40GbE 10km SMF Serial Proposal

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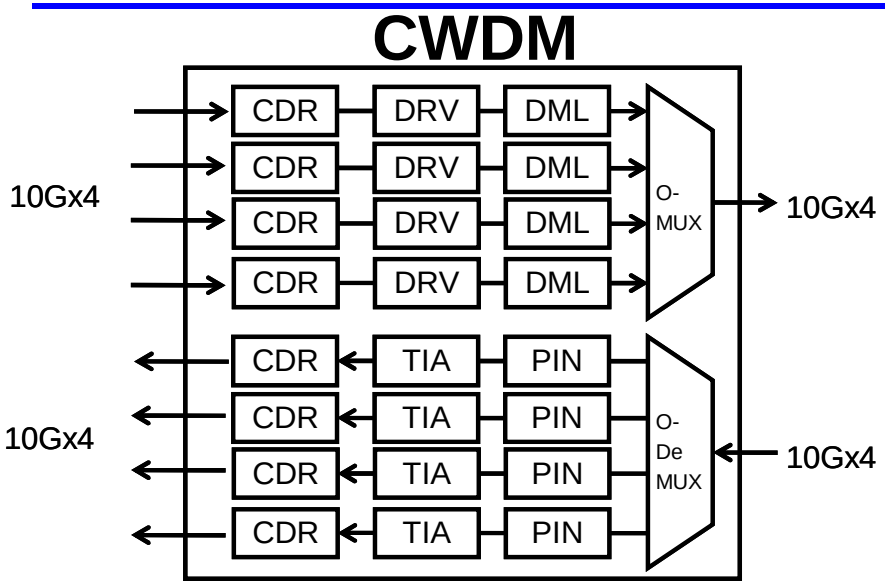
Introduction

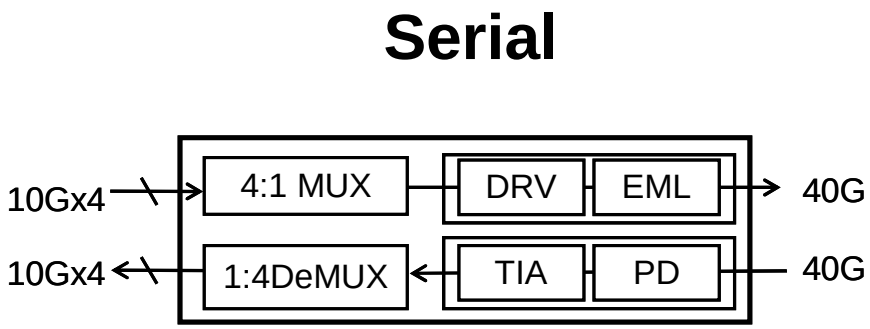
- 40GbE over 10km of SMF was adopted as an Objective to address servers, datacenters and access interconnection (*barbieri_01_0308, simsarian_01_0308*)

- Two options have been discussed
  - 40GbE 10km CWDM 4x10G (*cole_03_0308*)
  - 40GbE 10km Serial (*traverso_04_0308*)

- This proposal addresses the merits of Serial 40GbE
  - Equal or less power than CWDM both near-term and long-term
  - Stimulates new IC and optics development resulting in a cost advantage over CWDM modules when 40GE volume becomes significant (2011)
  - **Compatibility with OTN client side 40G modules**

Comparison of CWDM and Serial Features





Elements	CWDM	Serial
LD	4X10G 1.31µm Uncooled DML	40G 1.31µm Cooled EML
PD	4 X (10G PIN + TIA)	40G PIN + TIA
Electr. IF	MLD / XLAUI	MLD / XLAUI
Electrical	4x CDR (Bidirectional)	4:1 MUX /DMUX/CDR
O-MUX	CWDM MUX/DMUX (Zig-zag)	None
OTN compatibility	NO	YES

