400G & 4x100G SMF PMD Alternatives Study

400 Gb/s Ethernet Task Force

802.3 Plenary Session

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San Diego, CA

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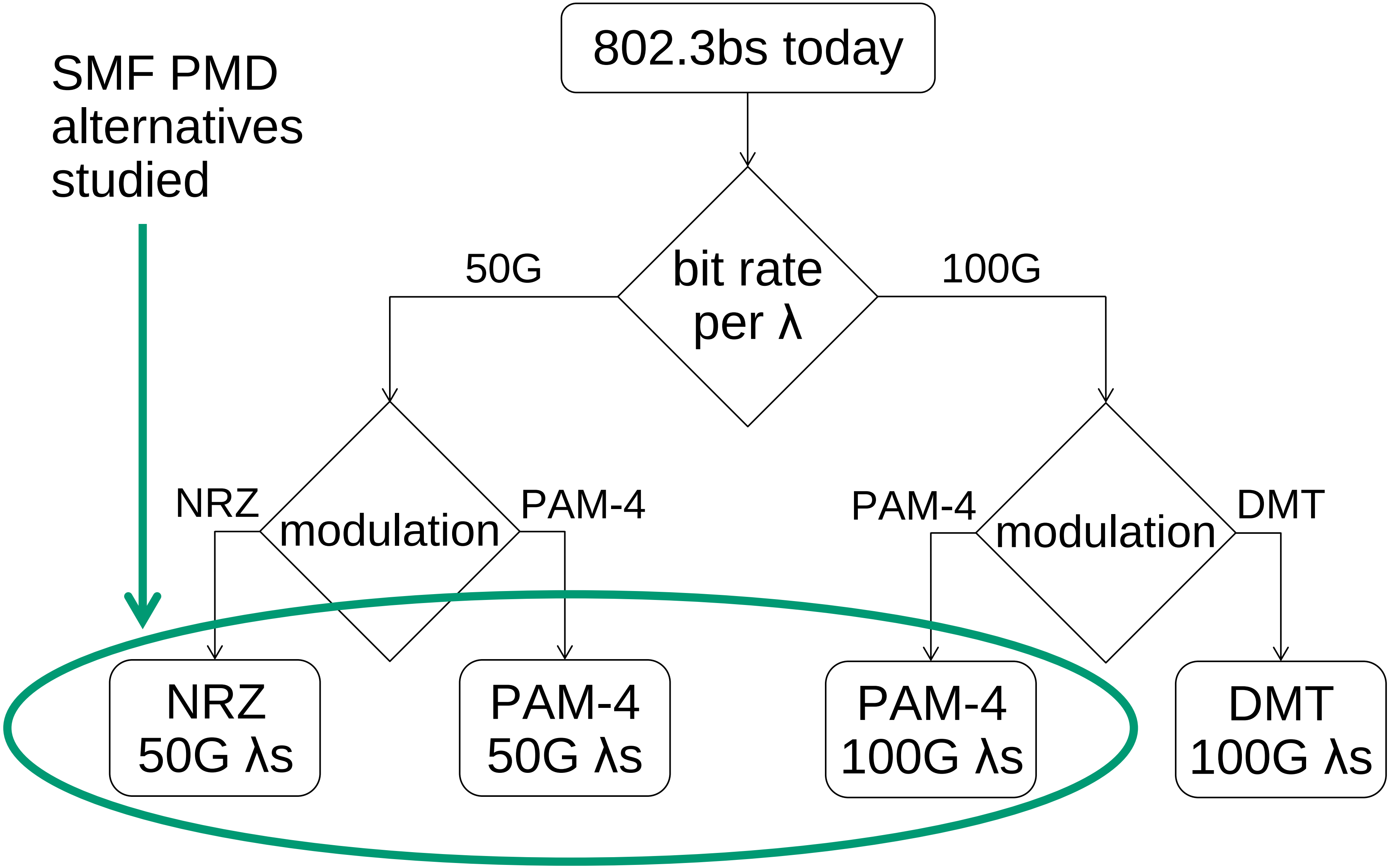
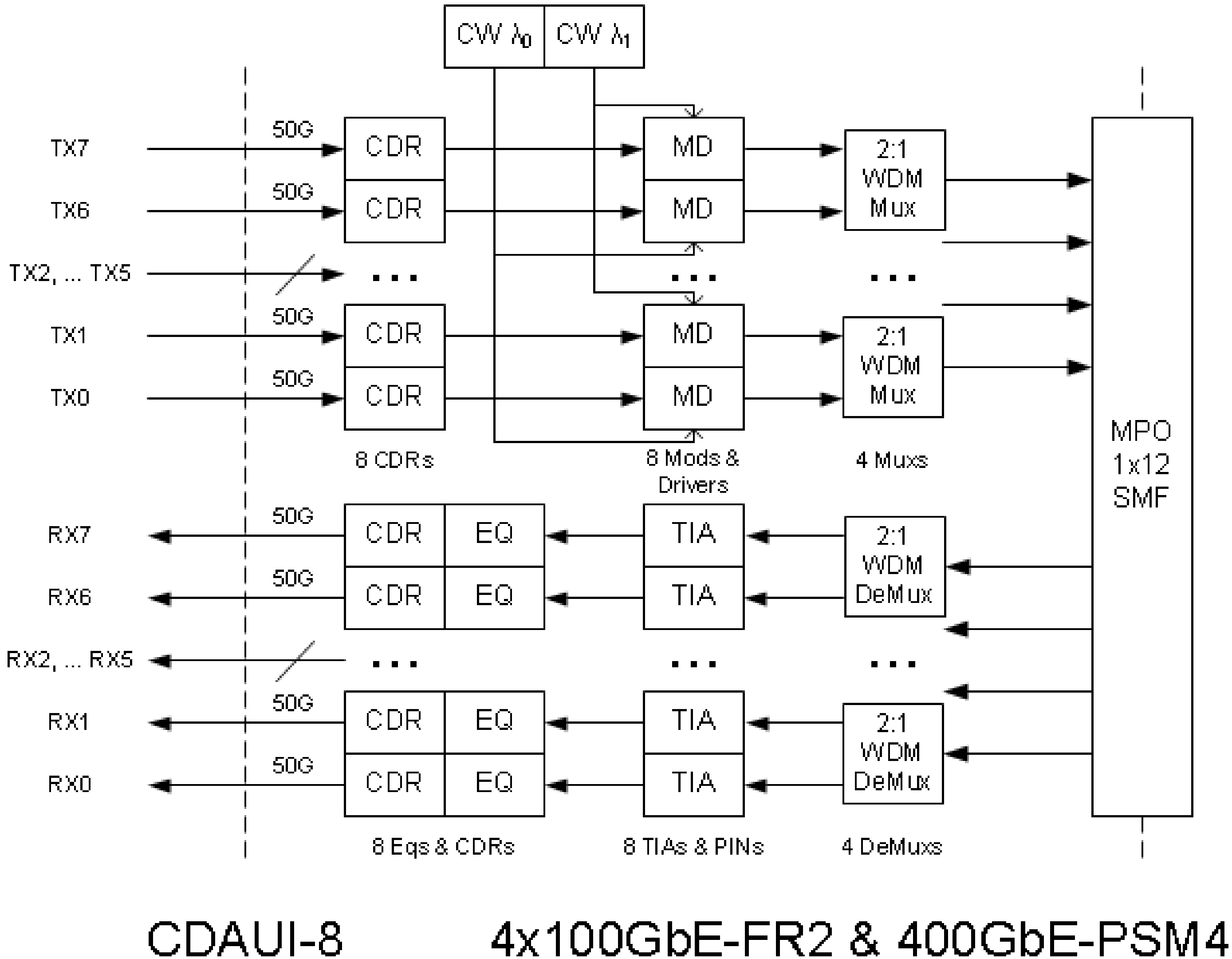
Duplex SMF & PSM4 PMDs Decision Tree

