SMF PMD Modulation Observations

400 Gb/s Ethernet Task Force

802.3 Plenary Session

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IEEE

Finisar®

Introduction

BTIs:

- C2C

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=9

- 10km SMF PMD

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=13

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=14

- 2km SFM PMD

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=19

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=20

http://www.ieee802.org/3/bs/public/15_01/big_ticket_items_3bs_01_0115.pdf#page=21

Shannon-Hartley Theorem

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

C ≙ Channel capacity

B ≙ Bandwidth

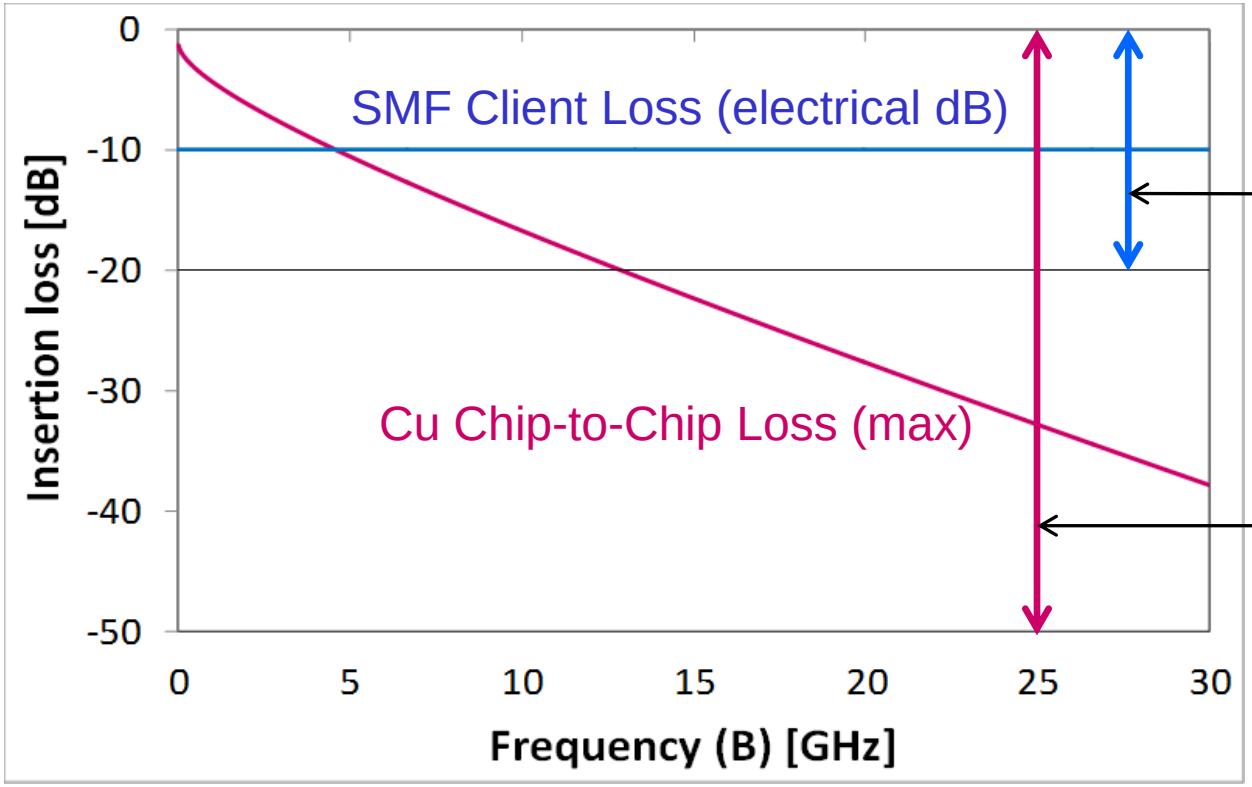
S ≙ Signal Power

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 vs. SMF Client: Channel Loss & TRX S/N



S/N (BTB) [dB]
SMF client TRX
(DML or EML, PIN, no FEC)

S/N (BTB) [dB]
Cu SerDes
(no FEC)

Limitation	Channel B	TRX S/N
Cu C2C	Yes	No
SMF Client	No	Yes

Results Summary

Guidance to increase C:

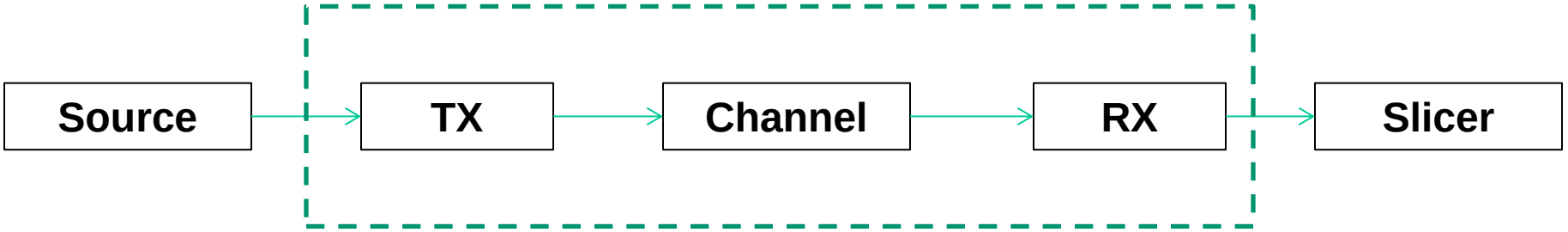
- If B limited, increase S/N to support higher order modulation (HOM)
- If S/N limited, increase B to support higher Baud rate

