

Optical Specifications of SMF PMDs Study

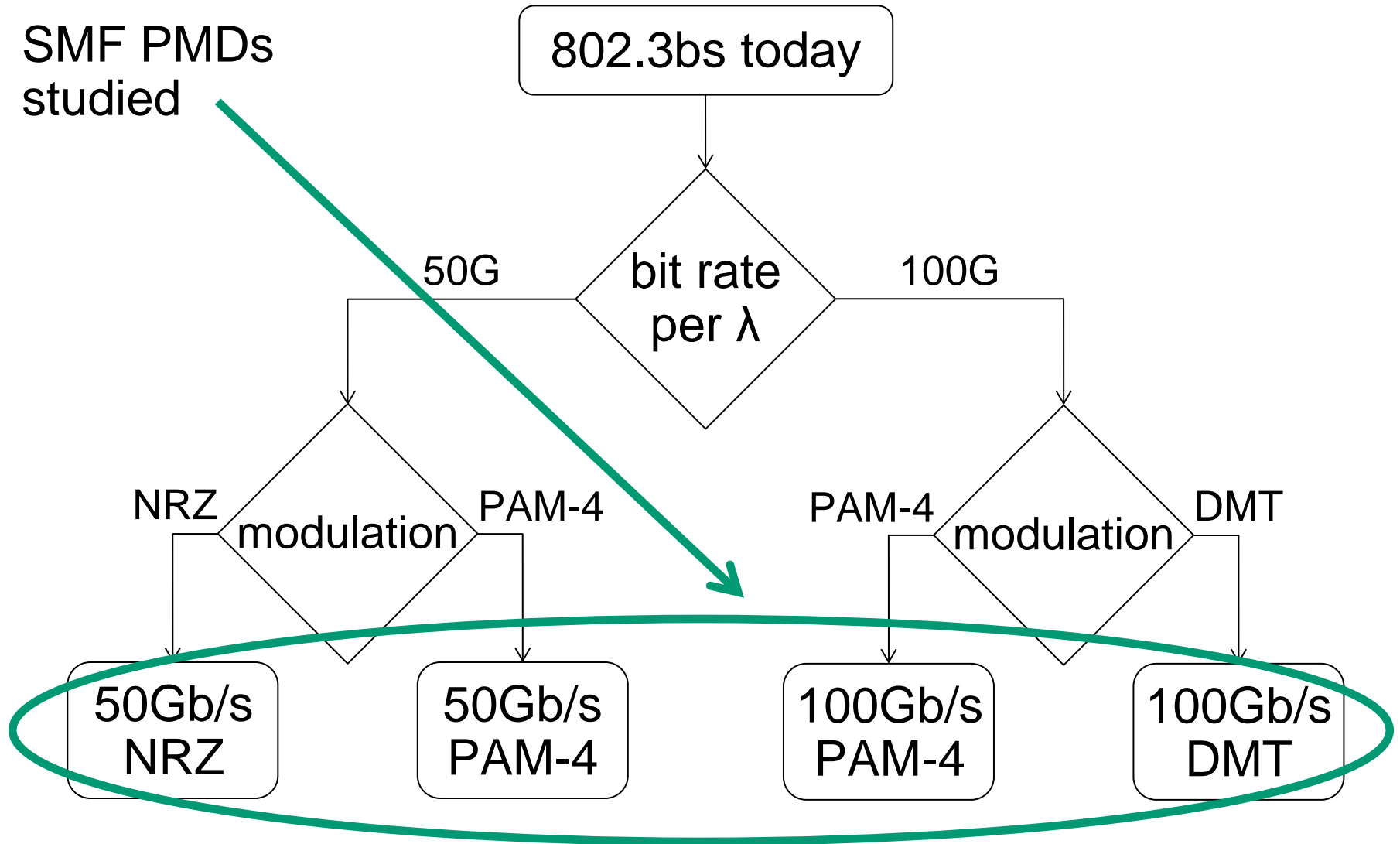
400 Gb/s Ethernet Task Force
SMF Ad Hoc Conference Call
30 September 2014
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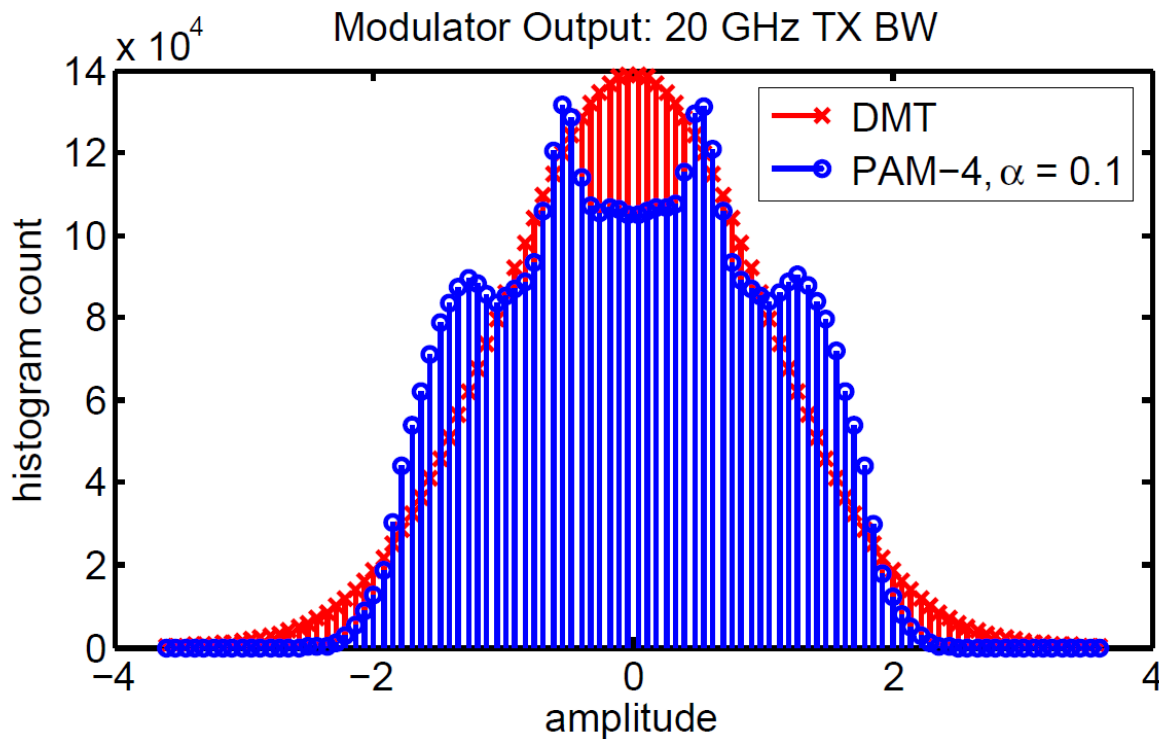
Duplex SMF & PSM4 PMDs Decision Tree

