

100 Gb/s Duplex Interconnects using Moderate PAM-N signaling

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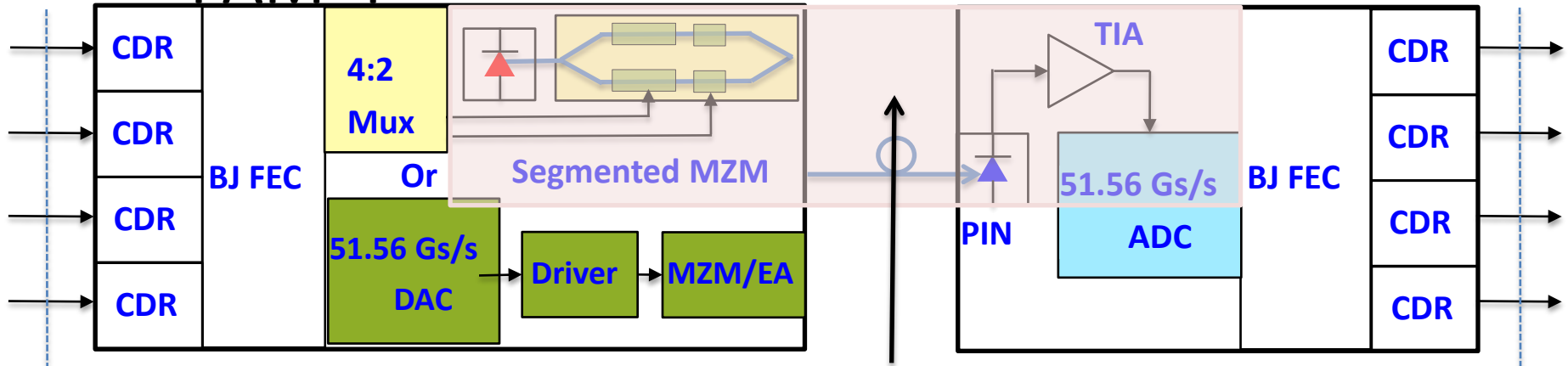


Agenda

- System Overview
- Electro-Optical BW Comparisons
 - PAM-N @ 37/27 GHz Bandwidth (TX/RX)
 - PAM-N @ 30/22 GHz Bandwidth (TX/RX)
- Optical Link Budgets Implications
 - MPI vs. Connector Reflectance
 - RIN vs. Eye position
 - ‘Center Eye’ Comparisons for PAM-4/6/8