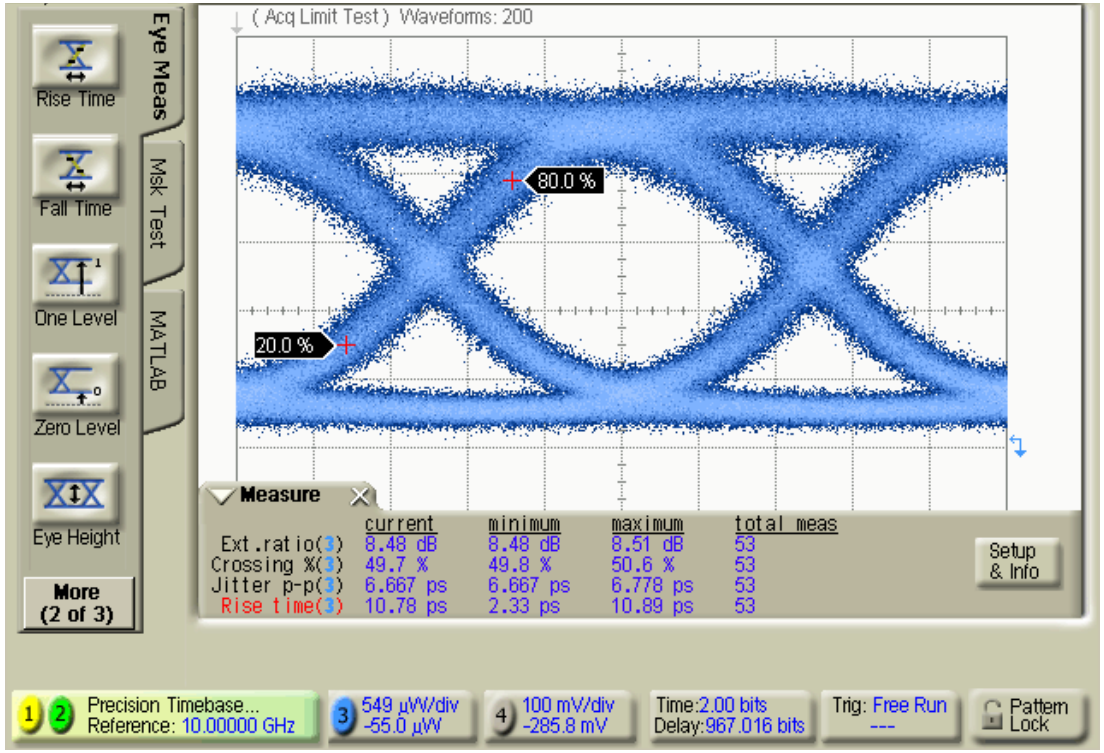
Technical Feasibility
40GbE Serial

- The Serial 40GbE PMD is feasible for a 10km link with 1310nm EML
- EML and PIN/TIA are in modest-volume production for 40G VSR today
  - **Low cost 40G EML and PIN/TIA to be available in 2008**
  - **Low cost TOSA/ROSA package to be available in 2009 / 2010**
- 40G (16:1) MUX/DMUX in SiGe has been shipping since 2004
  - **With simplified (4:1) for 40GbE, MUX/DMUX power can be reduced to 2.0W (SiGe) in 2009 and less than 1.5W (CMOS) in 2010 /2011**
- History has shown that electrical mux'ing is more reliable and simpler to manufacture than multi-channel implementations using optical mux'ing
  - **Produces better system end to end performance**

Technical Feasibility
40GbE 1310nm EML

Performance of 1310nm 40G EML is confirmed.
1310nm EML is ready for 40G serial application.

EML output waveform



40Gps
Lambda: 1310nm
Pf: +1.1dBm(Avg.)
ER: 8.8dB
Lambda: 1310nm

Industry trends supporting serial 40G

- **ITU-T SG15 WP2 Q6/15**
  Feb 2008 Meeting, new application code (1.3um 40G, 10km/20km/40km) was added in the previous 1.5um application in G959.1, which is enhanced to serial solution.