Interface	Limitation		Modulation Guidance
	Channel B	TRX S/N	
Cu C2C	Yes	No	HOM
SMF Client	No	Yes	NRZ

Fiber Bandwidth Limited Channel Examples

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

Ideal SMF Client System Model



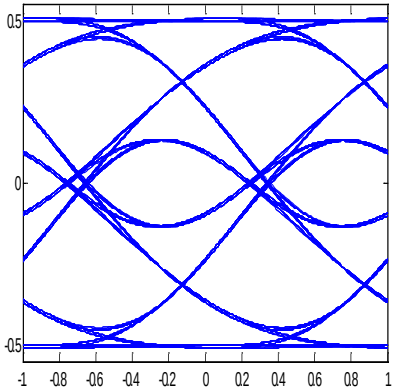
- SMF client channel assumed ideal
- (TX ∗ Channel ∗ RX) modelled as 4^{th} order BT filter
- B = α bit-rate
- Ex. bit rate = 56Gb/s
  - ex. 1: α = 0.25 → B = 14GHz
  - ex. 2: α = 0.30 → B = 17GHz

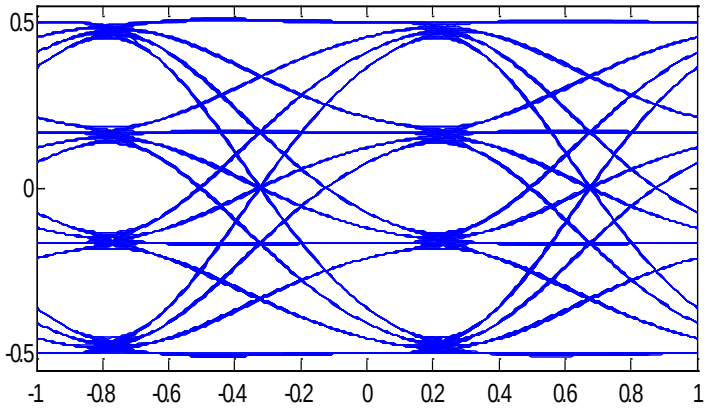
Slicer Input Eyes of Ideal SMF Client System

NRZ

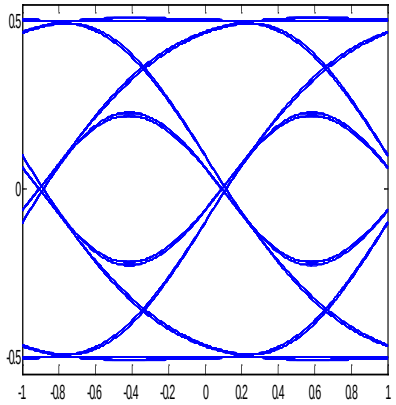
PAM-4

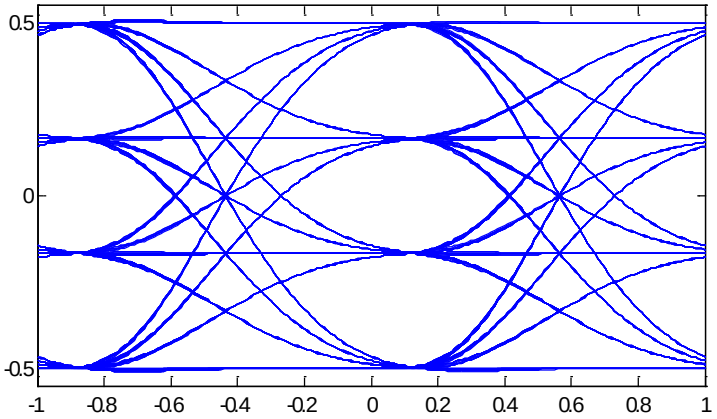
ex. 1
α = 0.25
(14GHz)



