# Modulation Proposal

IEEE P802.3df 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet TF

24 February 2022

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Shannon Capacity Theorem Modulation Guidance

$$C = B \log_2 (1 + S/N)$$

SMF Client Channel (electrical dB)

Cu Chip-to-Chip Channel (max)
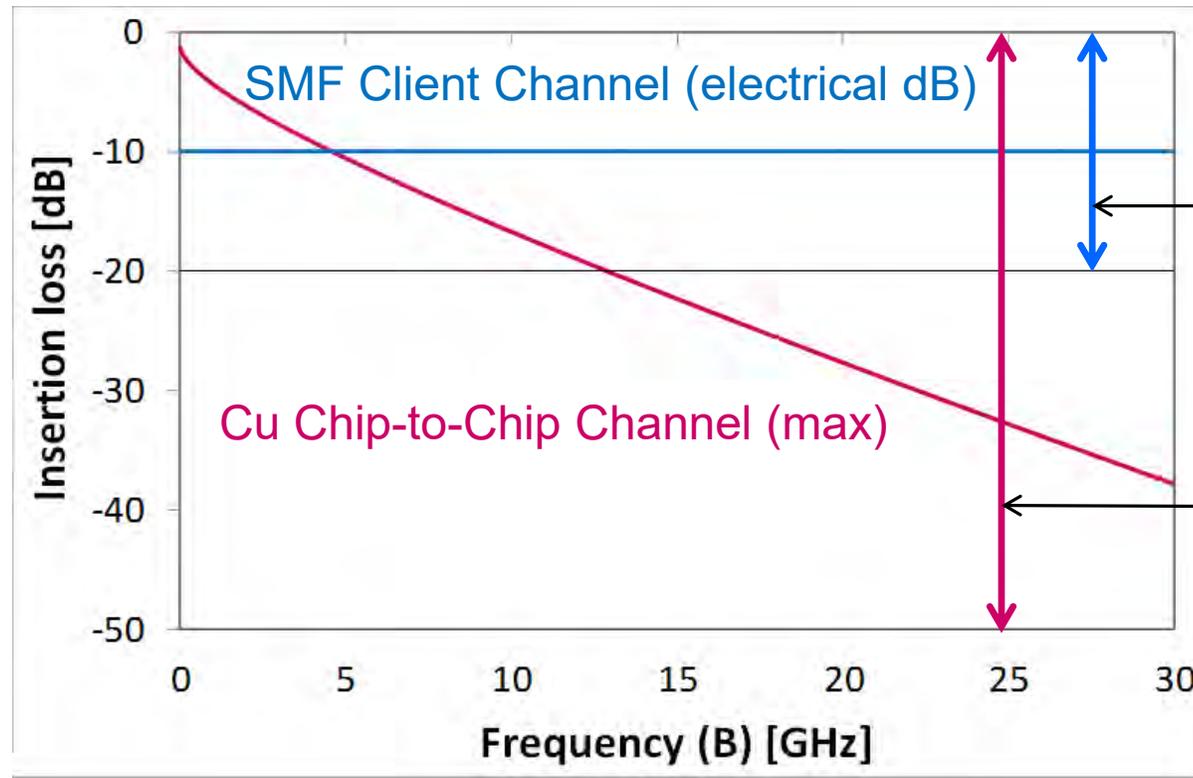
TRX BTB no FEC S/N type	Channel Freq (B)	TRX S/N	Shannon guidance
SMF	High	Low	NRZ
Cu (SerDes)	Low	High	PAM4

Cole, IEEE 802.3bs presentation, 12 Mar 2015

~3dB NRZ SNR Advantage over PAM4

NRZ (w /1dB offset)