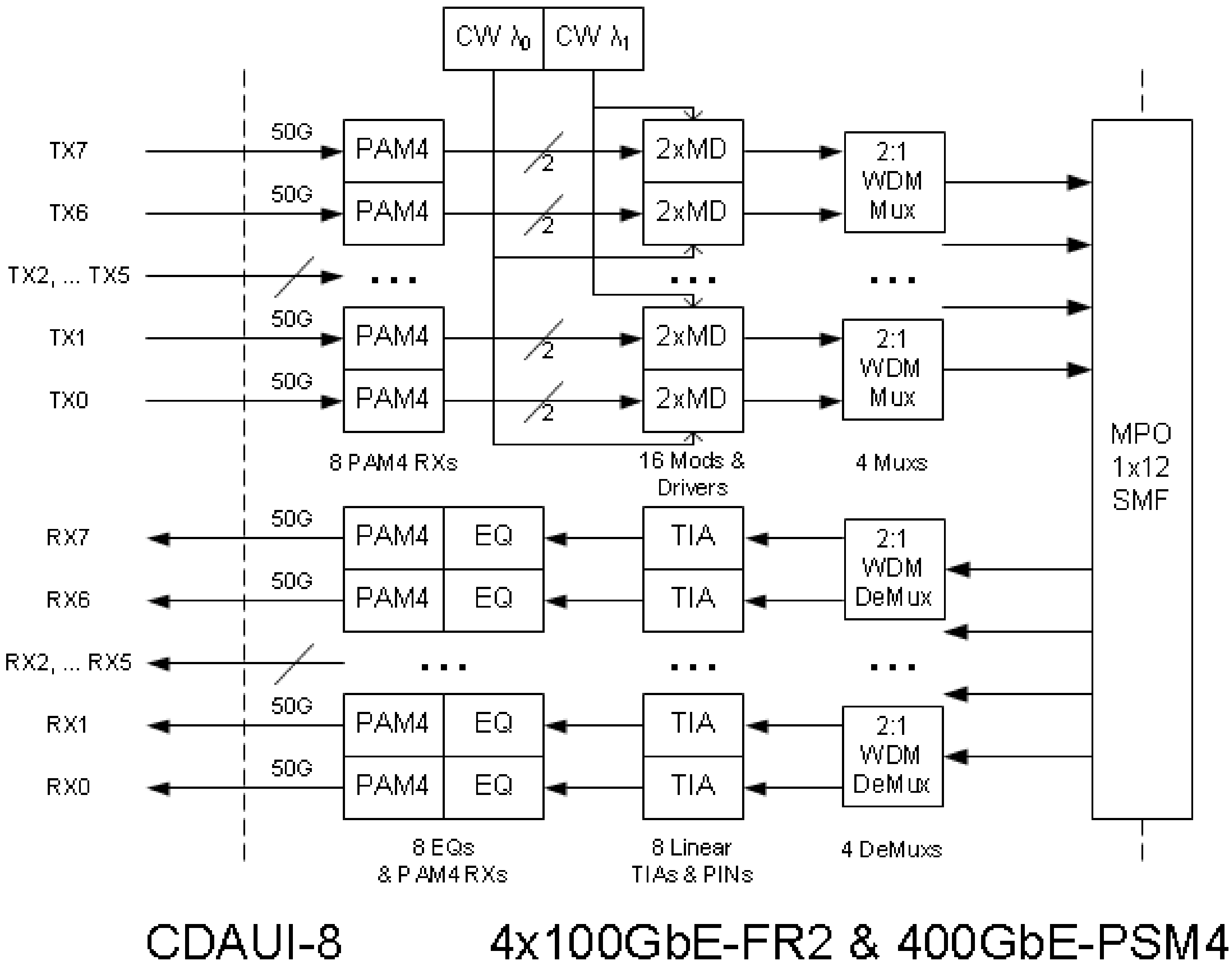
SMF PMD alternatives studied



400G PMD Alt 1: Quad NRZ MZ 2x50G λs



400G PMD Alt 2: Quad PAM-4 MZ 2x50G λs



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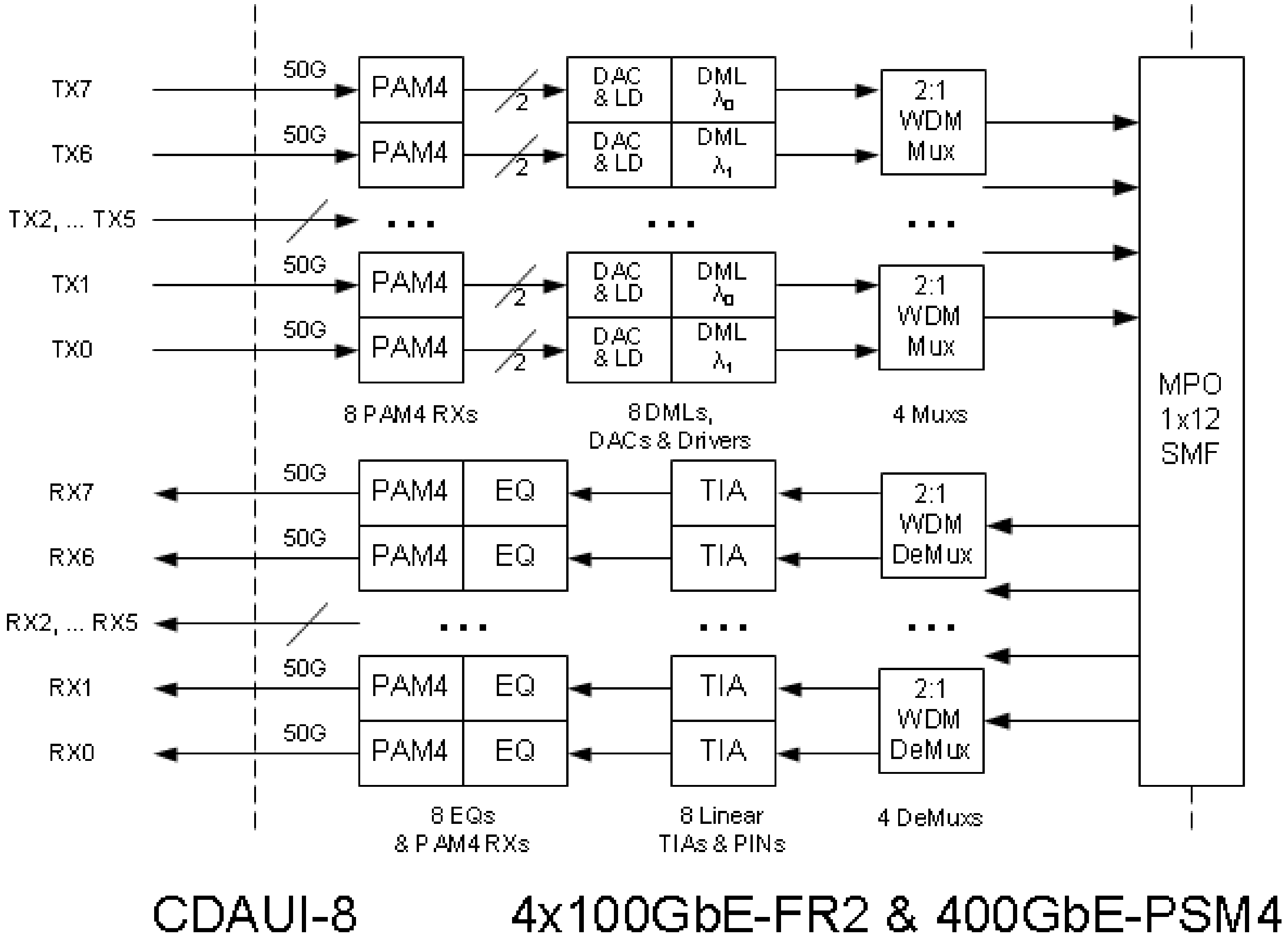
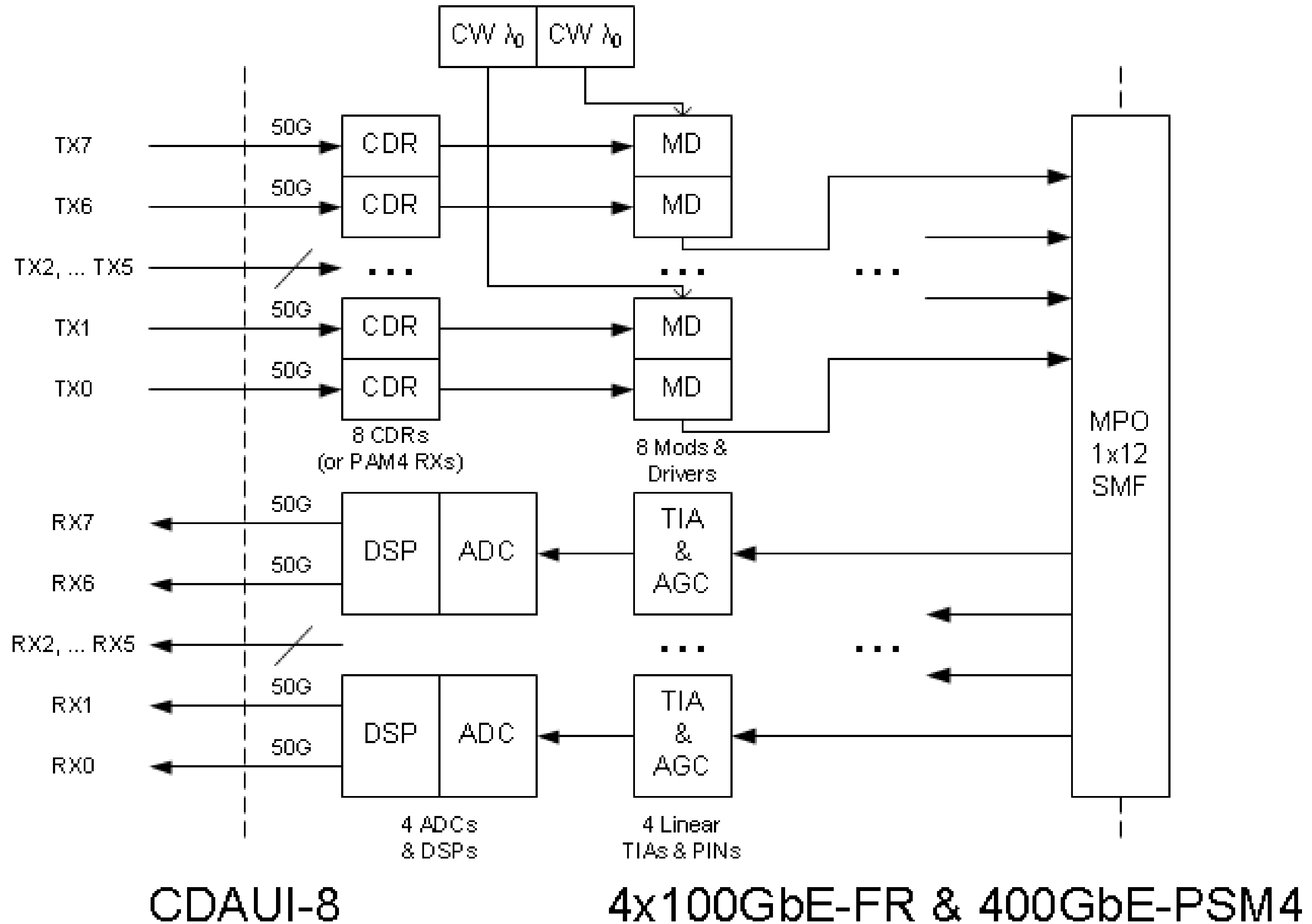
400G PMD Alt 3: Quad PAM-4 DML 2x50G λs



