400GBase-LR8: A Proposal for 10 km Objective Using 50 Gb/s PAM4 Signaling

Ali Ghiasi – Ghiasi Quantum LLC

IEEE 802.3bs Task Force – Pittsburg

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List of supporters

- Randy Rannow – APIC
- Mat Brown – APM
- Rick Rabinovich - ALE
- Vasu Parthasarathy – Broadcom
- Marco Mazzini – Cisco
- Gary Nicholl - Cisco
- Mike Furlong – Clariphy
- Steve Swanson – Corning
- Xu Yu - Huawei
- Sudeep Bhoja – Inphi
- Vipul Bhatt – Inphi
- Brian Welch – Luxtera
- Winston Way – NeoPhotonics
- Zhigang Gong – O-netcom
- Ken Jackson – SEI
- Ed Ulrich – Source Photonics

Addressing Big Ticketed Items (Page 13)

- Enhancement to Cole_3bs_02_0115.pdf (PAM4)
- Addressing following actions:
  - RX Technical feasibility
    - Next generation TIA deliver the necessary sensitivity
  - Dispersion penalty worst case
    - Measured result up to -32 ps/nm show insignificant penalty
  - TDP
    - Current TDP max is 2 dB with additional RX sensitivity data potentially TDP could be relaxed by 0.5-1.0 dB
  - MPI
    - Current specification assumes improved connectors with conservative penalty of 0.7 dB which can be adjusted as result of MPI adhoc study.

8x50G PAM4 10 km PMD Address 5 Criteria

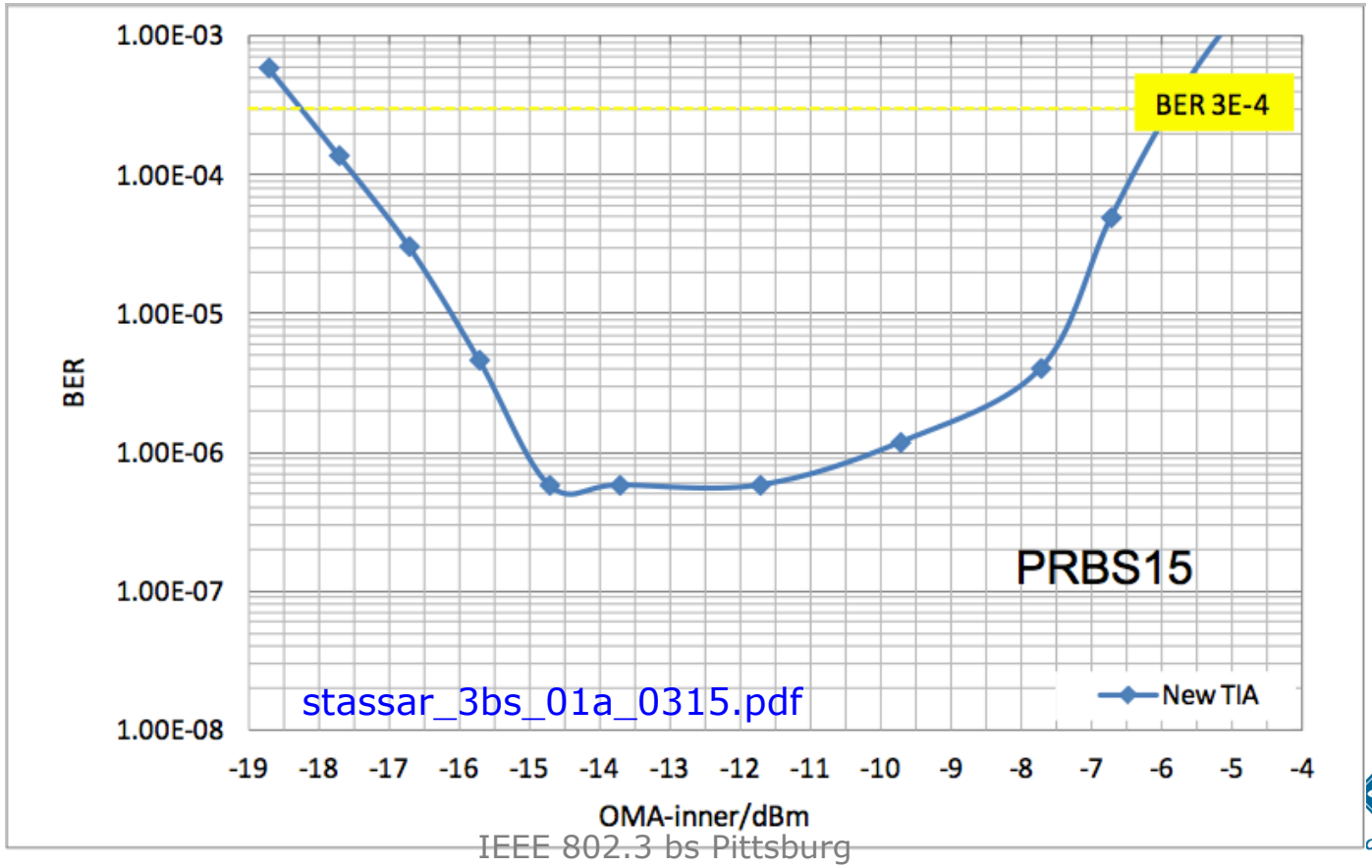
- Broad market potential
  - 50G PAM4 based on commonly used signaling combined with 25G lasers require minimum investment with broad applicability
- Compatibility
  - 8x50G PAM4 signaling is compatible with CDAUI-8 C2C, CDAUI-8 C2M, and next generation 50G PAM4 backplane and 50G PAM4 VCSELs
- Distinct identity
  - The 10 km objective can not be addressed by cascading five 2 km links and address high value applications
- Technical feasibility
  - 50G PAM4 technically robust
- Economic feasibility
  - Leverages broad set of 50G PAM4 SerDes and 25G transmitter.

