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Multivendor Feasibility Trials of 1550nm 40km 10GbE PMD using an EA Transmitter and PIN Receiver

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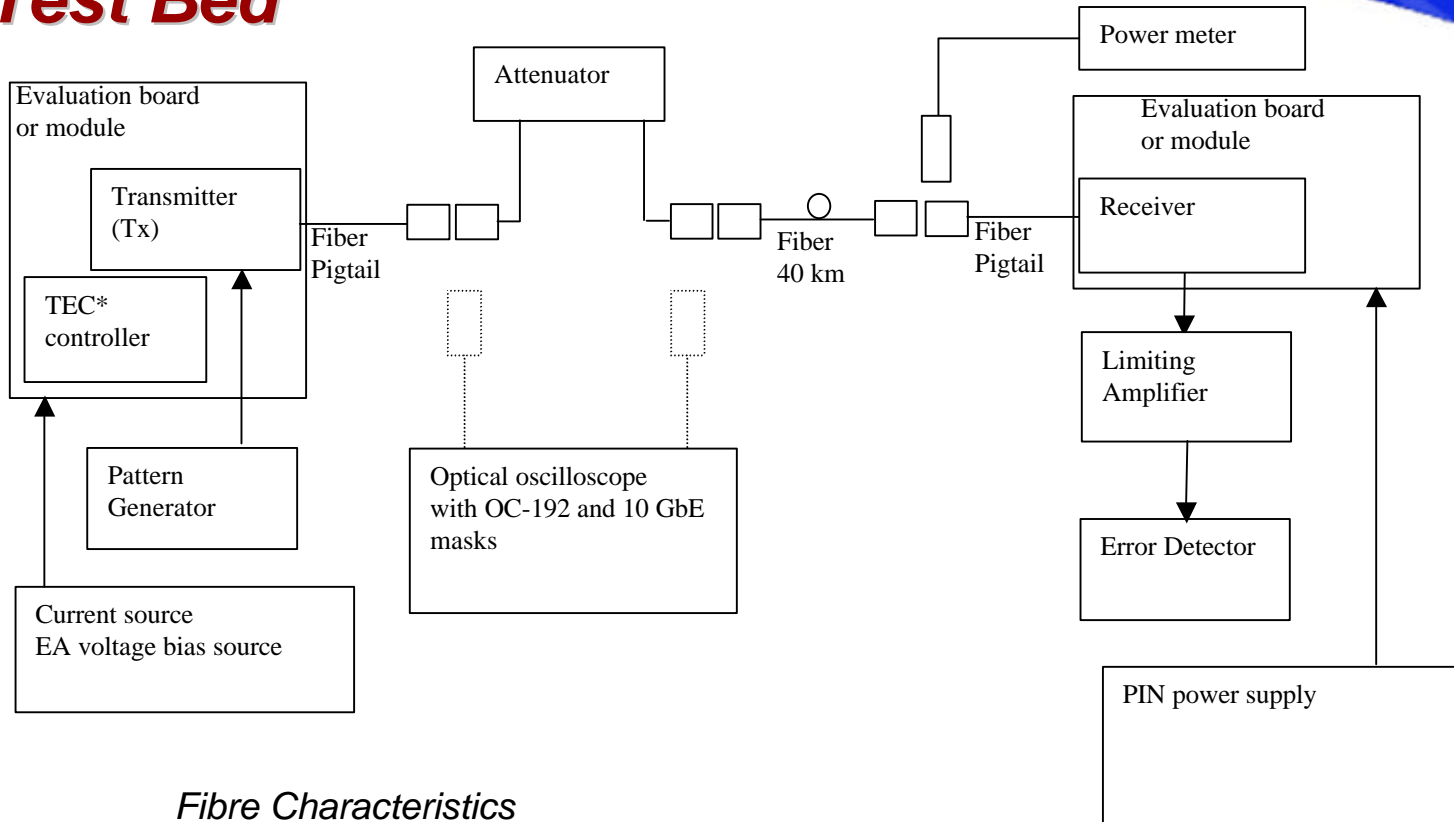
Robert Zona, Steve Buchheit

Intel

Objective

- **To independently confirm, experimentally, the feasibility of a 40km 1550nm PMD using multiple vendor's devices meeting the requirements of IEEE 802.3ae clause 52.**
- **To recommend changes to the 1550nm PMD specification as a result of experimental data and show a credible path to compliance.**

