SMF PMD Modulation Observations

400 Gb/s Ethernet Task Force

SMF Ad Hoc Conference Call

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IEEE

Finisar®

Shannon-Hartley Theorem

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

C ≜ Channel capacity

B ≜ Bandwidth

S ≜ Signal Power

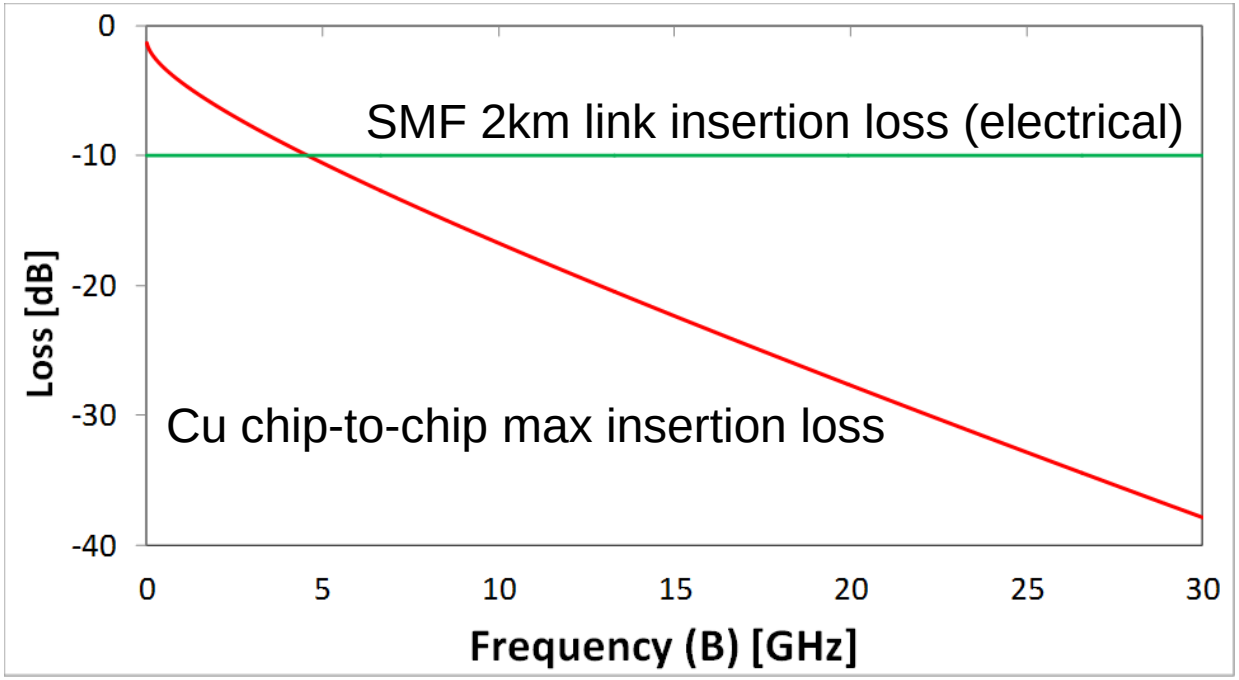
N ≜ Noise Power

Guidance to increase C:

- If B limited, increase S/N to support higher order modulation (HOM)
- If S/N limited, increase B to support higher Baud rate

Cu & SMF Client Channel Comparison

- Data points



- Observations
  - Cu channel is bandwidth (B) limited
  - SMF client channel is not bandwidth (B) limited

Cu & SMF Client Optics TRX S/N Comparison

- Data points
  - Cu SerDes S/N (BTB) = ~50dB (no FEC)
  - SMF DML TX, PIN RX client optics S/N (BTB) = ~16dB (electrical, no FEC)
- Observations
  - Cu TRX is not S/N limited
  - SMF client optics TRX is S/N limited