- **XLMD 40G TOSA/ROSA (www.xlmdmsa.org)**
  XLMD supports 40G TOSA/ROSA optical interface basically specified in ITU-T G959.1/others and it is under development, which is enhanced to serial solution. XLMD consists of Eudyna, Mitsubishi, NEC, Oki, Opnext, and Sumitomo.

- **1:4 MUX/DEMUX CMOS development**
  The industry is under development and it will be realized *at the latest* within a year, which is enhanced to serial solution.
  - **N.Nedovic, et al., D12-2, ISSCC2007, Fujitsu Laboratories of America (40G CDR)**
  - **T. Toifl, et al., D12-3, ISSCC2007, IBM (40G CDR in 65nm SOI CMOS)**
  - **C.Liao, et al., 5-2, ISSCC2008, National Taiwan University (40G Serial Receiver w/ EQL & CDR)**

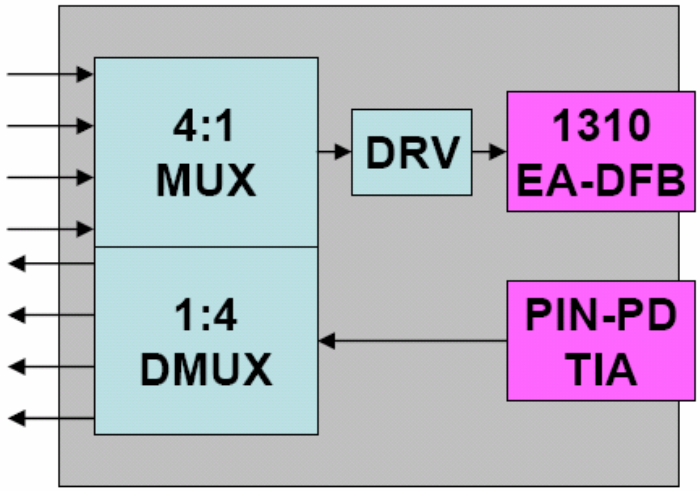
40GbE serial link budget

Link Power Budget and Penalties

Description	1	2
Operating Distance (m)	10000	10000
Fiber Modal BW (MHz-km)	1000000	1000000
Wavelength Range (nm)	1307-1317	307-1317
Link Power Budget (dB)	9.00	9.00
Channel Insertion Loss (dB)	6.21	6.17
Link Power Penalties (dB)	1.60	1.60
Dispersion Penalty (dB)	1.00	1.00
Unallocated Margin (dB)	0.19	0.23
Pisi (dB)	0.94	0.94

Link Budget 9.0dB

1.0dB above spreadsheet calculations



Transmit Characteristics

Description		
Signal Speed (Gbaud)	41.2500	41.2500
Wavelength (nm)	1307	1317
Trise / Tfall (20%-80%) (ps)	9.0	9.0
Max RMS Spectral Width (nm)	0.01	0.01
Max Avg Launch Power (dBm)	4.0	4.0
Min Avg Launch Power (dBm)	0.88	0.88
Min Optical Mod. Amp. (mW)	1.779	1.779
OMA ((dBm)	2.50	2.50
Min Extinction Ratio (dB)	8.0	8.0
Max RIN (dB/Hz)	-132	-132
Min Disp Wavelength (nm)	1324	1300

avoids double counting with dispersion penalty

Basics	Input=	**Bold**		Ts(20-80)	**9** ps
	Q=	**7.04**		Ts(10-90)	14 ps
	Base Rate=	**41250**	MBd	RIN(OMA)	**-132** dB/Hz
Transmitter				RIN at MinER	-134.8 dB/Hz
	Wavelength Uc	**1307**	nm	RIN_Coef=	**0.70**
	Uw (see notes)	**0.01**	nm	Det.Jitter	**1.0** ps inc.
	Tx pwr OMA=	**2.502**	dBm	DCD_DJ=	**1** ps TP3
	Min. Ext Ratio=	8.00	dB	Effect. DJ=	0.00 (UI) ex
	"Worst"ave.TxPwr	**0.88**	dBm	MPN k(OMA)	**0**
	Ext. ratio penalty	1.39	dBo	Tx eye height	67.1%