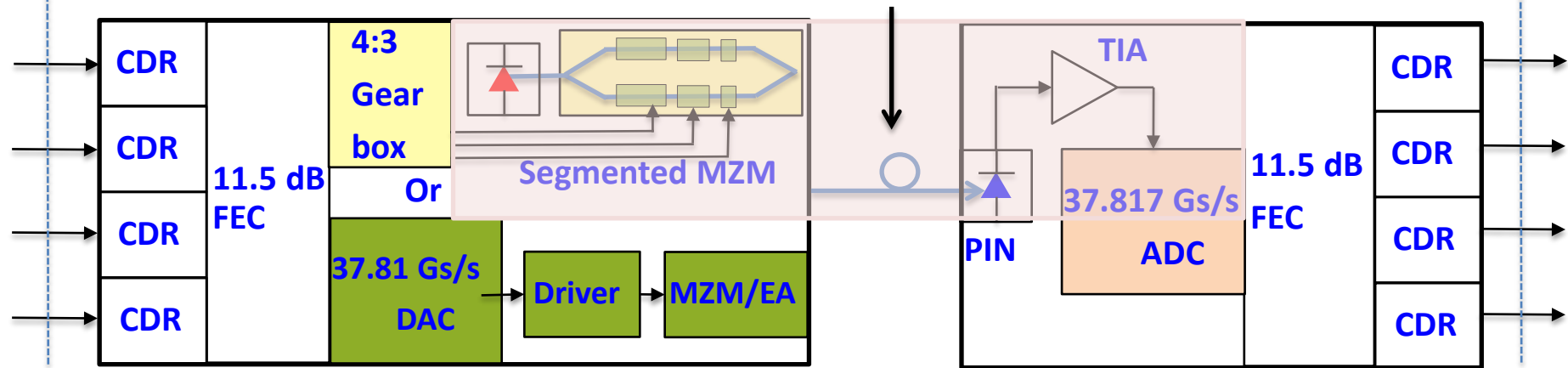
PAM-4 vs PAM-8 Implementation

- PAM-4



- PAM-8

Focus of Current Simulations



CAUI-4

CAUI-4

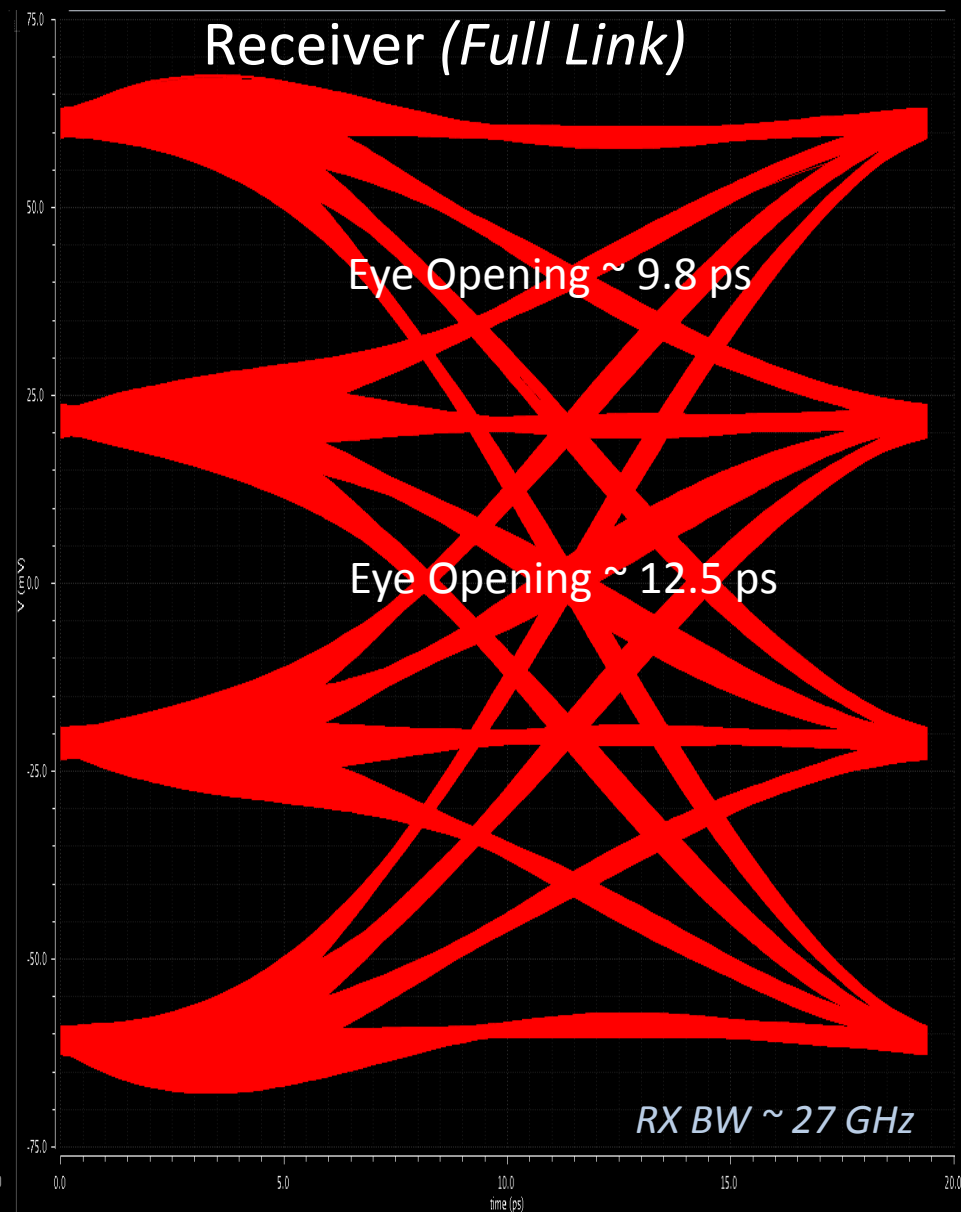
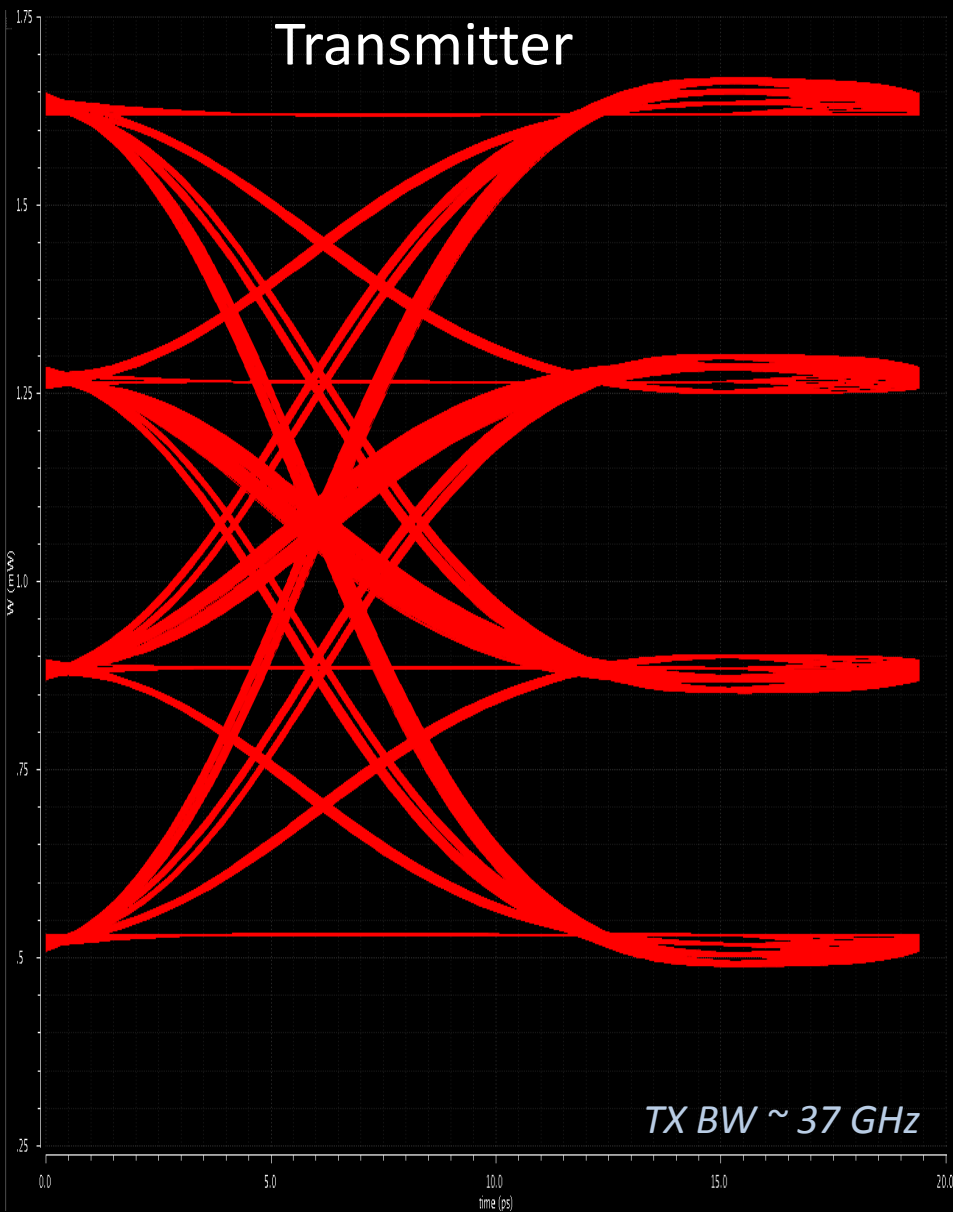
Link Deterministics

