PMD 1310 nm Serial, 10GBASE-L
Feasibility Demonstration Report

To be presented to IEEE 802.3ae in October 2001

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Introduction

This document is a report on compliance tests and tests of operation over multiple vendor links conducted by various participating companies, as part of an effort by members of IEEE 802.3ae to demonstrate feasibility of 10GBASE-L PMD types (1310 nm Serial).

Demonstrating feasibility will consist of two parts, as agreed in the Portland meeting. One is to present a credible path to full compliance with 802.3ae draft specifications, and the other is to demonstrate successful operation of multi-vendor links at a BER of less than 10^-12 over the rated distances.

Therefore, this document is divided in two major portions. The first half contains reports from each individual vendor, describing the tests performed on their own PMD. These tests were aimed at measuring to what degree these PMD units were compliant with the 802.3ae draft specifications. While measuring this compliance in itself is not required in order to prove feasibility, it is an obvious prerequisite. In order to describe a credible path to compliance, one must establish how far a PMD is from full compliance.

The second half of this document describes the results of multi-vendor link tests.

List of participating companies:

Agilent Technologies
Finisar
Hitachi Cable

Compliance Tests: Company A

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Compliance Tests: Company A

Test Plan:

Our test plan consisted of three steps:

Step 1. Determine link parameters. List all the link parameters required as inputs to the link model, and determine their values for the PMD under test. It was understood that this wasn't easy or perfect, but our obligation was to make the best effort. If a measurement was not performed, a reasonable explanation of estimated value was expected.

Step 2. Determine stressed distance. Use link distance and margin as the dependent variables, and all other parameters as independent variables (inputs). Plug these inputs into the link model. Determine the link distance at which margin becomes very small. In essence, this becomes our "stressed distance".

Step 3. Measure BER at the stressed distance. Target value is 10^-12.

The following sections describe the results of these three steps in more detail.

Brief description of the PMD under test:

10GBASE-LR, Electrical interface: XSBI, 300-pin connector, MDI interface: SC receptacle. Serial Number B257B41. DFB laser, uncooled, directly modulated. PIN photodiode. Reference Clock: 161 MHz.

Step 1: Determine Link Parameters

For the given PMD under test, the following parameters were determined, mostly through measurements. We had some difficulty obtaining the correct equipment to measure RMS spectral width because we wanted to use a high resolution Optical Spectrum Analyzer to make sure that the effect of chirping under modulation is measured. Based on inputs from our laser supplier, we were satisfied that a spectral width of less than 0.2 nm (RMS) was a reasonable and conservative estimate.

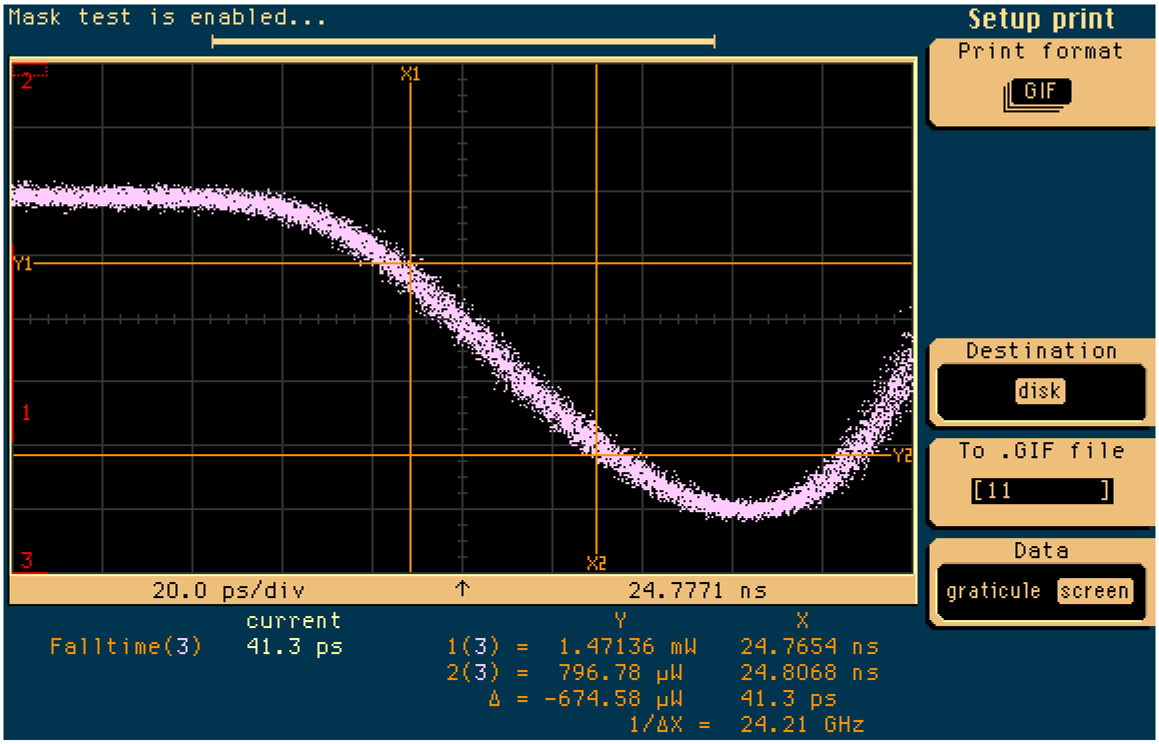
Table 1: Link Parameters

Specification	**Value**	**Units**	**Measured, Calculated, or TBD?**	**Compliance with 802.3ae claimed?**	**Notes**
Signaling Speed (nominal)	10.3125	GBd	Measured	Yes	
Wavelength	1308	nm	Measured	Yes	
RMS spectral width	<0.2	nm	TBD	Yes	Based on inputs from laser supplier.
SMSR	>35	dB	Measured	Yes	
Launch Power (OMA)	728	Microwatts	Measured	Yes	
Extinction Ratio	4	dB	Measured	Yes	
RIN12OMA	<-125	dB/Hz	TBD		Less than 125 dB/Hz, estimated from data on similar lasers/assemblies in another batch.
Fiber attenuation	0.31	dB/km	Measured	Not Applicable	
Connector loss	1.8	dB	Measured	Not Applicable	
Tx rise/fall time, 20%-80%	41.3	ps	Measured	Yes	Note 1
DCD DJ	0	ps	Measured	Yes	Note 2
Stressed Rx sensitivity	75	Microwatts	Measured	Yes	Note 3
(Informative) Rx sensitivity	60	Microwatts	Calculated	Not Applicable	Note 4

Note 1: Rise/Fall Time measurements

The fall time was 41.3 psec, 20%-80%. This is just on the border of compliance – it produces a Tx Eye Height of 49.5%, while 50% is required.

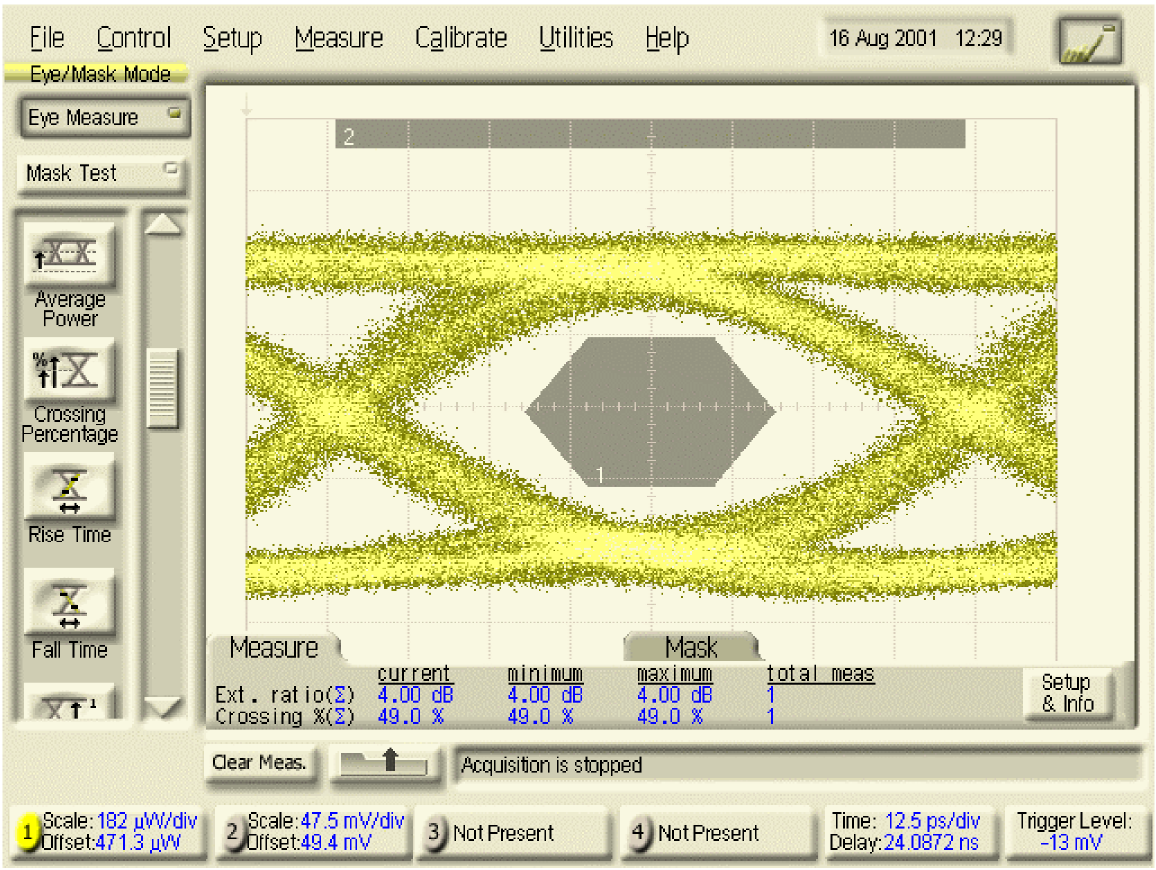
Figure 1: Fall Time of Transmitter, measured with Filter off.



