Technical feasibility of 56Gbaud PAM4 optical link budget based on experimental measurements

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400 Gb/s Ethernet Task Force
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Introduction

- There have been several previous presentations related to the use of 56Gbaud PAM4 (100Gb/s per channel) as a fundamental technology for addressing one or more of the 802.3bs SMF objectives.

- This presentation focuses on validating the technical feasibility of a 56Gbaud PAM4 optical link model, through experimental measurements.

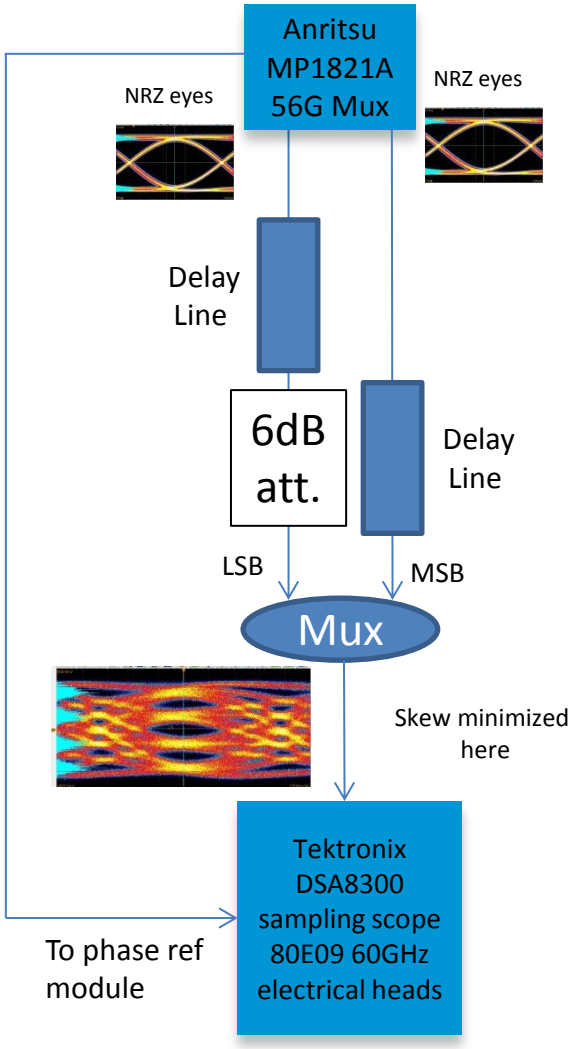
- The experimental setup used to obtain these results is not intended to be an implementation proposal.

Scope of this work

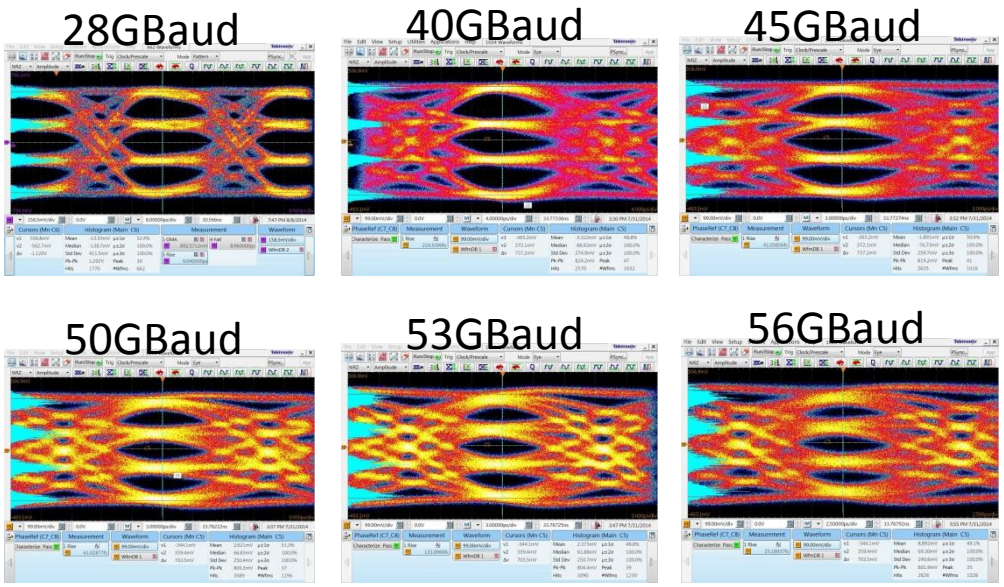
Verify technical feasibility of 56G PAM4 (>100Gb/s each) and proposed link budget.

- Understand pre-FEC limits over:
  - 2 km link (objective on Duplex SMF).
  - Up to 56 Gbaud (PAM4) on optical lanes.
- Steps followed:
  - Built PAM4 (up to 56GBaud) electrical generator.
  - Emulate PAM4 (up to 56GBaud) optical link.
  - Acquire waveforms, run post-processing.