400G PMD Alt 4: Quad PAM-4 MZ 1x100G λ



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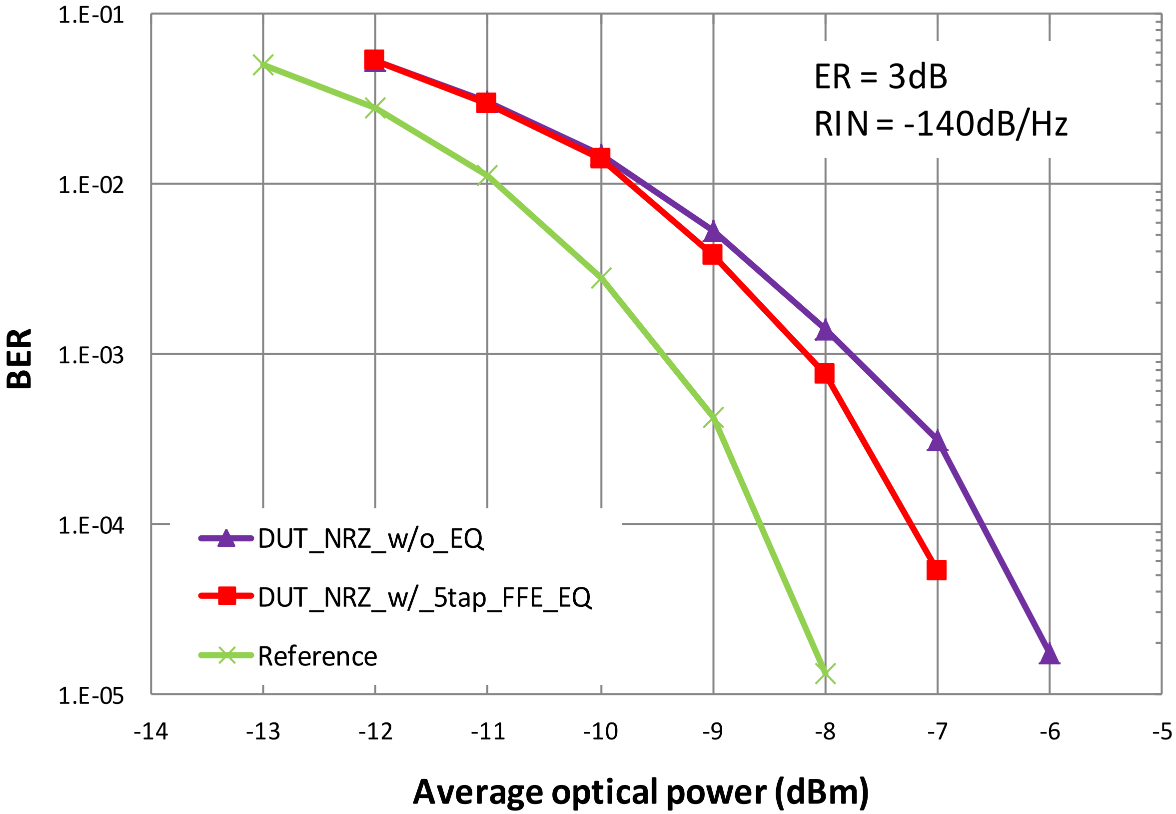
400G PMD Alternatives TX Nominal Specs

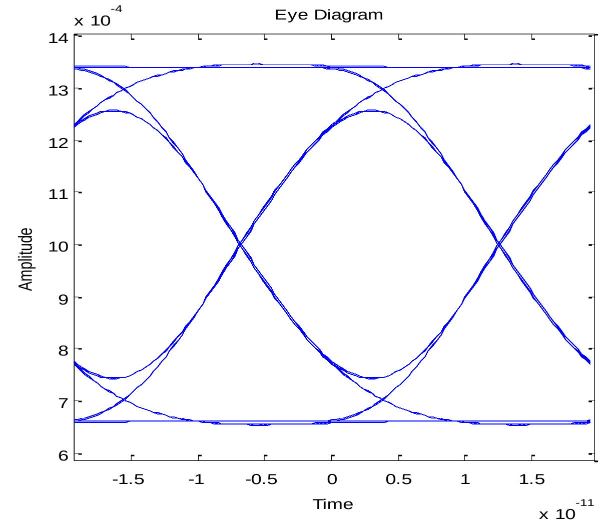
TX Specification	NRZ 4x λs MZ / DML LR4 No FEC		NRZ 2x λs MZ KR4 FEC	PAM4 2x λs MZ / DML KR4 FEC		PAM4 2x λs MZ / DML KP4 FEC		PAM4 1x λ MZ BCH FEC
Symbol Rate Gbaud	25.8		51.6	25.8		26.6		55.9
Operating BER	1e-12		5e-5	5e-5		2e-4		1e-3
Reach km	10		2.0	2.0		2.0		2.0
λs nm	1290 < 1310		1290, 1310	1290, 1310		1290, 1310		1310
TX OMA (min) (11-00) @TDP (max) dBm	**-1.3**	**-0.1**	**-2.0**	**-1.0**	**0.5**	**-1.5**	**0.0**	**-0.5**
ER (min) (11/00) dB	7	4	3	6	4	6	4	5
TX OMA (min) (01-00) @TDP (max) dBm	-1.3	-0.1	-2.0	-6.0	-4.5	-6.5	-4.0	-5.5
TDP (max) (01-00) dB	1.0	2.2	1.5	1.0	2.5	0.5	2.0	2.0
TX OMA - TDP (01-00) each lane (min) dBm	-2.3		-3.5	-7.0		-7.0		-7.5