Results Summary

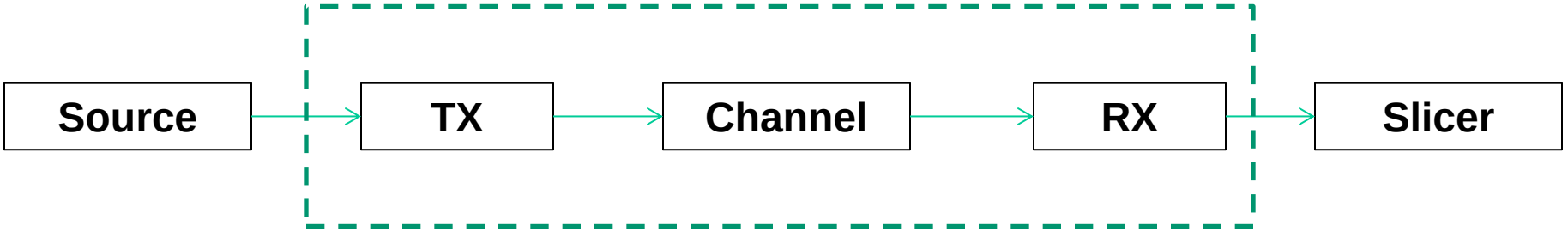
- To increase C:
  - If B limited, increase S/N to support higher order modulation (HOM)
  - If S/N limited, increase B to support higher Baud rate
- Observations:

Channel	Limitation		Modulation Guidance
	Channel B	TRX S/N	
Cu	Yes	No	HOM
SMF Client	No	Yes	NRZ

Fiber Bandwidth Limited Channel Examples

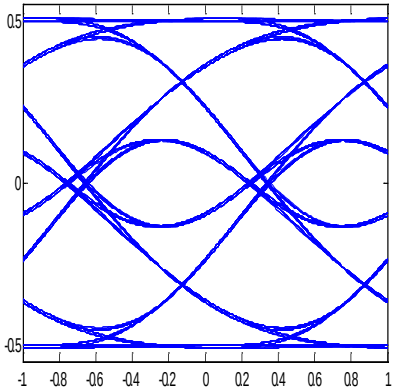
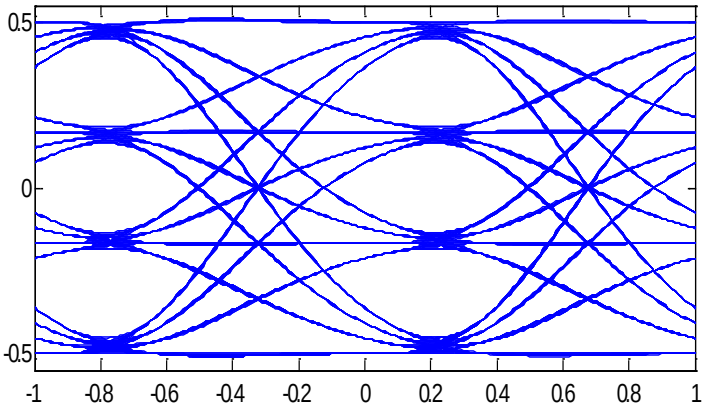
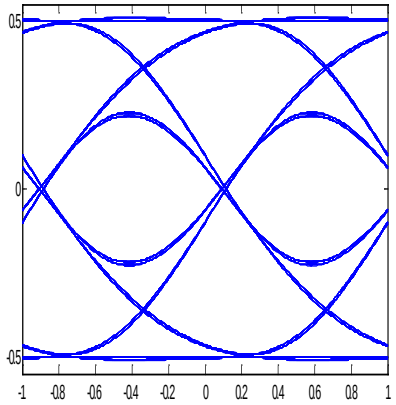
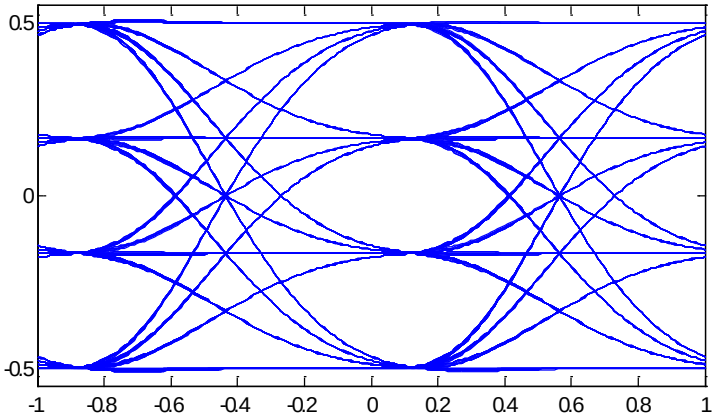
- SMF DWDM Transport
  - B = 50GHz
  - 100G/λ modulation: DP-QPSK
- MMF client
  - B = ~2GHz/km (OM3)
  - B (100m) = ~20GHz
  - ~2x for OM4
  - Very different from SMF client channel
  - 50G/λ modulation: PAM-4 is a good candidate (although NRZ has been demonstrated)
- Common modulation format across all channel types at 50G and higher per lane bit rate is not optimal