Note 2: Estimation of DCD DJ

As the measurements showed, DCD DJ was negligibly small.

Figure 2: Trans mit Eye, with Filter On.



Note 3: Stressed Receiver Sensitivity

Using the test pattern defined in sub-clause 52.9.12 (65 zeros; one; zero; 65 ones; zero; one; repeat), a stressed eye was obtained at 2 meters and at 10,000 meters. They are shown below.

No effort was made to inject additional ISI into the system, even without it, the stressed eye produced sufficient Vertical Eye Closure Penalty.

The stressed eye doesn't quite look like a traditional eye diagram because the Parallel BERT used in this test could only provide trigger to the DCA at slow word rates. Still, the effect of ISI-induced eye closure is made visible by the Y markers.

Figure 3: Stressed Receiver Input Signal, link length 2 meters

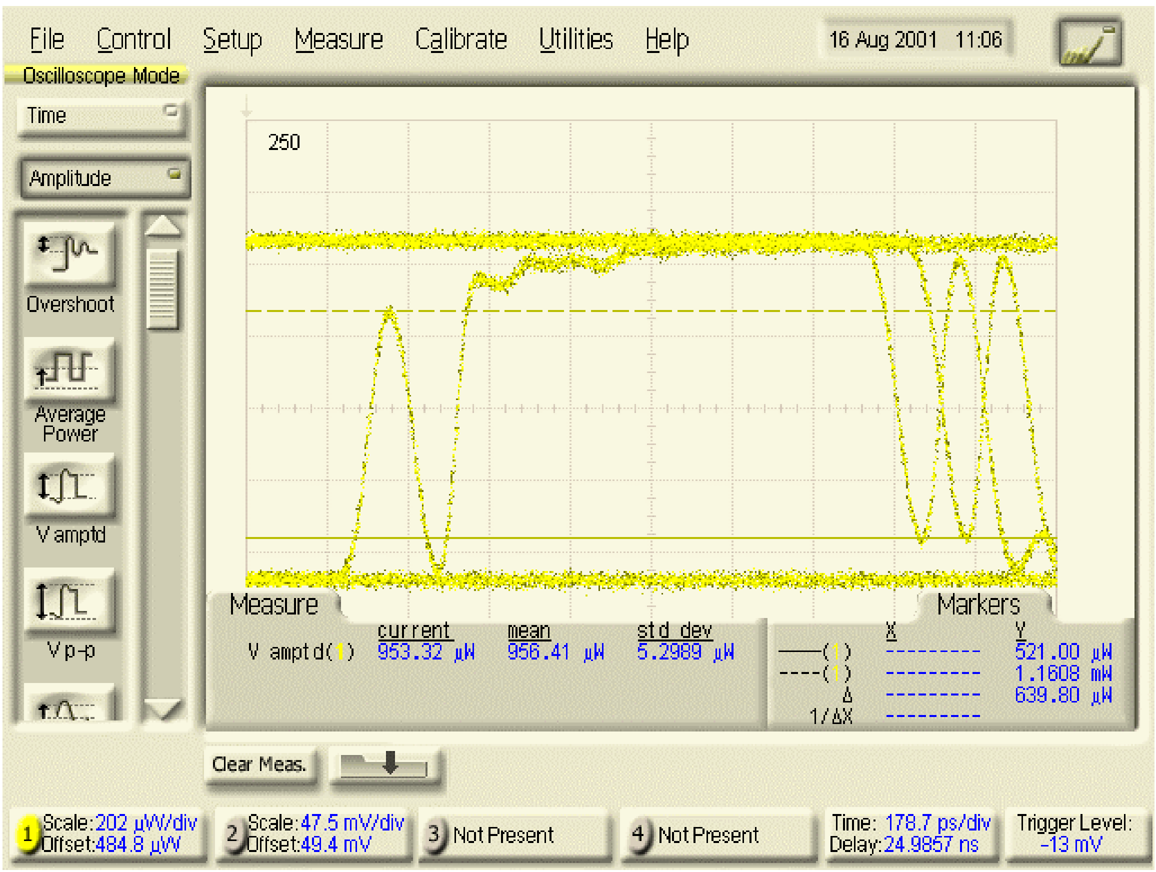
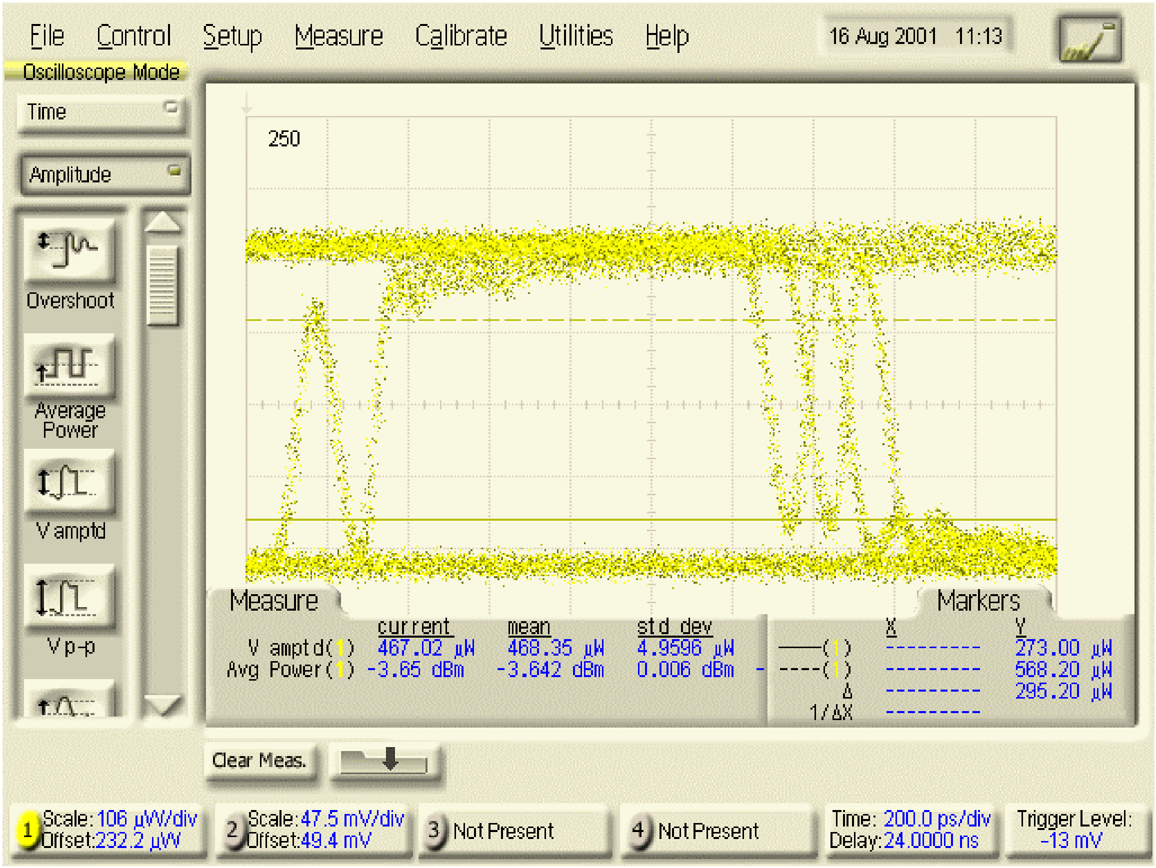


Figure 4: Stressed Receiver Input Signal, link length 10,000 meters



The eye produced here is not stressed in exact conformance to the requirements listed in subclause 52.9.12; sinusoidal jitter and 6 ps of DCD are not added. Since the transmitter exhibits very low DCD, the spirit of the eye closure penalty is all directed towards ISI. Perhaps this point is debatable, but the discrepancy is small.