SMF PMDs
studied



PAM-M PAPR Penalty (Electrical)

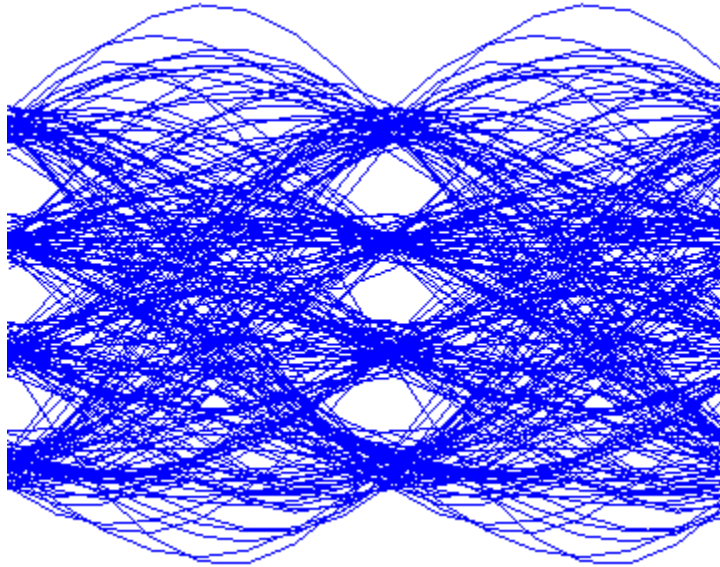
- PAM-M has excess bandwidth above Nyquist
- Transition modelled as raised cosine with roll-off factor = α
- Small values of α result in PAPR penalty, similar to DMT