Test Bed



Fibre Characteristics

	Length	Loss	Dispersion
Nortel	40.9km	8.4dB	731 pS/nm
Lucent	38.4km	8.9dB	659 pS/nm
Intel	50km	11.8dB	876 pS/nm

* TEC: Thermoelectric Cooler

- BER Measurements at room temperature only.
- No stressed receiver testing
- No jitter testing

40km Chromatic Dispersion Stress

50km fibre is a valid 40km stress test for dispersion

SMF dispersion coefficient, for G652 compliance, is given by:

$$D(\lambda) = \frac{S_{0\max}}{4} \left[\lambda - \frac{\lambda_0^4}{\lambda^3} \right]$$

where $S_{0\max} = -0.093\text{pS}/(\text{nm}^2.\text{km})$

and $\lambda_0 = 1300$ to 1324 nm

For operation over 1530 – 1565nm the worst case dispersion is 762 pS/nm

With 1530nm Tx and 1324nm zero dispersion wavelength we get 762 pS/nm at 48.8Km length

HENCE

Any wavelength compliant Tx tested over 50km of ITU G652 compliant SMF will be operating beyond the maximum dispersion for 40km of any other compliant transmitter and fibre.

i.e 50km fibre is a valid 40km stress test for dispersion

Results – 10^{-12} BER Dispersion Penalty over SMF @ 1550nm

Extinction Ratio	Intel 50km	Lucent 38km	Nortel 40km
4dB		0.2 dB	
6dB	3.3 dB	0.0 dB	3.5 dB
8.2 dB	2.4 dB	0.0 dB	2.2 dB
10 dB			1.0 dB
11 dB			0.6 dB*
12dB	2.0 dB		

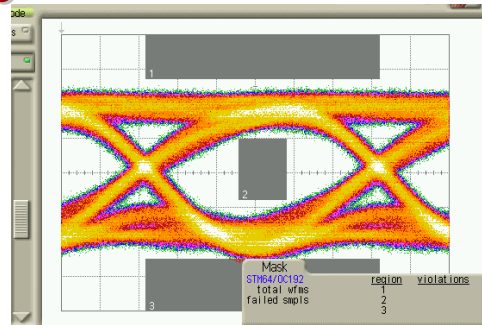
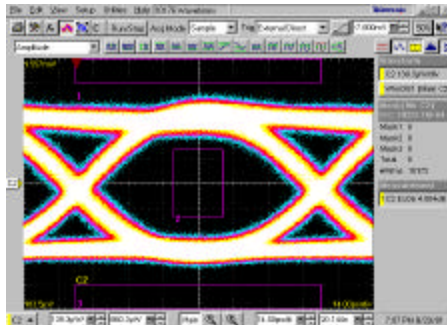
1 device tested by each vendor

**Worst dispersion penalty of 12 devices tested 1541-1556 nm
same devices tested over 75km had DP<2dB*

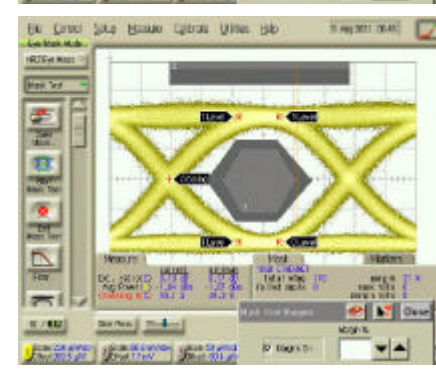
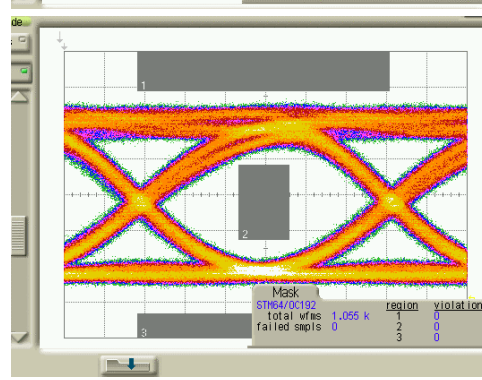
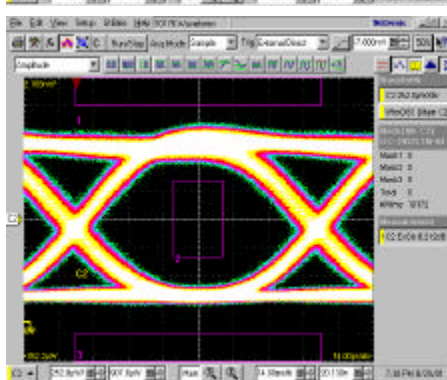
All vendors demonstrated 40km dispersion penalty 2dB or lower at high Extinction Ratio