Merits of 400Gbase-LR8 Based on PAM4

- 10 km duplex is required by 15% of router applications and can't be satisfied by 2 km
  - http://www.ieee802.org/3/bs/public/14_07/huang_3bs_01_0714.pdf
- Supports broad set PMD implementation
  - Supports DML, EML, and Silicon photonics
- Leverages broadest available PMA/PHY chips
  - More than 10 companies (PHY, ASIC, IP provider) either have or developing 50 Gb/s PAM4 solutions based on anticipated future 50 Gb/s PAM4 backplane and Cu cabling
- 50G PAM4 test equipment's readily available
- 400Gbase-LR8 addresses initial 400 GbE router deployment by ~2017.

Receiver Sensitivity the #1 Concern with 8x50G 10 km PAM4

- Next generation receiver with 15 pA/√Hz delivers OMA sensitivity of -18.3 dBm @ 3e-4
  - Even with 3 dB optical de-mux loss leaves 3.1 dB manufacturing margins!



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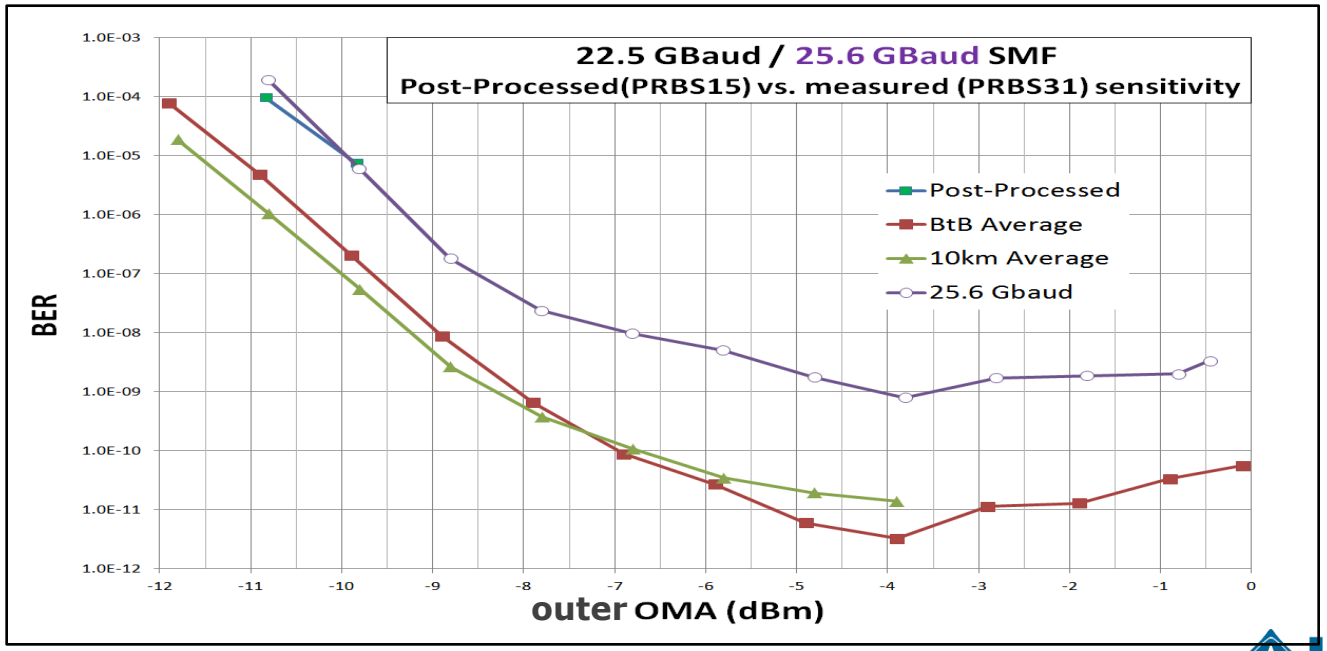
Receiver Sensitivity the #1 Concern with 8x50G 10 km PAM4

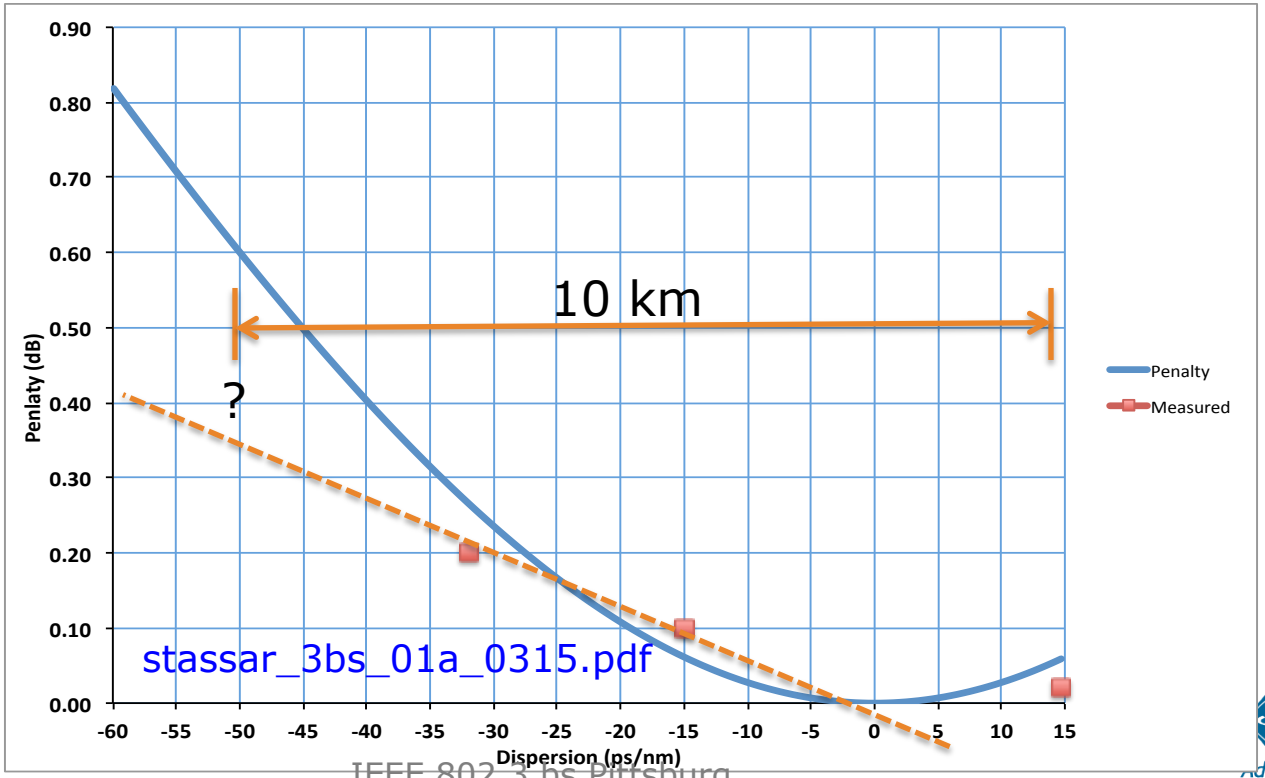
- Error floor ≪1e-6
  - Sensitivity -10.8 dBm@3e-4 BER
  - Result are for an older TIA, a 15 pA/√Hz TIA should deliver comparable performance to stassar_3bs_01a_0315
  - Some loss due to the microoptics are part of the measurement