400G PMD Alternatives RX Nominal Specs

RX Specification	NRZ 4x λs MZ / DML LR4 No FEC	NRZ 2x λs MZ KR4 FEC	PAM4 2x λs MZ / DML KR4 FEC	PAM4 2x λs MZ / DML KP4 FEC	PAM4 1x λ MZ BCH FEC
Symbol Rate Gbaud	25.8	51.6	25.8	26.6	55.9
Operating BER	1e-12	5e-5	5e-5	2e-4	1e-3
TX OMA (01-00) -TDP each lane (min) dBm	-2.3	-3.5	-7.0	-7.0	-7.5
Channel Insertion Loss dB	6.3	5.0	5.0	5.0	5.0
RX Sens. OMA pre-FEC each lane (max) dBm	**-8.6**	**-8.5**	**-12.0**	**-12.0**	**-12.5**
FEC Optical Gain vs. 1e-12 BER dB	0.0	2.6	2.6	3.2	3.8
Bandwidth Penalty vs. 25.8G dB	0.0	1.5	0.0	0.1	1.7
DeMux & TIA Penalty vs. 1Ch 26G Limiting dB	2.0	3.0	2.0	2.0	2.0
RX Sens. OMA LR4 eqv each lane (max) dBm	**-10.6**	**-10.4**	**-11.4**	**-10.9**	**-12.4**

NRZ MZ 51.6G λ TDP





ER(11/00) = 3dB

tR, tF = ~11ps

- TDP = ~1.5dB @ BER = 5e-5 w/ 5-tap FFE EQ RX
- TDP = ~2.0dB @ BER = 5e-5 w/ fixed REF RX
- Consistent with measurements

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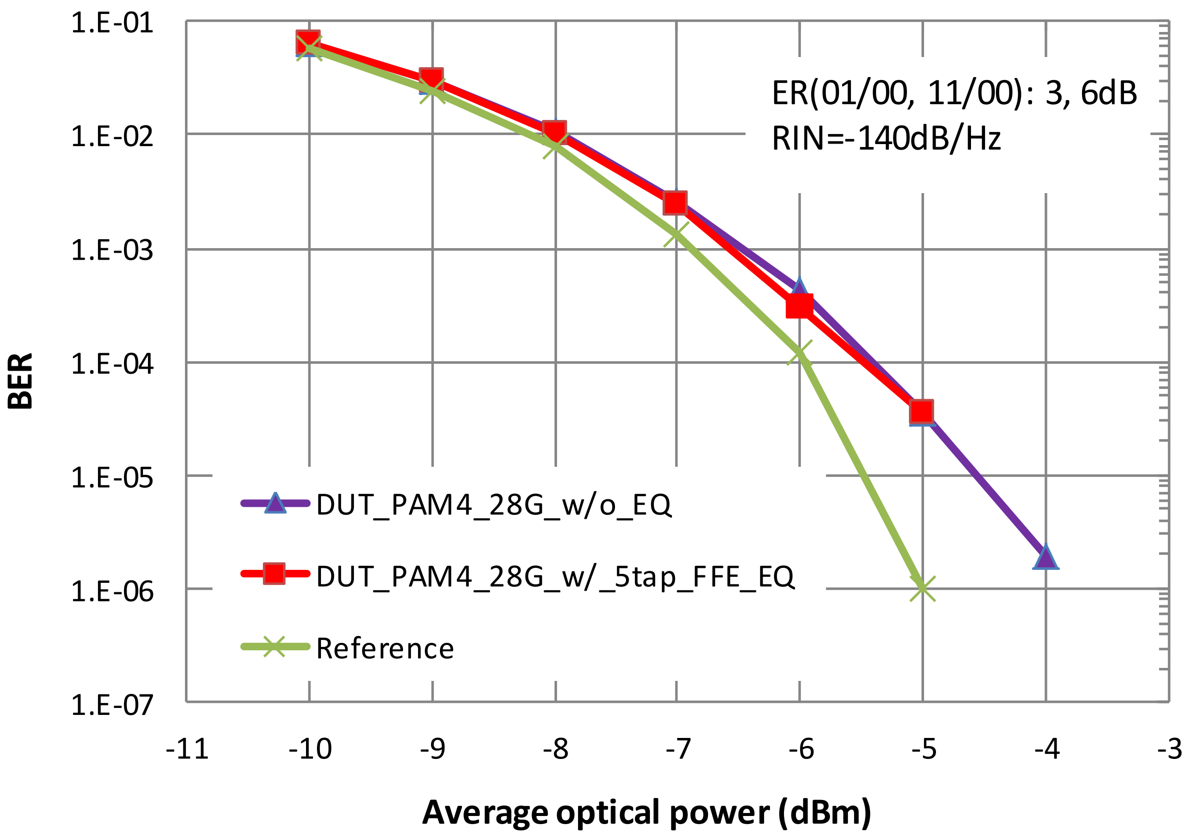
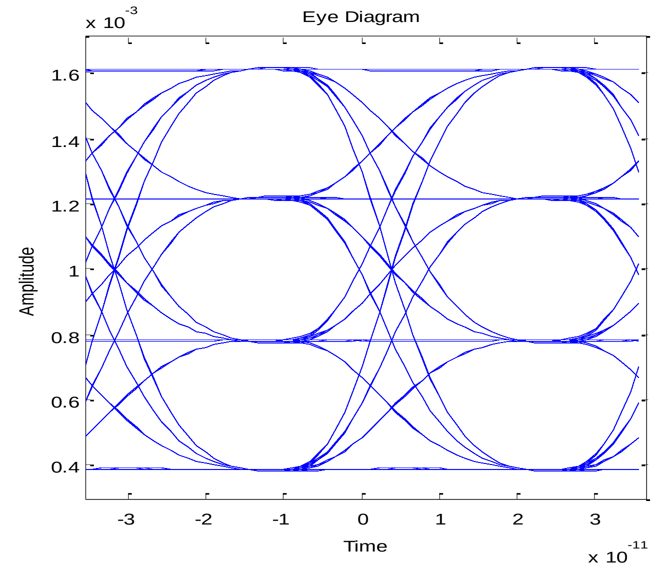
PAM-4 MZ 56G λ TDP