Ideal SMF Client System Model

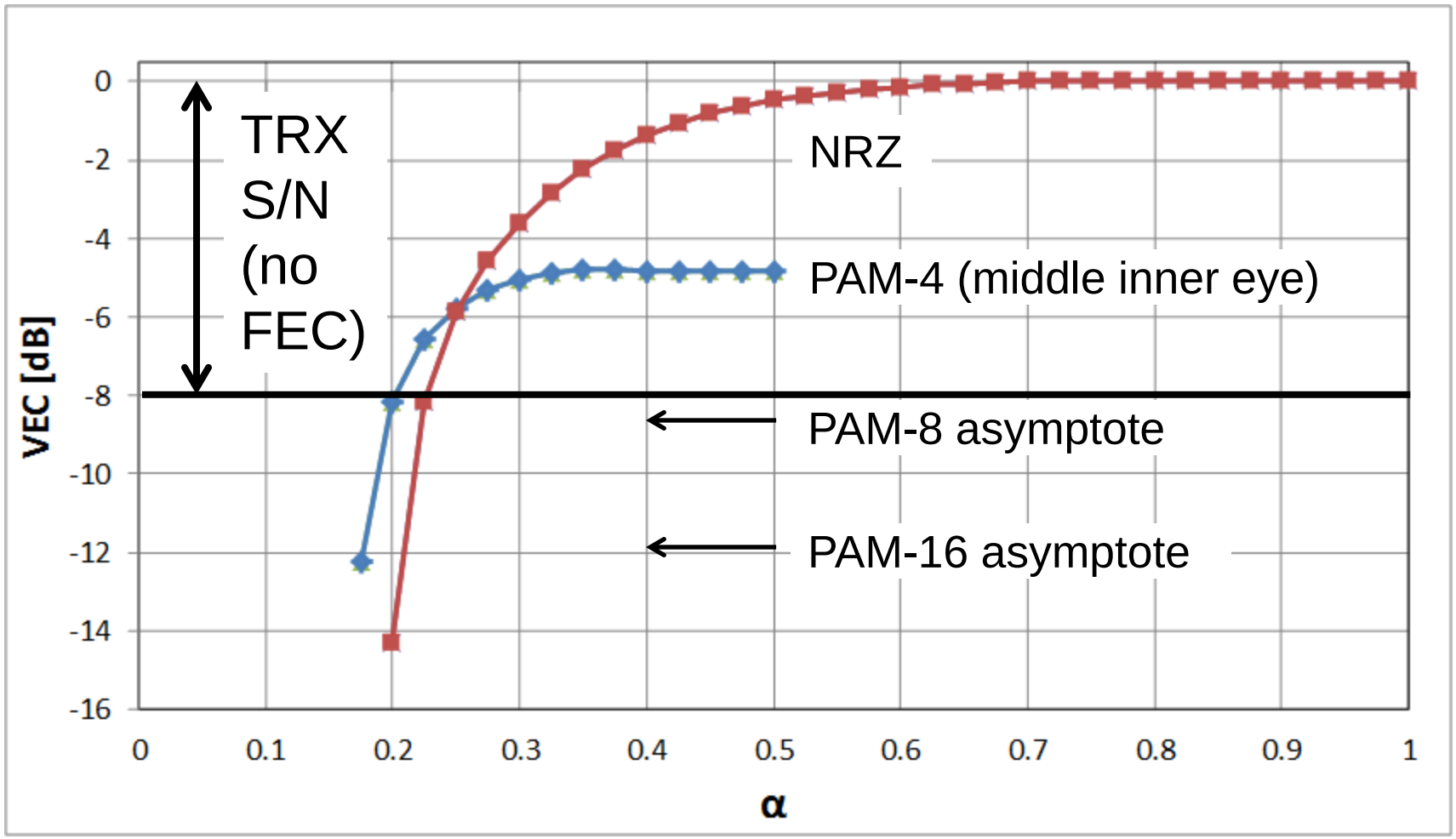


- SMF Client channel assumed ideal
- TX ∗ Channel ∗ RX modelled as 4^{th} order BT filter
- B = α bit-rate
- Ex. bit rate = 56G
  - α = 0.25 → B = 14GHz
  - α = 0.30 → B = 17GHz