M. Mazzini et. al. OFC 2015 post deadline

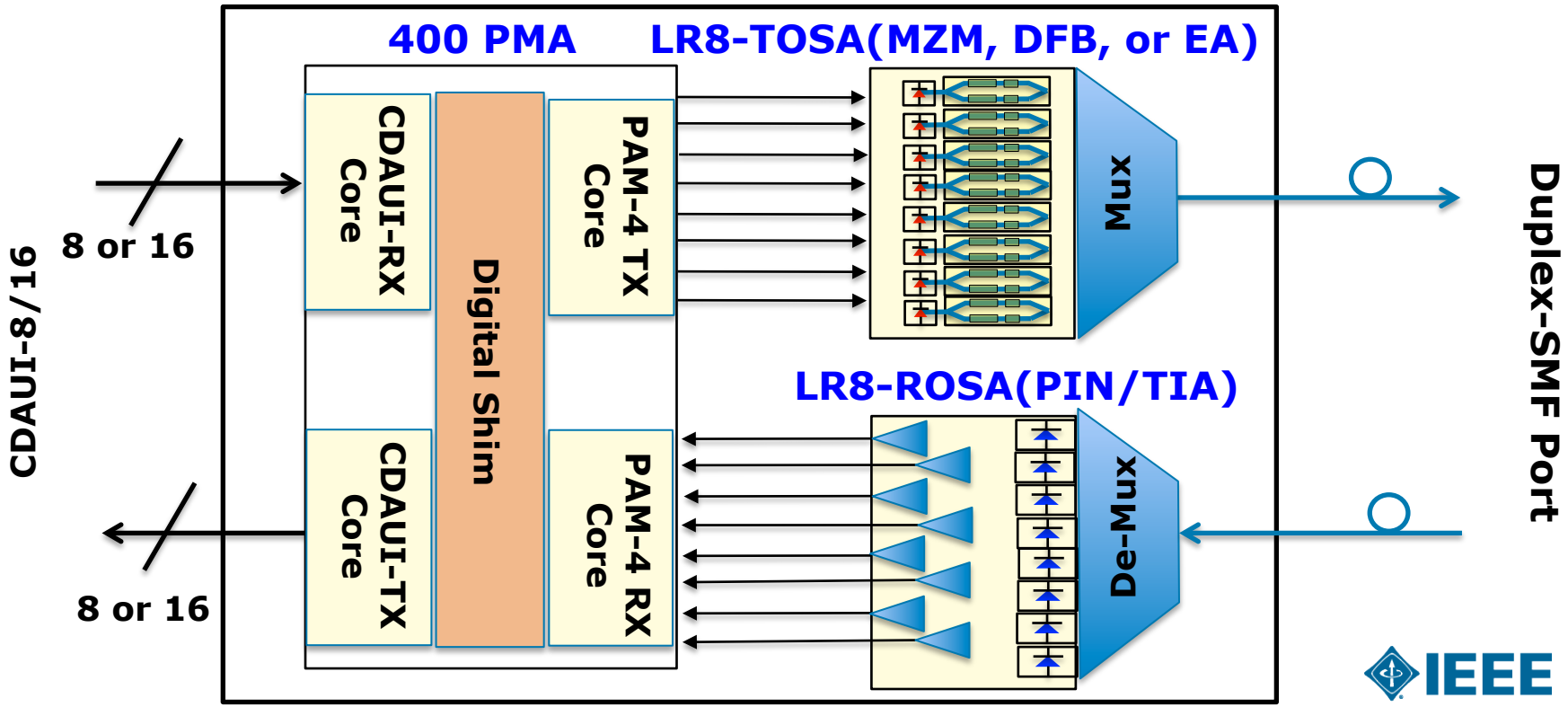
Dispersion Penalty is manageable

- Assuming G.695 fiber dispersion 10 km link has dispersion range -49.78 to 14.19 ps/nm over wavelength grid
  - The expected dispersion penalty @-50 ps/nm assumed 0.4 dB till further measured results become available



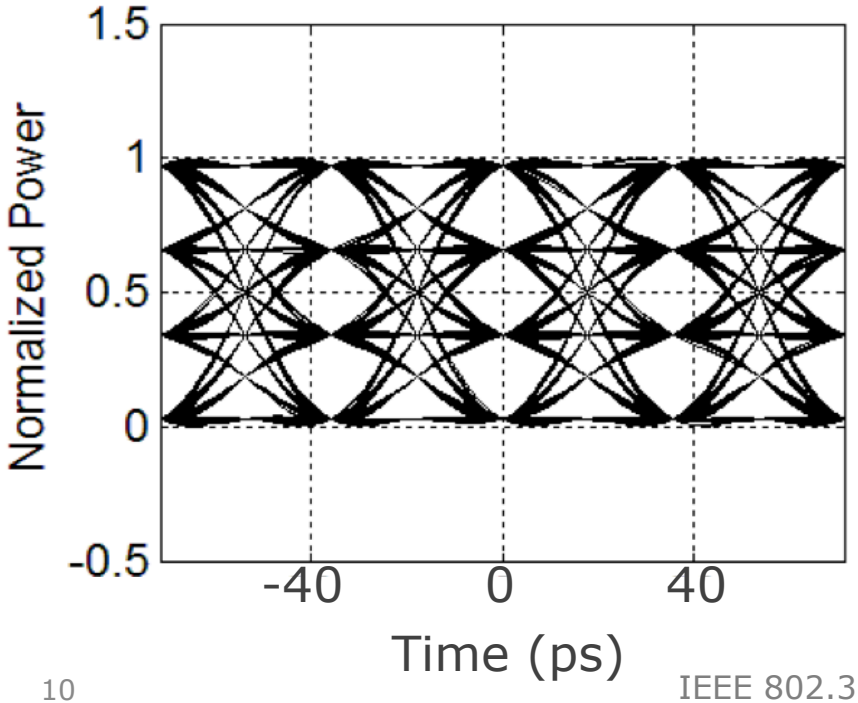
400Base-LR8 Implementation

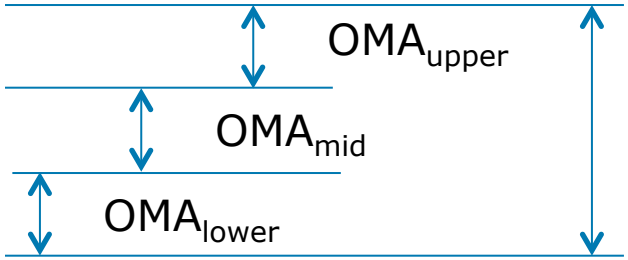
- Supports broad set of implementations leveraging 25G DML, EA, or Silicon Photonics
  - 400G PMA can leverage CDAUI-8 host retimers
  - The critical component is the low noise TIA.



Transmitter Specifications

- ER measured between level 00 and 11
- Sensitivity and link budget based on meeting all 3 inner eyes
  - OMA_{lower}, OMA_{mid}, OMA_{upper}.