Table 2: Vertical Eye Closure Penalties from stressed eye measurements

Distance (m)	**AN (mW)**	**A0 (mW)**	**Vertical Eye Closure Penalty (dB)**	**Comments**
2	0.956	0.640	1.75	
10,000	0.467	0.295	2.00	

Subsequently, the stressed receiver sensitivity was measured by adding attenuation to the 10 kilometer link, using the PRBS 2^31-1 pattern. Attenuation was dialed up until an error rate of 10^-9 was observed and then dialed back by 1 dB. This value was found to be 75 Microwatts, OMA.

Note 4: Estimate of nominal (informative) Rx Sensitivity

Given the limited bandwidth of our transmitter, and the absence of a golden transmitter, we could only estimate the value of nominal or ideal receiver sensitivity, recognizing that such estimation anyway had little value in determining the degree of compliance. If the penalties arithmetic is invoked to go from stressed to nominal sensitivity value, we run into a circular argument of what the margin is for a given link. In any case, the RIN value here was an estimate to begin with. In addition, as can be seen in Table 3, the Vertical Eye Closure Penalty was higher than 1.78 dB permitted by Table 52-14, and it would be even higher at 15 kilometers. This signals the presence of a bandwidth limiting effect that needs further investigation. Considering all these issues, we decided to use an estimate of 1 dB as the difference between stressed and nominal receiver sensitivity. In OMA terms, that value is 60 Microwatts.

Step 2: Determine stressed distance

By plugging in the values obtained in Step 1 into the link model, it can be shown that a link distance of 15 kilometers should be supported, with a small margin to spare. There was the practical difficulty of not having a 16 or 17 kilometers long fiber spool. An additional 1 or 2 km spool would have to be patched with connector junction which itself can introduce about one dB of loss. Therefore, we selected 15 kilometers as our “stressed distance.”

Step 3: Measure BER at the stressed distance

Guided by the outcome of Step 2, a fiber link 15 kilometers long was set up and the link was tested for Bit Error Rates. Operation at the stressed distance of 15 kilometers with a BER of less than 10^-12 was observed.

Table 3: BER vs. Distance, measurements

Distance (meters)	Measured BER	Notes
2	<10^-12	2^31-1 PRBS used. Fiber was G.652 compliant, not dispersion-shifted.
10,000	<10^-12	
15,000	<10^-12	

Link Power Budget

Based on the measurements and estimates derived above, we can now piece together a link power budget.

Available budget: 10*log(728/60) = 10.8 dB

Cable attenuation: 15 kms. * 0.31 dB/km = 4.65 dB
Connector Loss: 1.8 dB
Penalties:

- Pisi: 1.5 dB
- Pdj: 0.5 dB
- Pref: 0.5 dB
- Prin: 0.5 dB
- Pmpn: 0 dB
- Pcross: 0.2 dB

Total Penalties: 3.2 dB
Unallocated Margin: 1.15 dB

Concluding Remarks

Consistent with the 10GE link model and the specifications defined in 802.3ae draft 3.2, the PMD under test is able to support operation over the rated distance with a BER of less than 10^-12, with margin to spare.

Compliance Tests: Company B

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Compliance Tests: Company B

Test Plan:

Our test plan consisted of three steps:

Step 1. Determine link parameters. List all the link parameters required as inputs to the link model, and determine their values for the PMD under test. It was understood that this wasn't easy or perfect, but our obligation was to make the best effort. If a measurement was not performed, a reasonable explanation of estimated value was expected.

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Step 3. Measure BER at the stressed distance. Target value is 10^-12.

The following sections describe the results of these three steps in more detail.

Brief description of the PMD under test:

10GBASE-LR, Electrical interface: XSBI, 300-pin connector, MDI interface: fiber pigtail with SC connector. Serial Number S00004. DFB laser, uncooled, directly modulated. PIN photodiode. Reference Clock: 161 MHz.

Step 1: Determine Link Parameters

For the given PMD under test, the following parameters were determined, mostly through measurements.

Table 1: Transmit characteristics

Description	Value	Unit	Measured, Calculated or TBD?	Compliance with 802.3ae claimed?	Notes
Signaling Speed (nominal)	10.3125	GBd	Measured	Yes	
Clock tolerance	> +/-100	ppm	Measured	Yes	
Wavelength	1305.4	nm	Measured	Yes	
RMS spectral width	(0.09)	nm	Measured	Yes	Note 1
SMSR	-49.5	dB	Measured	Yes	
Average launch power	-0.2	dBm	Measured	Yes	
Launch Power in OMA	1.27 (1.02)	mW (dBm)	Measured	Yes	Note 2
Average launch power of OFF transmitter	< -40	dBm	Measured	Yes	
Extinction Ratio	6.93	dB	Measured	Yes	Note 2
RIN12OMA	-143.1	dB/Hz	Measured	Yes	
Return loss	-42.0	dB	Measured	Yes	
Rise/Fall time, 20%-80%	40.9	ps	Measured	Yes	Fig. 7

Note1 : The resolution of spectrum analyzer is 0.1nm

Note2 : The test pattern is the Square pattern (see table 4)

Table 2: Receive characteristics

Description	Value	Unit	Measured, Calculated, or TBD?	Compliance with 802.3ae claimed?	Notes
Signaling Speed (nominal)	10.3125	GBd	Measured	Yes	
Clock tolerance	> +/-100	ppm	Measured	Yes	
Wavelength	1306	nm			Note 3
Average receive power (max)	> +1.0	dBm	Measured	Yes	
Receive sensitivity in OMA	0.0347 (-14.6)	mW (dBm)	Measured	Yes	Note 4
Return loss	-45	dB	Measured	Yes	
Stressed receive sensitivity in OMA	0.0467 (-13.3)	mW (dBm)	Measured	Yes	Note 5
Vertical eye closure penalty	2.22	dB	Measured	Yes	
Receive electrical 3dB upper cutoff frequency	8.1	GHz	Measured	Yes	

Note 3 : The wavelength for measurements

Note 4 : Measured with a transmit signal having 7.4dB extinction ratio and 1.31dB vertical eye closure (see table 5)

Note 5 : Measured with a transmit signal having a 4.5 dB extinction ratio and 2.22dB vertical eye closure (see table 5)

Table 3: Attenuation and connector loss

Description	Value	Unit	Measured, Calculated, or TBD?	Compliance with 802.3ae claimed?	Notes
Fiber attenuation	0.32	dB/km	Measured	Not Applicable	
Connector loss	1.46	dB	Measured	Not Applicable	For two connectors

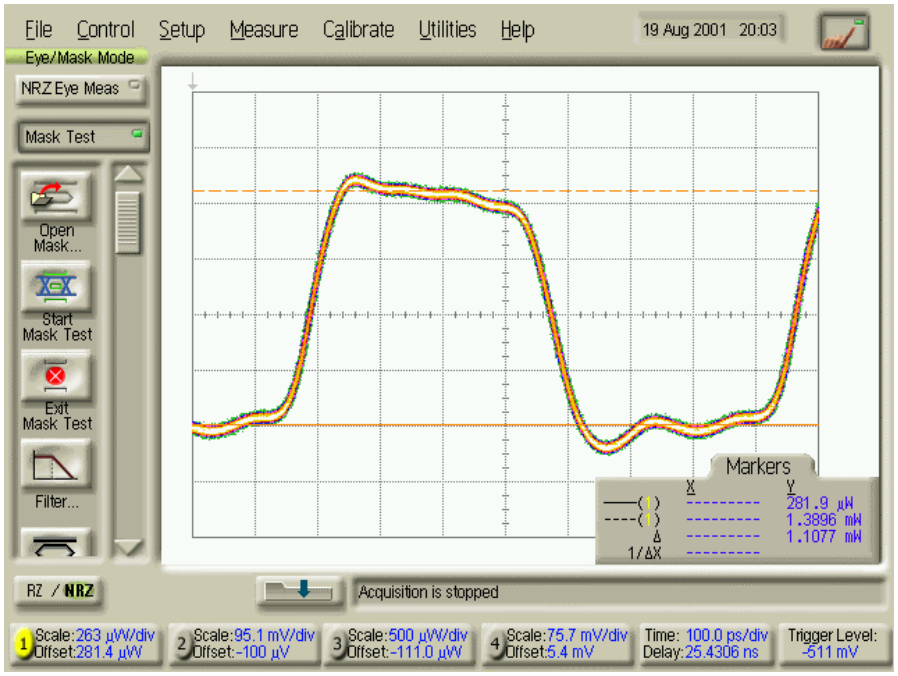


Fig.1: Transmit pattern with roll off filter (Square pattern)