PAM-4 (middle eye)
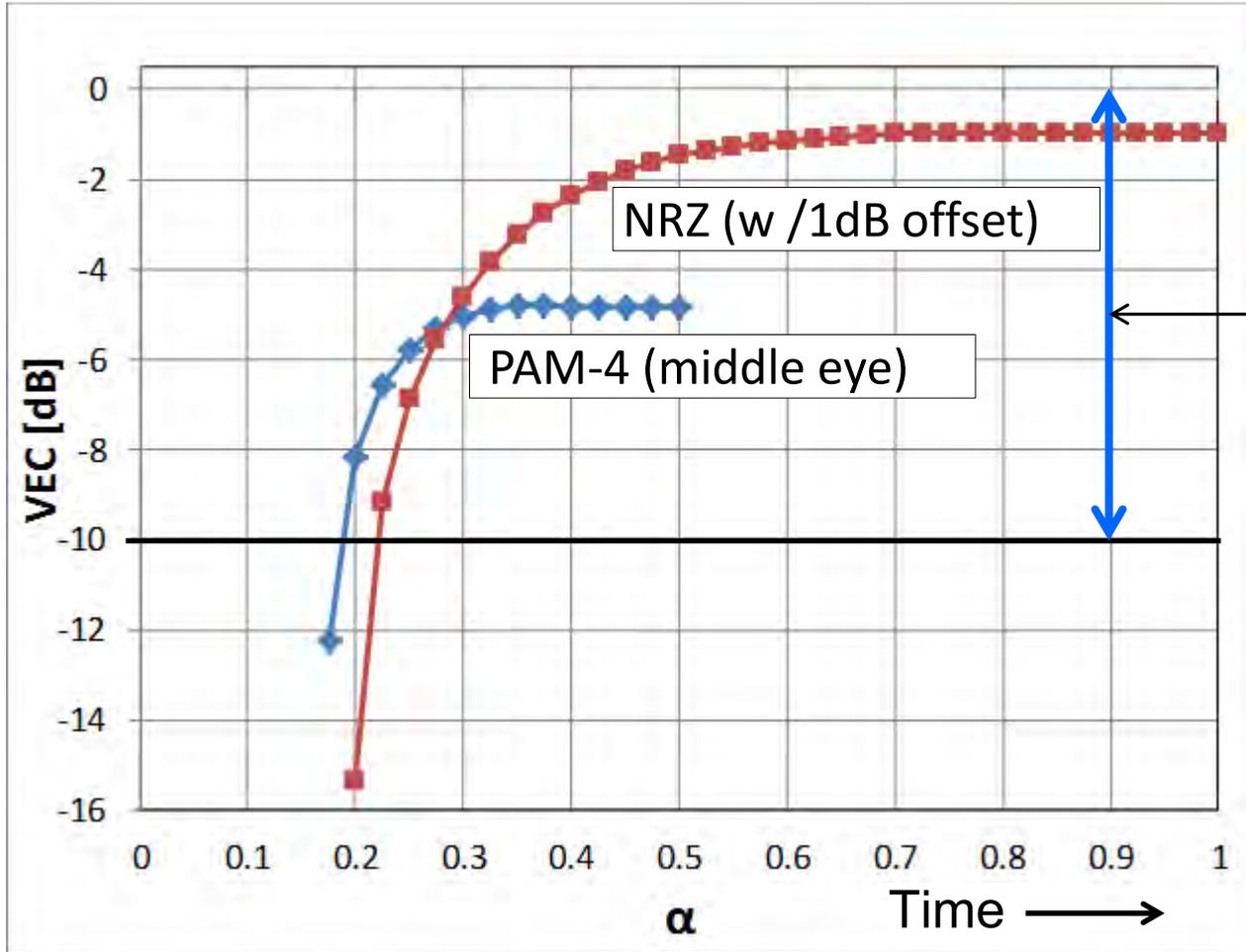
TRX S/N SMF

- BTB, no FEC

- noise penalty offsets VEC by ~1dB (B_{NRZ}/B_{PAM-4} dependent)

- $\alpha = B$ / bit-rate

Cole, IEEE 802.3bs presentation, 12 Mar 2015

Optics PAM4 Background

- 50Gb/s PAM4 development for ASIC SerDes and Cu channels started in 2012

- OIF standardized CEI-56G-VSR-PAM4 in 2014

- 802.3bs adopted 50Gb/s PAM4 for SMF channels in 2015:
  - Enabled reuse of 50G PAM4 SerDes technology
  - Reduced the cost & time to market of initial shipments
  - Chosen despite 50G NRZ being fundamentally the better long-term solution

- Predictably optical component bandwidth increased
  - 50GBaud technology, for 100G PAM4, is now mature and shipping in volume
  - 50Gb/s PAM4 3dB SNR, power, and cost penalties are permanently locked-in

- However, PAM4 for optics is an OK choice because of the technology ecosystem

Why not More of the Same?