PAM 4 electrical generator built with discrete components

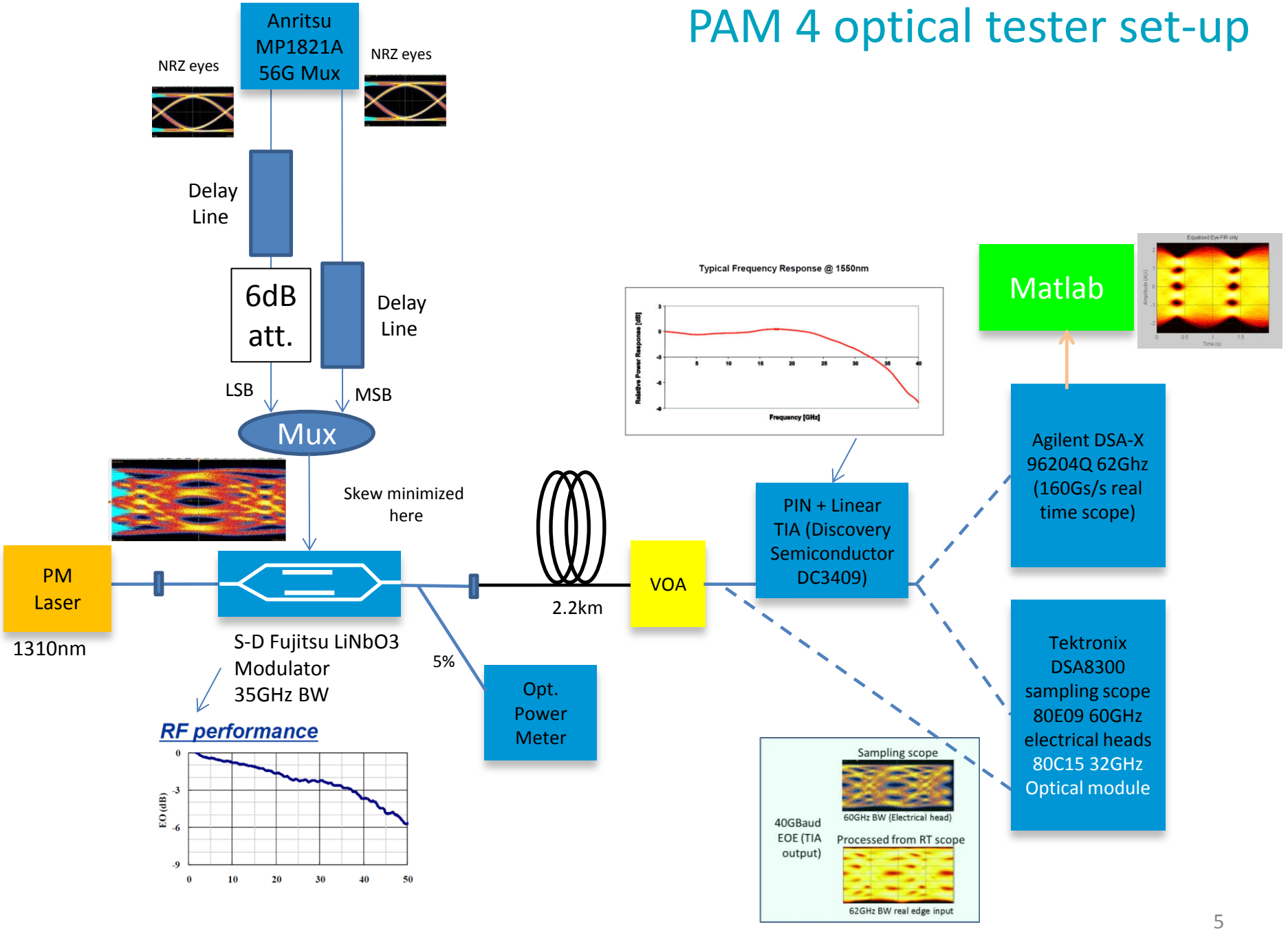


PRBS31 electrical eyes

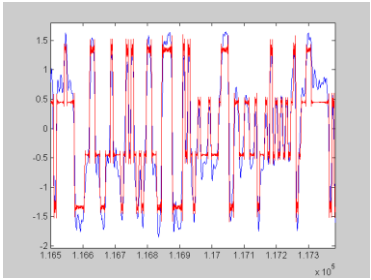
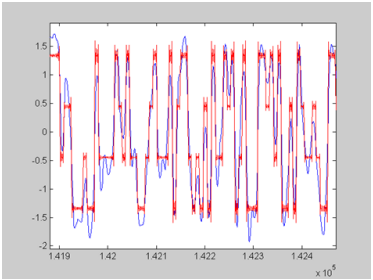
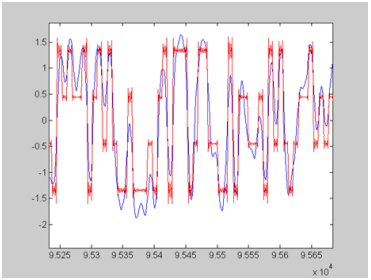
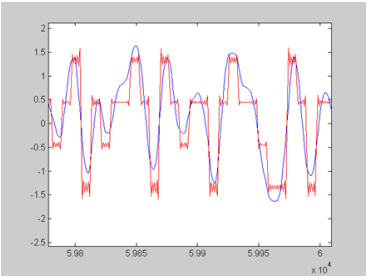
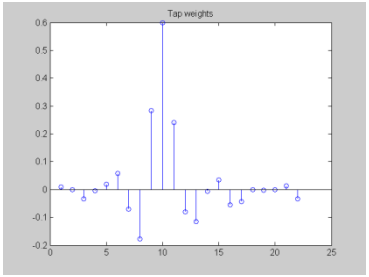
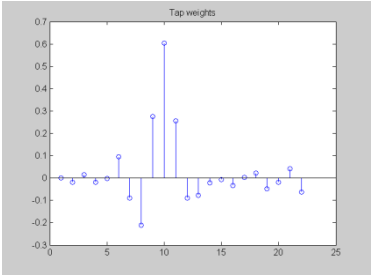
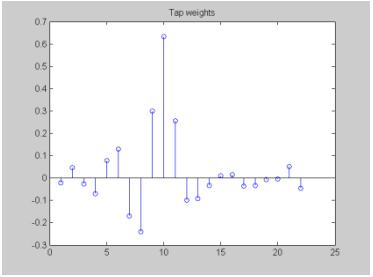
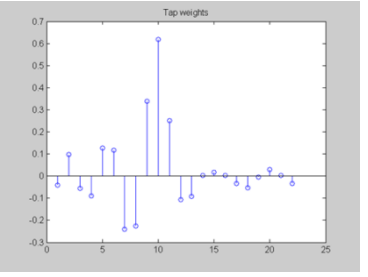