ELECTRO-OPTICAL BANDWIDTH

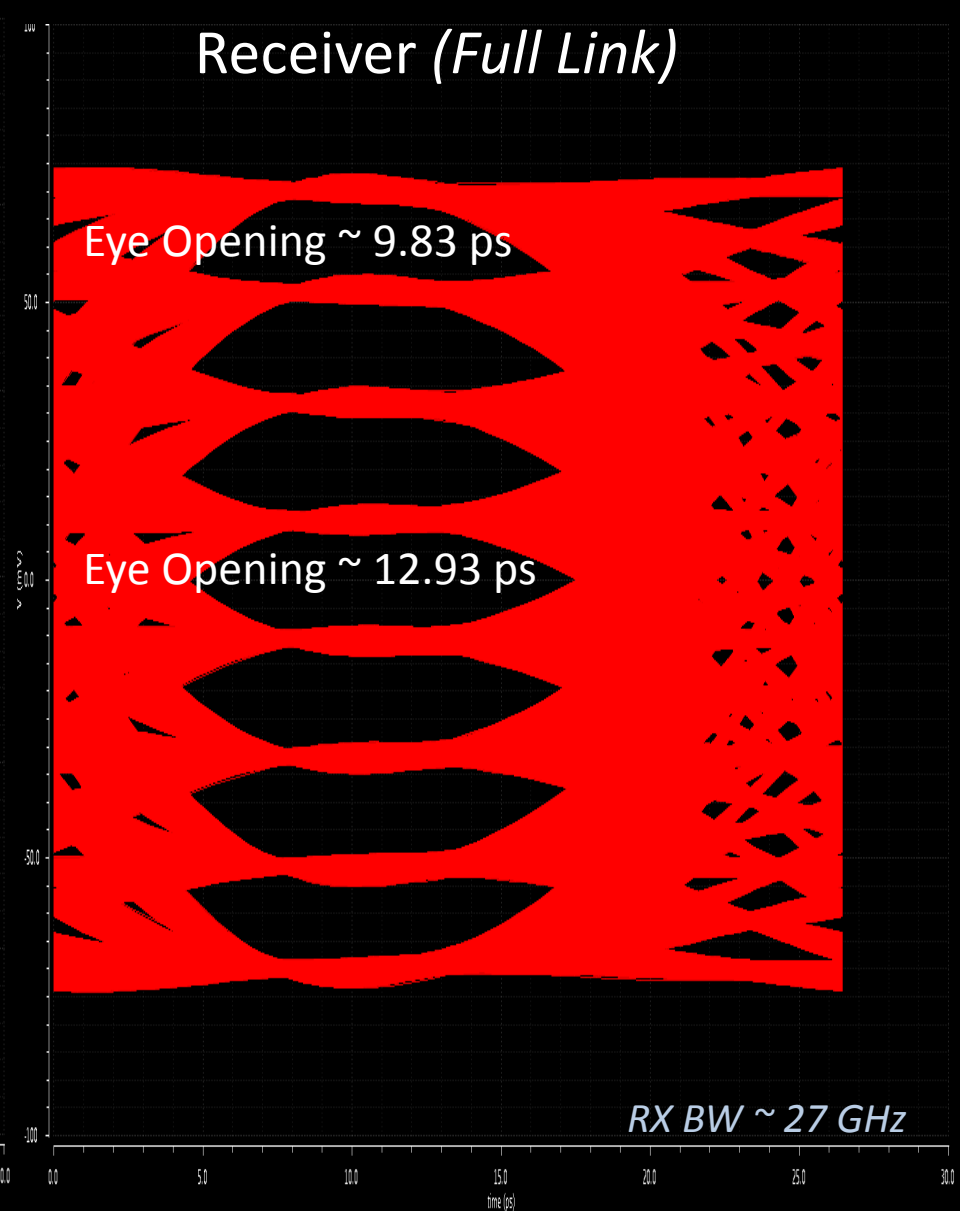
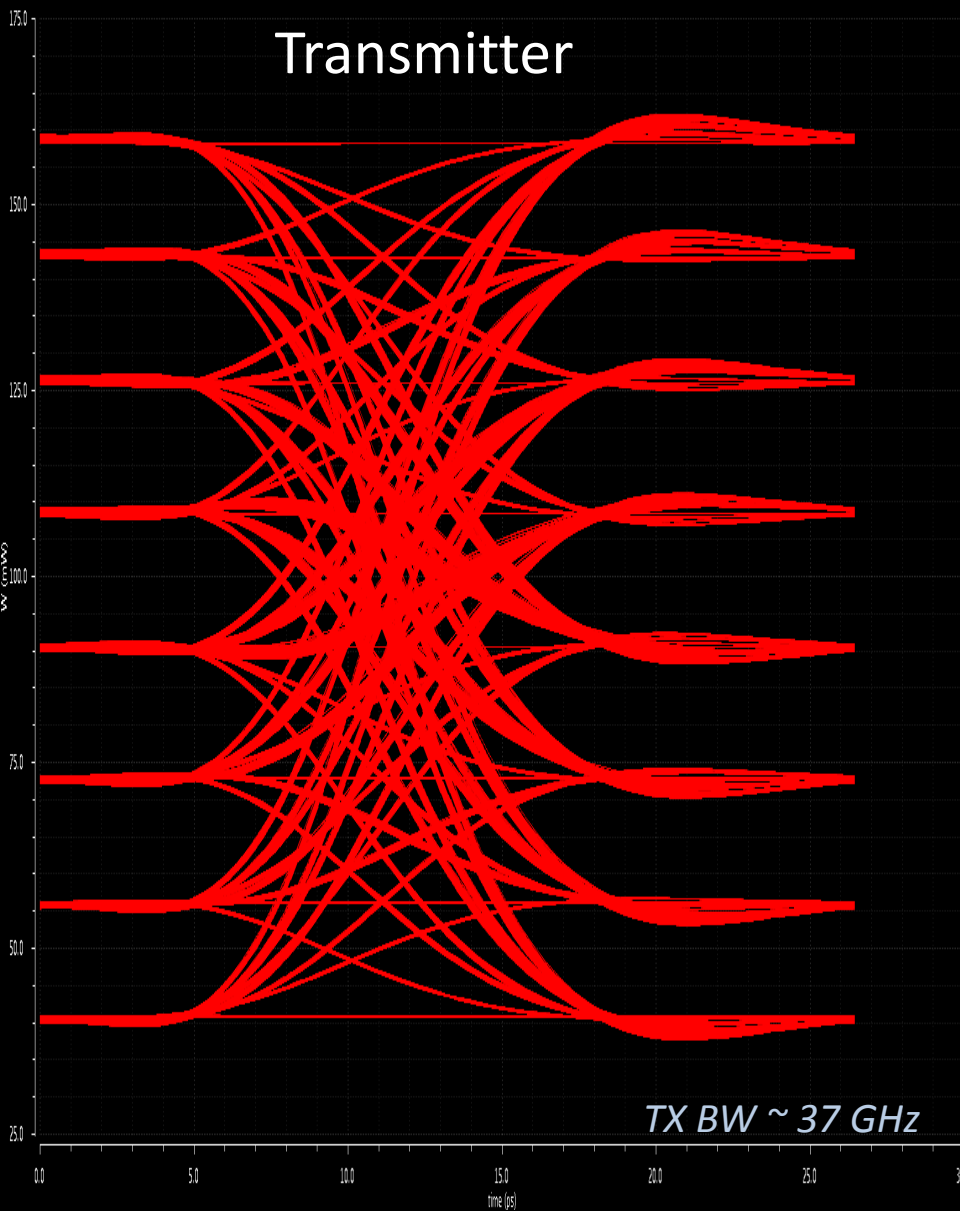
Electro-Opto-Electrical Simulations

- Focus on the optical 'channel' between module electronic interfaces
 - Optical Transmitter + Optical Receiver
- Bandwidth comparison vs. rate/modulation format
 - Deterministic effects only
 - No external jitter sources
 - Two stage CTLE as part of TIA
- PAM-4 @ 51.5612 Gbaud
- PAM-8 @ 37.8125 Gbaud
 - 10% overhead added for higher gain FEC