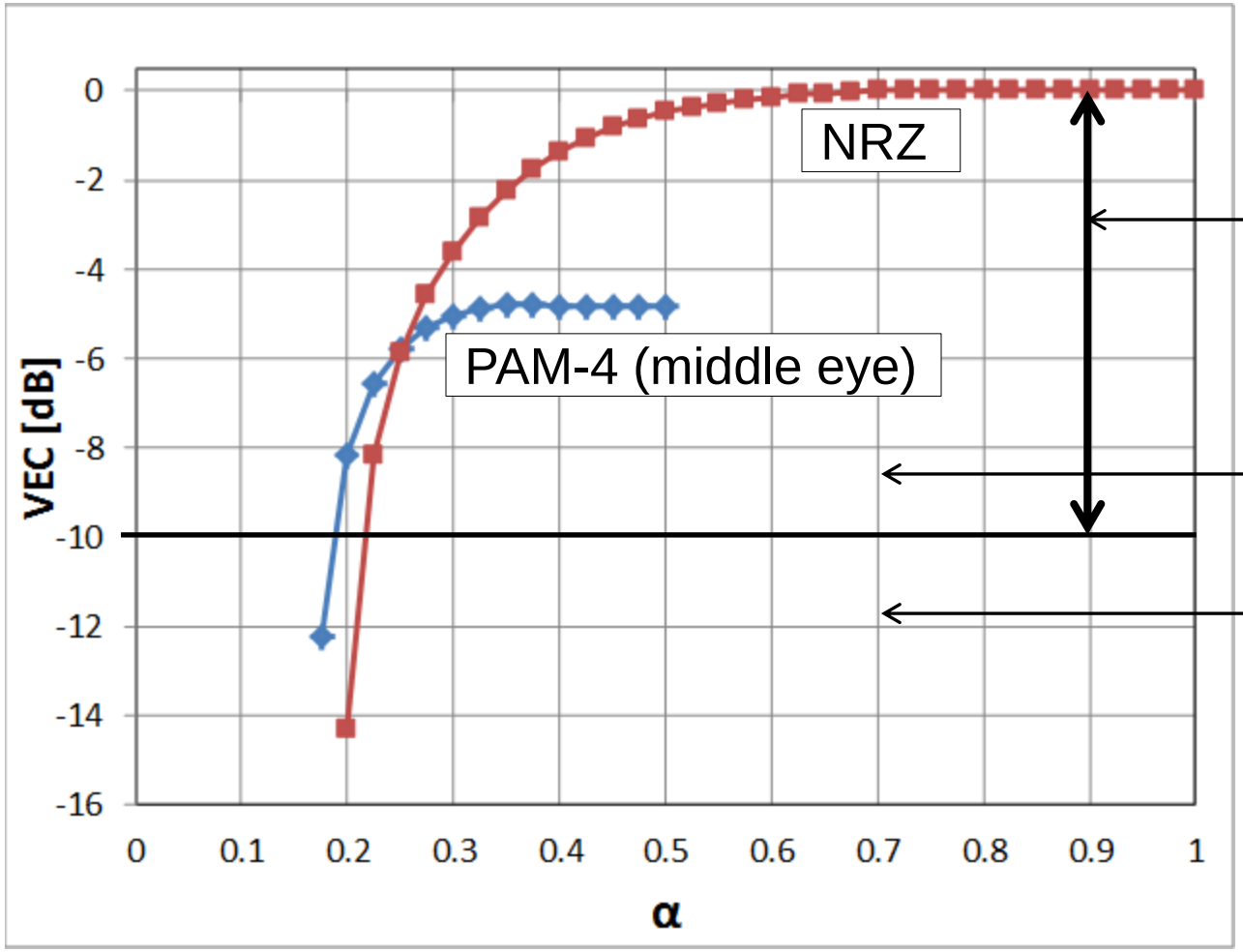


ex. 2
α = 0.30
(17GHz)





Vertical Eye Closure at Slicer Input



S/N (BTB) [dB]
SMF client TRX
(DML or EML, PIN, no FEC)