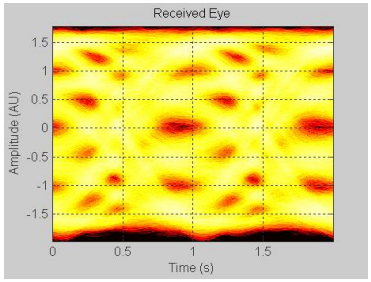
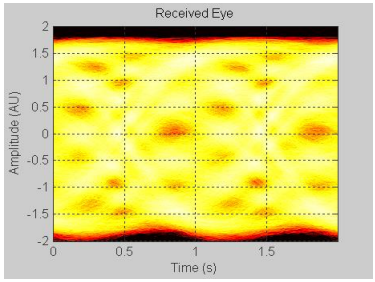
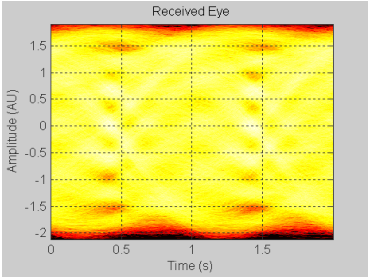
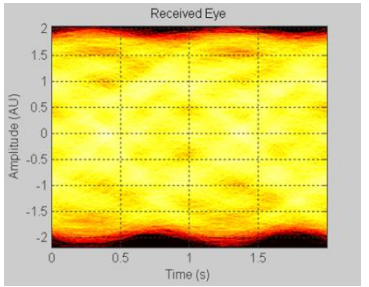
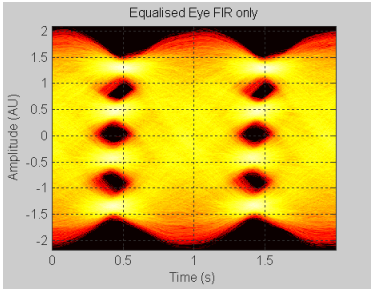
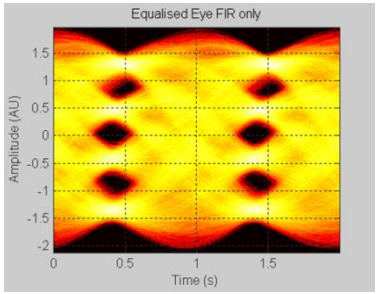
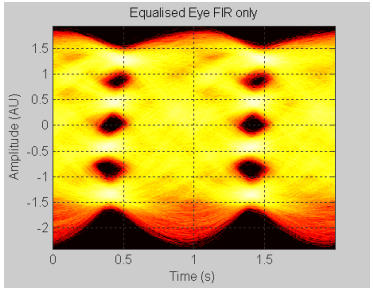
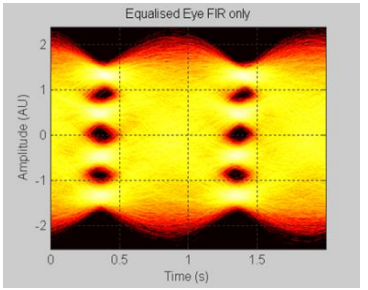


Increasing the bit rate RN also DN contribution (ISI due to BW limitations) increase.