Receive Characteristics

Description		
Signal Speed (Gbaud)	41.2500	41.2500
Wavelength Range (nm)	1290-1565	290-1565
Rx Bandwidth (MHz)	30,938	30,938
Receive Sensitivity (dBm)	-5.1117	-5.1117
Min Optical Mod. Amp. (mW)	0.2239	0.2239
Min Optical Mod. Amp. (dBm)	-6.50	-6.50

Rx sensitivity (OMA) -6.5dB → PIN

40GbE CWDM vs. Serial Power Comparison

40G 10km CWDM	Y2009* Power (W)	Y2011** Power (W)	40G 10km Serial	Y2009 Power (W)	Y2011 Power (W)
DML TOSA/Mux	0	0	**EML TOSA TEC + Laser Bias**	1.5	1.0
4X DML Driver	2.1	1.7	EML Driver	0.8	0.6
XFI CDR	1.8	1.0	**4:1 / 1:4 MUX/DMUX/CDR**	2.0†	1.5††
4X PIN/TIA ROSA	0.7	0.5	PIN/TIA	0.4	0.3
Other	0.4	0.4		0.1	0.1
Total Power	5.0	3.6	-	4.8	3.5
Ratio to CWDM	1	1	-	0.96	0.97

* Intermediate between “Now” and “2010” values from Tsumura’s presentation to the 40GbE SMF Ad-hoc

** Slightly reduced from the “2010” values from Tsumura - 40GbE SMF Ad-hoc

† SiGe

†† CMOS

Economic Feasibility

- **Known cost factors, reliable data**
- **Reasonable cost for performance**
- **Consideration of installation costs**

- Optical vendors generally agree that serial optics are the most cost effective in long term.
- Three optics vendors agree that cost cross-over (relative to CWDM) occurs in 2011 (If serial 40GbE is adopted in 802.3ba)
- The dominant costs for today's 40G SONET Serdes and driver are in the packaging. With relaxed spec's and the availability of lower-cost packaging, 40GbE cost will be far lower than 40G SONET at the outset.
- LX4 was never cost effective for SMF application; it was only effective for legacy MMF prior to lower-cost EDC availability.
- CWDM product development (by PMD vendors) and qualification (by systems vendors) would incur significant costs with an only short-lived cost advantage.

40GbE CWDM vs. serial Cost Comparison

4X10G 10km CWDM	Cost Factor	40G 10km Serial	YR 2009 Cost Factor	YR 2011 Cost Factor
4X DML TOSA + Optical MUX	1	**EML TOSA TEC + Laser Bias**	2-3x*	1x
4x DML Driver	1	EML Driver	4x	<1x
Quad XFI CDR	1	**4:1 / 1:4 MUX/DMUX/CDR**	3x	2x
4X PIN/TIA ROSA + Optical DMUX	1	PIN/TIA	4x*	1x
Total Cost	1	-	2.8x*	1x

