% - 80% Note 3
OMA	0.370mW (-4.32 dBm)	0.582mW (-2.37 dBm)	Yes	Yes	Peak-peak Note 2
$RIN_{12}OMA$	-135 dB/Hz	-135 dB/Hz	Yes	Yes	Note 5
Ave launch power of OFF transmitter	-80 dBm	-80 dBm	Yes	Yes	
Extinction Ratio	7.2 dB	7 dB	Yes	Yes	

Link Parameters (Vendor A)

Transmit Characteristics (continued)

Description	Value	Measured	Compliance with 802.3ae	Notes
Encircled Flux @ 19um	95%	Yes	Yes	Note 5
Encircled Flux @ 4.5um	10.3%	Yes	Yes	Note 5

Note 1: Based on vendor specification

Note 2: Compliant with triple trade-off table specified in draft 3.2

Note 3: Values are for the slower time, T_{fall}, based on square root of the difference of the squares calculation (IEEE802.3ae Draft 3.2, Clause 52.9.8) using 2 – 12 GHz filters (1^{st} – O/E, 2^{nd} – Scope)

Note 4: Resolution of measurement equipment is 0.1 nm

Note 5: Average of randomly-chosen samples

Link Parameters (Vendor A)

Receiver Characteristics

Description	Value Part 1	Value Part 2	Measured	Compliance with 802.3ae	Notes
Signal speed	10.3125 Gbps	10.3125 Gbps	Yes	Yes	
Wavelength Response	840nm (min) 860nm (max)	840nm (min) 860nm (max)	No	Yes	Note 1
Return Loss	<12 dB	<12 dB	No	Yes	Note 2
Stressed Receive Sensitivity OMA	0.100mW -10.0 dBm	0.106mW -9.7 dBm	Yes	Yes	Part 2 2^7-1 pattern

Link Parameters (Vendor A)

Receiver Characteristics

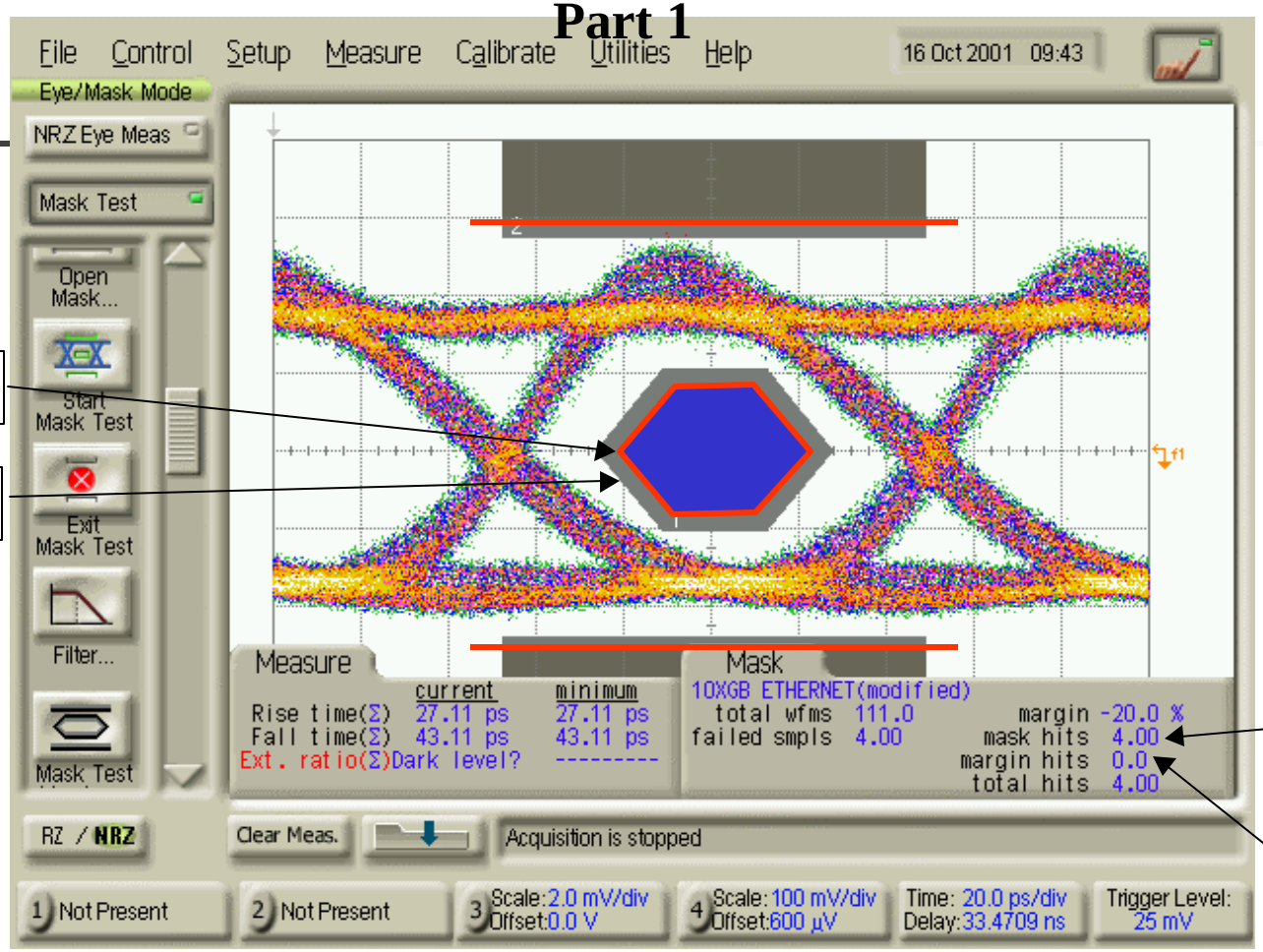
Description	Value Part 1	Value Part 2	Measured	Compliance with 802.3ae	Notes
Receive Sensitivity OMA	-13.8 dBm	-14.8 dBm	Yes	Yes	Informative
Vertical eye closure penalty	3.5 dB	3.5 dB	Yes	Yes	
Receive electrical 3 dB cutoff upper frequency	<9 GHz	<9 GHz	Yes	Yes	