Slicer Input Eyes of Ideal SMF Client System

	NRZ	PAM-4
α = 0.25 (14GHz)		
α = 0.30 (17GHz)		

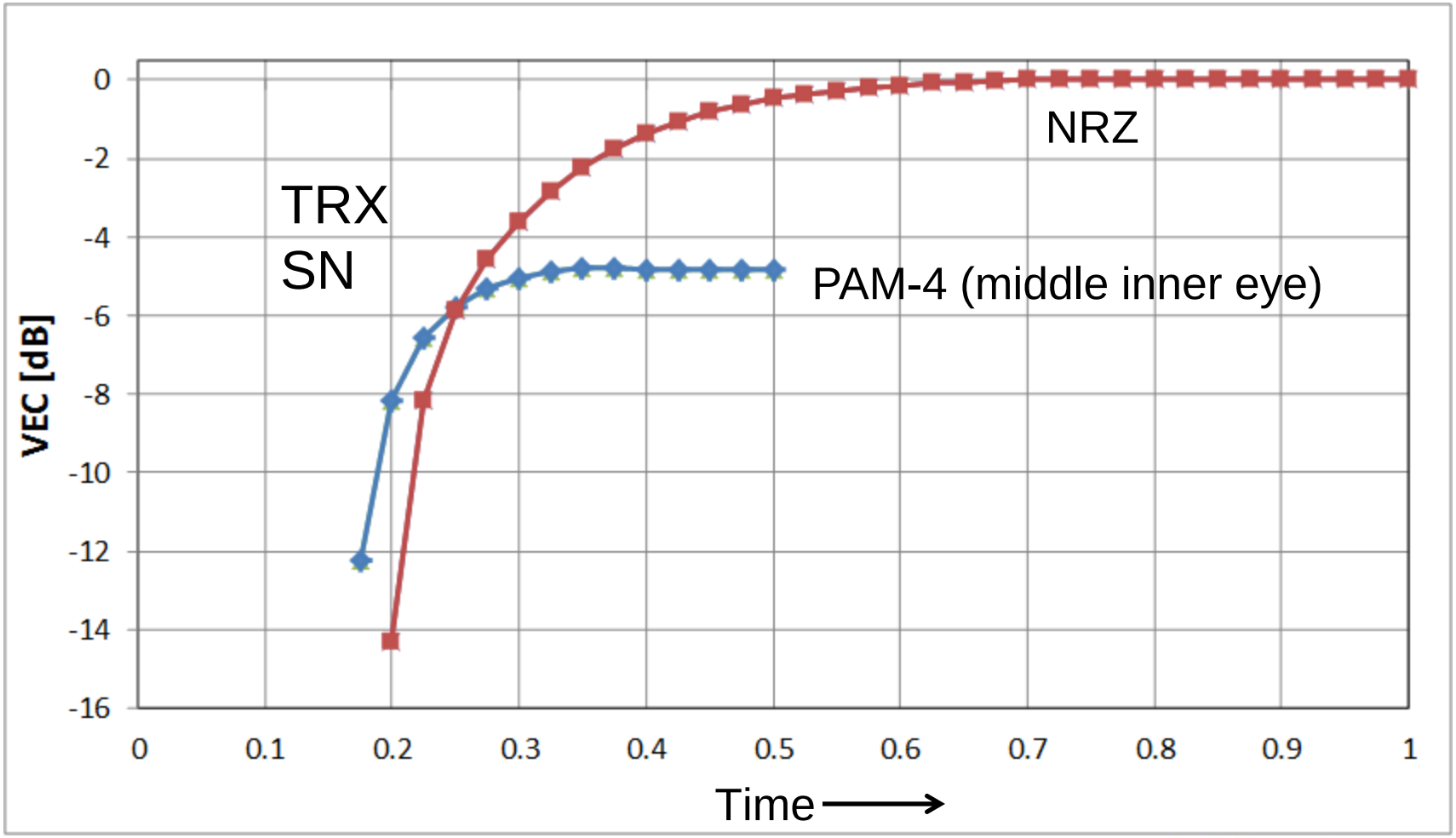
Vertical Eye Closure at Slicer Input



Noise penalty offsets VEC by ~1dB depending on B_{NRZ}/B_{PAM-4}

VEC & Component Bandwidth

VEC improves with component bandwidth which improves over time, so Time can equivalently be the x-axis variable