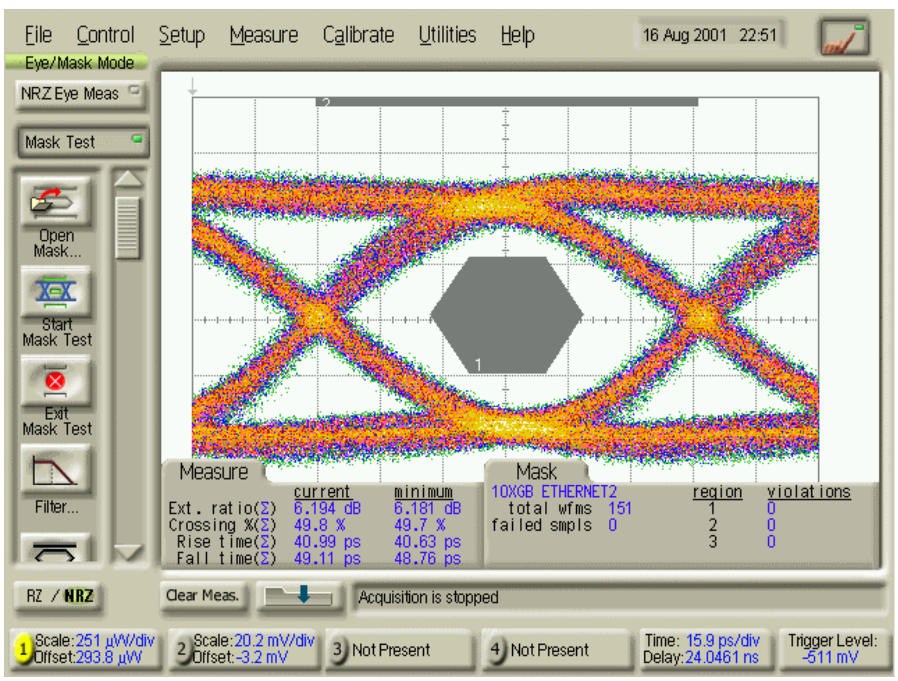


Fig.2: Transmit eye pattern with roll off filter (PRBS 2^{31}-1)

Table 4: Vertical eye closure penalties from eye measurements

pattern	AN [mW]	A0 [mW]	Vertical eye closure penalty [dB]
Normal	1040	770	1.31
Stressed	720	432	2.22

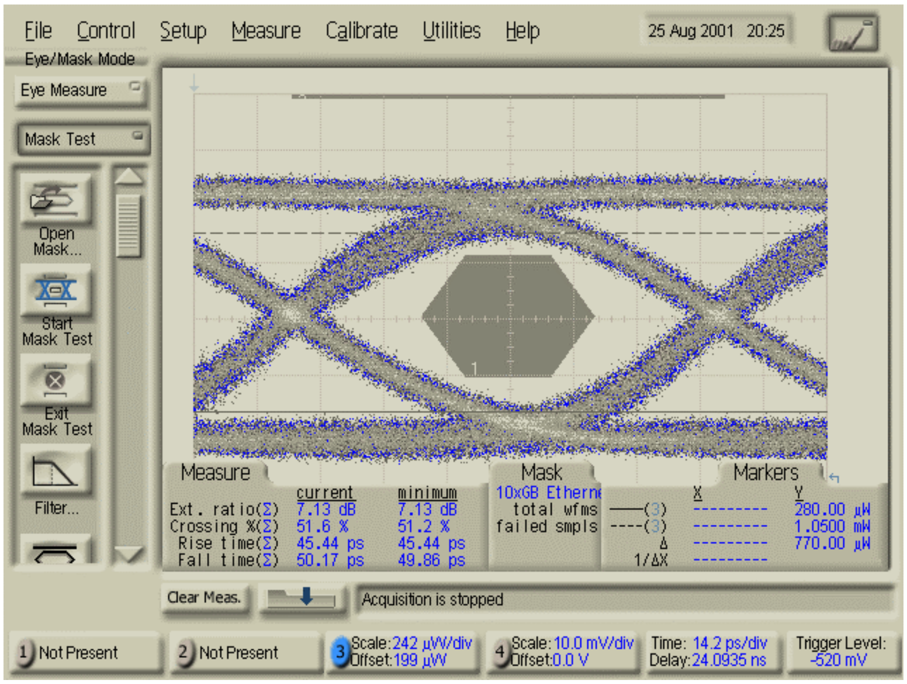


Fig.3: Normal receiver input signal

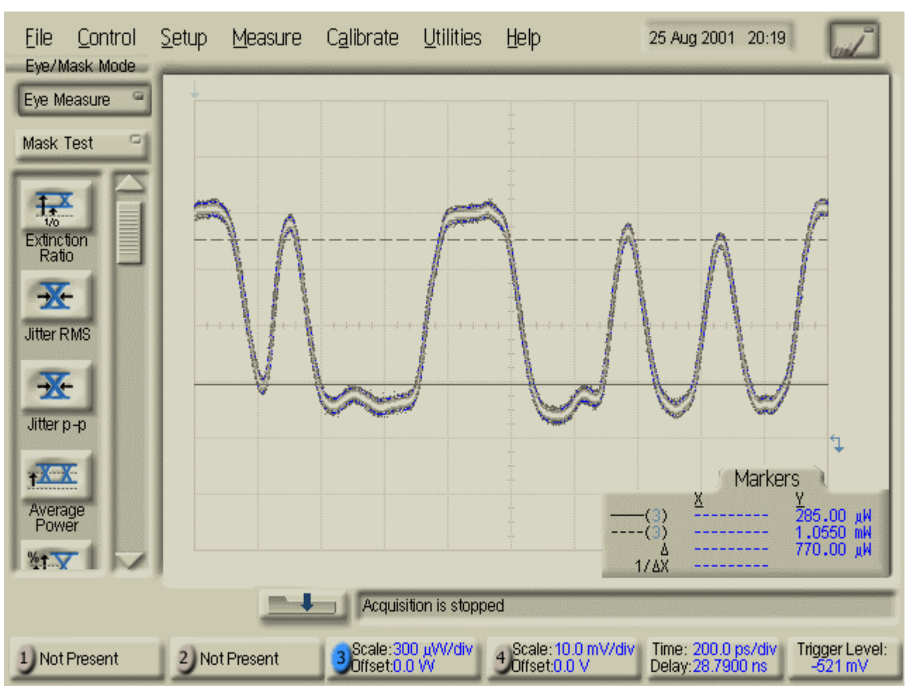


Fig.4: Normal receiver input signal (Pattern trigger)