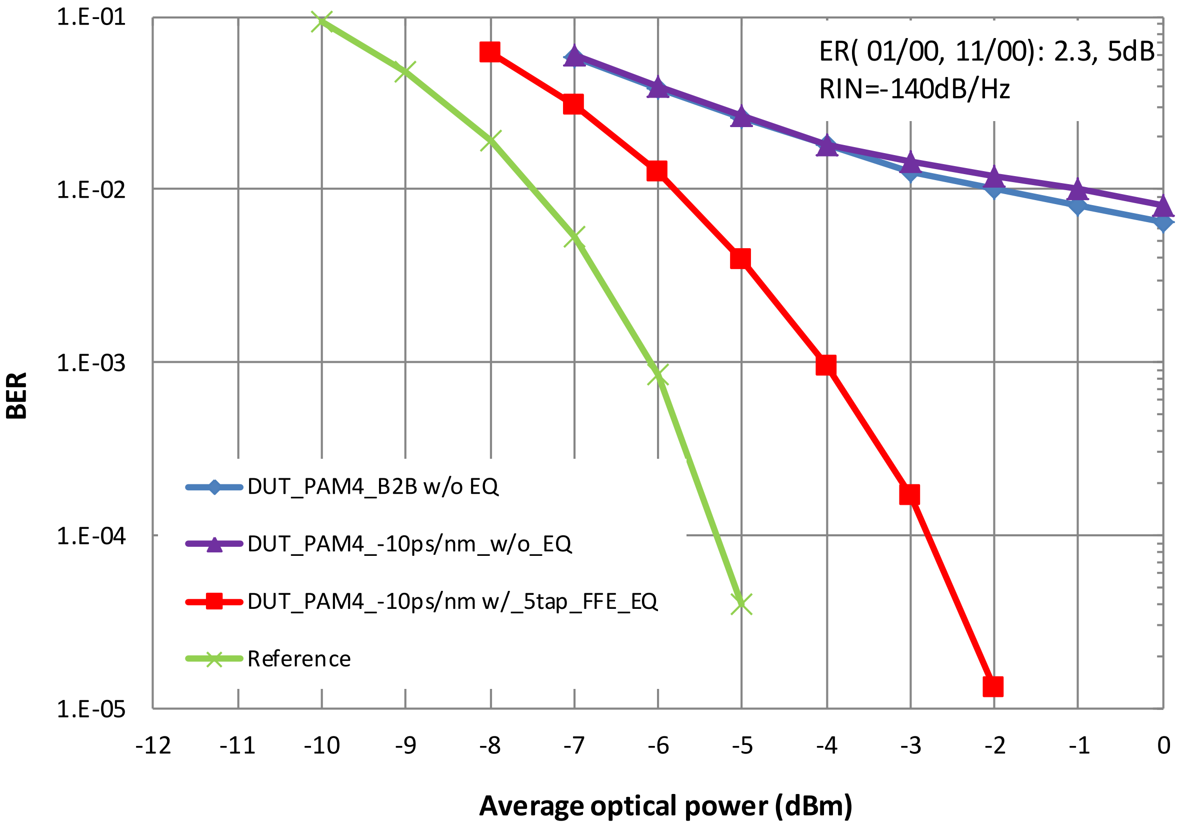


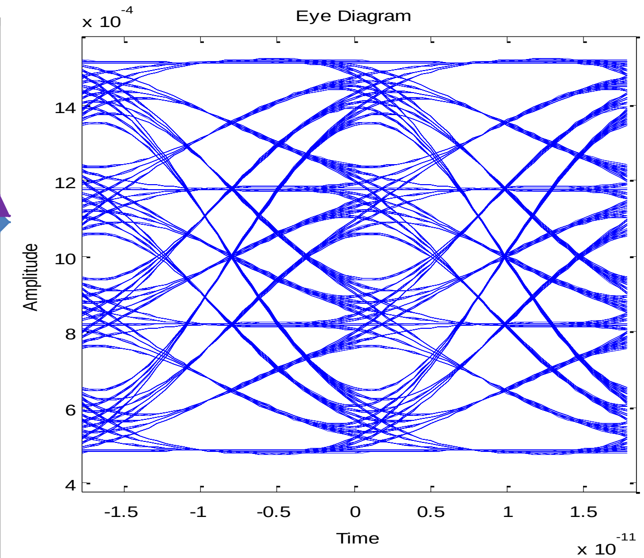


ER(11/00) = 6dB
tR, tF = ~11ps

- TDP = ~1.0dB @ BER = 5e-5
- TDP = ~0.5dB @ BER = 2e-4

PAM-4 MZ 111.8G λ TDP





ER(11/00) = 5dB
tR, tF = ~11ps

- TDP = ~2dB @ BER = 1e-3 w/ 5-tap FFE EQ RX
- Error floor > BER = 1e-3 w/ fixed REF RX

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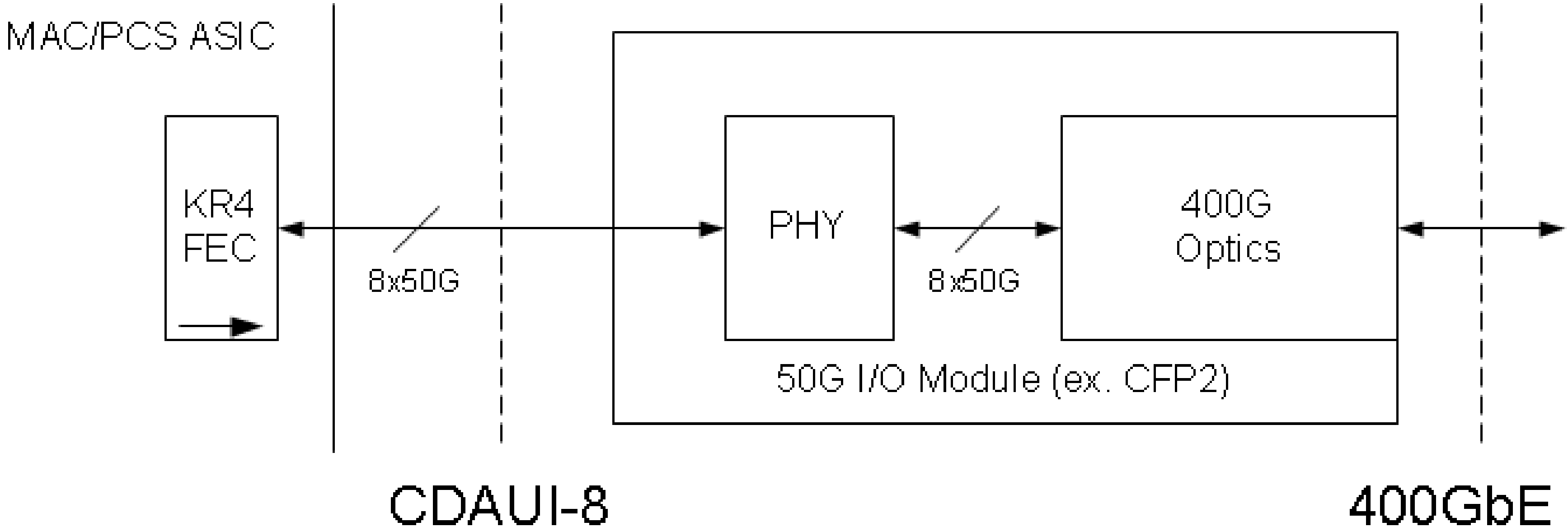
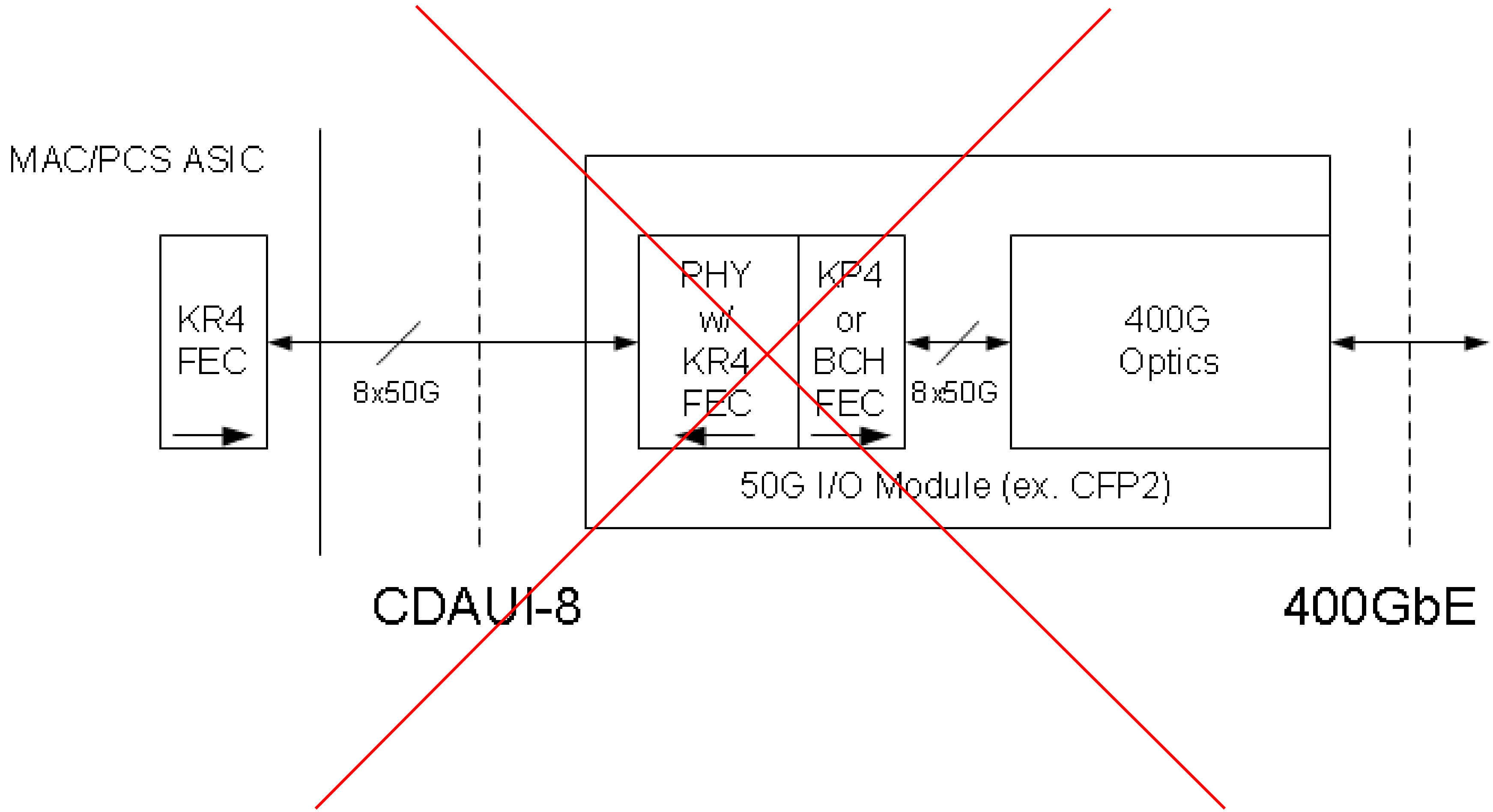
400G KR4 FEC CDAUI-8 Host Architecture