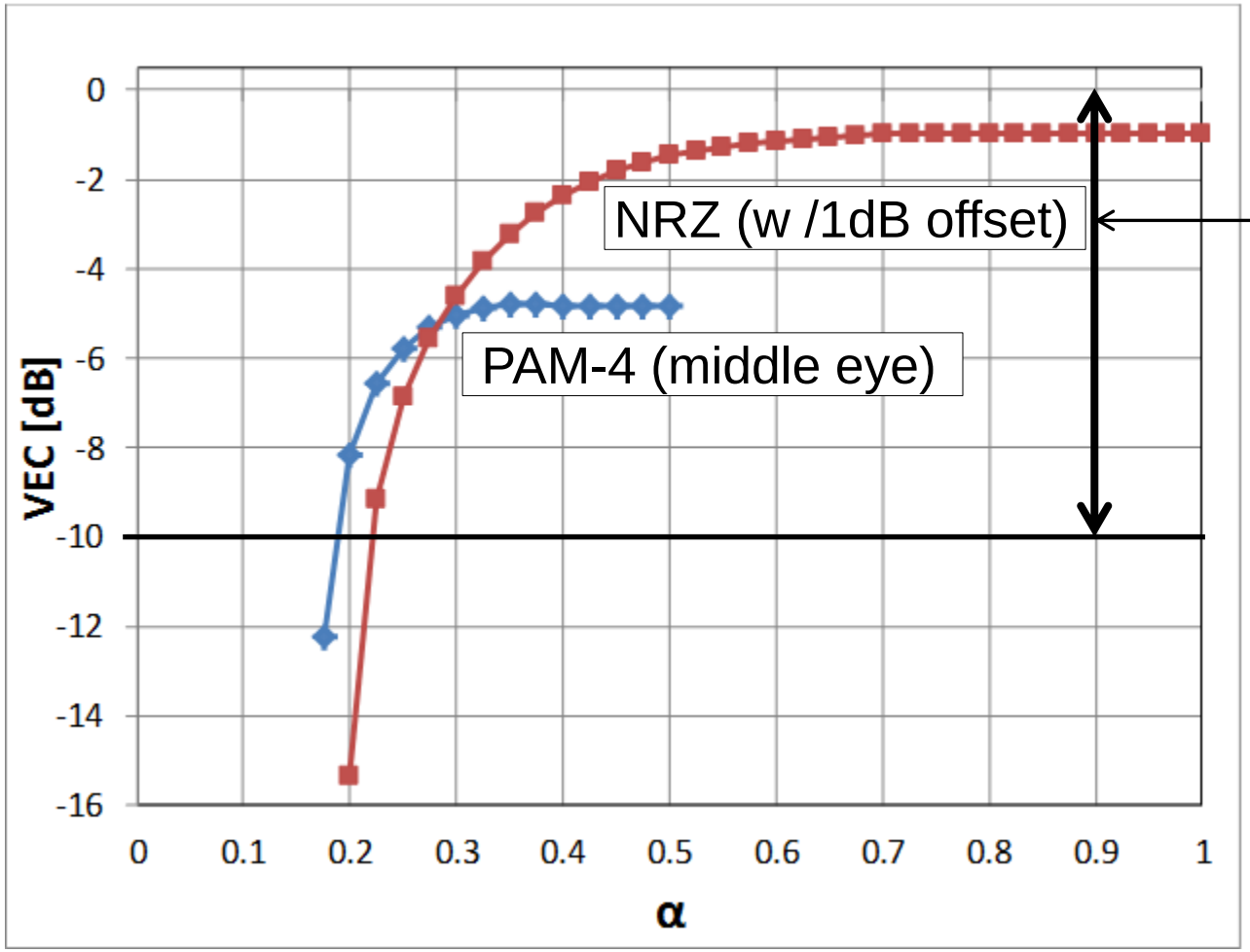
DMT QAM-16 & PAM-8 asymptotes*

PAM-16 asymptote*

*Ideal SNR penalties cole_3bs_01_0914

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

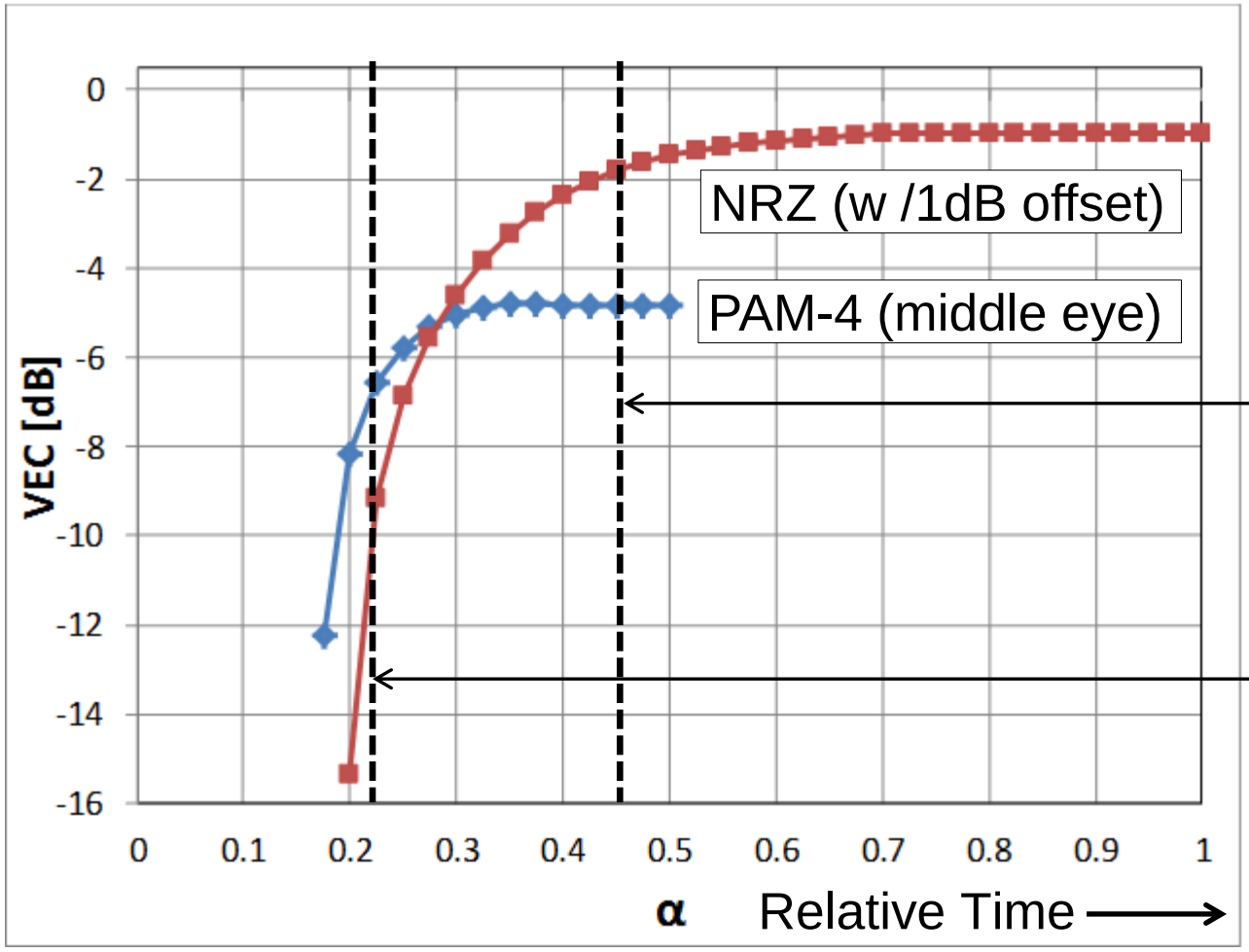
Vertical Eye Closure at Slicer Input w/ Offset



S/N (BTB) [dB]
SMF client TRX
(DML or EML, PIN, no FEC)

Component Bandwidth & VEC

VEC improves with component bandwidth which increases over time. So equivalently Time can be the x-axis variable.



α ≈ B/56Gb/s SMF client TRX (today w/ strong TX & RX EQ)

α ≈ B/112Gb/s SMF client TRX (today w/ strong TX & RX EQ)

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" because component bandwidth and optics margin (among others) increase over time
- The arguments and SMF PMD examples used in support of "Serial wins over time", apply equally to: "Serial NRZ wins over time"