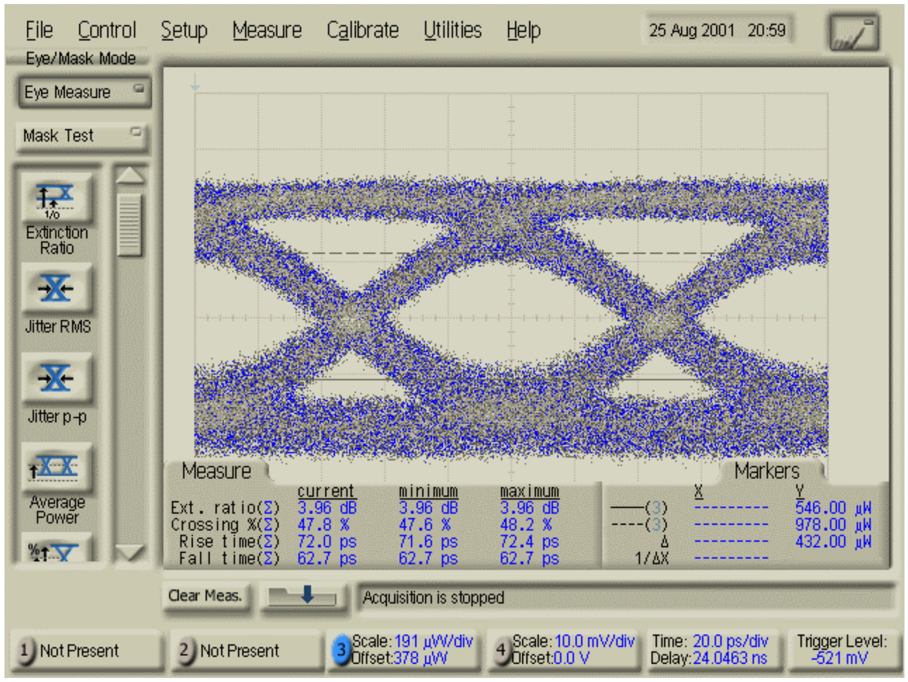


Fig.5: Stressed receiver input signal

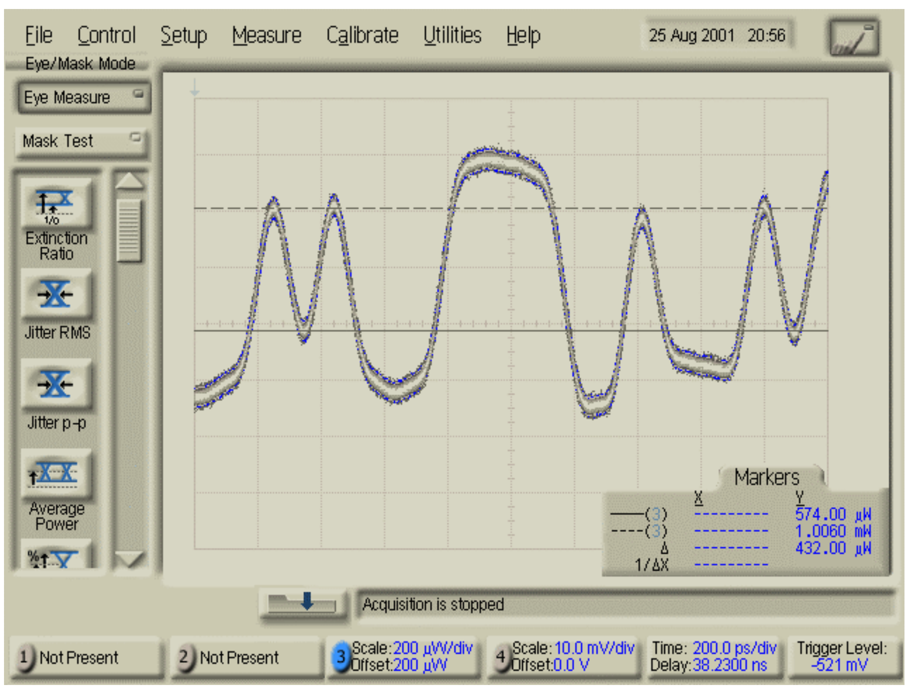


Fig.6: Stressed receiver input signal (Pattern trigger)

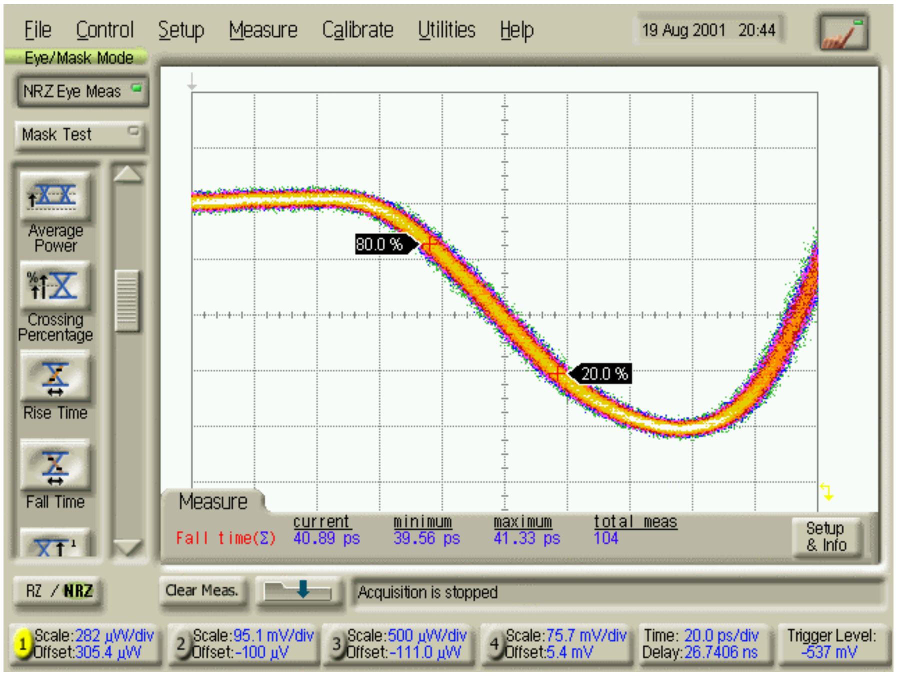


Figure 7: Measurement of fall time, 20%-80%

Step 2: Determine stressed distance

By plugging in the values obtained in Step 1 into the link model, it can be shown that at a link distance of 31 kilometers can be supported, with a small margin to spare. Given some practical aspects related to fiber spool and additional connector loss if we were to stretch it further, we selected 31 kilometers as our "stressed distance."

Step 3: Measure BER at the stressed distance

Guided by the outcome of Step 2, a fiber link 31 kilometers long was set up. The link was tested for Bit Error Rates. Operation at the stressed distance of 31 kilometers with a BER of less than 10^-12 was observed.

Table 5: BER vs. Distance, measurements

Distance (meters)	Measured BER	Notes
2	<10^-12	2^31-1 PRBS used. Fiber was G.652 compliant, not dispersion-shifted.
13,000	<10^-12	
25,000	<10^-12	
31,000	<10^-12	

Link Power Budget

Based on the measurements and estimates derived above, we can now piece together a link power budget.

Available budget: 1.02 – (-14.6) = 15.62 dB

Cable attenuation: 31 kms. * 0.32 dB/km = 9.92 dB
Connector Loss: 1.46 dB
Penalties:

- Pisi: 1.30 dB
- Pdj: 0.34 dB
- Pref: 0.0 dB
- Prin: 0.01 dB
- Pmpn: 0 dB
- Pcross: 0.09 dB

Total Penalties: 1.74 dB
Unallocated Margin: 2.5 dB

Concluding Remarks

Consistent with the 10GE link model and the specifications defined in 802.3ae draft 3.2, the PMD under test is able to support operation over the rated distance with a BER of less than 10^-12, with margin to spare.