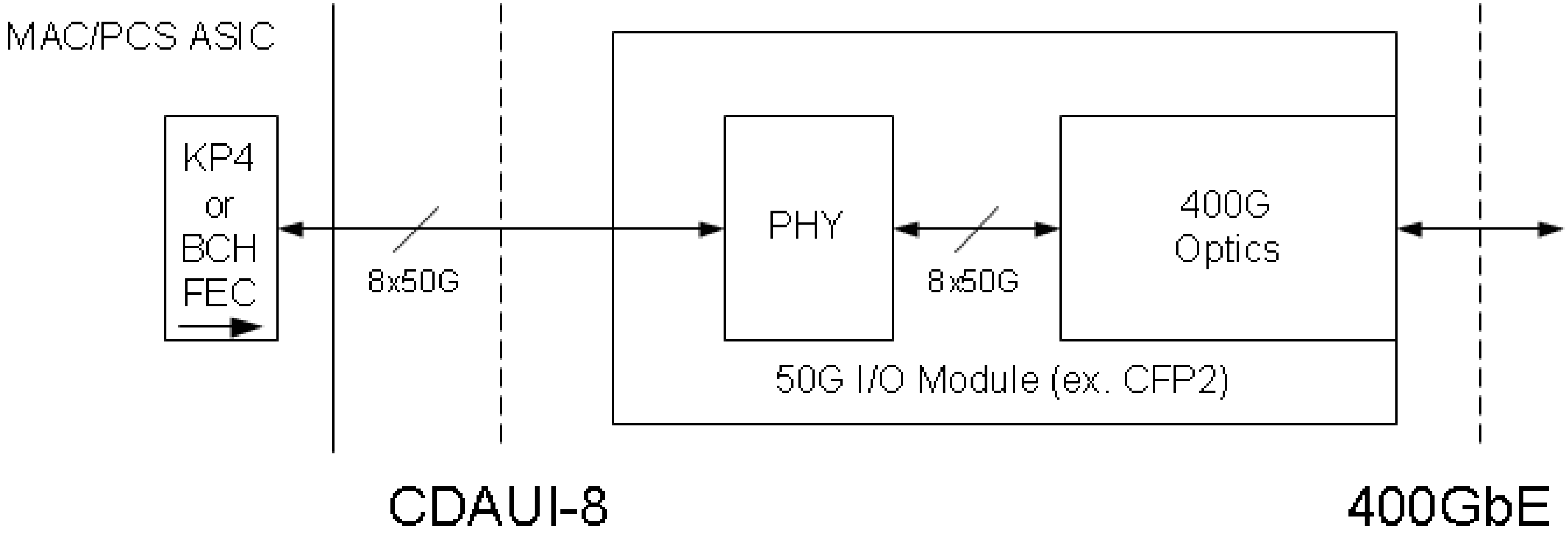
- Nominal Specs allocate all FEC coding gain to the optics