- At some point, we really should listen to Shannon
- Higher order modulation is progressively more expensive
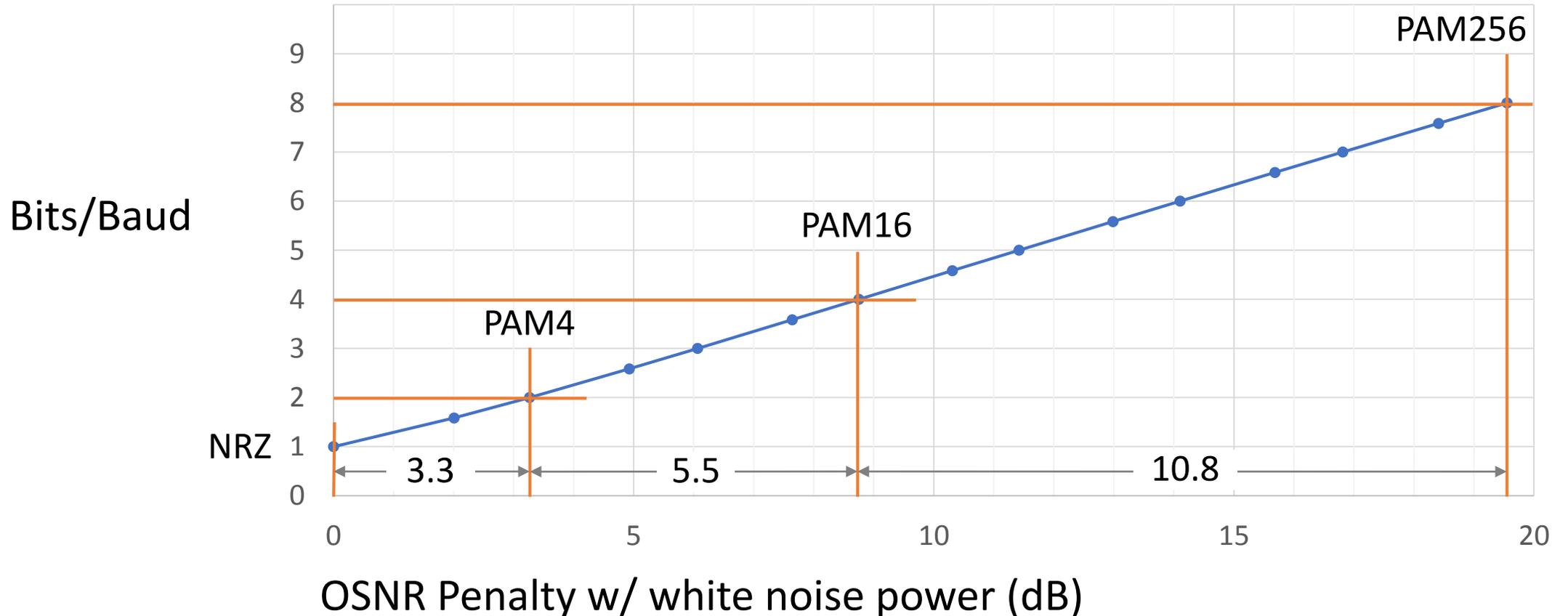
# Does Noise Type Matter?