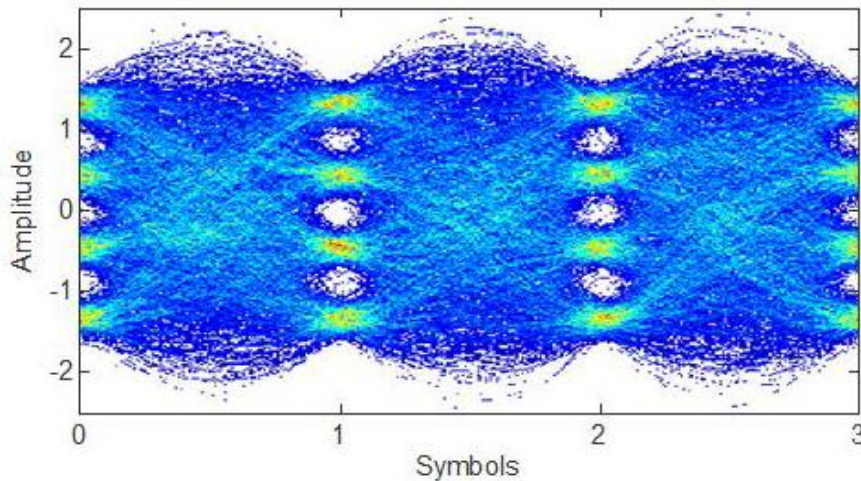
Example:

- TX BW = 20GHz
- $\alpha = 0.1$
- Post-clipping SNR = 24dB
- PAPR penalty = 2dB

PAM-M PAPR Penalty Examples



PAM-4, 107 Gb/s, BER= 3.40×10^{-3} , Q=4.91, $\alpha_{\text{RRC}}=0.01$



- **100G/lambda PAM-4**
- [hirai 3bs 01 0914](#)
- 51.2-GBaud NPAM-4
- BER floor = $\sim 3e-4$
- $\alpha = 0.1$ ([rao 3bs 01b](#))
- PAPR penalty >2dB

- **Four Wavelength 400G**
- [bhatt 3bs 01a 0714](#)
- 107Gb/s PAM-4
- BER floor = $\sim 4e-4$
- $\alpha = 0.01$ (?)
- PAPR penalty >2dB

PAM-M Ideal Modulation Penalty (Optical)

- β_{PAPR} = PAM-M PAPR loss coeff.
 - $10 \cdot \log_{10}(1/\sqrt{\beta_{\text{PAPR}}})$ @ $\alpha = 0.1$, 24dB SNR = 1 dB
- PAM-M mod. penalty = $10 \cdot \log_{10}((M - 1)/\sqrt{\beta_{\text{PAPR}}})$
 - PAM-4, $\alpha = 0.1$ = 4.8 + 1.0 = 5.8 dB
- Modulation penalty decreases S in SNR therefore:
 - Reduces TX OMA of symbol eye

TX Limit, Mux Loss & Modulation Penalty

- Eye safety limit (1310nm) = 14.1dBm AOP
- Mux loss
 - 2:1 ratio = 1.0 dB
 - 4:1 ratio = 2.0 dB
 - 8:1 ratio = 3.0 dB
- Modulation penalty
 - 50G NRZ = 0.0 dB
 - 50G PAM-4 = 4.8 dB
 - 100G PAM-4 ($\alpha = 0.1$, 24dB SNR) = 5.8 dB
 - 100G DMT-k (25G DML, +/- 3σ clipping) = 8.8 dB
- Modulation 5% accuracy penalty = 0.2 dB
- DMT-k sub-carrier I & Q channel power split factor penalty
 - $F_k = 10 * \log_{10} (2 * k)$

TDP 2km

2km	8x50G NRZ	8x50G PAM4	8x50G PAM4	4x100G PAM4	4x100G DMT-k
Source	Mod	Mod	DML	Mod	25G DML
Grid	LAN WDM	LAN WDM	LAN WDM	CWDM	LAN WDM
FEC	KP4	KP4	KP4	BCH	BCH
Operating BER	2.0e-4	2.0e-4	2.0e-4	1.0E-03	1.0E-03
TX analog BW	20	20	20	20	21
RX analog BW	40	20	20	31	21
RX FFE taps or FFT pts.	3	3	3	13	k
TDP dB	1.8	0.7	1.0	2.0	2.5