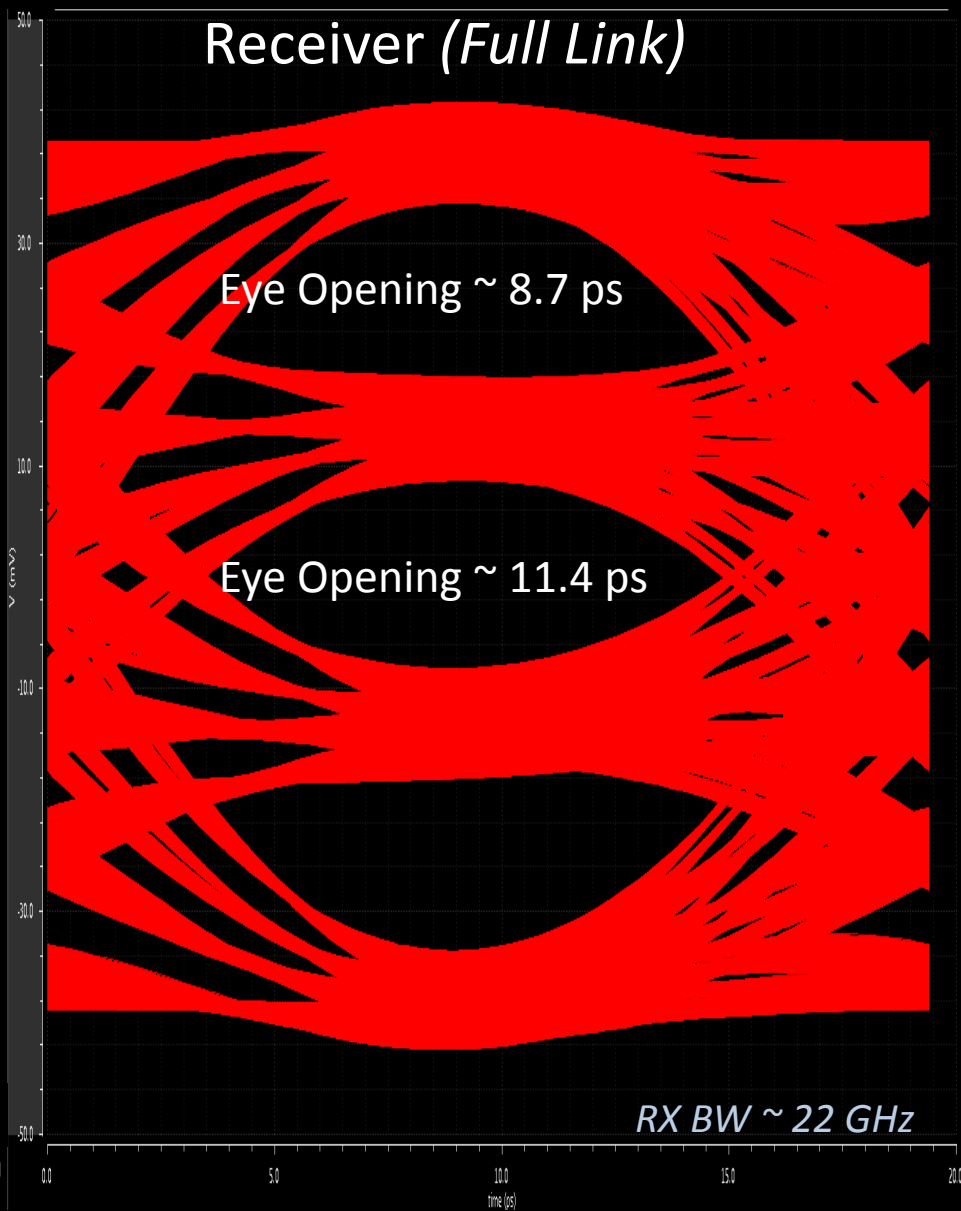
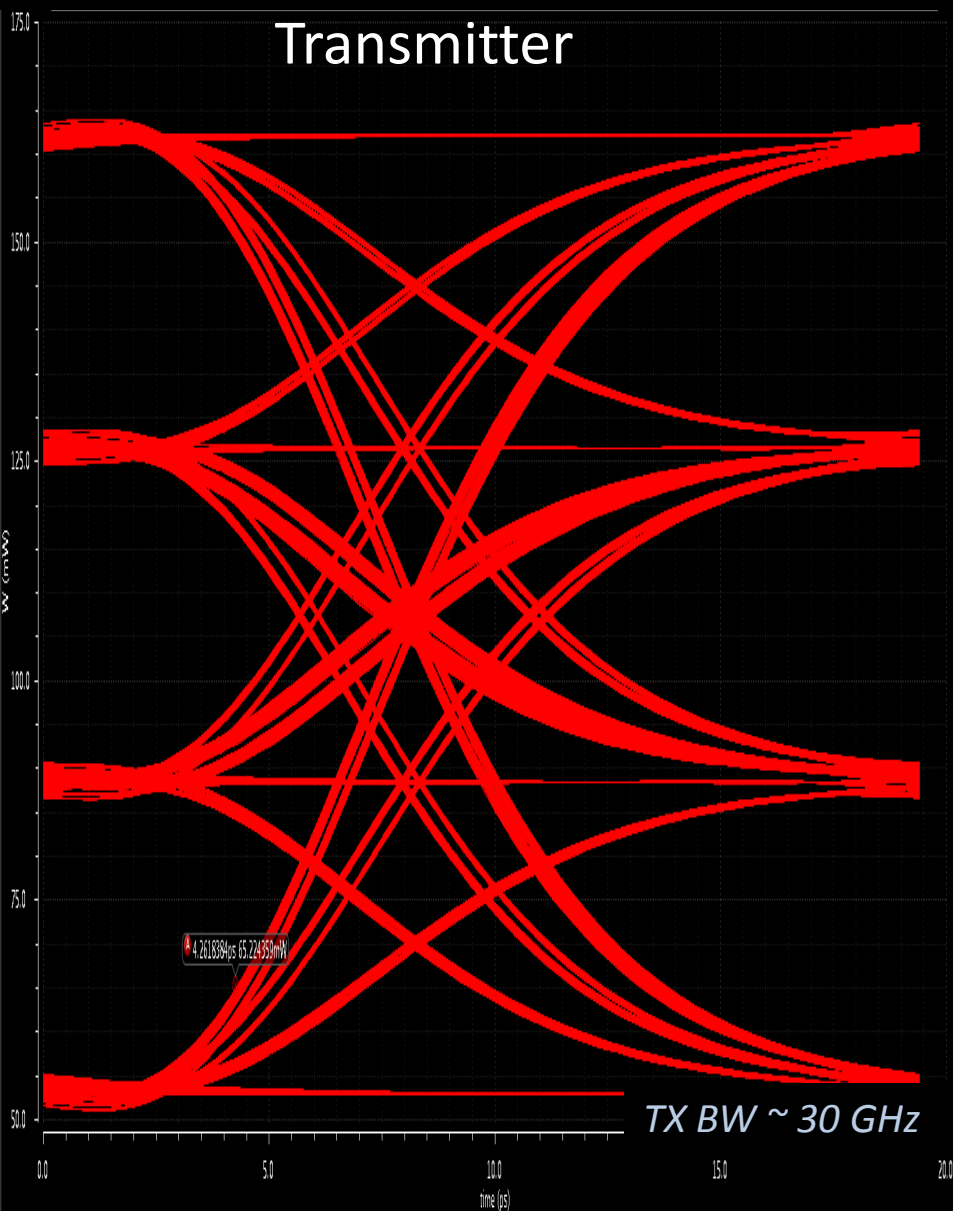
PAM4 @ 51.5625 Gbaud



PAM8 @ 37.8125 Gbaud (10% Overhead)