Note 1: Response very predictable based on PIN Diode material

Note 2: Estimated; consistent with Gigabit Ethernet

Tx Eye Pattern (Vendor A)

Part 1



10Gb E Mask

20% Margin

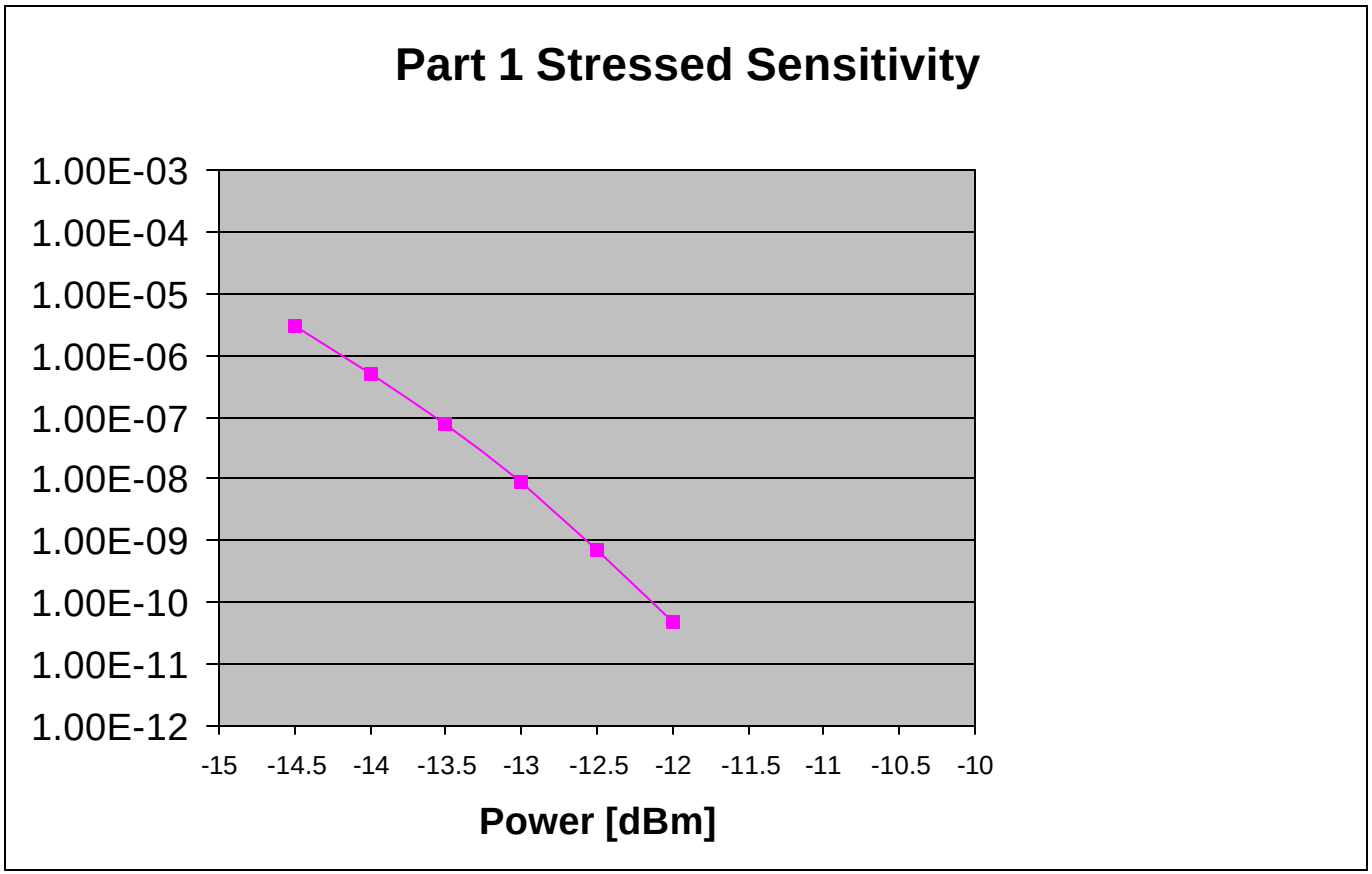
Margin Hits (not mask)