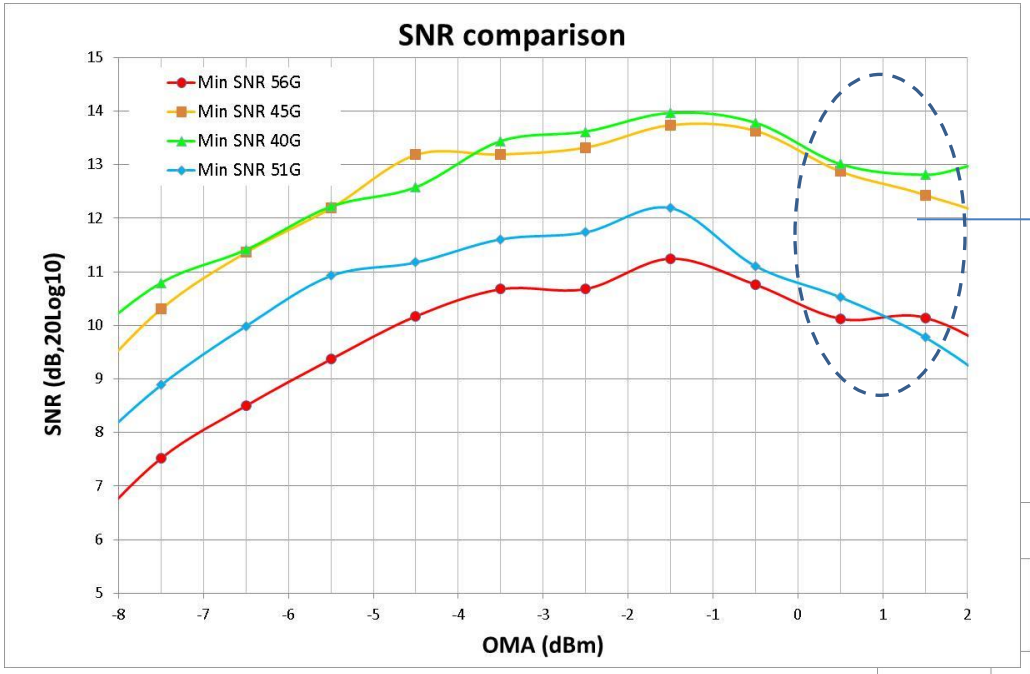
PAM 4 optical tester set-up



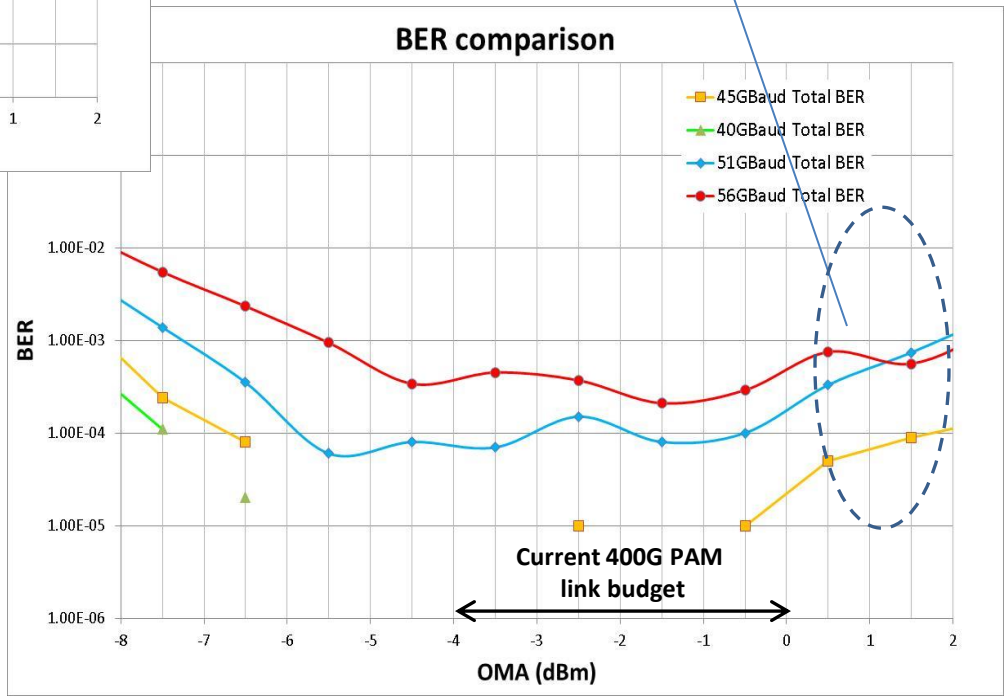
Processing - characteristics at different rates (-3dBm input power).

	40GBaud PAM4	45GBaud PAM4	51GBaud PAM4	56GBaud PAM4
Acquired (blue) training (red) sequences				
FFE taps Settings [22 taps, T/2]				
Received eye				
Equalized eye				
	Total BER 0 (<1E-5)	Total BER 0 (<1E-5)	Total BER 8.04E-05	Total BER 1.85E-4

PAM4: measured BER and calculated SNR versus rate and OMA (2km).



Degrations
due to PIN TIA overload distortion
(see backup)



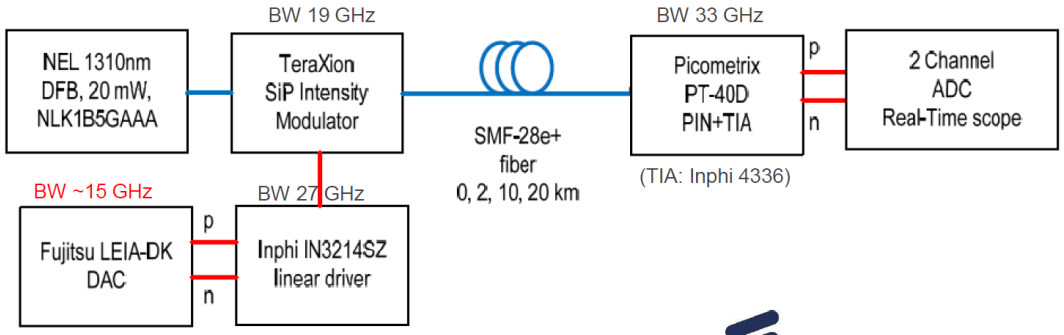
SNR (dB) calculated as:

EyeOpens = MeanLevel(2:end)-MeanLevel(1:end-1);
EyeNoise = StdLevel(1:end-1)+StdLevel(2:end);
EyeSNR = 20*log10(EyeOpens./EyeNoise);

Comparing with previous works (bhatt_3bs_01a_0714)

Experiment

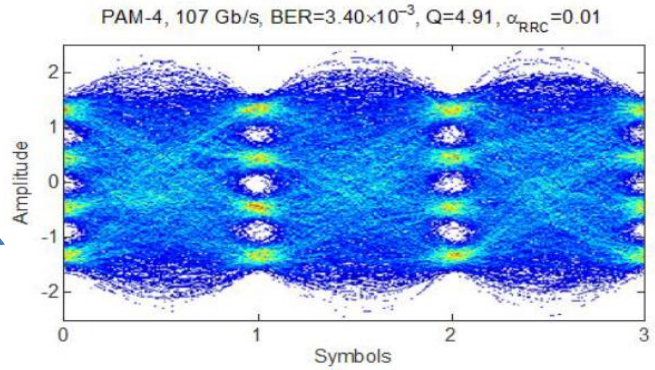
Independently, a team of contributors from Teraxion, Ericsson and McGill University have taken experimental measurements of various PAM links, including 100G per wavelength, PAM4, 2 km. In the next few slides, we present their results. For details, see references [1], [2].

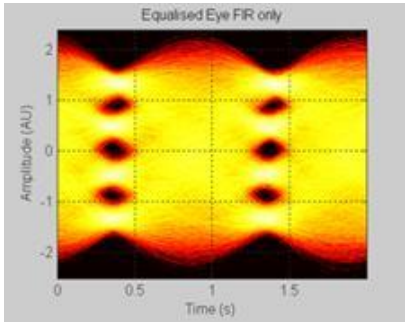


TeraXion ERICSSON McGill

Eye Diagrams

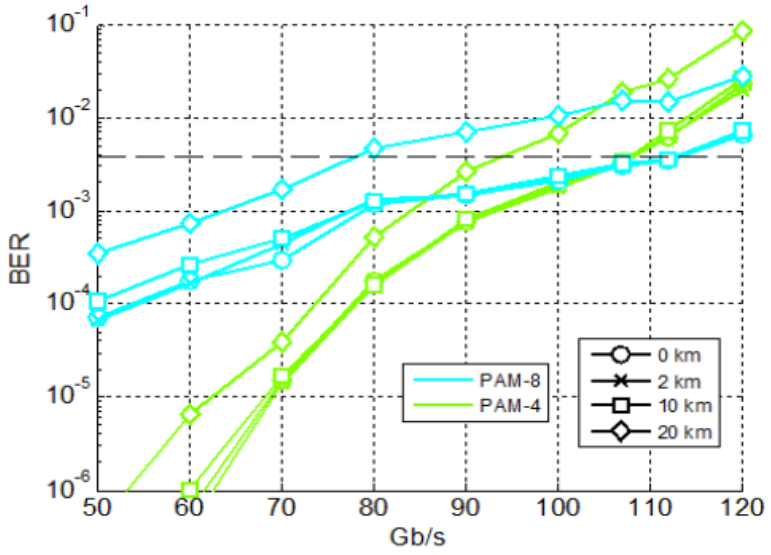
bhatt_3bs_01a_0714
PAM-4, 107 Gb/s
BER 3.4E-3