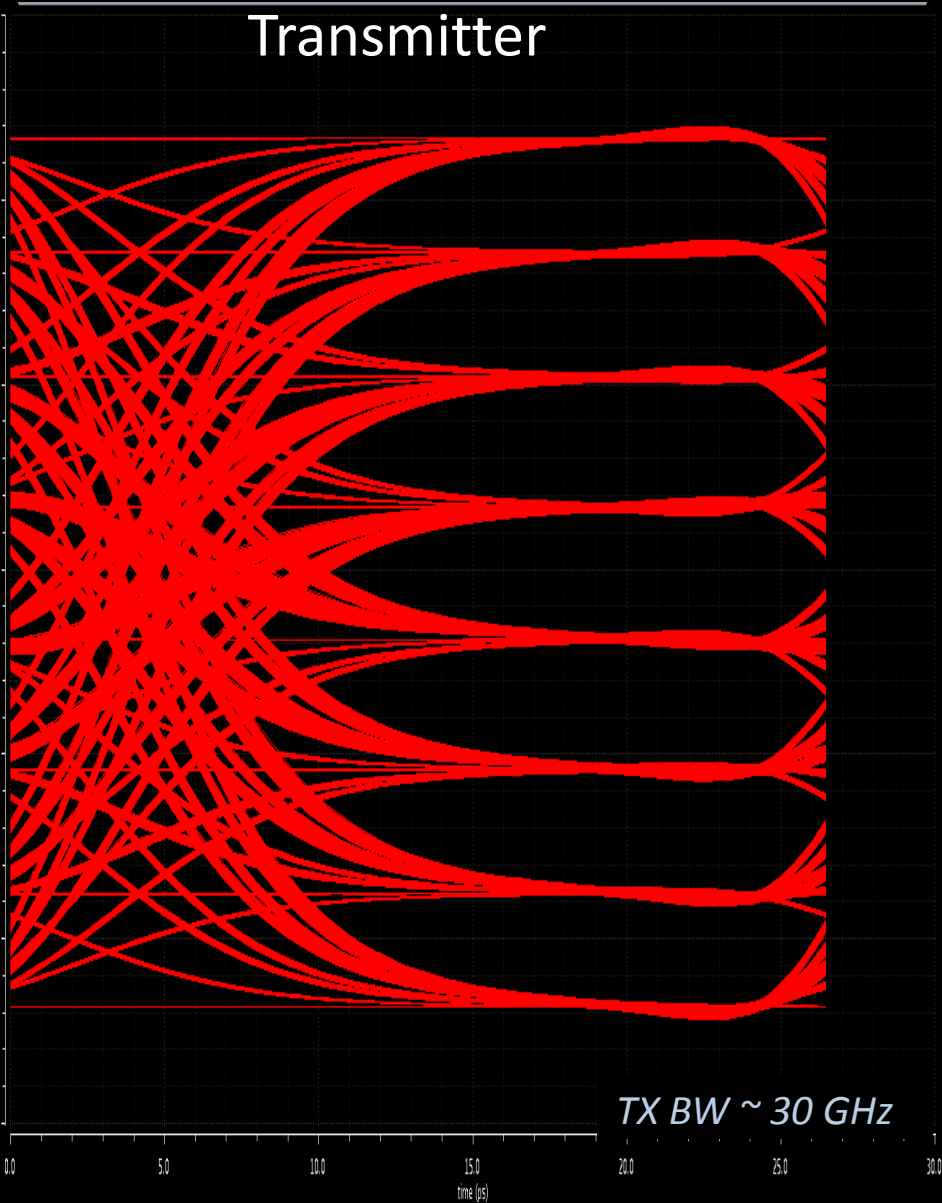


PAM4 @ 51.5625 Gbaud

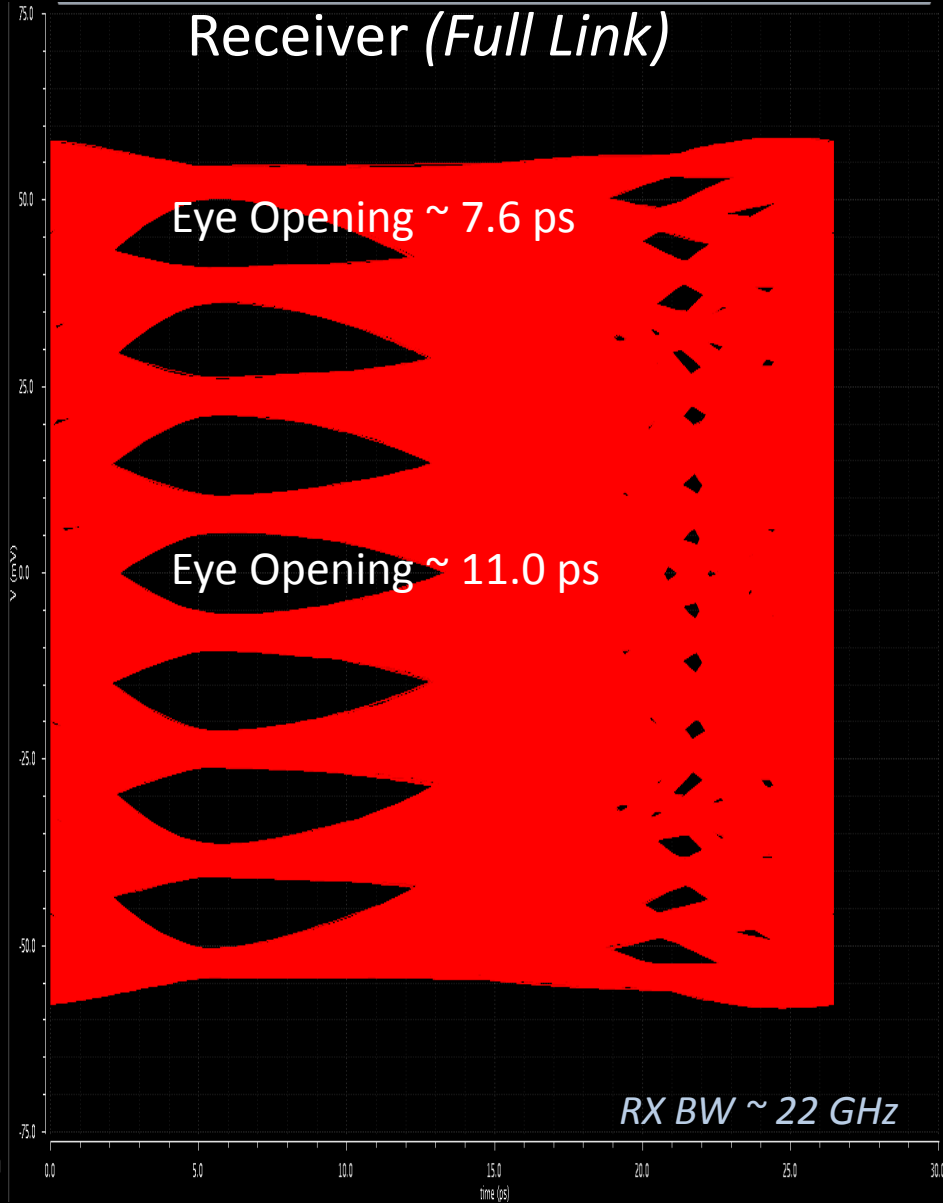


PAM8 @ 37.8125 Gbaud (10% Overhead)

Transmitter



Receiver (Full Link)



Deterministic Eye Opening

	Eye Opening – Max	Eye Opening - Min
PAM4 – High BW	12.5 ps	9.8 ps
PAM8 – High BW	12.9 ps	9.8 ps
PAM4 – Reduced BW	11.4 ps	8.7 ps
PAM8 – Reduced BW	11.0 ps	7.6 ps