Results – Tx Eye

4dB
Extinction
Ratio



8.2dB
Extinction
Ratio

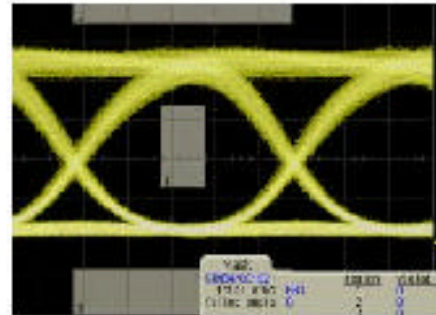
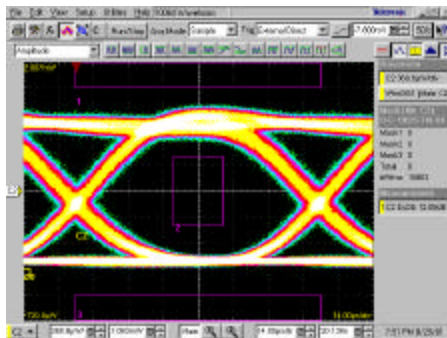


INTEL

LUCENT

NORTEL

12 dB
Extinction
Ratio



11 dB
Extinction
Ratio

- All vendors Mask Compliant with OC192 & IEEE 802.3ae mask
- Typical Eye closure penalty < 1dB at high extinction ratio

3dB TDP Penalty is feasible

Results - Transmit Power/OMA-DP

OMA-TDP > -1.39dBm as per draft 3.2 spec is feasible

Mean Power

	Nortel	Lucent	Intel
4 dB ER	-1 dBm	+0.1 dBm	+0.6 dBm
6 dB ER	-1 dBm	-0.55 dBm	+0.6 dBm
8.2dB ER	-1 dBm	-1.1 dBm	+0.7 dBm
10 dB ER	-1 dBm		
12 dB ER			+1.0 dBm

With assumed transmitter penalty of ~1dB
OMA-TDP > -1.39dBm achieved at high
Extinction ratio only.

$$\text{OMA-TDP} = 2P_{\text{mean}} \frac{1 - \frac{1}{\text{ER}}}{1 + \frac{1}{\text{ER}}} - \text{DP} - 1\text{dB}$$

OMA-TDP (Draft 3.2 spec OMA-TDP > -1.39 dBm)
Typical Tx penalty estimated as 1dB from eye plots

	Nortel	Lucent	Intel
4 dB ER		-1.7 dBm	
6 dB ER	-4.7 dBm	-0.8 dBm	-2.9 dBm
8.2dB ER	-2.5 dBm	-0.4 dBm	-1.0 dBm
10 dB ER	-0.9 dBm		
11 dB ER	-0.3 dBm		
12 dB ER			+0.5 dBm

All vendors demonstrated min Tx power of -1 dBm mean & OMA-TDP > -1.39dBm at high extinction ratio.

Results - Receive Sensitivity/OMA at 0km Fibre

-15.4 dBm Receiver OMA required by draft 3.2 is not feasible

IEEE 802.3ae draft 3.2
Requires Rx OMA of -15.4 dBm
And stressed OMA of -11.4 dBm

$$\text{Sens_dB}(\infty) = \text{Sens_dB}(\text{ER}) + 10 \log\left(\frac{1 + \frac{1}{\text{ER}}}{1 - \frac{1}{\text{ER}}}\right)$$

Sens_dB(∞) - 1dB

for ideal Tx (inf extinction 100% open eye)

$\infty - +$

	Nortel	Lucent	Intel
4dB ER	-13.5 dBm	-12.4 dBm	-12.8 dBm
6 dB ER	-14.7 dBm	-14.4 dBm	-14.5 dBm
8.2 dB ER		-15.8 dBm	-15.3 dBm
10 dB ER	-15.7 dBm		
12 dB ER			-16.4 dBm
Infinite ER (calc)*	-16.6dBm	-17.1 dBm	-16.9 dBm
Ideal Tx	-17.6 dBm	-18.1 dBm	-17.9 dBm
Estimated			
Estimated OMA	-14.6 dBm	-15.1 dBm	-14.9 dBm