Company C

10GBASE-LR Feasibility report for 802.3ae

Vendor C

October 2001

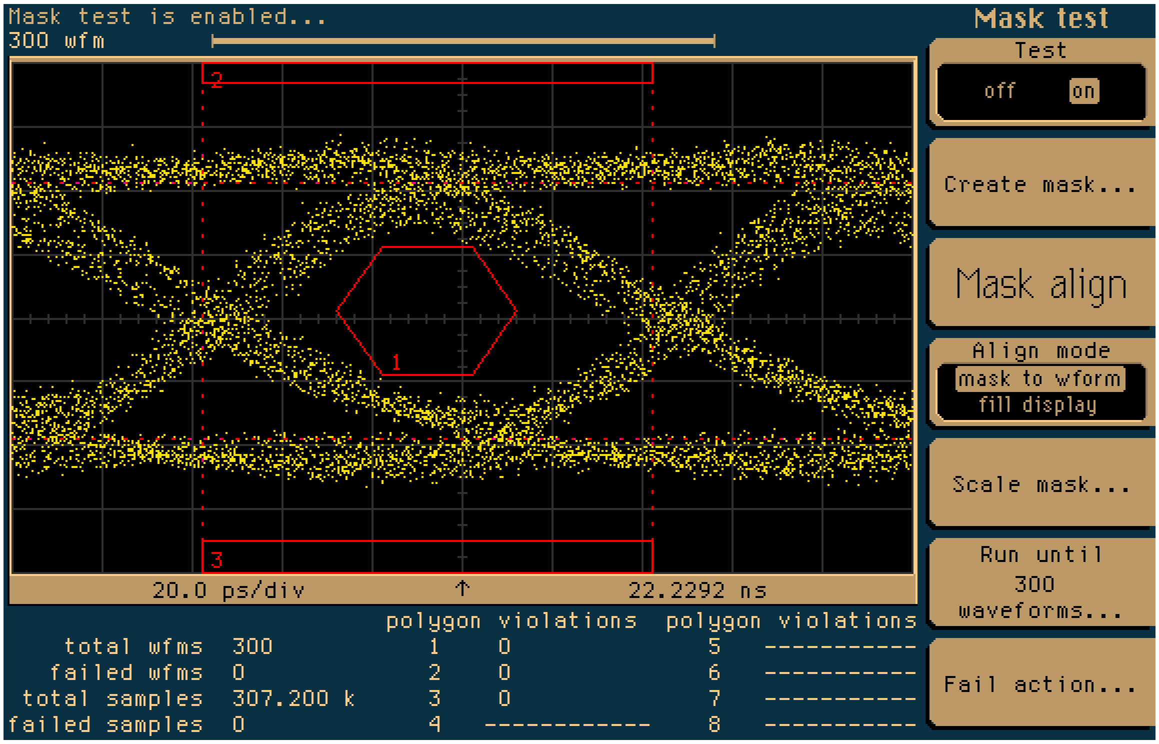
Contents

1. Description of experiment

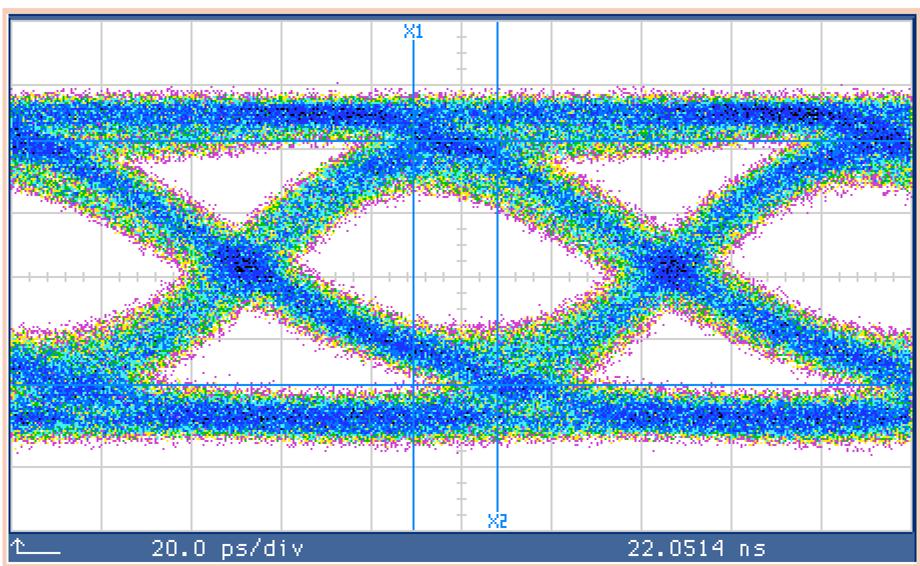
10GBASE-LR style electro-optics with laser driver, connected to standard test equipment and CDR.
Two samples to different build standards
Tested over 10 to 50 km SMF under lab conditions at room temperature
Measurements of powers and losses and nominal sensitivity
Eye measurement
Jitter bathtub measurements, subject to large calibration error
Stressed eye test not used

2. Measured results: High Tx power, 50 km

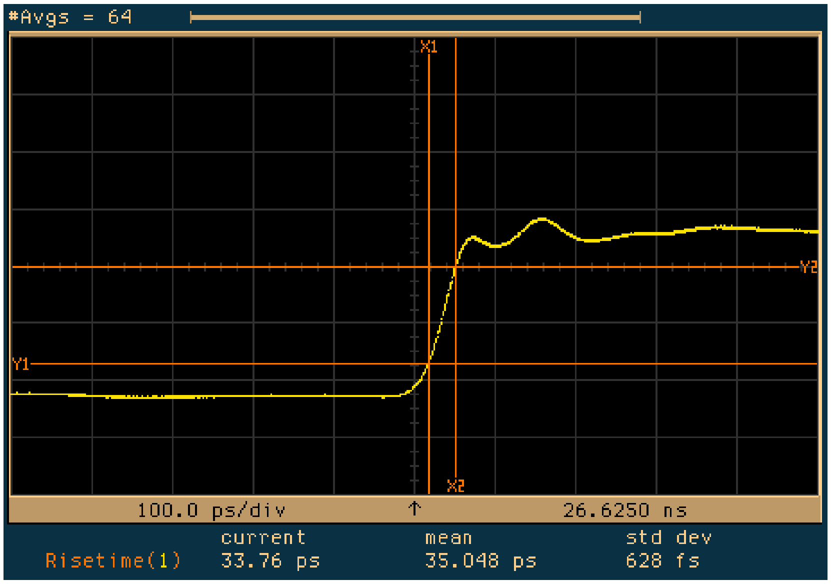
Case 50 km, measured						
Specification	**Sample 1 Value**	**Sample 2 Value**	**Units**	**Derivation**	**802.3ae D3.2 com-pliant?**	**Notes**
Signaling Speed	10.3125	10.3125	GBd	Set	Yes	
Laser Wavelength	1302.3	1302.2	nm	Measured	Yes	+/- 0.5 nm accuracy
RMS spectral width	0.06	0.06	nm	Estimated	Yes	From similar parts
SMSR	46.8	43.6	dB	Measured	Yes	
Launch Power (OMA)	5.24	4.37	dBm	Calculated	No	
Launch Power (mean)	5.2	3.5	dBm	Measured	No	The extra power is needed to compensate the attenuator losses for the BER measurement
Extinction Ratio	4.84	6.2	dB	Measured	Yes	Measured on PRBS at 2.5 GBd
RIN_OMA	-134	-135	dB/Hz	Measured	Yes	No back reflection
Tx rise/fall time, 20%-80%	34.2/ 58.7	34/69	ps			Measured unfiltered on long patterns
Eye margin	<0	<0	%	Measured	No	Fails mask by a few %
VECP of Tx under test (0 km)	~2.5	~2.8	dB	Measured	N/A	1. 2. from eye
DCD	0.015	0	UI	Measured	Yes	from scope eye at TP2
TJ	<=0.70	<=0.72	UI	Measured	No	at TP2
DJ	<=0.30	<=0.13	UI	Measured	Marginal	at TP2
SigmaRJ	0.028	0.045	UI	Measured	No	at TP2 2^31 PRBS
Fiber length	50.32	50	km	*Meas/Vendor*	Yes	
Fiber attenuation	0.327	0.33	dB/km	Vendor	Yes	At 1310 nm
Fibre dispersion minimum	1309	?	nm	Measured	Yes	
Connector loss	0.8	0.8	dB	1.Measured 2.Estimated	Yes	Not very accurate
BER	<1e-12	<1e-12		Measured	Yes	Without attenuator
Nominal Rx sensitivity (OMA)	-15.8	-15.6	dBm	Measured	Yes	
Receive electrical 3dB upper cutoff frequency	8.5	8.5	GHz	Estimated	Yes	
Rx overload	2.5	not known	dBm	Measured	Yes	Mean power at high extinction ratio
Rx reflectance	low	low	dB	Estimated	Yes	