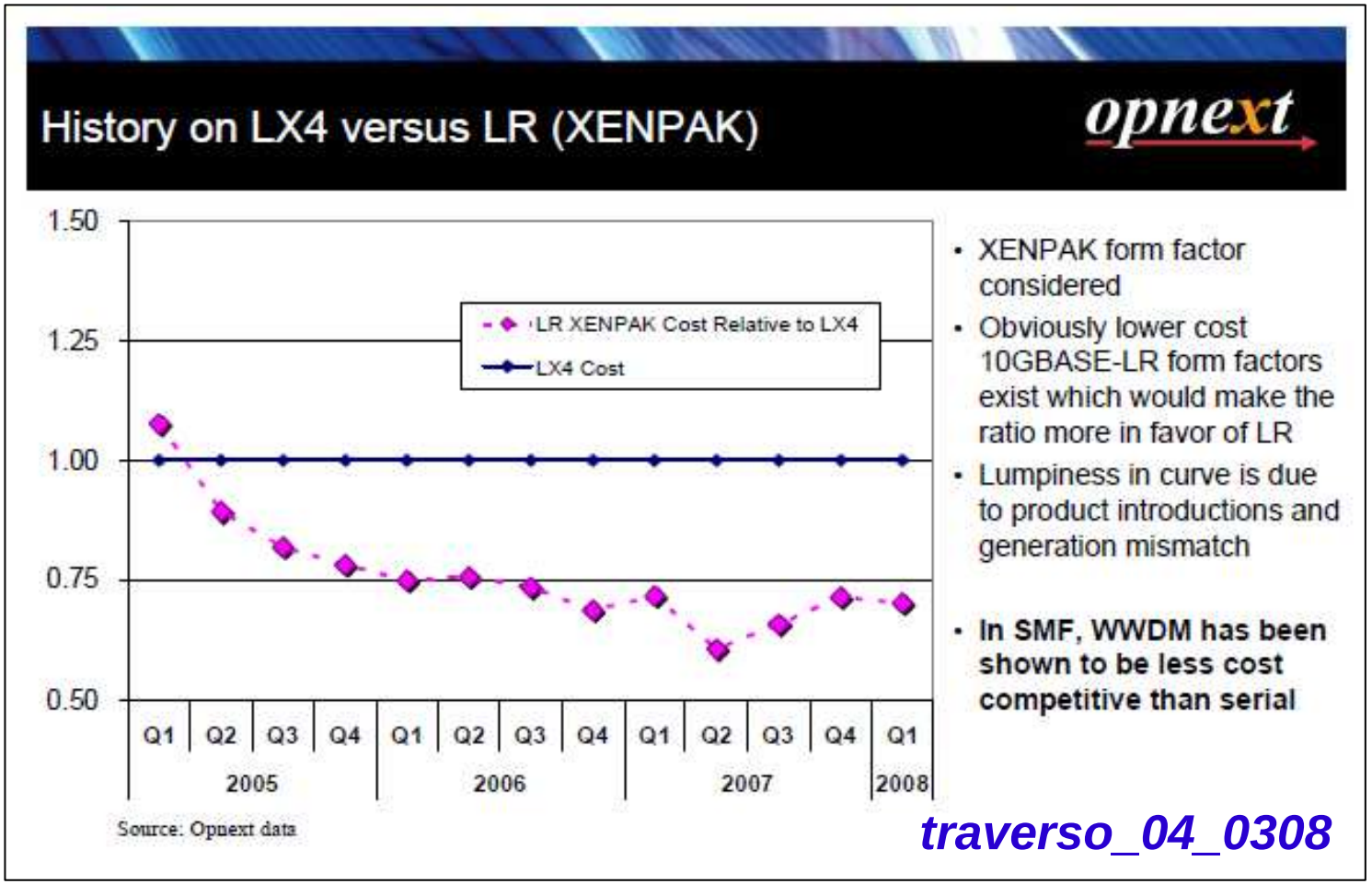
*Today's 40G component cost is dominated by the package, low yield due to older process technology, and modest-volume production,. Also, suppliers are targeting long-haul DWDM specs, which have more challenging specs than Ethernet requires.

With the availability of low cost package, faster process, and higher volume of Ethernet the cost for 40G optics and Serdes will be significantly reduced. Beyond 2011, 40G components will continue to reduce in cost, while CWDM component costs will flatten.

The same trend was evidenced in the10G deployment.

History of LX4 Relative Cost

CWDM solution remains less cost competitive



40GBASE-LR transmit characteristics

Description	40GBASE-LR	Unit
Signaling speed (nominal)	41.25	GBd
Signaling speed variation from nominal (max)	±100	ppm
Center wavelength (range) (1)	1307 - 1317	nm
Side mode suppression ratio (min)	35	dB
Average launch power (max) (1)	+4	dBm
Average launch power (1), (2) (min)	TBD	
Launch Power (min) in OMA minus Tx penalty (1), (3)	2.5	dBm
Optical Modulation Amplitude (4) (min)	TBD	dBm
Tx Penalty (3) (max)	TBD	dB
Average launch power of OFF transmitter (5) (max)	-30	dBm
Extinction ratio (1) (min)	8	dB
$RIN_{12}OMA$ (max)	-132	dB/Hz
Optical Return Loss Tolerance (1) (max)	12	dB
Transmitter Reflectance (6) (max)	-12	dB
Transmitter eye mask definition	TBD	