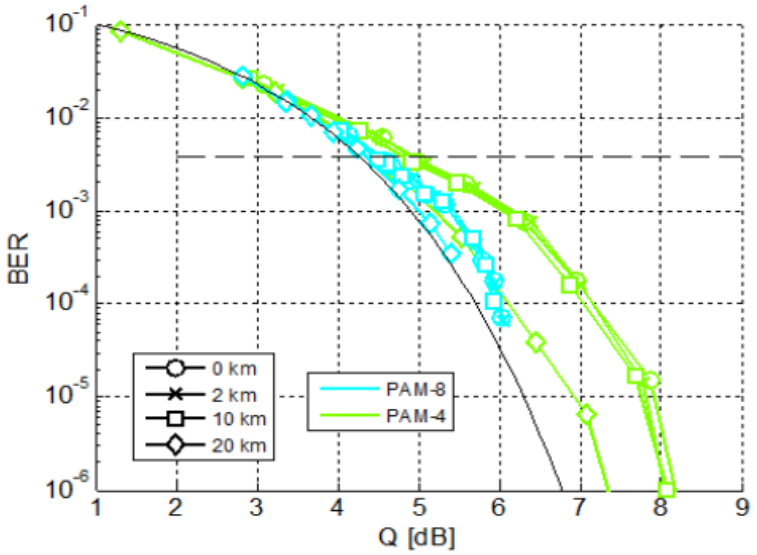


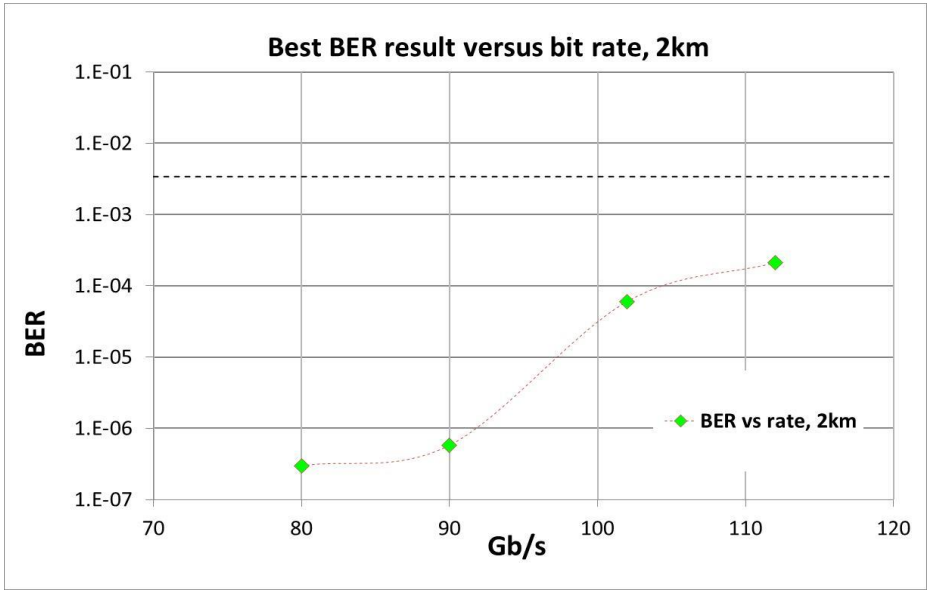


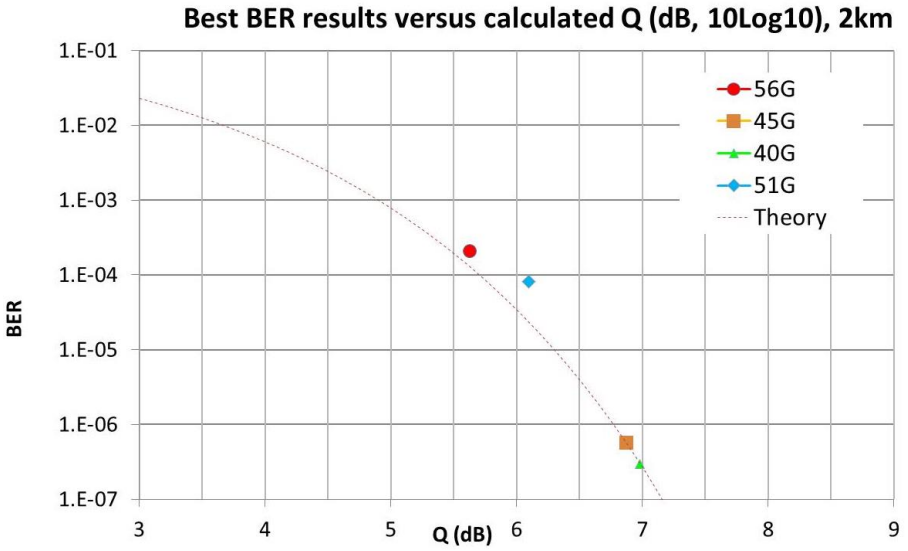
This work
PAM-4, 112 Gb/s
BER 1.85E-4

Comparison with previous works - bhatt_3bs_01a_0714









This work (3.4E-3 line kept just as reference)

Summary

- Technical feasibility of 56G PAM4, for a potential 400G CWDM solution (>100Gb/s each wavelength) has been verified.

- Link model validation (400G on Duplex SMF - 2 km) - results in line with previous works.

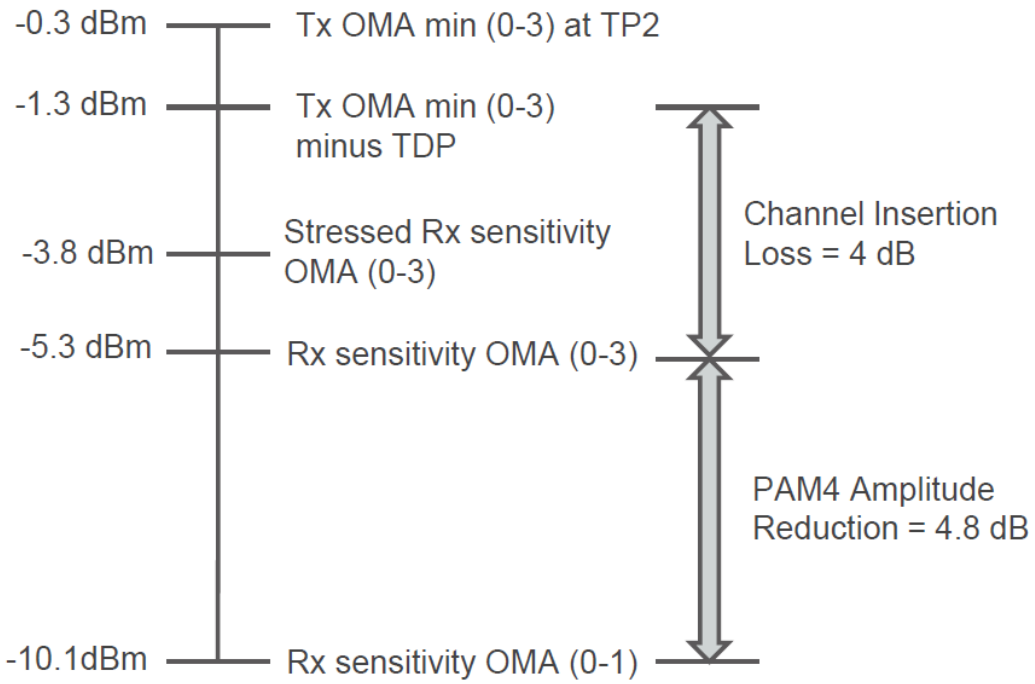
- Improved PAM4 electrical generator and ADC (ENOB > 5bits) should provide better results.
-
- Beyond 100Gb/s (50GBaud) operation a FEC able to correct BER > 1E-4 seems needed.