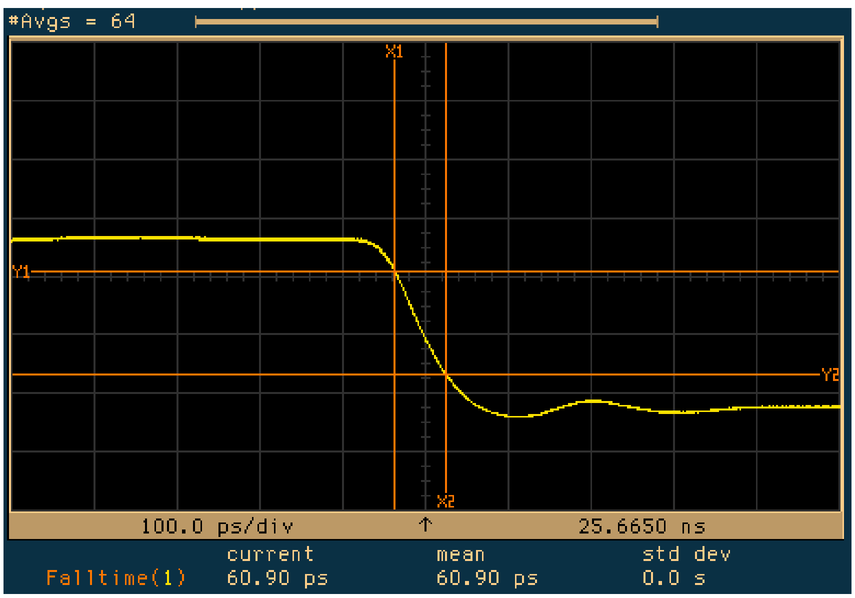
Sample 1 eye



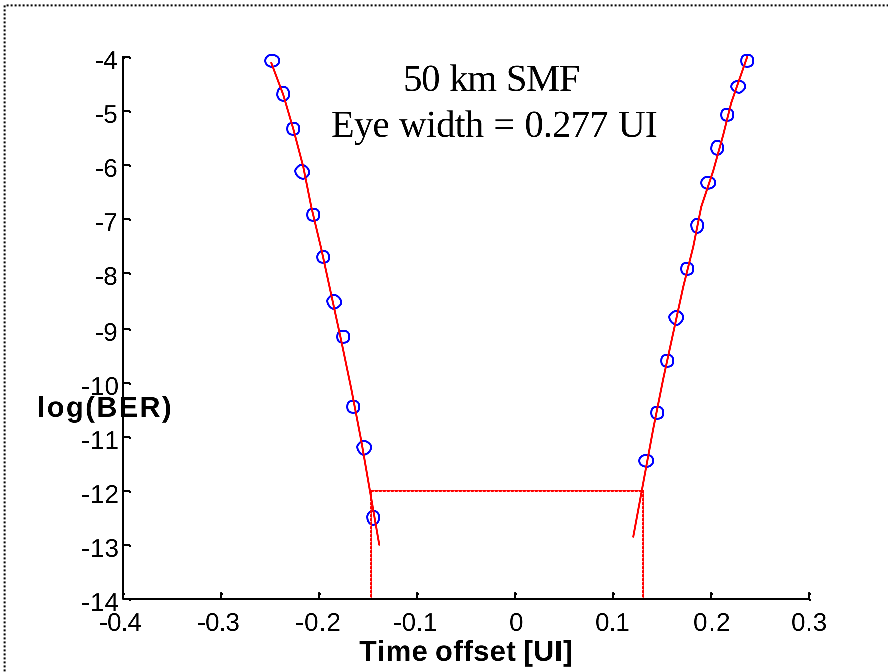
Sample 2 eye



Sample 1 rise time

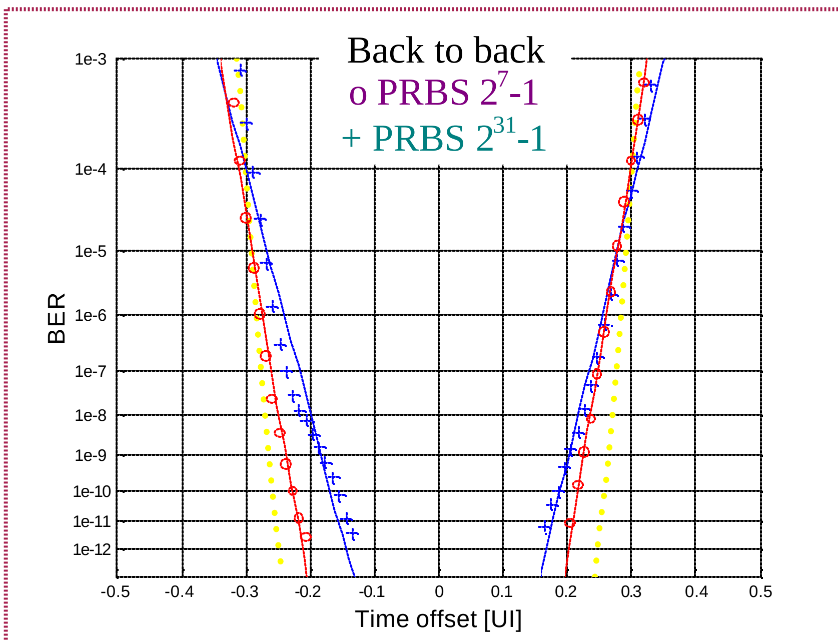


Sample 1 fall time

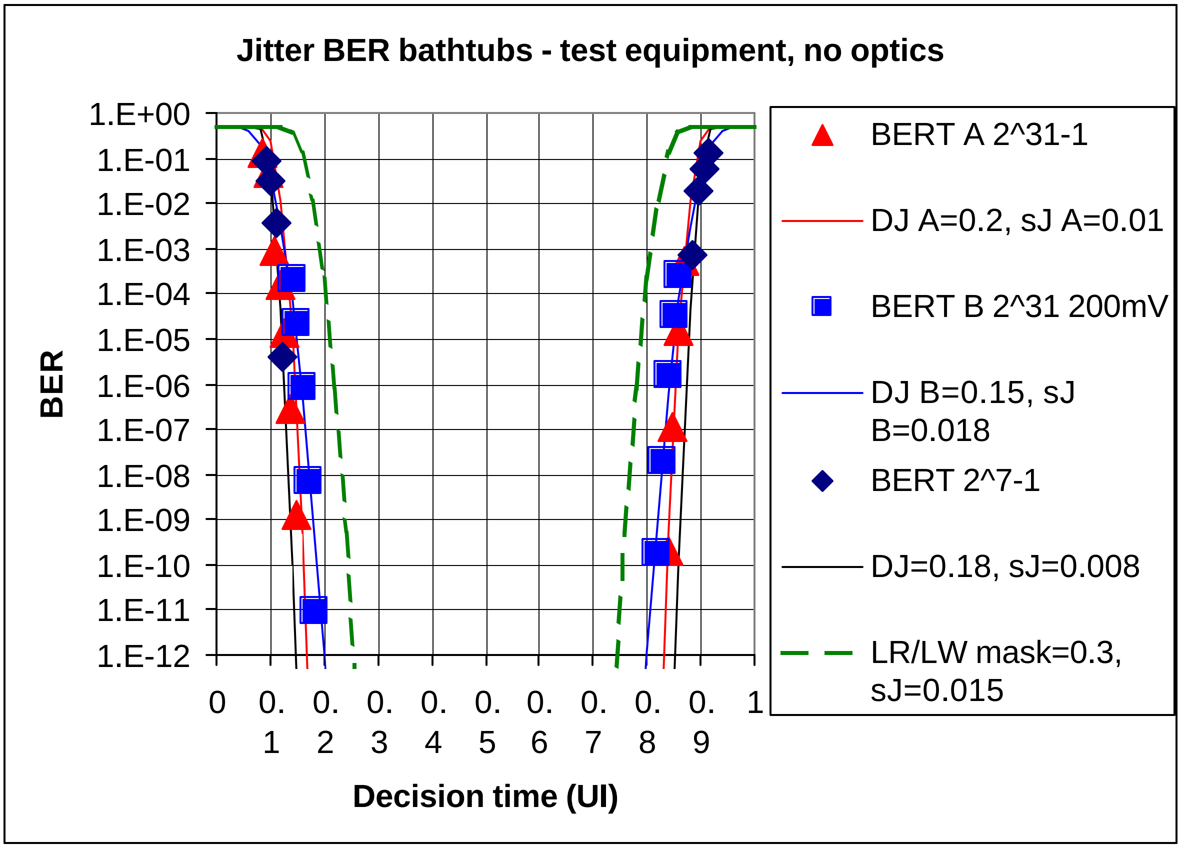


Sample 1 jitter bathtub after 50 km SMF

The instrument jitter was not known but is very significant. A very conservative estimate of 3 ps DJ, 0 RJ, was used for the budget calculations below.



Sample 2 jitter bathtub, back to back



This diagram shows the significance of the instrument jitter: up to 0.2 UI of DJ can come from the instruments while the target spec is 0.3 UI. Correction by calibration or deconvolution is not straightforward.

3. Predicted results for minimum Tx power, worst 10 km losses

In the previous section the transmitted power was higher than the draft standard allows. In the table below the previous results have been adjusted for to the *minimum* allowed transmitted OMA, and highest allowed link losses for a 10 km link.