Component Bandwidth Observations

- "Serial wins over time" example statements:
  - "The general consensus (including CWDM advocates) is that serial will be cost effective in long term." (p.14)

    Matt Traverso, et. al, "40GbE 10km SMF Objective: Serial", IEEE 802.3ba Task Force, July 14-17, 2008
  - "All optical technologies have matured (are maturing) over time to the lowest size, cost, power" (p.2)

    Gary Nicholl, "100Gb/s Single Lambda Optics –Why ?", OIDA 100GbE per Lambda for Data Center Workshop, June 12-13 2014
- "Serial wins over time" is equivalent to stating that component bandwidth increases over time
- All of the arguments and evidence, including SMF PMD examples used in support of "Serial wins over time", apply equally to: "NRZ wins over time"

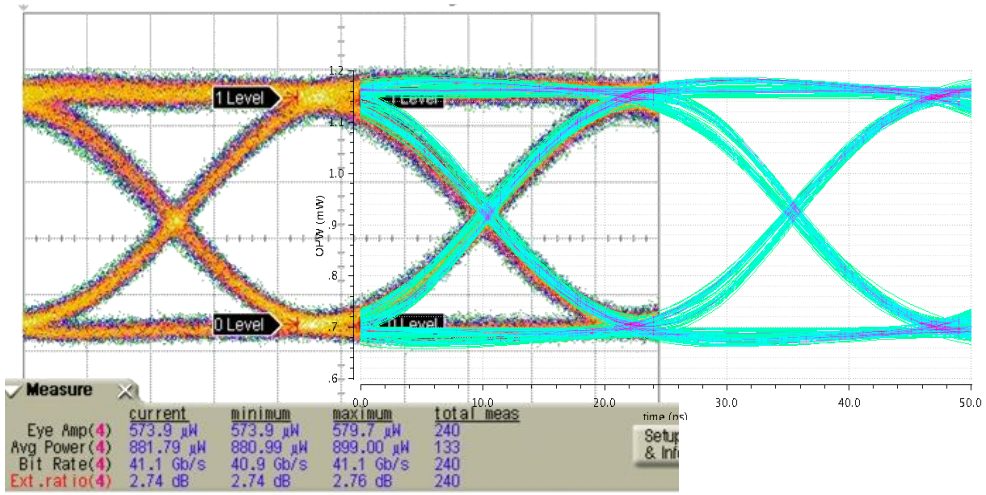
Component Bandwidth Timing Questions

- Example component bandwidth timing question:
  - "The discussion is not if 100Gb/s single lambda is compelling but when … is it technically feasible ?" (p.4)

    Gary Nicholl, "100Gb/s Single Lambda Optics –Why ?", OIDA 100GbE per Lambda for Data Center Workshop, June 12-13 2014
- 50G/λ SMF Q&A
  - Q: When is 50Gb/s single lambda NRZ technically and economically feasible?
  - A: Now; see following pages

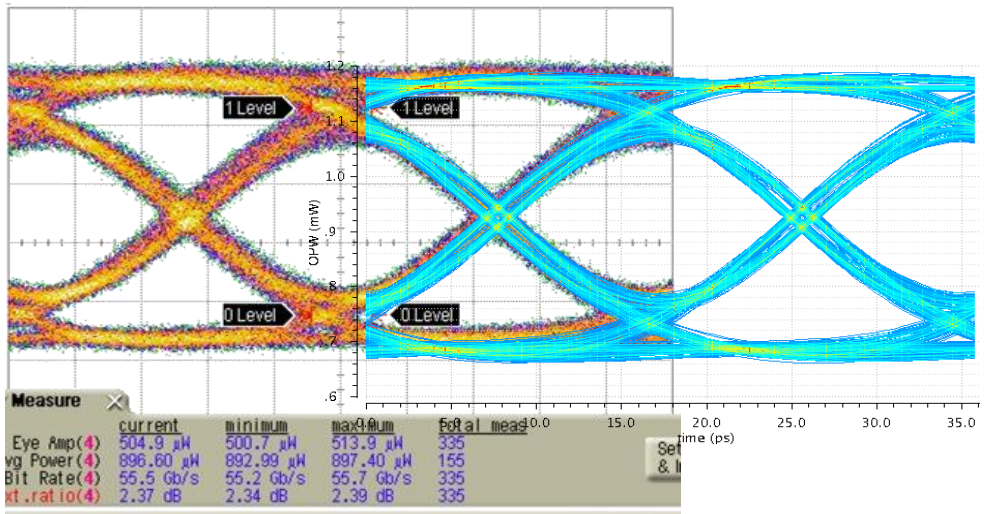
    (Although it was not in 2000 and 2008)
- 100G/λ SMF Q&A
  - Q: When is 100Gb/s single lambda NRZ technically and economically feasible?
  - A: Not now, but likely >2020