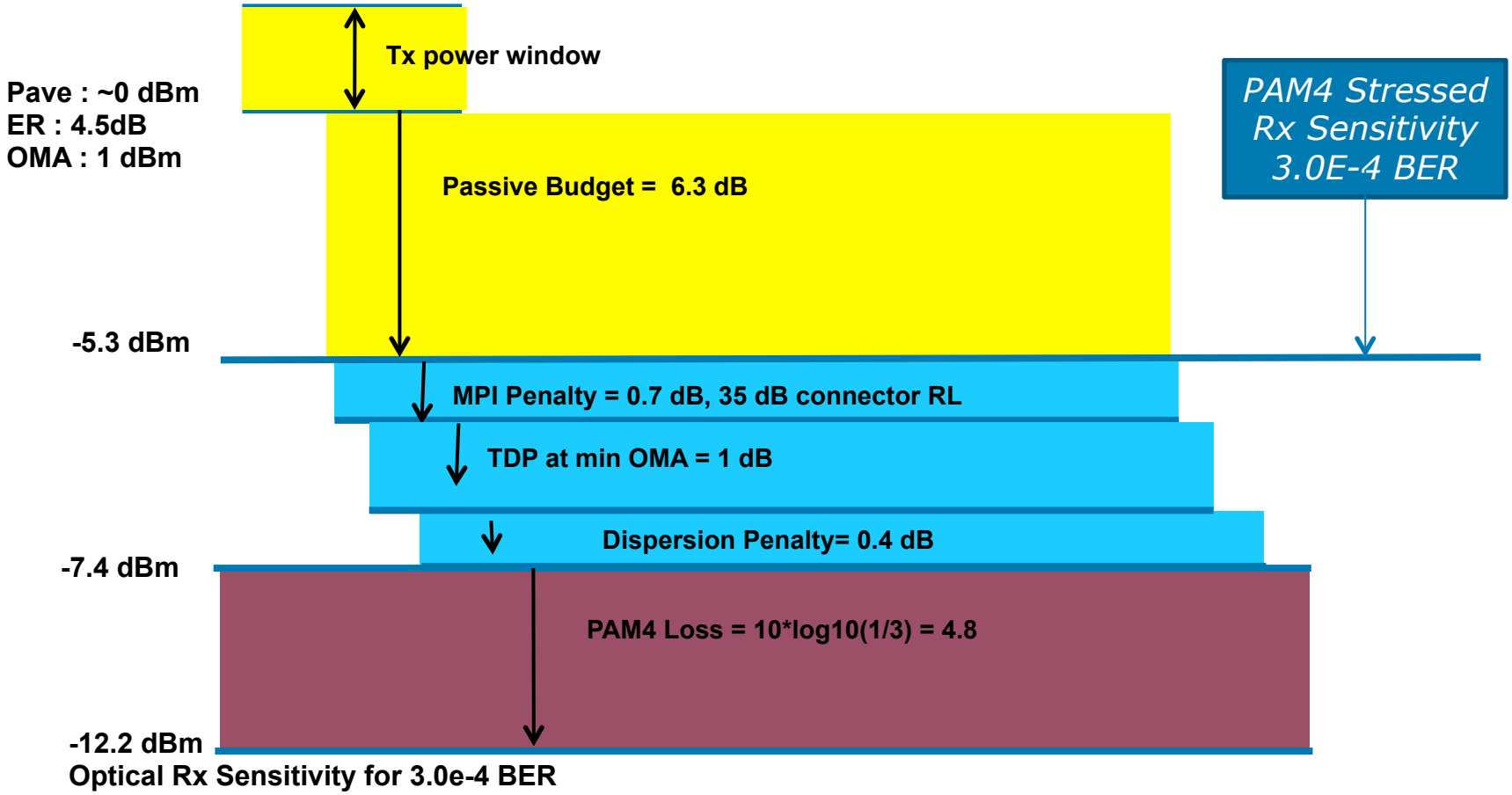




50 Gb/s PAM4 10 km Transmit Characteristics

Parameters	Min	Nominal	Max	Unit
Signaling Rate, each lane		26.56±100 PPM		GBd
Pre-FEC Operating BER		3.0E-4		
Average launch power each	-2		3.0	dBm
OMA, each lane	1		4.0	dBm
TDP each lane			2	dB
Launch power OMA -TDP	0.0			dBm
Launch power OMA_{upper}, OMA_{mid}, OMA_{lower}	TBD			dBm
RIN			-140	dB/Hz
Extinction ratio	4.5			dB
Transmitter 3 dB bandwidth	21			GHz
Transmitter reflectance			-20	dB
Optical return loss tolerance	26			dB