400G Strong FEC CDAUI-8 Host Architecture 1



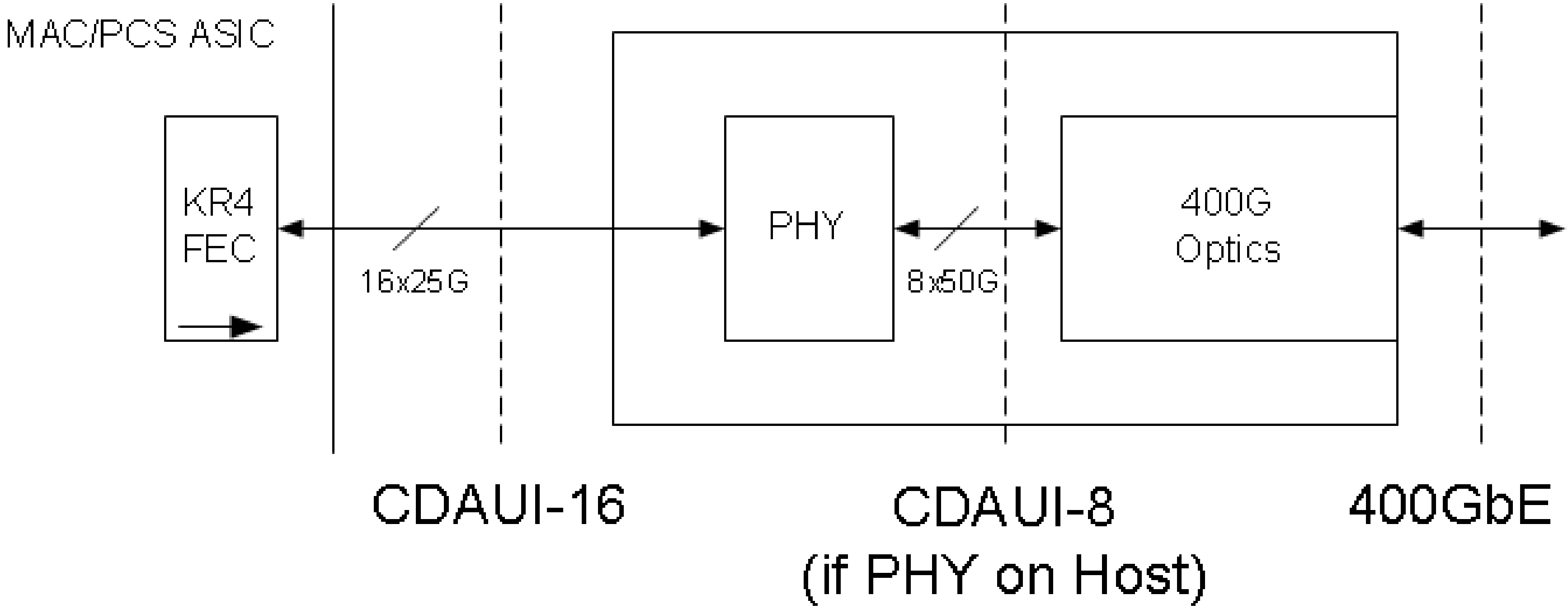
- PMD unfriendly architecture

400G Strong FEC CDAUI-8 Host Architecture 2



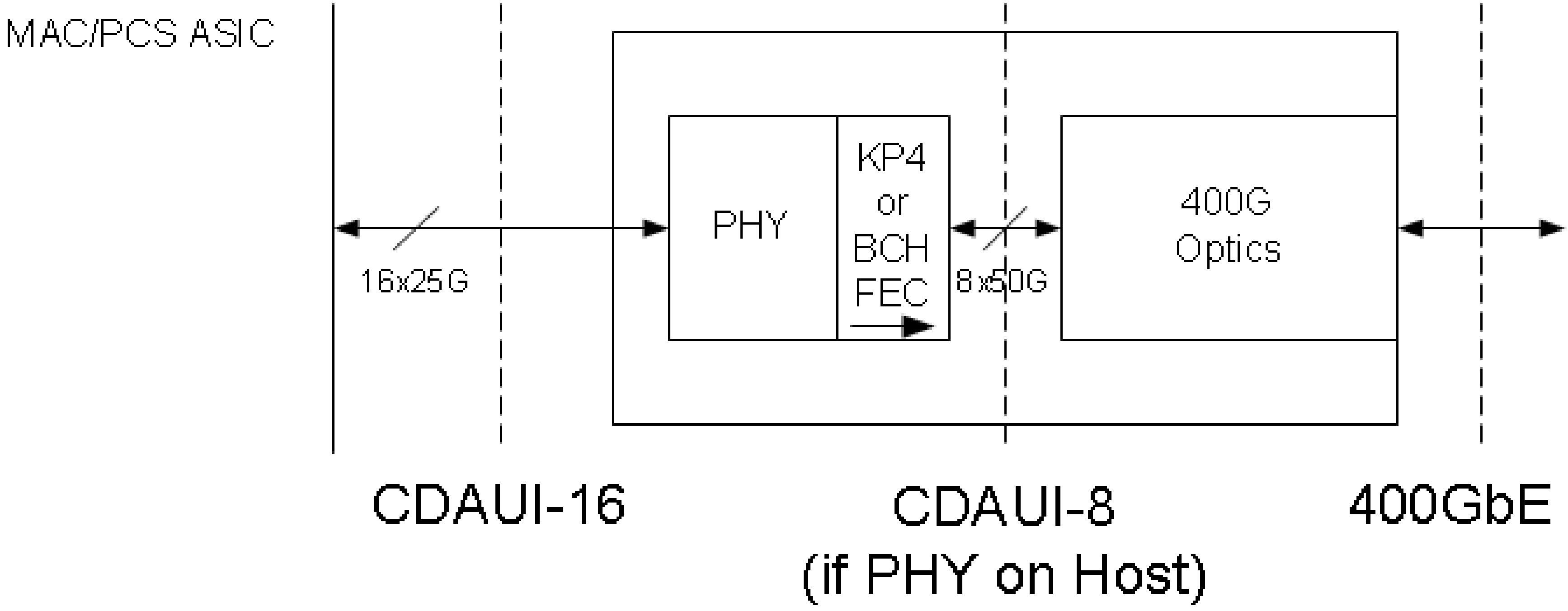
- PMD friendly architecture
- Assumes no CDAUI-8 DFE

400G KR4 FEC CDAUI-16 Host Architecture



- Nominal Specs allocate all FEC coding gain to the optics

400G Strong FEC CDAUI-16 Host Architecture



- CDAUI-16 interface operates with no FEC
- FEC in PHY is OK for Gen1 architecture

400G & 4x100G SMF PMDs Observations

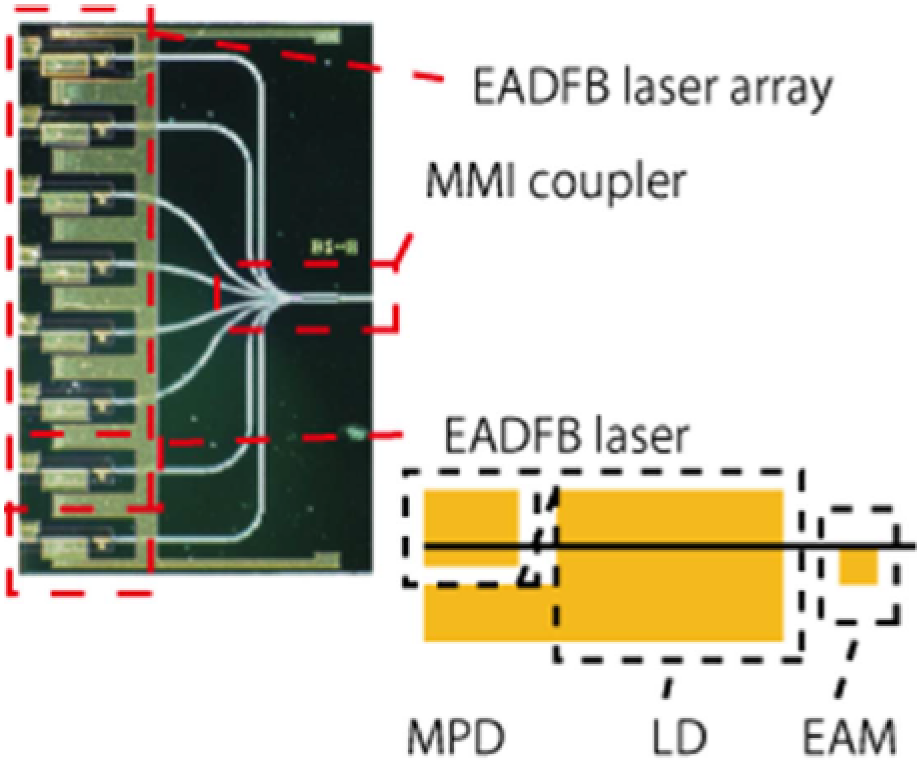
- NRZ MZ 2x50G λs 2km optics
  - With KR4 FEC are less difficult than LR4
  - KR4 FEC and lower loss offset 2x higher baud rate
  - BCH FEC enables 10km link budget
- PAM-4 MZ and DML 2x50G λs 2km optics
  - With KP4 FEC are similar difficulty as LR4
  - KP4 FEC and lower loss offset 5dB SNR penalty
  - BCH FEC enables 10km link budget
- PAM-4 MZ 1x100G λ 2km optics
  - Even with BCH FEC are more difficult than LR4
  - BCH FEC and lower loss do not offset 2x higher baud rate and 5dB SNR penalty

400G & 4x100G SMF PMDs Observations

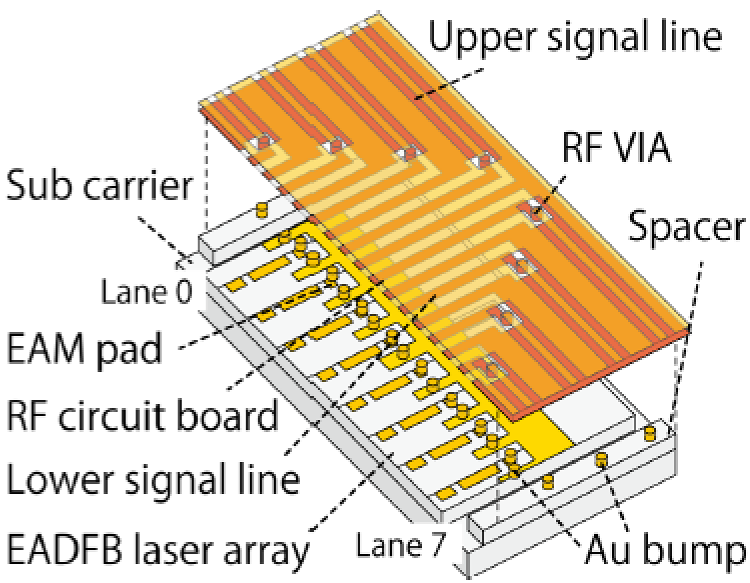
- FEC (KR4, KP4, BCH, or other) belongs in the host ASIC
  - Incremental cost is negligible unlike inside the PMD
- CDAUI-8 & CDAUI-16 need to be specified in 802.3bs
  - PMD optical specifications are tightly coupled to the electrical interface in a cost optimized architecture