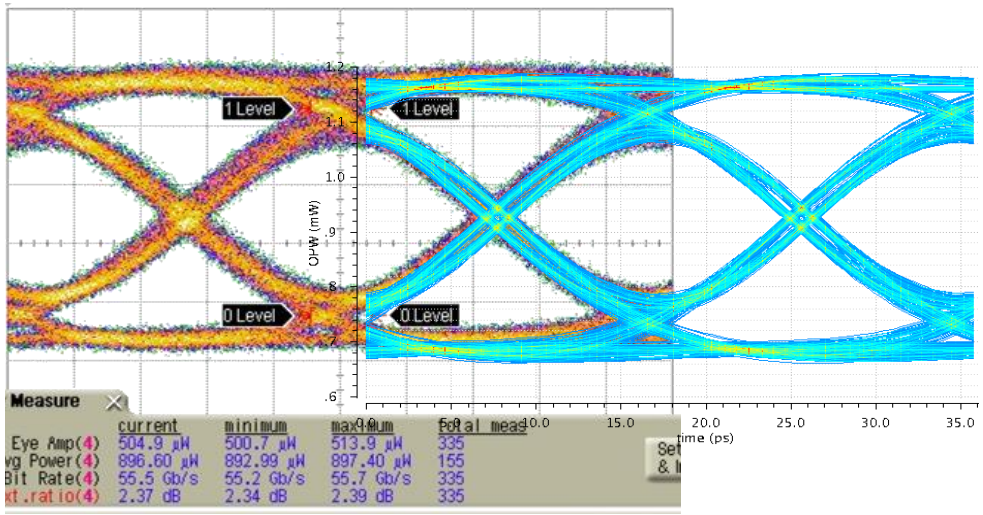
50G Component Bandwidth Timing

- When is 50G NRZ SMF λ technically feasible and cost effective?
- Not in 2000: 40G Serial NRZ spec. (OC768) premature
- Not in 2008: 4x10G WDM specified
- Not in 2013: 50G Serial PAM-4 considered
- **Now**: see data on following pages

100G Component Bandwidth Timing

- When is 100G NRZ SMF λ technically feasible and cost effective?
- Not in 2008: 4x25G NRZ LWDM specified
- Not in 2013: 4x25G NRZ CWDM & PSM4 specified
- **Not Now**: 2x50G NRZ WDM, 100G Serial PAM-4, 100G Serial DMT under consideration
- >2020

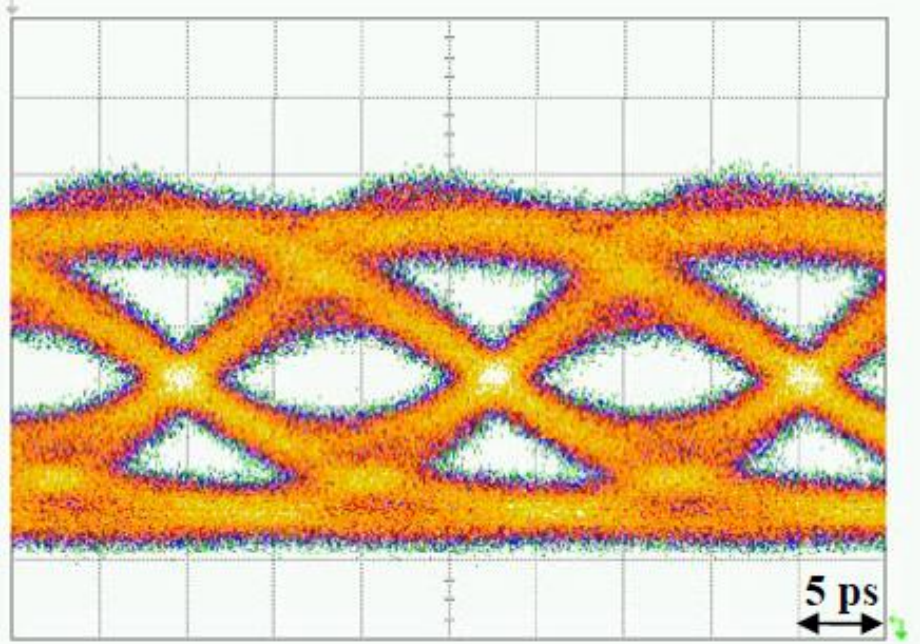
Finisar 56Gb/s NRZ SiPIC CWL-Modulator



- Optical DCA eye
- 56Gb/s
- PRBS9
- Red: Measurement
- Blue: Simulation

- Finisar 2x50G hybrid SiPIC fabricated at ST Micro
- ECOC 2014 paper, PD.2.4 has technical details
- RX Sens. 56G (OMA) = -6dBm (@ 1e-5) (41G = -9.5dBm)
- SiP TX suitable for 50G NRZ λ WDM applications with λ specific CW lasers and grating couplers, with external Mux
- SiP RX unsuitable for 50G λ WDM apps. like 2km or 10km 400Gb/s Ethernet (OK for 50G NRZ 500m PSM apps.)