400Gbase-LR8 Link Budget



50 Gb/s PAM4 10 km Receive Characteristics

Parameters	Min	Nominal	Max	Unit
Signaling Rate, each lane		26.56±100 PPM		GBd
Pre-FEC Operating BER		3.0E-4		
Post-FEC Operating BER		1E-13		
Receiver sensitivity AOP	-8.4			dBm
Receiver sensitivity OMA, each lane	-7.4			dBm
Receiver sensitivity OMA_{uppper}, OMA_{mid}, OMA_{lower} each lane	-12.2			dBm
Receiver 3 dB upper cutoff frequency	21			GHz
Receive reflectance			-26	dB

400Gbase-LR8 Fiber and Connector Requirements

- MPI penalty calculated assuming 6 mid-span connectors.

Parameters	Value	Unit
Nominal fiber specifications wavelength	1310	nm
Cabled optical fiber attenuation (max)	0.43 [I] or 0.5 [II]	dB/km
Zero dispersion wavelength (λ0)	1300≤λ0≤1324	dB
Dispersion slope S0 (max)	0.093	ps/nm^2.km
Number of connectors	6	
Connector return loss (min) [III]	35	dB

I. The 0.43 dB/km at 1295 nm attenuation for optical fiber cables is derived from Appendix I of ITU-T G.695.
II. Attenuation per ANSI/TIA/EIA 568-B3-2000 outside plant cabling.
III. Connector discrete reflectance per ISO/IEC11801.

50 Gb/s PAM4 Link Budget

Parameters	Nominal	Unit
Passive Loss	6.3	dB
MPI	0.7	dB
TDP at minimum OMA (max) [I]	1.0	dB
Dispersion penalty	0.4	dB
Total Link Budget	8.4	dB

I. TDP can increase to 2.0 dB if OMA is increases by 1.0 dB.

400GBase-LR8 LAN-WDM Lane Assignment

Lane	Center Frequency (THz)	Center Wavelength (nm)	Wavelength Range (nm)
L0	235.4	1273.55	1272.55 to 1274.54
L1	234.6	1277.89	1276.89 to 1278.89
L2	233.8	1282.26	1281.25 to 1283.28
L3	233.0	1286.66	1285.65 to 1287.69
L4	231.4	1295.56	1294.53 to 1296.59
L5	230.6	1300.05	1299.02 to 1301.09
L6	229.8	1304.58	1303.54 to 1305.63
L7	229.0	1309.14	1308.09 to 1310.19

Area of Further Study

- Current MPI penalty is moderately conservative based on worst case lossless interferometric penalty which is too conservative
  - Based on the outcome of MPI study group potentially connector return loss could be relaxed to 26 dB
  - Another approach to support 26 dB connector is to trade off loss with MPI penalty
- Update dispersion penalty at -50 ps/nm as measured result become available.

Summary

- 400Gbase-LR8 addresses the critical early deployment in routers and OTN applications following the foot steps of 100 GbE initial deployment
  - Volume likely very modest and similar to initial phase of 100Gbase-LR4 deployment
  - 400Gbase-LR8 proposal leverages PAM-4 signaling from CDAUI-8 and possibly using identical host PHY/retimer
  - 400Gbase-LR8 leverages 25G transmitters (DML, EA, Si MZM)
  - 400Gbase-L8 does require an incremental improvement on the TIA which is already available at least from one source
- 400Gbase-LR8 with modest volume and requiring early deployment can't support or tolerate development of new signaling or 50G lasers.

Thank You!