(1) For further study
(2) Informative
(3) Tx penalty may be TDP, TWDP, and may combine other Tx parameters
(4) Even if Tx penalty <1, the OMA (min) must exceed this value
(5) Examples of an OFF transmitter are: no power supplied to the PMD, laser shutdown for safety conditions.
(6) Transmitter reflectance is defined looking into the transmitter.

40GBASE-LR receive characteristics

Description	40GBASE-LR	Unit
Signaling speed (nominal)	41.25	GBd
Signaling speed variation from nominal (max)	± 100	ppm
Center wavelength (1), (2) (range)	1290 - 1565	nm
Average receiver power (1), (3) (max)	+4	dBm
Average receive power (4), (5) (min)	TBD	dBm
Receiver sensitivity (max) in OMA (1)	-6.5	dBm
Receiver reflectance (max)	-27	dB
Stressed receiver sensitivity in OMA (max)	TBD	dBm
- Vertical eye closure penalty (target)	TBD	dB
- Stressed eye jitter (target)	TBD	UI pk-pk
TP4 jitter allocation	TBD	UI

(1) For further study

(2) For compatibility with OTN

(3) The receiver shall be able to tolerate, without damage, continuous exposure to an optical input signal having a power level equal to the Average Receive Power (max) plus at least 1dB.

(4) Informative

(5) For further study; depends on connector loss

40GBASE-LR link power budget

Parameter	40GBASE-LR	Unit
Power budget *(1)*	9.0	dB
Operating distance	10	km
Channel insertion loss *(1), (2)*	6.2	dB
Allocation for penalties	TBD	dB
Additional insertion loss allowed	TBD	dB

(1) For further study
(2) Connector loss under further study

Summary

- 802.3ba adoption of the 40GbE Serial PMD for 10Km SMF will:
  - Provide OTN compatibility (ITU-T 40G Serial 10Km)
  - Accelerate the development of low cost optics and serdes
  - Bypass a CWDM standard/product development, eliminating:
    - An entire standardization cycle
    - An entire product development cycle
    - An entire product qualification cycle
  - It will do so with:
    - No schedule delay
    - Lower power than CWDM modules
    - Lower cost than CWDM about the time of volume demand
  - Accelerate the deployment of high volume 40Gb Ethernet

Appendix - 40G Serial 10km ITU-T code consented at the February 2008 meeting in Geneva

8-14 – Single-channel IrDI parameters and values for tributary signal class NRZ 40G intra-office applications

Parameter	Units	P1I1-3D1
General information		
Maximum number of channels	-	1
Bit rate/lne coding of optical tributary signals	-	NRZ 40G
Maximum bit error ratio	-	10^{-12}
Fibre type	-	G.652
Interface at point MII-S		
Operating wavelength range	nm	1307 – 1317
Source type	-	SLM
Maximum spectral power density	mW / 10MHz	ffs
Minimum side mode suppression ratio	dB	35
Maximum mean output power	dBm	+4
Minimum mean output power	dBm	0
Minimum extinction ratio	dB	8.2
Eye Mask	-	NRZ 40G
Optical path from point MPI-S to MPI-R		
Maximum attenuation	dB	6
Minimum attenuation	dB	0
Maximum chromatic dispersion at upper wavelength limit	ps/nm	±16
Maximum chromatic dispersion at lower wavelength limit	ps/nm	±16
Minimum optical return los at MPI-S	dB	24
Maximum discrete reflectance between MPI-S and MPI-R	dB	-27
Maximum differential group delay	ps	7.5
Interface at point MPI-R		
Maximum mean input power	dBm	+4
Minimum sensitivity	dBm	-7
Maximum optical path penalty	dB	1
Maximum reflectance of optical network element	dB	-27