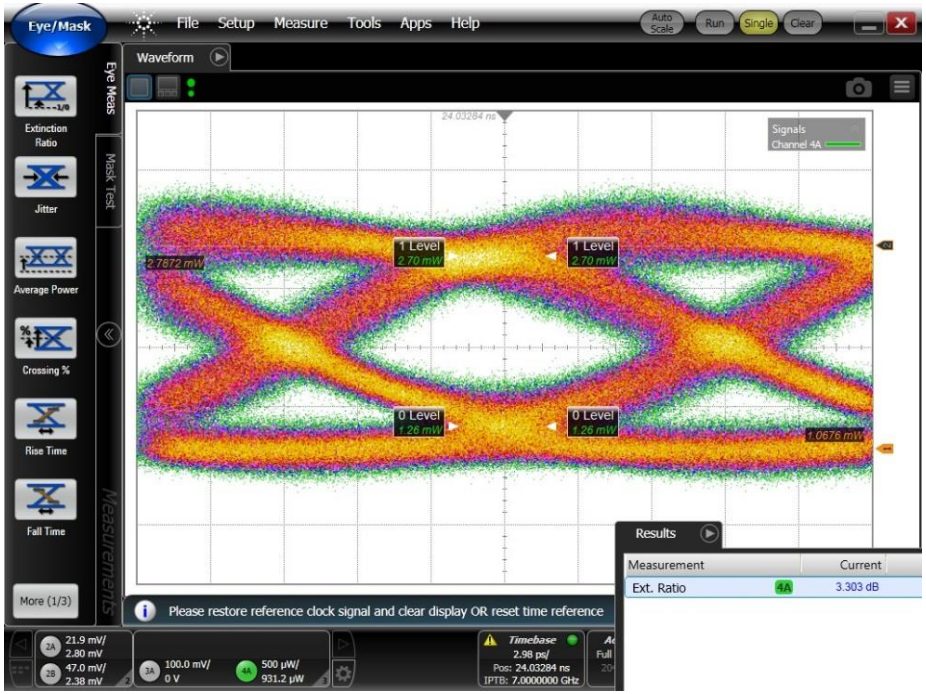
Hitachi/Oclaro 56Gb/s NRZ BH-DFB DML Data



- Optical DCA eye
- 56Gb/s
- PRBS31
- 55^{o}C
- 65mA I_{bias} (comment)
- Hitachi BH-DFB DML

- "It is thus concluded that the RS-BH DFB laser is a good candidate for use as a low power consumption light source in 400-GbE and OTU5 applications."
- K. Nakahara, et. al, "56-Gb/s Direct Modulation in InGaAlAs BH-DFB Lasers at 55°C," OFC 2014, Th3A.1, p.3 (Hitachi CRL and Oclaro joint paper)