Mask (not margin)

Measured extinction ratio – 7.2 dB, T_{fall} = 33.2psec (de-convolved)
2^{31}-1 PBRS data pattern w/ 2 – 12 GHz filters (1st-O/E, 2nd-Scope)

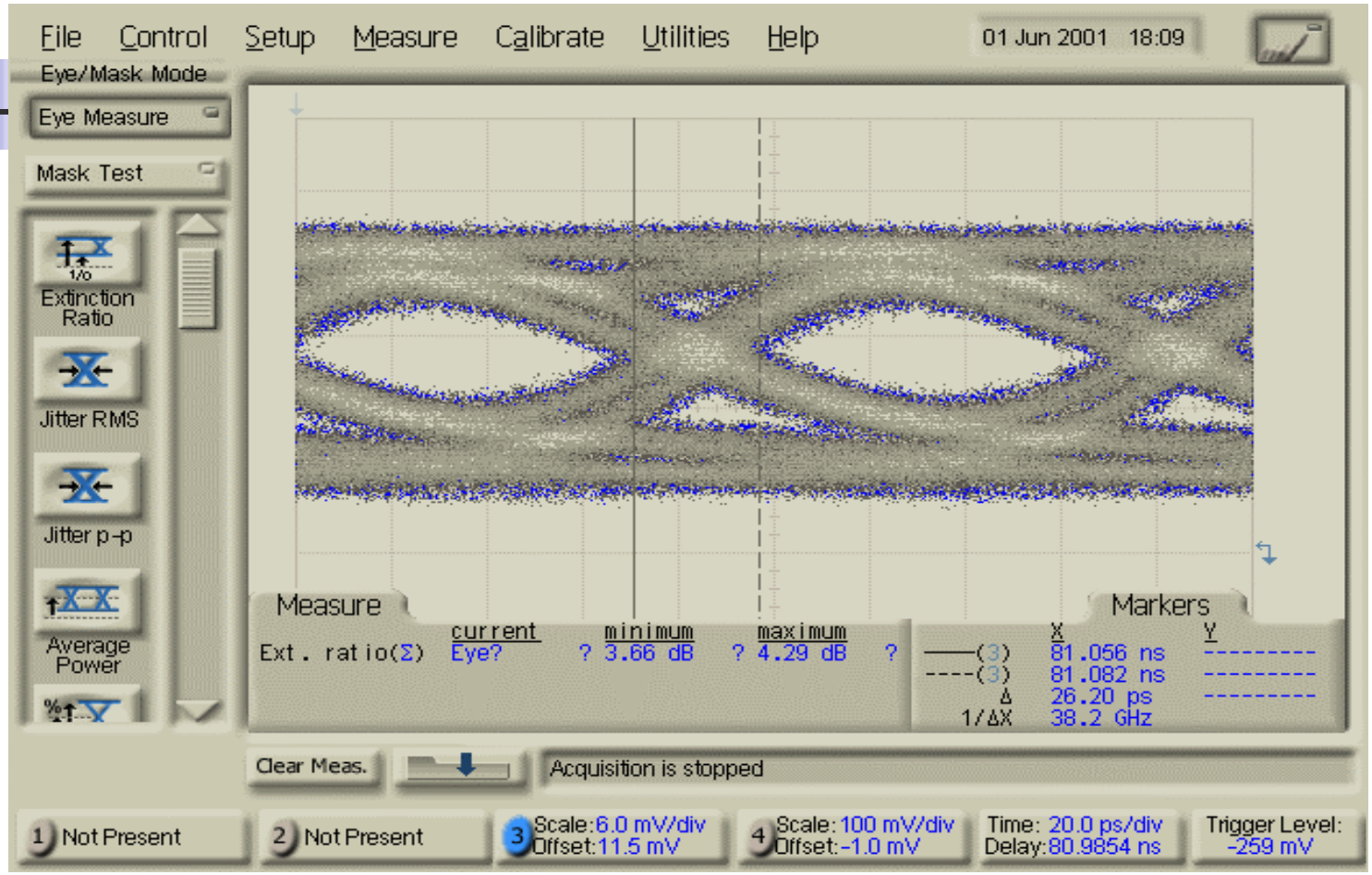
Measured BER Curve

(Vendor A)