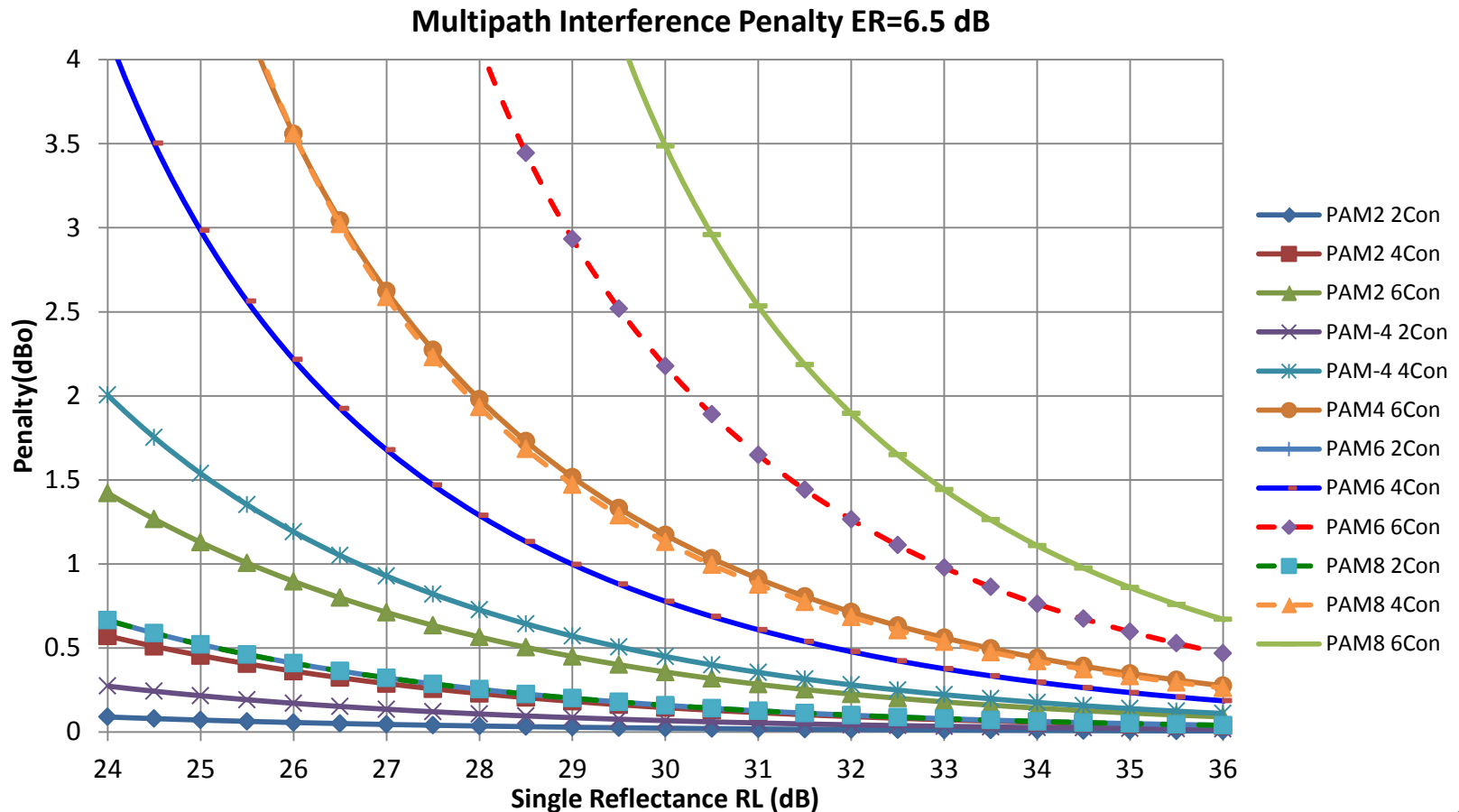
- Absolute deterministic eye opening consistent for a given bandwidth
 - Component bandwidth relief unlikely for lower rate / higher order PAM formats
- Lower bandwidths induce higher order jitter
 - Likely would require multi-tap DFE to cancel out ISI

MPI, RIN, and other Penalties

LINK BUDGET

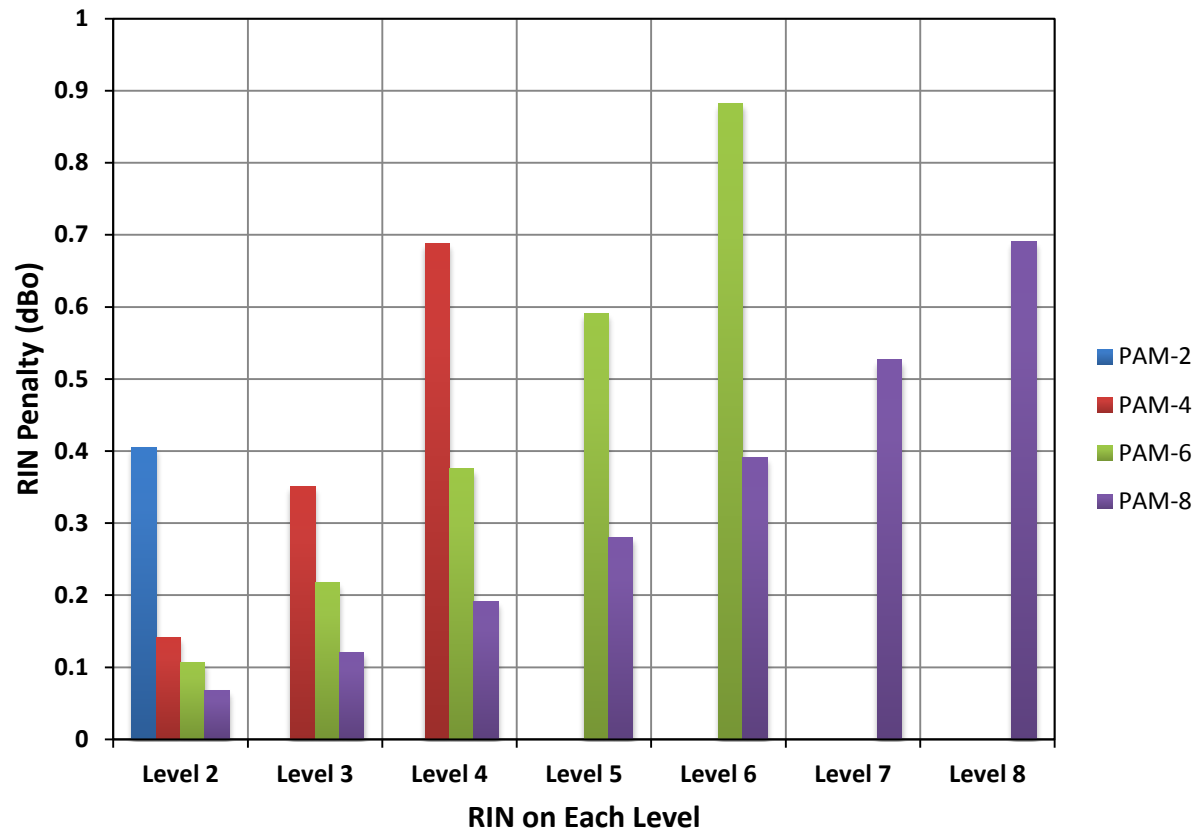
MPI Penalty

- To support any higher order modulation and 4 mid span connectors plus TOSA/ROSA the return loss must improve based on analysis in http://www.ieee802.org/3/100GNGOPTX/public/mar12/plenary/ghiasi_03_0312_NG100GOPTX.pdf
 - To limit max MPI penalty to ~1.1 dBo and Mean penalty~0.8 dBo
 - PAM-4 require -30 dB RL, PAM-6 require -32 dB RL, and PAM-8 require -34 dB RL