Methodology as per [cole_3bs_01a_0714](#), updated with jitter, and residual quantization effects for 100G PAM-4 & DMT

TDP 10km

10km	8x50G NRZ	8x50G PAM4	8x50G PAM4	4x100G PAM4	4x100G DMT-k
Source	Mod	Mod	DML	Mod	25G DML
Grid	LAN WDM	LAN WDM	LAN WDM	LAN WDM	LAN WDM
FEC	BCH	BCH	BCH	BCH	BCH
Operating BER	1.0E-03	1.0E-03	1.0E-03	1.0E-03	1.0E-03
TX analog BW	21	21	21	21	21
RX analog BW	42	21	21	32	21
RX FFE taps or FFT pts.	3	3	3	13	k
TDP dB	2.3	0.7	1.5	2.5	3.0

Methodology as per [cole_3bs_01a_0714](#), updated with jitter, and residual quantization effects for 100G PAM-4 & DMT

RX Channel Loss & FEC Gain

- 2km Channel Insertion Loss & MPI Penalty = 5 dB
 - 4.0 dB channel base loss
 - up to 1.0 dB MPI Penalty
- 10km Channel Insertion Loss & MPI Penalty = 7 dB
 - 6.3 dB channel base loss
 - up to 0.7 dB MPI Penalty
- FEC Optical Gain (vs. $1e-12$ BER)
 - KR4 = 2.6 dB
 - KP4 = 3.2 dB
 - BCH (2858, 2570, $t=24$) = 3.8 dB

RX DeMux Loss & Bandwidth Penalty

- DeMux loss
 - 2:1 ratio = 1.0 dB
 - 4:1 ratio = 2.0 dB
 - 8:1 ratio = 3.0 dB
- Bandwidth Penalty (vs. 25G NRZ)
 - 50G NRZ = 1.5 dB
 - 50G PAM-4 = 0.0 dB
 - 100G PAM-4 = 1.0 dB
 - 100G DMT = 0.0 dB
- FEC overhead Bandwidth Penalty
 - KR4 (0%) = 0.0 dB
 - KP4 (3%) = 0.1 dB
 - BCH (8%) = 0.2 dB
 - BCH (DMT, 25G DML) = 0.0 dB

RX Design Penalty

- 50G TIA device noise penalty (vs. 25G) = 1.0 dB
- Linear TIA AGC noise penalty (vs. Limiting) = 0.5 dB
- TIA cross-talk penalty
 - 25G NRZ = 0.2 dB
 - 50G NRZ = 0.4 dB
 - 50G PAM-4 (linear) = 0.3 dB
 - 100G PAM-4 (linear) = 0.4 dB
 - 100G DMT-k (linear) = 0.3 dB
- Analog equalizer non-idealities or ADC quantization penalty
 - 50G NRZ 3-tap FFE = 0.4 dB
 - 50G PAM-4 3-tap FFE = 0.5 dB
 - 100G PAM-4 6-bit ENOB ADC = 0.4 dB
 - 100G DMT-k 6-bit ENOB ADC = 0.6 dB

400G 2km Duplex SMF PMDs TX Specs

TX Specifications	4x25G NRZ LR4 No FEC MOD / DML		8x50G NRZ KP4 FEC MOD	8x50G PAM4 KP4 FEC MOD / DML		4x100G BCH FEC PAM4 MOD	4x100G DMT BCH FEC 25G DML
	Operating BER	1.0E-12		2.0E-04	2.0E-04		1.0E-03
ER Full Scale (min) dB	7.0	4.0	4.5	7.0	4.5	7.0	4.5
TX OMA pre-Mux (min) @TDP (max) dBm	0.7	1.9	1.0	1.7	2.0	3.0	4.5
Mux Loss dB	2.0		3.0	3.0		2.0	2.0
TX OMA (min) @TDP (max) dBm	-1.3	-0.1	-2.0	-1.3	-1.0	1.0	2.5
Modulation Penalty dB	0.0		0.0	5.0		6.0	9 + Fk
TX OMA Eye (min) @TDP (max) dBm	-1.3	-0.1	-2.0	-6.3	-6.0	-5.0	-6.5 - Fk
TDP (max) dB	1.0	2.2	1.8	0.7	1.0	2.0	2.5
TX OMA Eye - TDP each lane (min) dBm	-2.3		-3.8	-7.0		-7.0	-9 - Fk