Stressed Receive Input

(Vendor A) Reference Tx

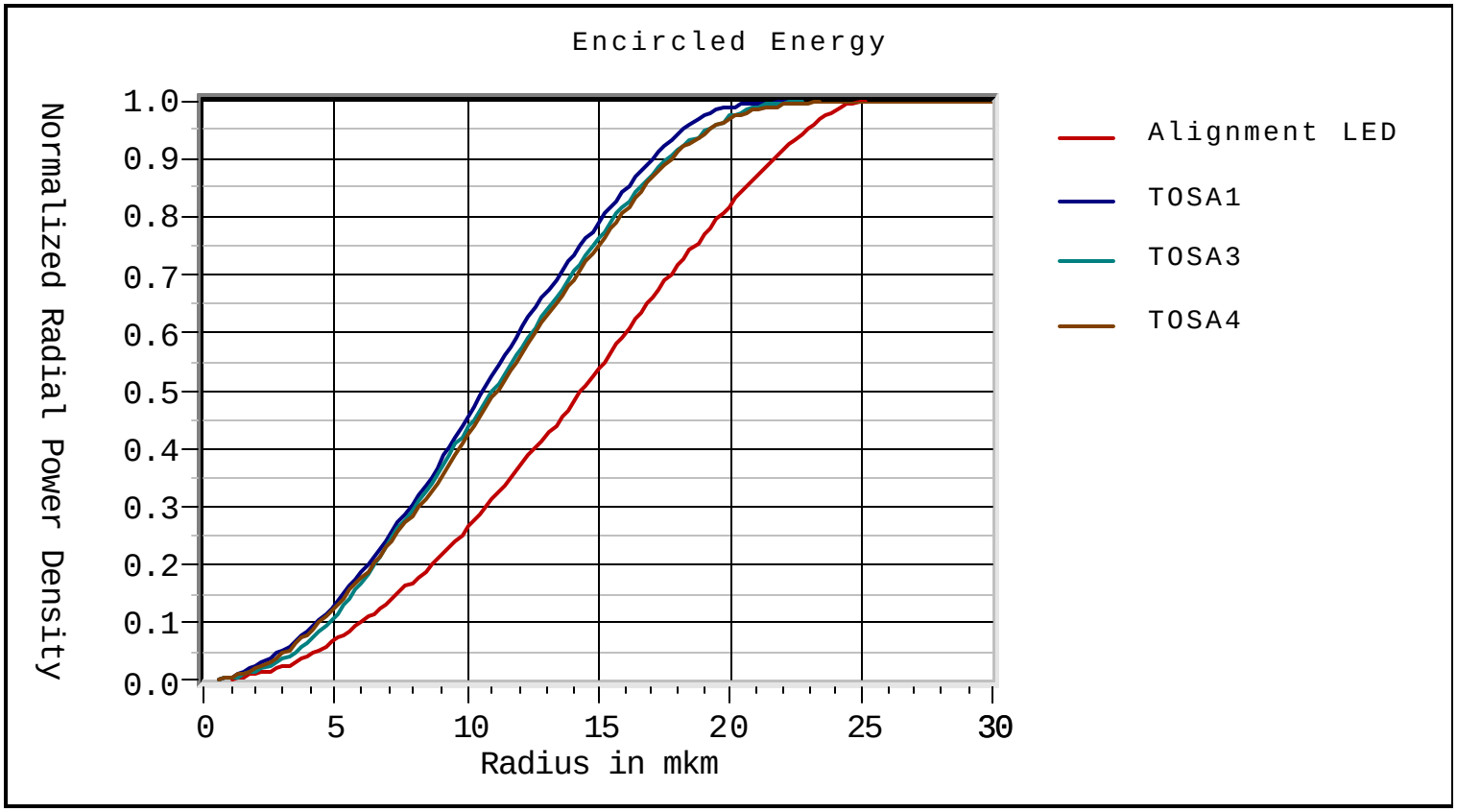


Stressed eye as measured with the 7.6 GHz Golden receiver.

p-p closure = 3.2 dB,. Peak closure = 3.5 dB

Encircled Flux Measurement

(Vendor A)
Random Tx OSA DUTs



Path to Compliance
(Vendor A)

Vendor A ⇒ Critical Performance Issues

- Nearly complete set of data taken from each of two modules
- Path: Verification of compliance through complete testing of production volumes

Vendor B performance data

Link Parameters (Vendor B)

Specification	Value Part 1	802.3ae 10GBASE-S Value	Units	Compliance	Notes
Signal Speed	10.3125	**10.3125**	GBd	Yes	
TRANSMITTER					
Wavelength	843	**ttc**	nm	-	ttc = triple trade-off curve
RMS spectral width	0.59	**ttc**	nm	-	ttc = triple trade-off curve
Launch power in OMA	-1.3	**ttc**	dBm	-	ttc = triple trade-off curve
Triple trade-off curve				No	Spectral width not on curve
Trise/Tfall	54.5 (fall)	**35**	ps	No	

Link Parameters (Vendor B) continued

Transmitter (cont.)	Value Part 1	802.3ae 10GBASE-S Value	Units	Compliance	Notes
Ave. Launch power	-1.3	**-1.3**	dBm	Yes	Eye safe limit = -1.3 dBm
Extinction ratio	3	**3**	dB	Yes	
$RIN_{12}OMA$	Not measured	**-125 dB/Hz**	dB/Hz	-	
Encircled flux	Data not available	**19 mm >86%** **4.5 mm =< 30%**		Yes	
Fiber Link					
Fiber Attenuation	Not measured	**3.5**	dB/km	-	Assume 3.5 dB/km
Connector Loss	Not measured	**1.5**	dB	-	Assume 1.5 dB
Receiver					
Stressed Rx sensitivity	-4.8	**-7.08**	dBm	No	Estimated

Path to Compliance (Vendor B)

- Vendor B $\Rightarrow$ Critical Performance Issues