Instead of white, let's consider linear vs. freq. noise signal (ex. capacitive cross-talk)

PAM256

PAM16

Bits/Baud

PAM4

NRZ

2.5

7.8

OSNR Penalty w/ linear vs. freq. noise signal (dB)
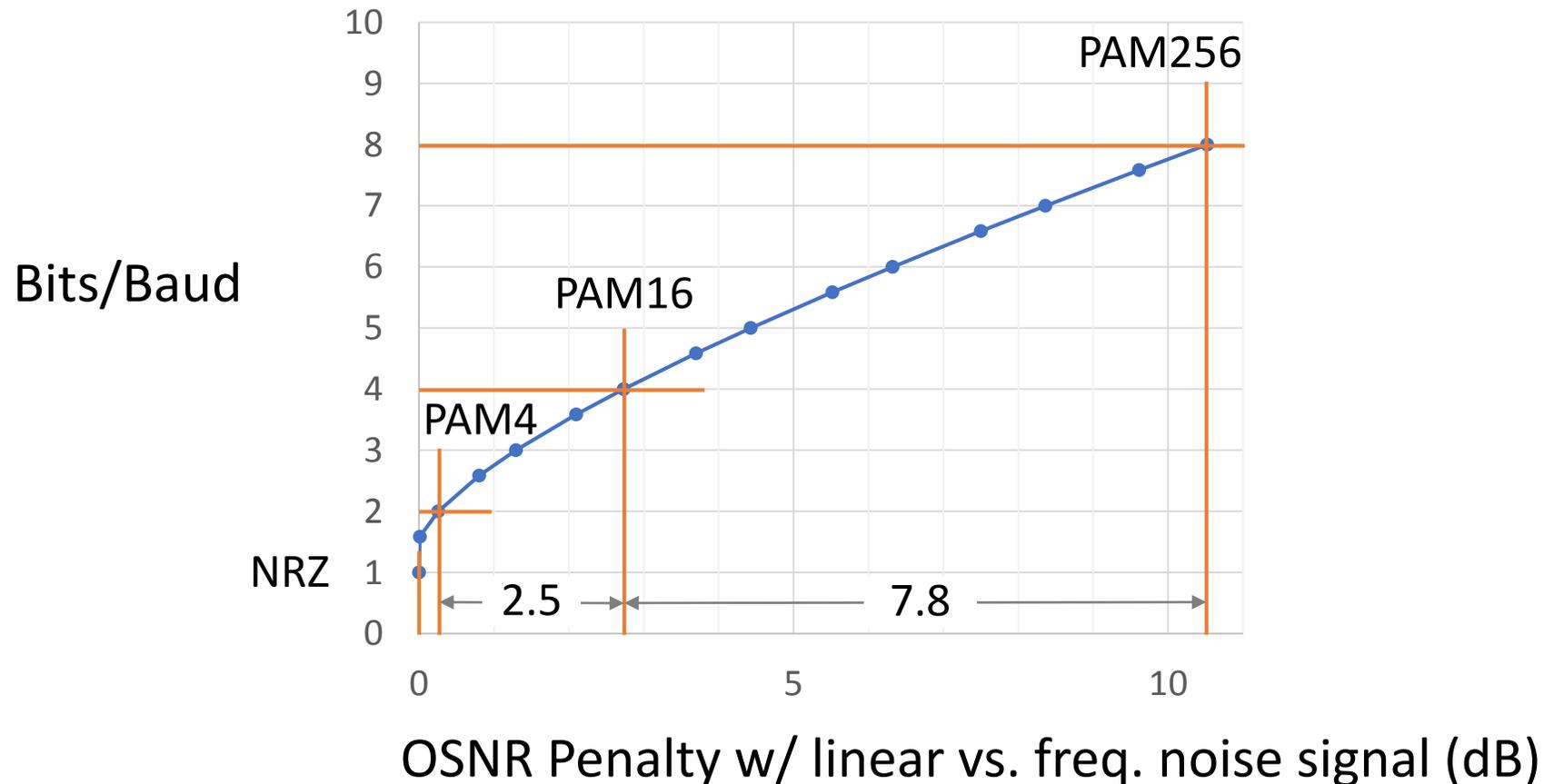
Below What BW is PAM6 Better than PAM4?