400G 2km Duplex SMF PMDs RX Specs

RX Specifications	NRZ 4x25G LR4 No FEC MOD / DML	8x50G NRZ KP4 FEC MOD	8x50G PAM4 KP4 FEC MOD / DML	4x100G BCH FEC PAM4 MOD	4x100G DMT BCH FEC 25G DML
Symbol (or Sample) Rate Gbaud (or GS)	25.8	53.2	26.6	55.9	55.9
Operating BER	1.0E-12	2.0E-04	2.0E-04	1.0E-03	1.0E-03
TX OMA Eye - TDP each lane (min) dBm	-2.3	-3.8	-7.0	-7.0	-9 - Fk
Channel Insertion Loss & MPI penalty dB	6.3	5.0	5.0	5.0	5.0
RX Sens. OMA pre-FEC each lane (max) dBm	-8.6	-8.8	-12.0	-12.0	-14 - Fk
FEC Optical Gain v. 1e-12 BER dB	0.0	3.2	3.2	3.8	3.8
DeMux Loss + Lane BW Penalty dB	2.0	4.6	3.1	3.2	2 - Fk
TIA, Xtalk, Quantization Penalties dB	0.2	1.8	1.3	1.8	1.3
RX Sens. OMA post- DeMux v. LR4 dBm	-10.8	-12.0	-13.2	-13.2	-13.5

400G 2km Duplex SMF PMDs Comparison

400G 2km - LR4 specs 4x25G NRZ No FEC MOD & DML	8x50G NRZ KP4 FEC MOD	8x50G PAM-4 KP4 FEC MOD DML	4x100G PAM-4 BCH FEC MOD	4x100G DMT-K BCH FEC 25G DML	
TX OMA delta (pre-Mux) dB	0.3	1.0	0.1	2.3	2.6
RX Sens. delta (post-DeMux) dB	-1.2	-2.4	-2.4	-2.4	-2.7
Total delta dB	1.5	3.4	2.5	4.7	5.3

Every RX Sens. delta is idealized, incomplete, and optimistic

400G (4x100G) PSM4 PMDs TX Specs

TX Specifications CWDM Grid	4x25G NRZ CWDM4 KR4 MOD / DML		2x50G NRZ KP4 FEC MOD	2x50G PAM4 KP4 FEC MOD / DML		1x100G BCH FEC PAM4 MOD	1x100G DMT BCH FEC 25G DML
	Operating BER	5.0E-05		2.0E-04	2.0E-04		1.0E-03
ER Full Scale (min) dB	6.5	3.5	4.5	7.0	4.5	7.0	4.5
TX OMA pre-Mux (min) @TDP (max) dBm	-2.0	0.0	-1.5	-0.8	-0.5	0.0	2.0
Mux Loss dB	2.0		1.0	1.0		0.0	0.0
TX OMA (min) @TDP (max) dBm	-4.0	-2.0	-2.5	-1.8	-1.5	0.0	2.0
Modulation Penalty dB	0.0		0.0	5.0		6.0	9 + Fk
TX OMA Eye (min) @TDP (max) dBm	-4.0	-2.0	-2.5	-6.8	-6.5	-6.0	-7 - Fk
TDP (max) dB	1.0	3.0	1.8	0.7	1.0	2.0	2.5
TX OMA Eye - TDP each lane (min) dBm	-5.0		-4.3	-7.5		-8.0	-9.5 - Fk