- Through improvements to IC's and tweaks to laser Transponder B module will be brought into compliance
  - Note: The reported reduced sensitivity with all links operating with a BER of < 10-12 represents an extra 2.28 dBm of margin that will be available in a compliant module.

Other 10GBASE-S Performance Demonstrations

- OFC 2000, March 2001, Baltimore, MD
- IEEE Interim Meeting, Sep 2000, New Orleans, LA
- NFOEC 2000, Denver, CO
- N+I 2001, Sep 2001, Atlanta, GA
  - System interoperability demonstration @ 10GEA booth
  - 10GBASE-SW & SR links with XSBI and XAUI based modules
- ECOC 2001, Sep 2001, Amsterdam
  - IBM reported 20 Gbit/s link using VCSELs and SiGe driver (r.t. 20 ps, DJ = 11ps)

10GBASE-S is Technically Feasible Because....

- Successfully interoperated between two 10GBASE-S module vendors with 150% link distance, 450 m over the least margined fiber type (2000 MHz-km standard fiber).
- Vendor A demonstrated compliance on all measured parameters
- Vendor B demonstrated credible path to compliance
- Compliance or path to compliance were described via a comparison of measured vs IEEE required link parameters

10GBASE-S is Technically Feasible Because....

- Multiple vendors exist (2 demonstrated)
  - Picolight
  - Cielo
- Two other vendors plan to support 10GBASE-S
  - IBM
  - Stratos Lightwave

Conclusion

- 10GBASE-S is technically feasible
  - Link operates at BER of $<10^{-12}$ over all specified link distances/fiber types
  - Even with some performance issues, such as spectral width, rise time, and receiver sensitivity, the link model is overly conservative and the 10GBASE-S PMDs operated beyond required link distances