Appendix 1: NTT NRZ EML 8x50G λs TX

8Ch-EADFB laser array chip



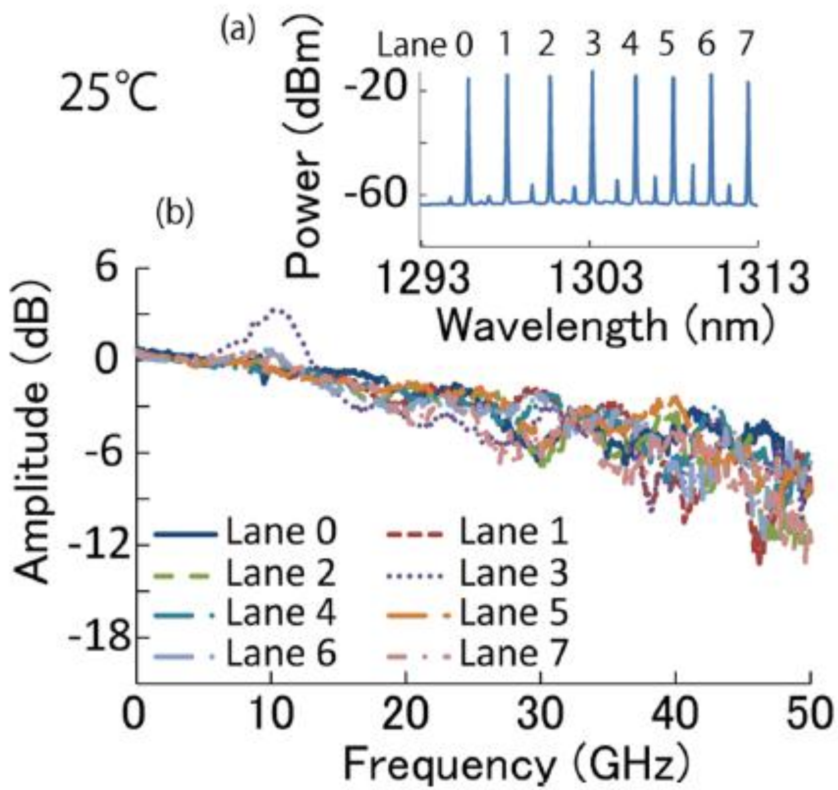
Array chip and RF circuit board



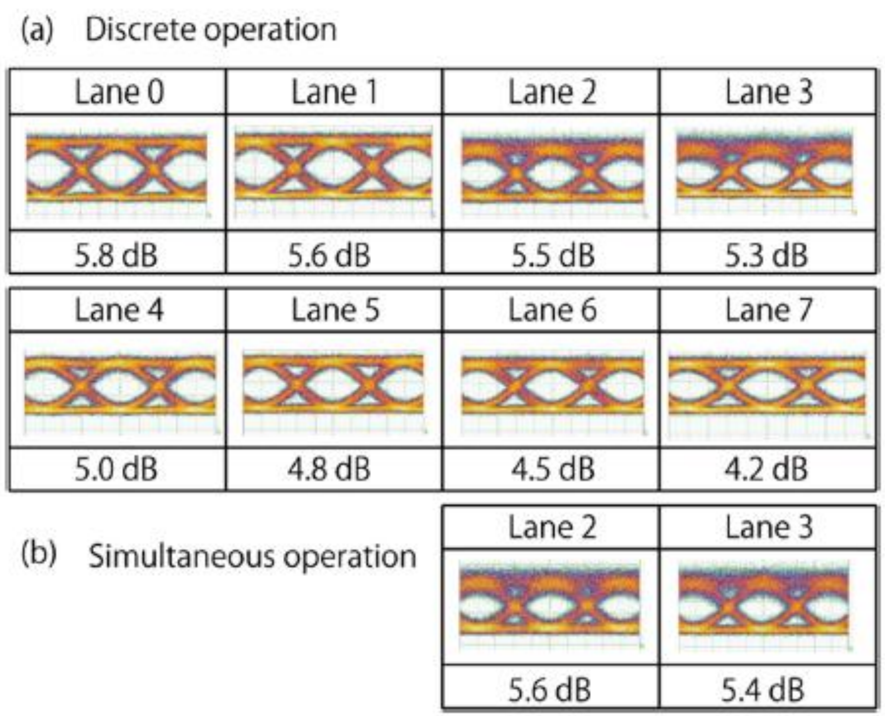
Kanazawa et al., Electronics Letters, Vol. 50, No. 7, pp.533-534, 2014

Appendix 1: NTT NRZ EML 8x50G λs TX

E/O response and lasing spectrum



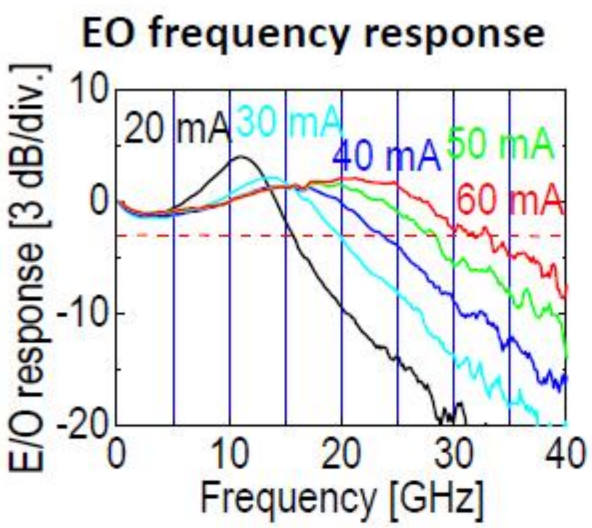
50Gb/s eye diagrams

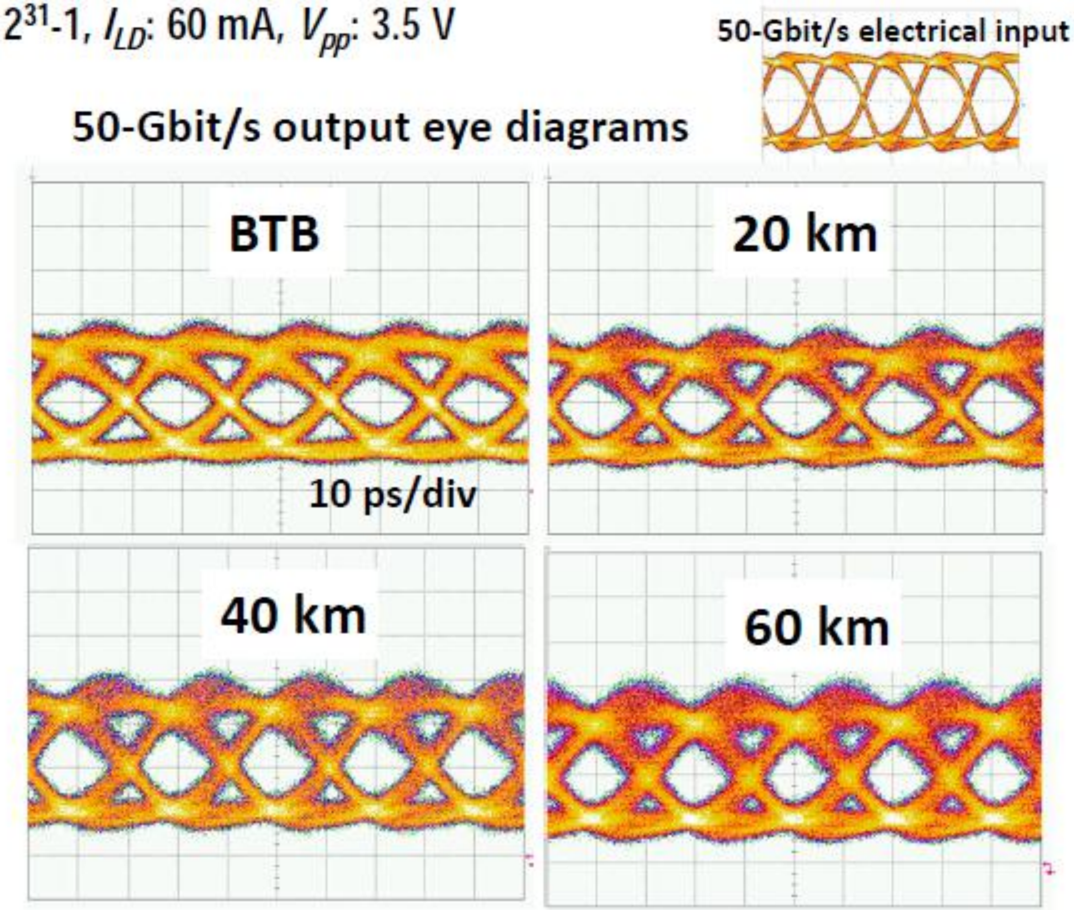


Kanazawa et al., Electronics Letters, Vol. 50, No. 7, pp.533-534, 2014

Appendix 2: NTT NRZ DML 50G λ TX

Exp. conditions: 50 Gb/s, NRZ, PRBS 2^{31}-1, I_{LD}: 60 mA, V_{pp}: 3.5 V





- wavelength: 1302 nm
- P_{avg}: 5.0 dBm
- Dynamic ER: 4.5dB

Kobayashi et al., Int. Semiconductor Laser Conference (ISLC), 2012, TuB1

Thank you