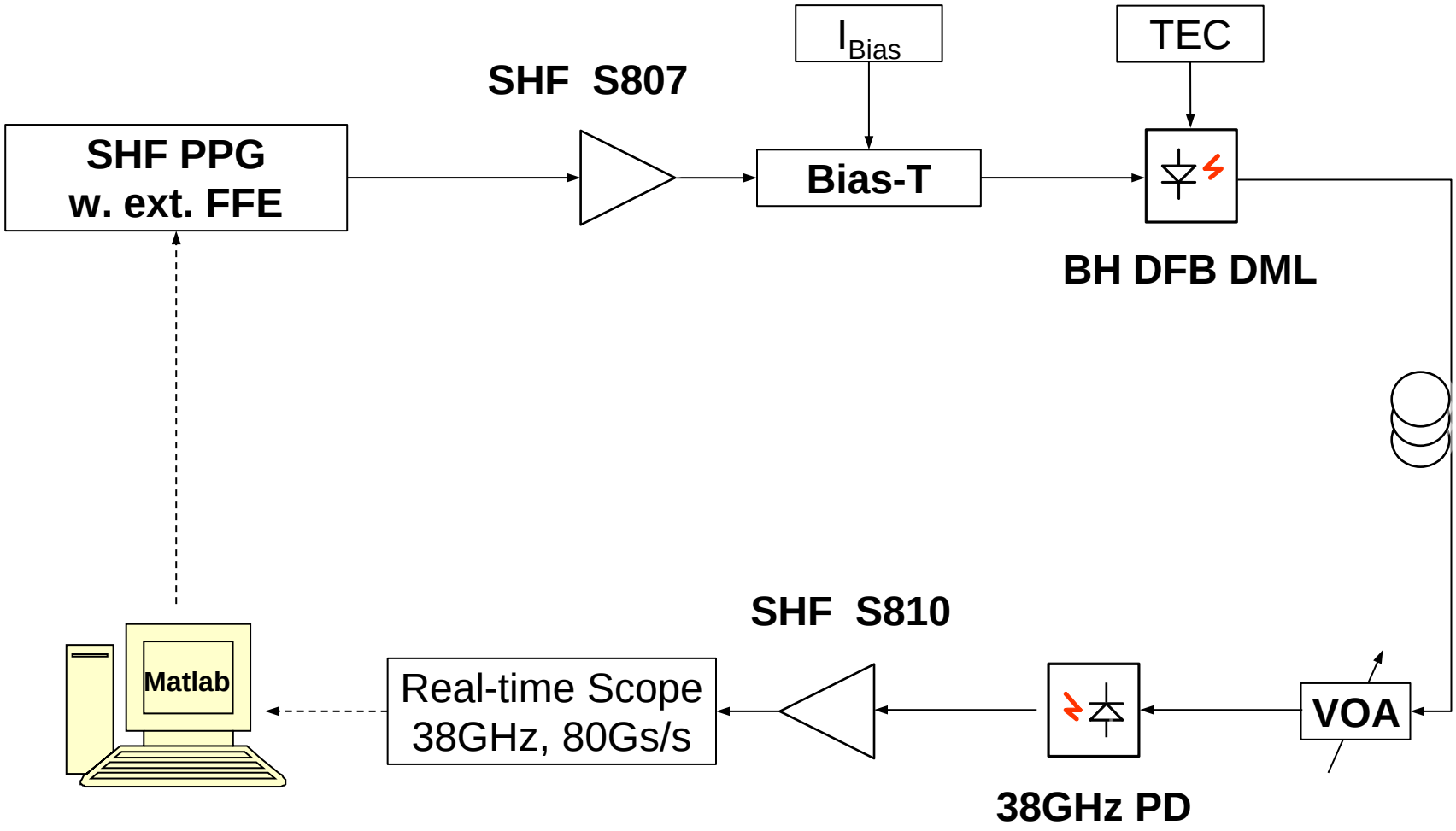
Finisar 56Gb/s NRZ BH-DFB DML Data



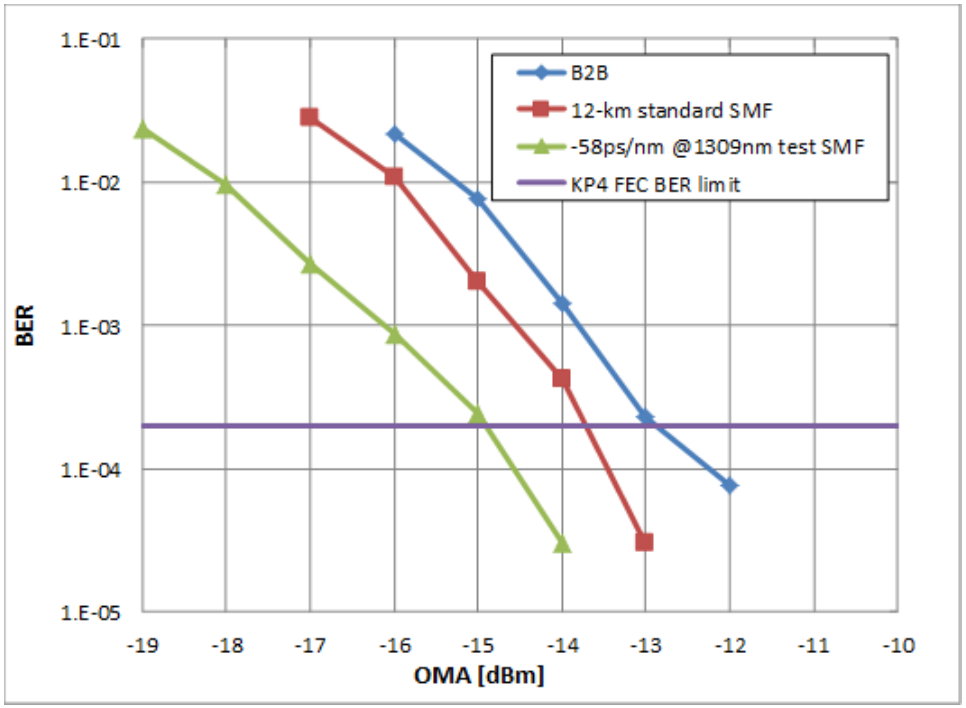
- Optical DCA eye
- 56Gb/s
- PRBS15
- 50°C
- 65mA I_{bias}
- Finisar BH-DFB DML

- Submitted as OFC 2015 post-deadline paper
- Includes reliability data

Experimental Set-up



Finisar 56Gb/s NRZ BH-DFB DML Data



- 1309 λ RX sensitivity dBm OMA
  - B2B
  - 12 km standard SMF
  - -58ps/nm test SMF
- 56Gb/s
- SSPR
- 3-tap T-spaced FFE
- BH DFB DML at 50ºC
  - ER = 4.8dB
  - 60mA I_{bias}

- Max. poz. dispersion test SMF not available at this time
- 802.3bs TF should consider max. poz. dispersion limit not based on 1300nm ZD SMF as such fiber does not exist

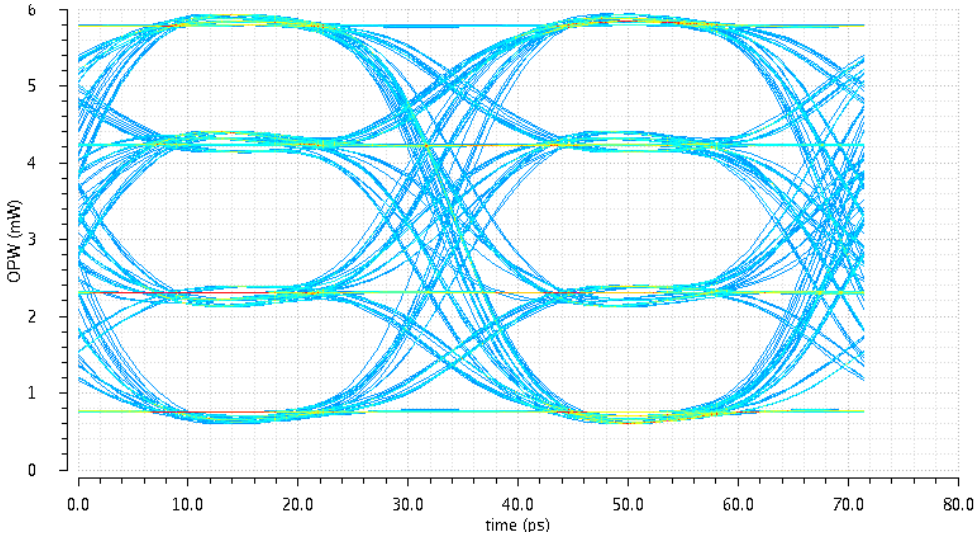
Discussion

- For SMF client interfaces, NRZ is the preferred choice if feasible, because it has the highest optics margin
- If not feasible, Parallel, WDM, or HOM, separately or in combination are required
- As component bandwidth increases with time, NRZ optics margin improves the most which drives down cost
  (ex. 10G Serial NRZ optics)
- HOM (ex. PAM-4) permanently locks in S/N penalty limiting margin improvement, even as component bandwidth increases
- Presented measurements require additional verification to confirm accuracy
- More measurements are required to support baseline specifications.