Case 10 km worst, inferred						
Specification	**Sample 1 Value**	**Sample 2 Value**	**Units**	**Derivation**	**802.3ae D3.2 com-pliant?**	**Notes**
Signaling Speed	10.3125	10.3125	GBd	Set	Yes	
Laser Wavelength	1302.3	1302.2	nm	Measured	Yes	+/- 0.5 nm accuracy
RMS spectral width	0.06	0.06	nm	Estimated	Yes	From similar parts
SMSR	46.8	43.6	dB	Measured	Yes	
Launch Power (OMA)	-3.80	-3.80	dBm	Predicted	Yes	
Launch Power (mean)	-3.84	-4.67	dBm	Predicted	Yes	
Extinction Ratio	4.84	6.2	dB	Measured	Yes	Measured on PRBS at 2.5 GBd
RIN12OMA	-134	-135	dB/Hz	Measured	Yes	No back reflection
Tx rise/fall time, 20%-80%	34.2/ 58.7	34/69	ps			Measured unfiltered on long patterns

Eye margin	<0	<0	%	Measured	No	Fails mask by a few %
VECP of Tx under test (0 km)	~2.5	~2.8	dB	Measured	N/A	
DCD	0.015	0	UI	Measured	Yes	from scope eye at TP2
TJ	<=0.70	<=0.72	UI	Measured	No	at TP2
DJ	<=0.30	<=0.13	UI	Measured	Marginal	at TP2
SigmaRJ	0.028	0.045	UI	Measured	No	at TP2 2^31 PRBS
Fiber length	10	10	km	Predicted	Yes	
Fiber attenuation	0.5	0.5	dB/km	Worst	Yes	At 1310 nm
Fibre dispersion minimum	1309	?	nm	Measured	Yes	
Connector loss	2	2	dB	Worst	Yes	
BER	<1e-12	<1e-12		Measured	Yes	
Nominal Rx sensitivity (OMA)	-15.8	-15.6	dBm	Measured	Yes	
Receive electrical 3dB upper cutoff frequency	8.5	8.5	GHz	Estimated	Yes	
Rx overload	2.5	not known	dBm	Measured	Yes	Mean power at high extinction ratio
Rx reflectance	low	low	dB	Estimated	Yes	

4. Analysis and discussion

The measured parameters were input to 10GEPBud3_1_14.xls and the following figures obtained. To model the eye encroachment seen by measurement, the risetime had to be reduced by ~4 ps.

Case 50 km, measured	Sample 1		Sample 2		Budget analysis
Available budget:	21.04		19.97		dB
Cable attenuation:	16.47		16.5		dB
Connector Loss:	0.8		0.8		dB
Penalties:-					
Pisi: (= VECP)		2.54		2.86	dB
Pdj:		0.17		0.1	dB
Preflection:		0.02		0.02	dB
Prin:		0.08		0.07	dB
Pmpn:		0		0	dB
Pcross:		0.18		0.22	dB
Total Penalties:	2.99		3.27		dB
Losses + penalties	20.26		20.57		dB
Margin:	0.78		-0.60		dB

However, even in the case of the negative calculated margin, a positive margin was measured.

Case 10 km worst, inferred		Sample 1	Sample 2		Budget analysis
Available budget:	12.00		11.80		dB
Cable attenuation:	5		5		dB
Connector Loss:	2		2		dB
Penalties:-					
Pisi: (= VECP)		2.54		2.86	dB
Pdj:		0.17		0.1	dB
Preflection:		0.02		0.02	dB
Prin:		0.08		0.07	dB
Pmpn:		0		0	dB
Pcross:		0.18		0.22	dB
Total Penalties:	2.99		3.27		dB
Losses + penalties	9.99		10.27		dB
Margin:	2.01		1.53		dB

In both cases some margin remains. The dispersion penalty is small so the analysis as a loss limited system is valid.

A robust link can be built, even with transmit eyes which fail the draft standard, and jitte which appears to fail the draft standard.

Operation over multiple vendor links
Between Company A and Company B

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Operation over multiple vendor links
Between Company A and Company B

Test Plan

Our test plan consisted of three steps:

Step 1. Determine link parameters. Three sets of link parameters were collected – two sets of PMD specifications measured by the two vendors as part of compliance tests conducted earlier, and one set of channel insertion loss parameters (fiber attenuation and connector loss) that both vendors agreed to use as a common test platform.

Step 2. Determine test distance. This value should be preferably equal to or greater than 10 kilometers.

Step 3. Measure BER at the test distance. A proposed definition of successful multi-vendor link testing was the achievement of a BER of less than 10^-12 at the test distance.

Step 1. Determine link parameters

Both vendors supplied their respective measured PMD parameters. Details are provided in earlier sections of this document.

The following channel insertion loss parameters were used. These were measured values.

Table 1: Attenuation and connector loss

Description	Value	Unit
Fiber attenuation	0.31	dB/km
Connector loss	1.8	dB

Step 2: Determine test distance

While the requirement was to demonstrate satisfactory performance at 10 kilometers, the two vendors felt comfortable that operation over 15 kilometers can be demonstrated, based on the examination and comparison of individual PMD specifications.

Step 3. Measure BER at the test distance

A 15-kilometer link was set up (demonstration at even longer distances was possible but considered unnecessary). The PMD units were driven with 2^23-1 PRBS pattern, per the agreement between coordinators of various PMD groups in a recent teleconference. The test setup is shown in Figure 1. The results are listed in Table 2. The Test Motherboard is essentially an SMA-to-300-pin converter, with additional circuits for power supply and status LEDs.

Figure 1: Test Setup

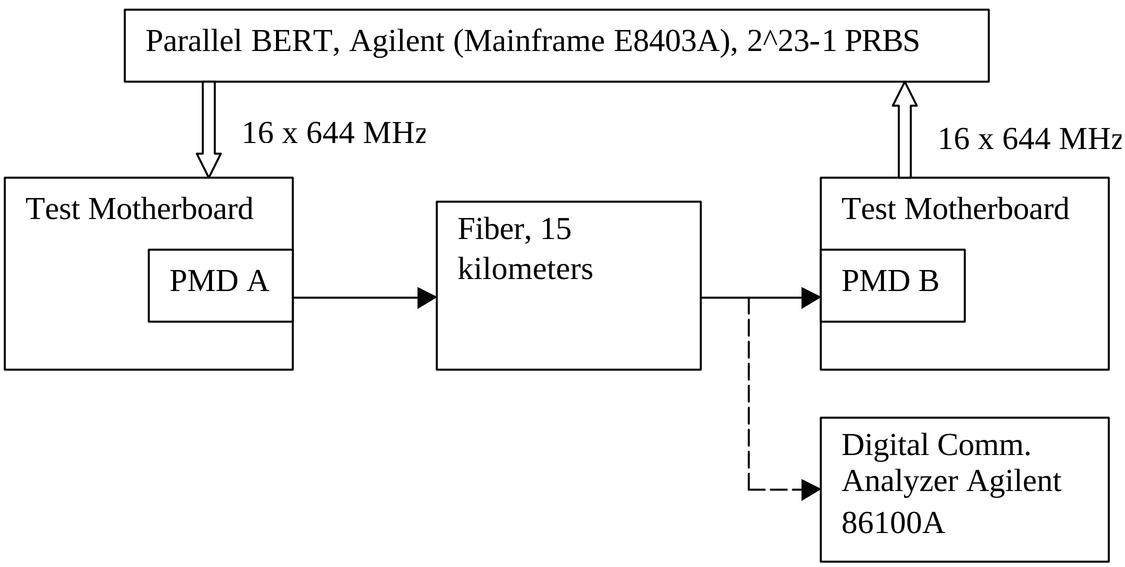

Table 2: Measured error rates

Transmitter	Receiver	Optical power at TP2, OMA, dBm	Optical power at TP3, OMA, dBm	Link length, kilometers	Measured BER
A	B	-1	-7.45	15	<10^-12
B	A	+1	-5.45	15	<10^-12

Conclusion

A 15 kilometer long fiber optic link consisting of a PMD from vendor A at one end and a PMD from vendor B at the other end was able to successfully support a BER of less than 10^-12.

Concluding Remarks

This document has described the contribution by some members of the 1310 Serial PMD Feasibility group. These contributions include measurements of the degree of compliance of each vendor's PMD to 802.3ae Draft 3.2, and the degree of successful operation of multi-vendor links.

Two conclusions can be drawn.

1. Participation is less than expected.
2. The PMD units tested so far have exhibited a high degree of compliance to specifications and successful operation of inter-vendor links.