BER simulation parameters: 224Gb/s, white noise power spectral density (NPSD), 4th order BT filter, 9-tap RX FFE
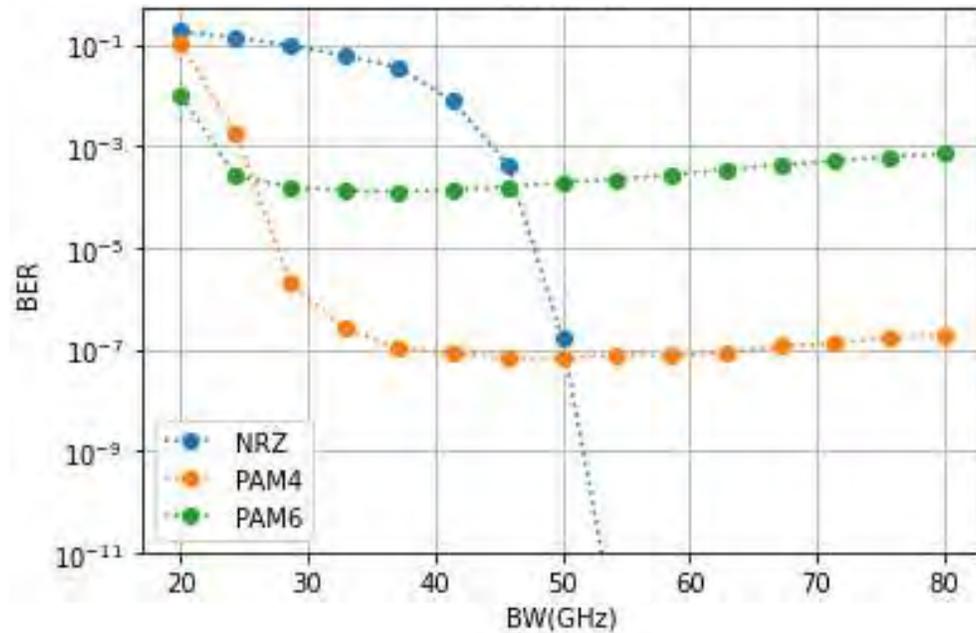
2.3x NSPD
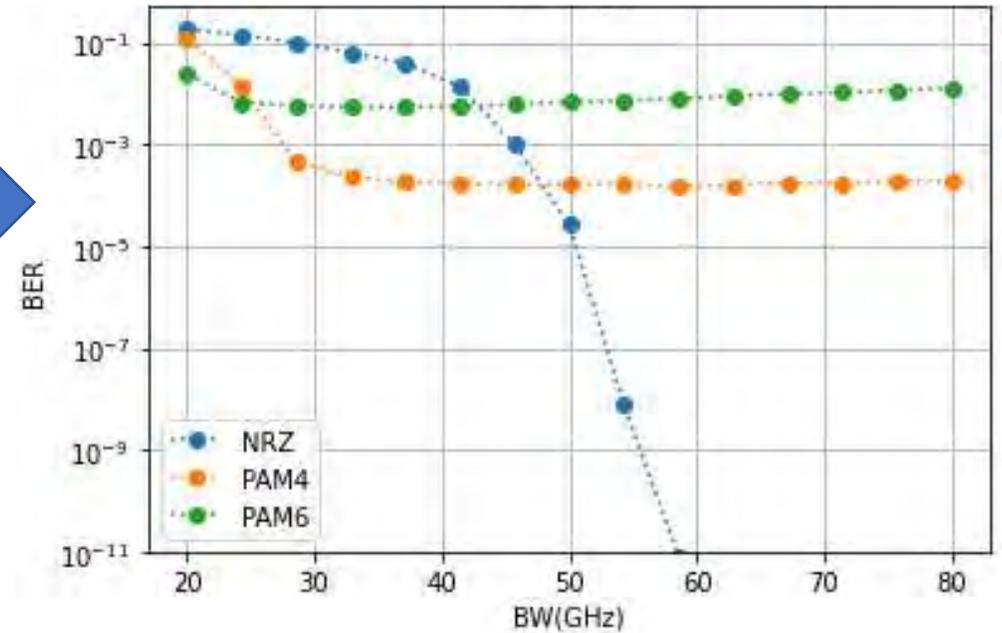
- 224Gb/s PAM6 is better than PAM4 below 25GHz BW
- This is not a useful operating region because the BER is excessive