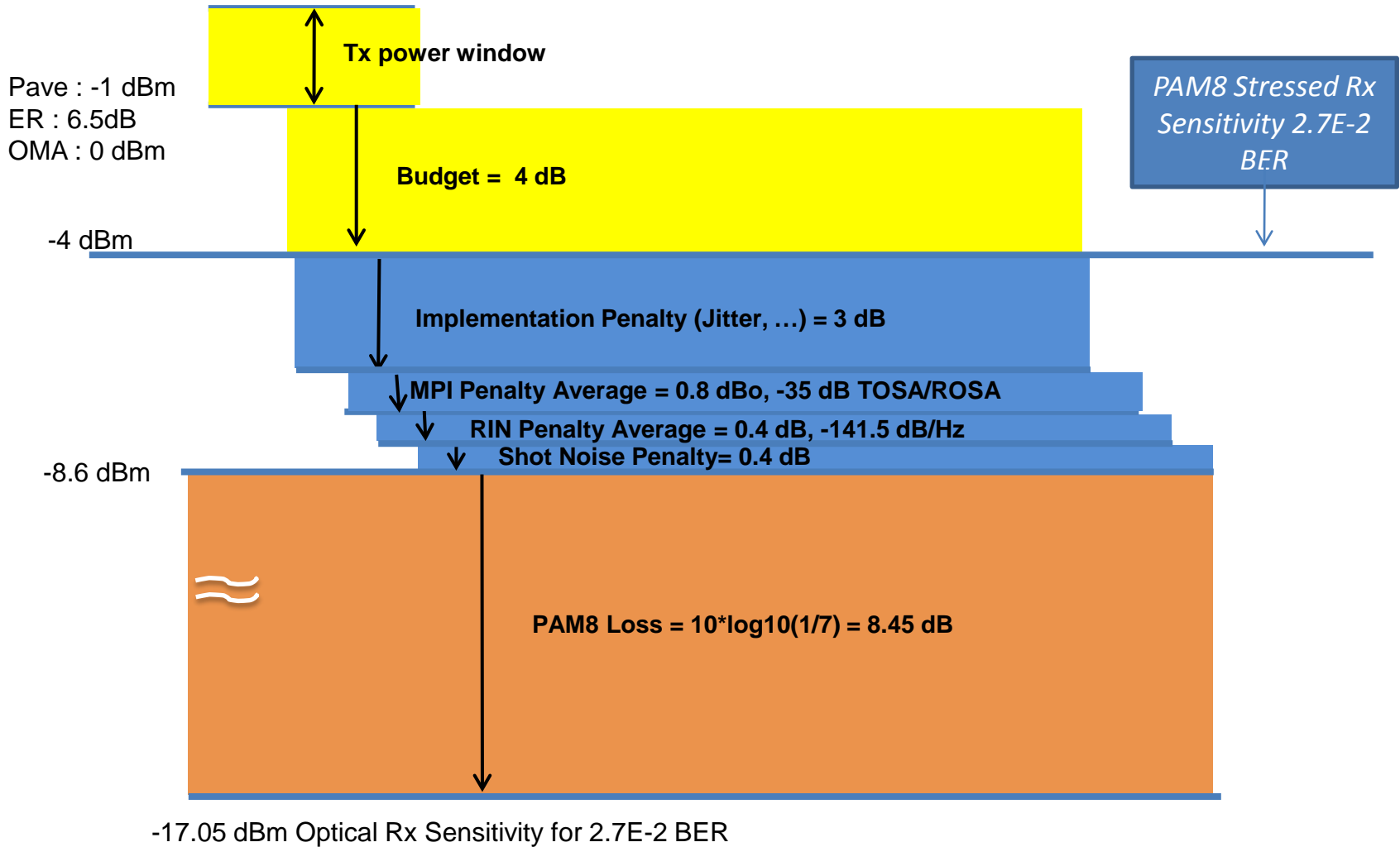


RIN Penalty

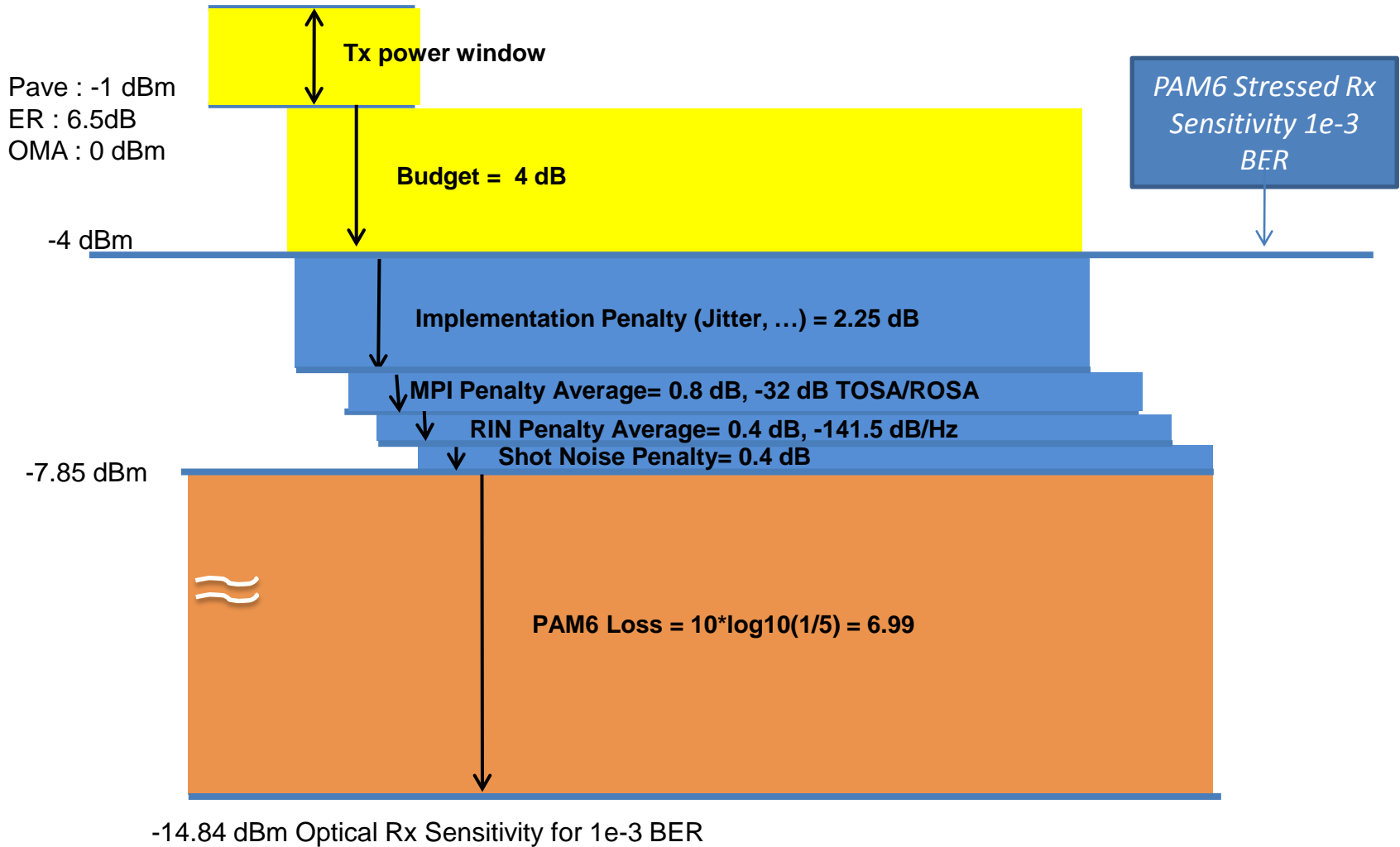
- Considering PAM-4, PAM-6, and PAM-8
 - To maintain ~ 0.4 dBo average optical penalty the required PAM-2 RIN is -137 dB/Hz and -141.5 dB/Hz for PAM-4 with $Q=4.1$ ($2.2E-5$), PAM-6 with $Q=3.1$ ($1e-3$), and PAM-8 with $Q=2.0$ ($2.2e-2$)