50G NRZ SiP PIC TX Data Example



40Gb/s, PRBS9 TX optical eye diagram at π/2 bias:

- Measurement data,
- Simulation

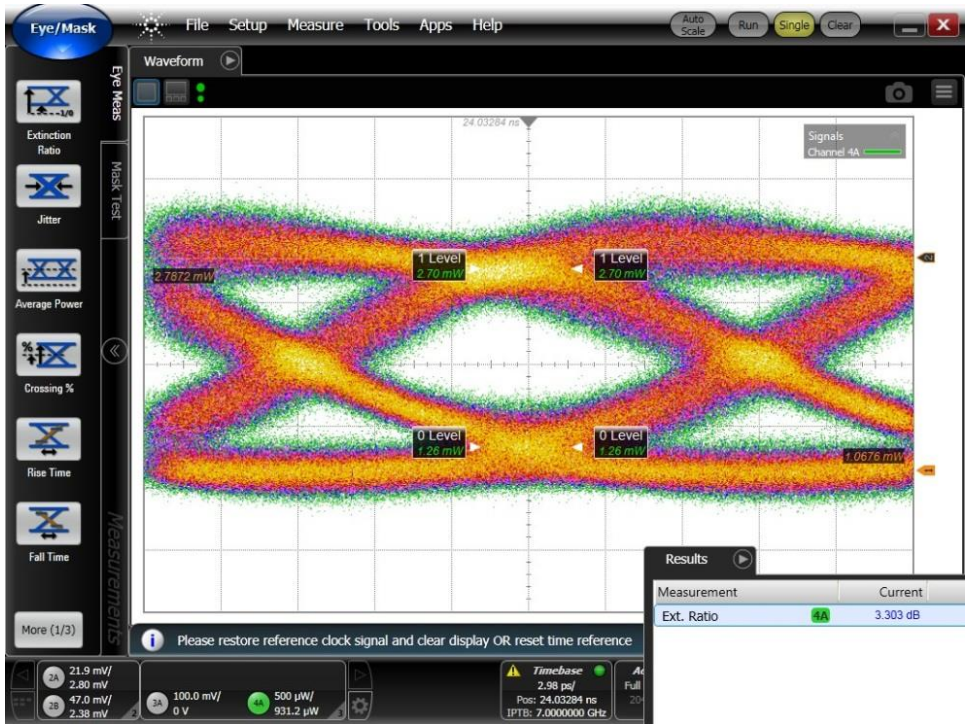


56Gb/s, PRBS9 TX optical eye diagram at π/2 bias:

- Measurement data,
- Simulation

Finisar 2x50G hybrid SiP PIC fabricated at ST Microelectronics

50G NRZ DML TX Data Example



56Gb/s, PRBS15 TX, 65mA bias, 50ºC Finisar DML chip

- Detailed results submitted for publication as OFC-2015 post-deadline paper
- 50G NRZ EML data presented by K. Kojima, et. al.

Discussion

- For SMF client interfaces, NRZ is the preferred choice unless it's not feasible
- Over time, NRZ optics margins improve and cost drops
- HOM, like PAM-4, permanently locks in S/N penalty which never goes away, even as components improve
- Multiple factors not in this presentation include:
  - Dispersion Penalty
  - MPI
  - other
- Data to be presented includes:
  - TX power
  - RX sens.
  - TDP, including Dispersion
  - other

SMF PMD Modulation Observations

Thank you