Average Power
For 1E-12
BER

All vendors demonstrated min Rx sensitivity of -15.3 dBm at high extinction ratio (or OMA of <-14.6 dBm i.e negative margin against draft 3.2 OMA spec BEFORE manufacturing, age and temperature effects)

Results – System Margin at 10^{-12} BER

13 dB Path loss not feasible with acceptable margin

Margin against measured
40km cable loss
OMA-TDP – Rx OMA – cable loss

Margin against –11dB spec path loss
(as per Telcordia GR253 OC192 IR-2)
OMA-TDP – Rx OMA – 11dB

Margin against 13dB spec path loss
(as per IEEE 802.3ae draft 3.1)
OMA-TDP – Rx OMA – 13dB

	Nortel	Lucent	Intel *
4dB ER		4.5 dB	-
6 dB ER	1.5 dB	5.5 dB	2.6 dB
8.2 dB ER	3.7 dB	5.8 dB	4.5 dB
10 dB ER	5.3 dB		
11 dB ER	5.9 dB		
12 dB ER			6.0 dB

	Nortel	Lucent	Intel
4dB ER		2.4 dB	
6 dB ER	-1.1 dB	3.4 dB	1.0 dB
8.2 dB ER	1.1 dB	3.7 dB	2.9 dB
10 dB ER	2.7 dB		
11 dB ER	3.3 dB		
12 dB ER			4.4 dB

	Nortel	Lucent	Intel
4dB ER		0.4 dB	
6 dB ER	-3.1 dB	1.4 dB	
8.2 dB ER	-0.9 dB	1.7 dB	0.9dB
10 dB ER	0.7 dB		
11 dB ER	1.3 dB		
12 dB ER			2.4dB

* Corrected for 40km attenuation

- All vendors demonstrated high Extinction ratio lab operation over 40km of SMF & >2.7 dB margin for 11 dB path
- Insufficient margin to reach 13 dB path loss with confidence
- High Extinction Ratio essential to maintain margin at 11dB path loss

Vendor Interoperability Test

- **Interoperability successfully achieved**
 - >40 km of SMF fiber (41.2km, 8.2dB loss)
 - 10⁻¹² BER Rx Sensitivity
 - Intel - Nortel at LAN rate
 - Lucent - Nortel at WAN rate
- **Dispersion penalty < 2 dB verified**
- **Average receive power minimum < -14 dBm verified**
- **>3.5dB margin against -1dBm Tx & 11dB path loss specification**

Dispersion Penalties

Extinction Ratio	Intel Tx Nortel Rx	Lucent Tx Nortel Rx	Nortel Tx Intel Rx	Nortel Tx Lucent Rx
8.2 dB		2.0 dB	0.8 dB	0.0 dB
12.1 dB	1.9 dB			

Margin against -1dBm Tx and 11dB insertion loss

Extinction Ratio	Intel Tx Nortel Rx	Lucent Tx Nortel Rx	Nortel Tx Intel Rx	Nortel Tx Lucent Rx
8.2 dB		3.5 dB	3.7 dB	6.0 dB
12.1 dB	4.3 dB			

Conclusions

- **-1 dBm Tx powers with compliant eye mask demonstrated**
 - **Typical eye closure <1dB at eye centre**
- **<2dB Path penalty over 40km SMF demonstrated**
 - **1dB eye closure + 2dB dispersion penalty = 3dB TDP confirmed**
- **<-14 dBm average power 10^{-12} BER Rx sensitivity demonstrated**
 - **-15.4 dBm OMA as per draft 3.2 is not feasible**
- **13 dB path budget not achieved with sufficient margin**
 - **13dB path loss could be achieved with higher cost APD solution**
- **11dB path loss and 'real' 40km fibres demonstrated with margin**
 - **High extinction ratio needed to avoid excessive path penalties**
- **3 party Multivendor Interoperability to 11dB path loss demonstrated**

Path To Clause 52 Compliance

- *Modify PMD target to 11dB path loss*
- *Revise specification based upon demonstrated performance:*

Signalling speed	9.95328	10.3125	GBd
wavelength	1530-1565	1530-1565	nm
Average launch power min	-1	-1	dBm
Extinction Ratio min	8.2	8.2	dB
Dispersion penalty max	2.0	2.0	dB
Average receive power max*	-1	-1	dBm
Average receive power min	-14	-14	dBm

- *Review stressed receiver and jitter budgets*
- *Review OMA vs. Extinction ratio specification method*
- * - *Based upon 1550nm with ~0.9 amps/watt PIN diode responsivity.*