  Several FEC options which meet this requirement have been previously presented in 802.3bs.

Thank You

Back-up

Four-Wavelength 400G on Duplex SMF: Link model (proposed into bhatt_3bs_01a_0714)



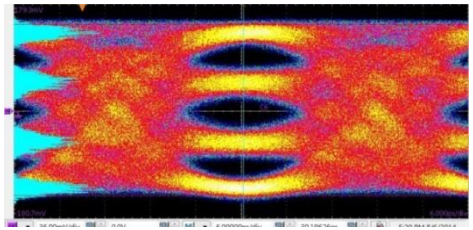
Penalties:
About 2.5 dB (1.5 dB residual ISI after equalization, 1 dB other penalties)

Assumptions:
WDM mux + demux loss: 4.6 dB, included in TP2, TP3 specs.
Effective TIA NEP: 21 pA/sqrt(Hz)
Tx bandwidth: 28 GHz
Rx bandwidth: 28 GHz

Methodology:
Use equalization in Rx to reduce ISI penalty.
Make up for PAM4 amplitude reduction with KP4 FEC.
Pre-FEC: Q ~ 4, BER ~ 1e-5
Post-FEC: Q > 7.34, BER < 1e-13
Plan for margin

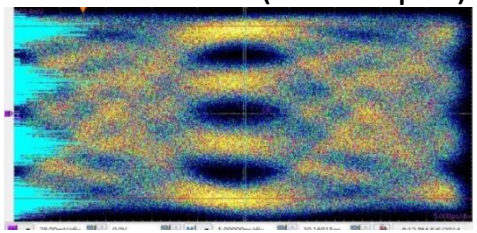
Processed (real time) vs Sampling scope eyes

30GBaud EO (TP2)



32GHz bandwidth
Optical head

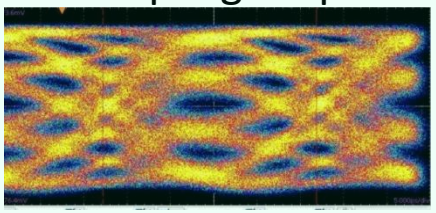
36GBaud EOE (TIA output)



40GHz bandwidth
Electrical head

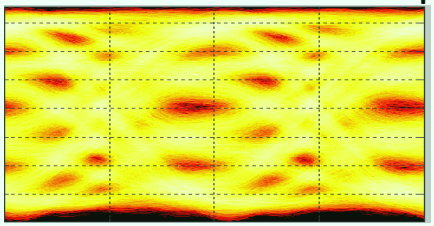
40GBaud EOE (TIA output)

Sampling scope

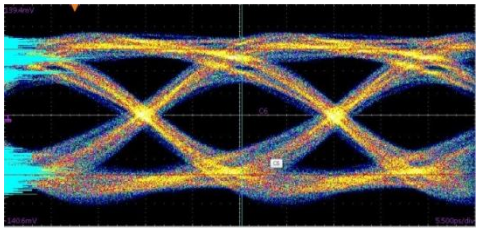


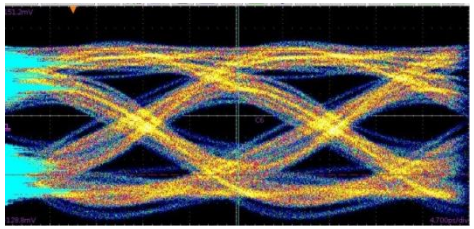
60GHz BW (Electrical head)