Appendix

56Gb/s PAM-4

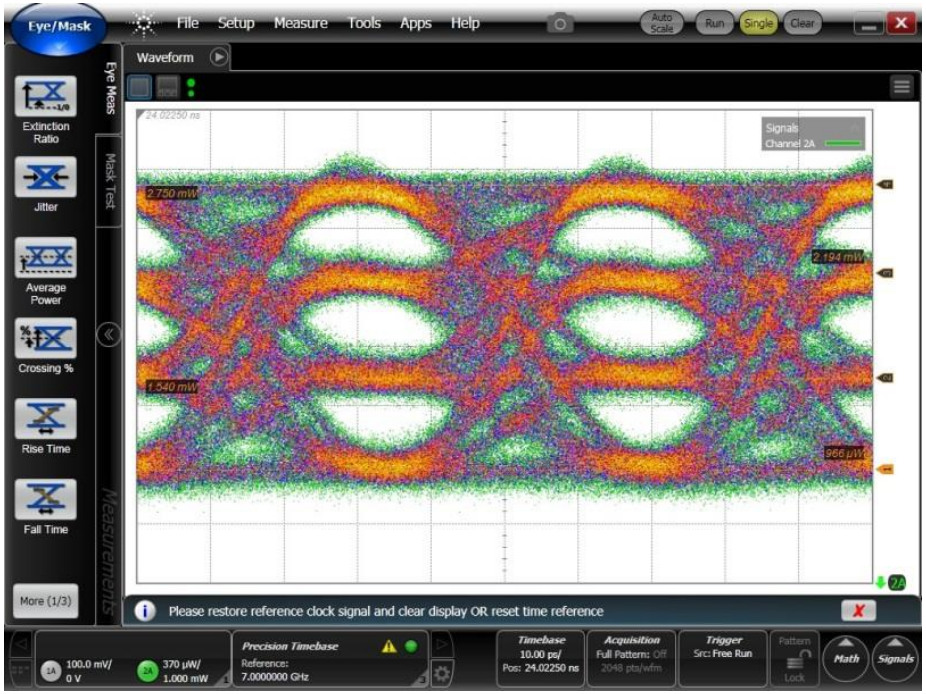
Finisar 56Gb/s PAM-4 SiPIC CWL-Modulator



- Simulated optical eye
- PAM-4
- 56Gb/s (28GBaud)
- PRBS9
- Same devices as p. 14

- SiP TX suitable for 50G λ PAM-4 WDM applications with λ specific CW lasers and grating couplers, with external Mux
- SiP RX highly unsuitable for 50G λ PAM-4 WDM apps. like 2km or 10km 400Gb/s Ethernet (marginal for 50G PAM-4 500m PSM apps.)

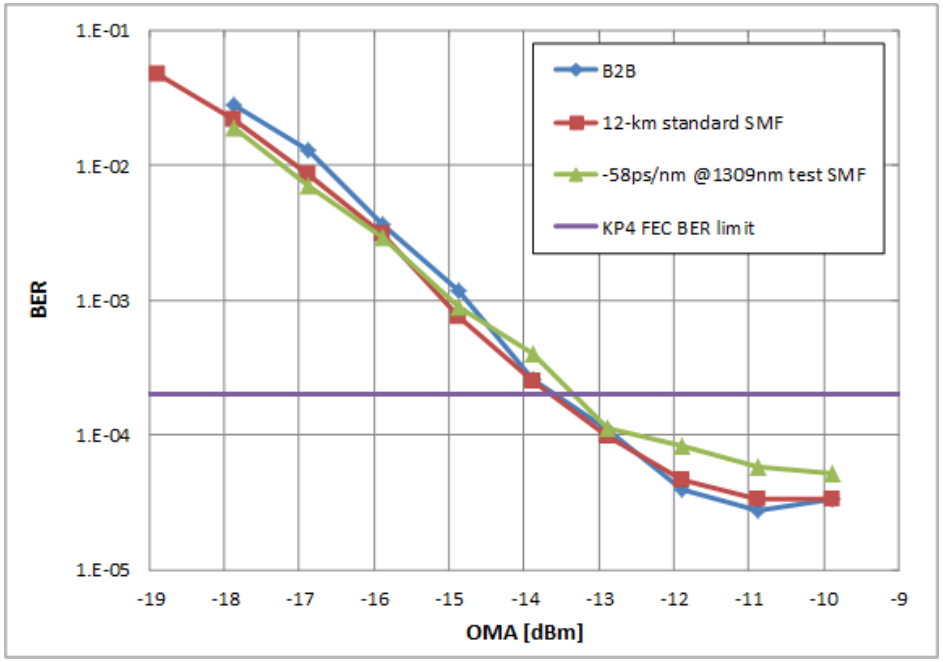
Finisar 56Gb/s PAM-4 BH-DFB DML Data



- Optical DCA eye
- 56Gb/s (28GBaud)
- SSPR
- 50°C
- ER (11/00) = 4.7dB
- 60mA I_{bias}
- Finisar BH-DFB DML

- Same test set-up as on page 17, except Micram AWG used to drive BH DFB DML

Finisar 56Gb/s PAM-4 BH-DFB DML Data



- 1309 λ RX sensitivity dBm OMA (inner eye)
  - B2B
  - 12 km standard SMF
  - -58ps/nm test SMF
- 56Gb/s (28GBaud)
- SSPR
- 5-tap T/2-spaced FFE
- BH DFB DML at 50ºC
  - ER(11/00) = 4.7dB
  - 60mA I_{bias}

- Max. poz. dispersion test SMF not available at this time
- PIN RX insufficient for 50G λ PAM-4 WDM 10km 400Gb/s Ethernet; optical amplification required

SMF PMD Modulation Observations

Thank you