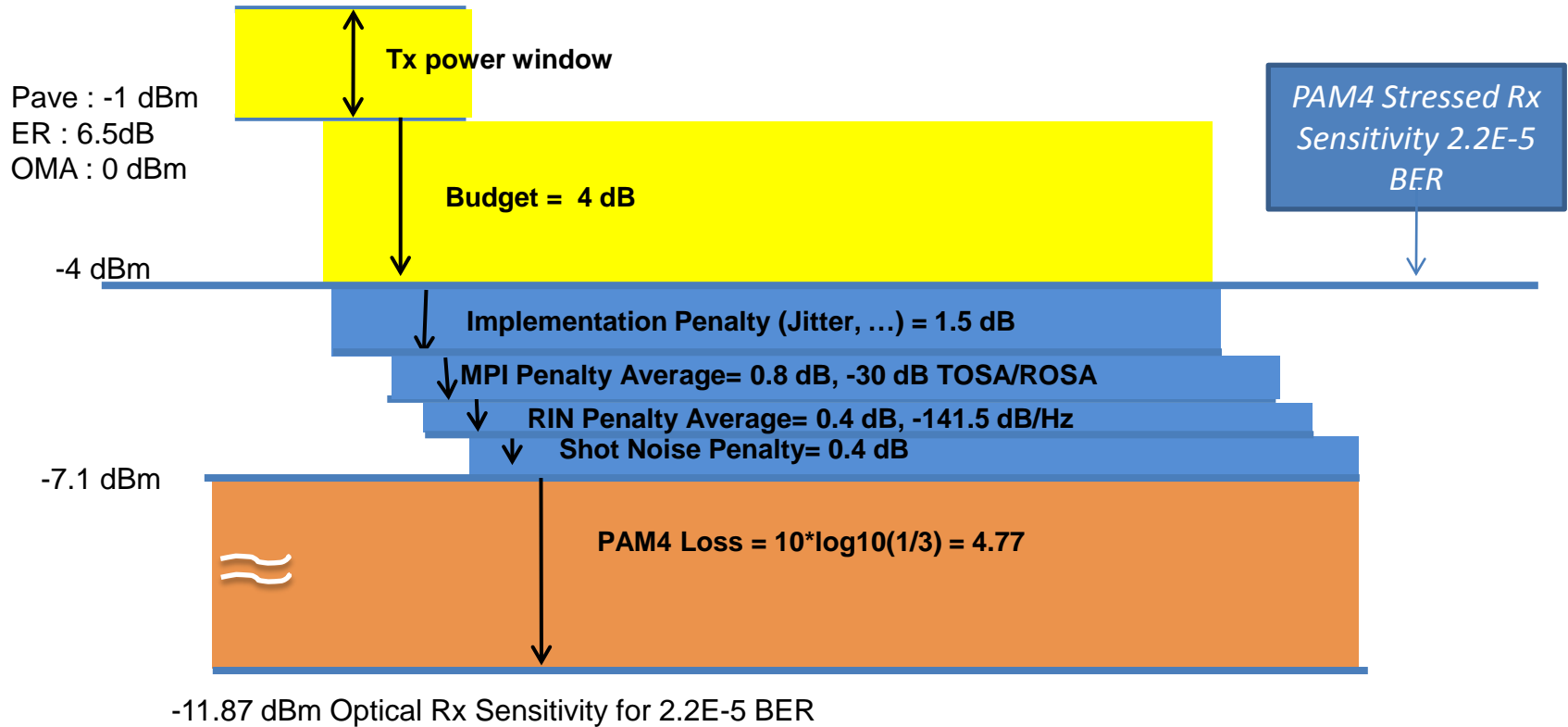
PAM8 Link Budget



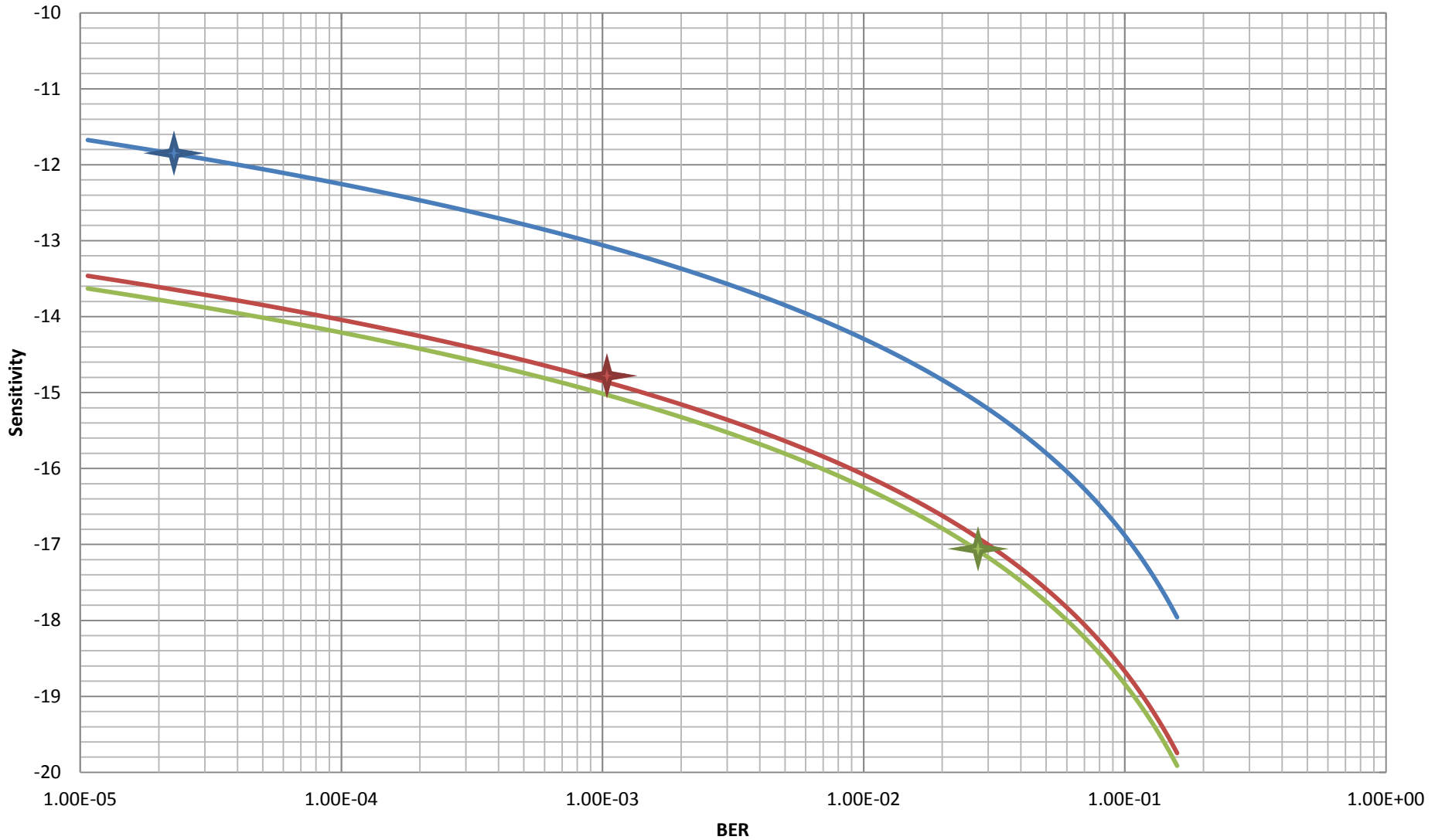
PAM6 Link Budget



PAM4 Link Budget



Sensitivity Curves



— PAM - 4 — PAM - 6 — PAM - 8

Summary

- **Bandwidth:** Lower rate / Higher order PAM signaling shows no appreciable relaxation of electro-optical bandwidth
 - Absolute deterministic eye opening consistent for a given bandwidth
- **Link Budget:** Higher order PAM requires higher quality optical connectors
 - -34 dB RL vs. -30 dB RL
 - Other RL combinations are possible where TOSA/ROSA may have different RL than connectors
- **Sensitivity:** Higher order PAM requires better receiver sensitivity.
 - Accounting for BER relaxation of higher order FEC
 - At approximately the same bandwidth as low order PAM
 - Lower order PAM like PAM-4 require about 20% faster than PAM-8 electronics but can operate with less complex electronics and lower latency
 - PAM-8 will have lower Baudrate ~20% but require more complex electronics
 - Less investigation to date PAM-6 might be a nice compromise between PAM-4 and PAM-8 by offering lower baudrate, latency, and penalty.