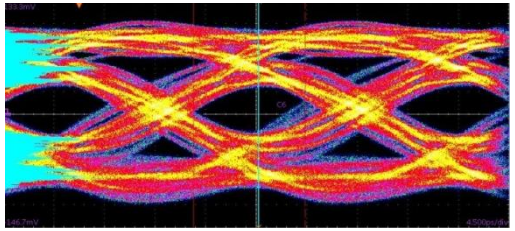
Processed from RT scope

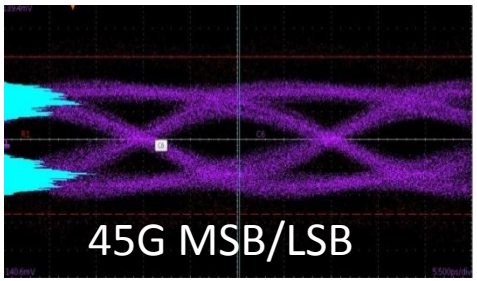


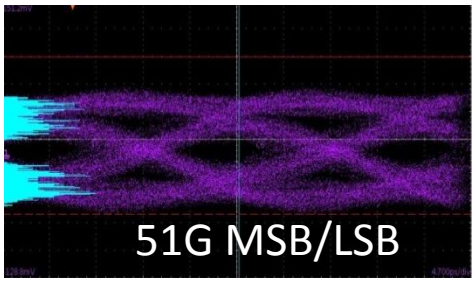
62GHz BW real edge input

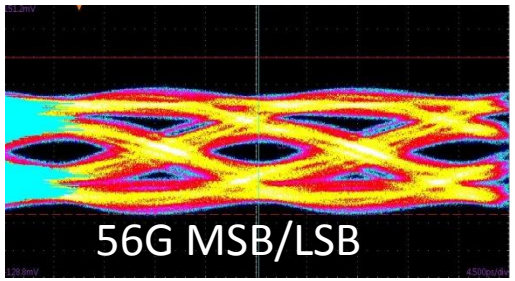






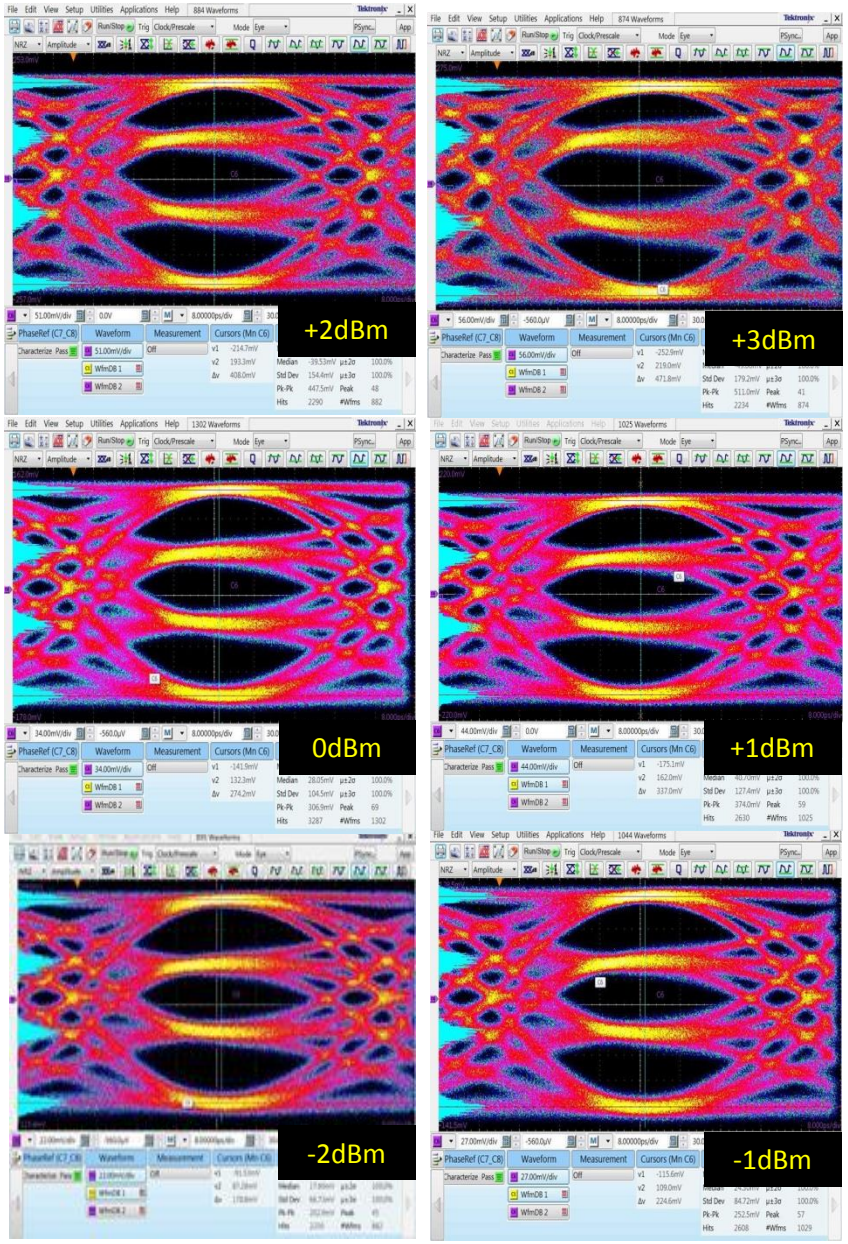






Cannot get a «clear» PAM4 eye beyond 45GBaud: MSB/LSB eyes showing ISI impairment.

PIN/TIA overload: PAM4 levels compression (test done at 16GBaud).



PIN/TIA overload lead into PAM4 level compression.
Formula defined to quantify it is:

$$\text{Compression \%} = \frac{\text{Max(Eye ampl) - Min (Eye ampl)}}{\text{Max(Eye ampl)}}$$

Below table showing >1dB impact on SNR, with no propagation dependence as expected.

Condition	Input PWR	PIN/TIA VMA	Compression %
Back to back	3	469.5	40%
	2	402.5	27%
	1	343.1	17%
	0	274.17	16%
	-1	225.19	12%
	-2	179.27	10%
Condition	**Input PWR**	**PIN/TIA VMA**	**Compression %**
2.2km fiber	3	467	41%
	2	401	29%
	1	336.77	18%
	0	269.62	14%
	-1	216.58	11%
	-2	172.62	9%