Example Eyes

NRZ   PAM4   PAM6

BW = 80 GHz
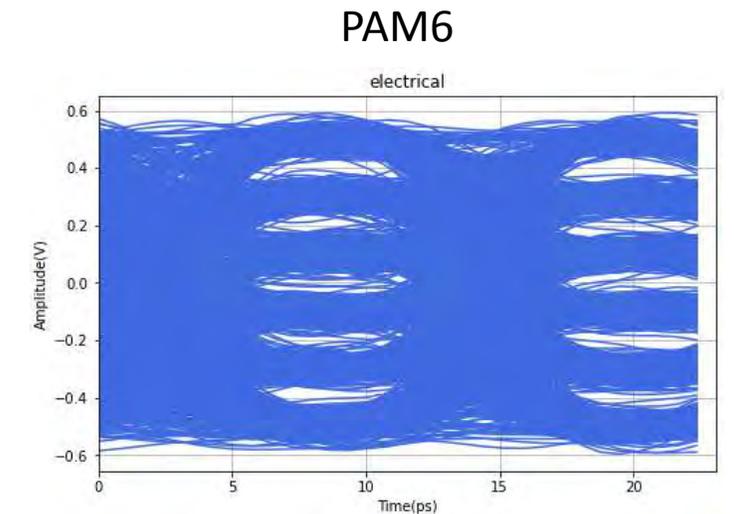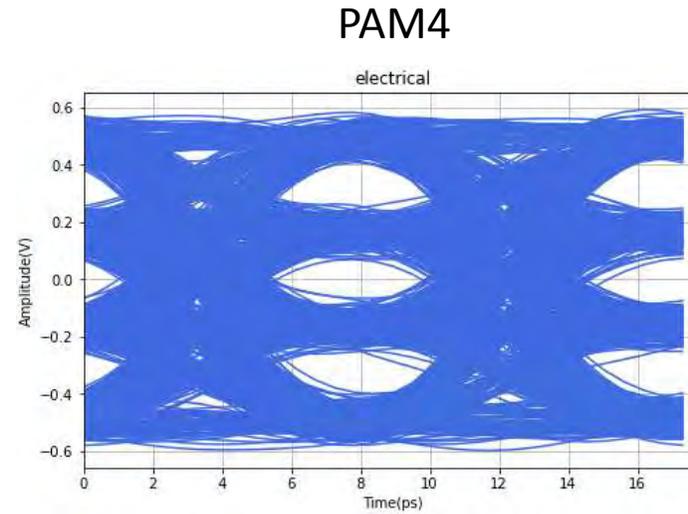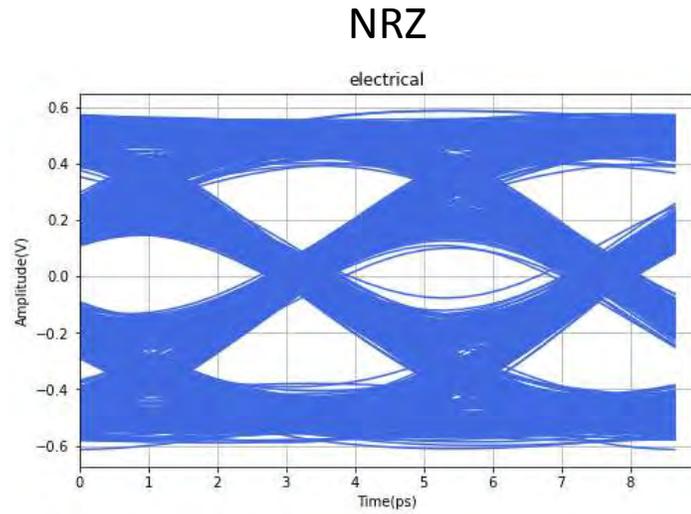
BW = 100 GHz
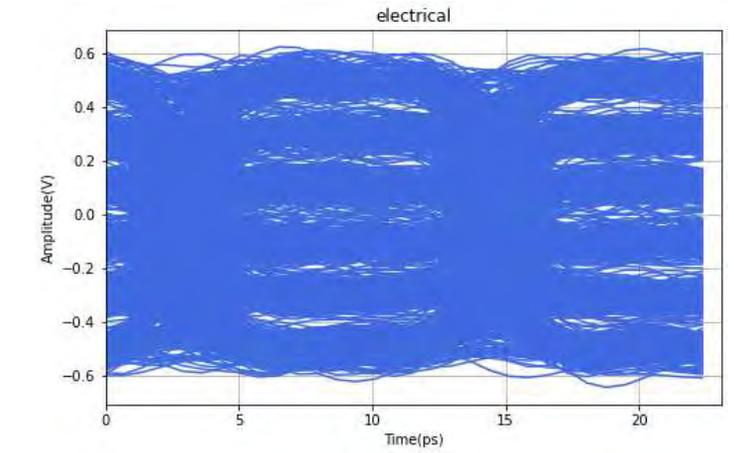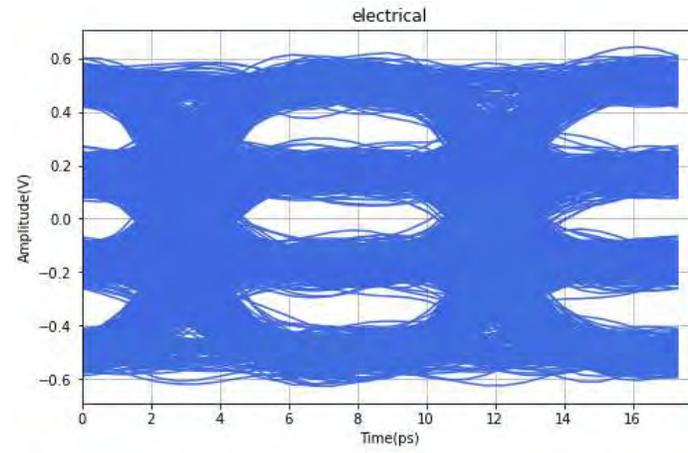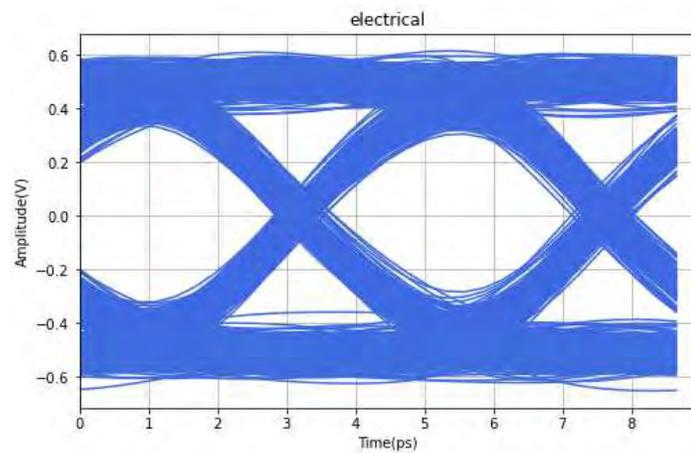
Modulation Proposal: Keep Optics PAM4

- 112GBaud will be mature when 224Gb/s per wavelength optics ship in volume

- PAM6 vs. PAM4 permanently locks-in additional 1.7dB OSNR penalty w/ white noise power (0.5dB OSNR penalty w/ linear vs. freq. noise signal)

- Because of the importance of technology ecosystem, C2M (VSR) should remain PAM4 (same argument used in .3bs), despite Cu BW limitation arguments

- What about high loss Cu channels (ex. CRn, KRn)?
    - baseline: PAM4
    - extended reach: PAM6
    - This is what 802.3bj did with KR4 and KP4, after a lengthy fight (let's avoid it)

- Additionally, PAM6 could be used for C2M with gearbox in the optics

Modulation Proposal

Thank you