400G (4x100G) PSM4 PMDs RX Specs

RX Specifications CWDM Grid	4x25G NRZ CWDM4 KR4 MOD / DML	2x50G NRZ KP4 FEC MOD	2x50G PAM4 KP4 FEC MOD / DML	1x100G BCH FEC PAM4 MOD	1x100G DMT BCH FEC 25G DML
Symbol (or Sample) Rate GBaud (or GS)	25.8	53.2	26.6	55.9	55.9
Operating BER	5.0E-05	2.0E-04	2.0E-04	1.0E-03	1.0E-03
TX OMA Eye - TDP each lane (min) dBm	-5.0	-4.3	-7.5	-8.0	-9.5 - Fk
Channel Insertion Loss & MPI penalty dB	5.0	5.0	5.0	5.0	5.0
RX Sens. OMA pre-FEC each lane (max) dBm	-10.0	-9.3	-12.5	-13.0	-14.5 -Fk
FEC Optical Gain dB	2.6	3.2	3.2	3.8	3.8
DeMux Loss + Lane BW Penalty dB	2.0	2.6	1.1	1.2	0 - Fk
TIA, Xtalk, Quantization Penalties dB	0.2	1.8	1.3	1.8	1.3
RX Sens. OMA post- DeMux v. CWDM4 dBm	-9.6	-10.5	-11.7	-12.2	-12.0

400G (4x100G) PSM4 PMDs Comparison

4x100G 2km - CWDM4 specs 4x25G NRZ KR4 FEC MOD & DML	2x50G NRZ KP4 FEC MOD	2x50G PAM-4 KP4 FEC MOD DML	1x100G PAM-4 BCH FEC MOD	1x100G DMT-K BCH FEC 25G DML	
TX OMA delta (pre-Mux) dB	0.5	1.2	-0.5	2.0	2.0
RX Sens. delta (post-DeMux) dB	-0.9	-2.1	-2.6	-2.4	-2.4
Total delta dB	1.4	3.3	1.6	4.6	4.4

Every RX Sens. delta is idealized, incomplete, and optimistic

400G 10km Duplex SMF PMDs TX Specs

TX Specifications LAN WDM Grid	4x25G NRZ LR4 No FEC MOD / DML		8x50G NRZ BCH FEC MOD	8x50G PAM4 BCH FEC MOD / DML		4x100G BCH FEC PAM4 MOD	4x100G DMT BCH FEC 25G DML
	Operating BER	1.0E-12		1.0E-03	1.0E-03		1.0E-03
ER Full Scale (min) dB	7.0	4.0	4.5	7.0	4.5	7.0	4.5
TX OMA pre-Mux (min) @TDP (max) dBm	0.7	1.9	2.0	2.2	3.0	3.0	4.5
Mux Loss dB	2.0		3.0	3.0		2.0	2.0
TX OMA (min) @TDP (max) dBm	-1.3	-0.1	-1.0	-0.8	0.0	1.0	2.5
Modulation Penalty dB	0.0		0.0	5.0		6.0	9 + Fk
TX OMA Eye (min) @TDP (max) dBm	-1.3	-0.1	-1.0	-5.8	-5.0	-5.0	-6.5 - Fk
TDP (max) dB	1.0	2.2	2.3	0.7	1.5	2.5	3.0
TX OMA Eye - TDP each lane (min) dBm	-2.3		-3.3	-6.5		-7.5	-9.5 - Fk

400G 10km Duplex SMF PMDs RX Specs

RX Specifications LAN WDM Grid	NRZ 4x25G LR4 No FEC MOD / DML	8x50G NRZ BCH FEC MOD	8x50G PAM4 BCH FEC MOD / DML	4x100G BCH FEC PAM4 MOD	4x100G DMT BCH FEC 25G DML
Symbol (or Sample) Rate Gbaud (or GS)	25.8	55.9	28.0	55.9	55.9
Operating BER	1.0E-12	1.0E-03	1.0E-03	1.0E-03	1.0E-03
TX OMA Eye - TDP each lane (min) dBm	-2.3	-3.3	-6.5	-7.5	-9.5 - Fk
Channel Insertion Loss & MPI penalty dB	6.3	7.0	7.0	7.0	7.0
RX Sens. OMA pre-FEC each lane (max) dBm	-8.6	-10.3	-13.5	-14.5	-16.5 -Fk
FEC Optical Gain v. 1e-12 BER dB	0.0	3.8	3.8	3.8	3.8
DeMux Loss + Lane BW Penalty dB	2.0	4.7	3.2	3.2	2 - Fk
TIA, Xtalk, Quantization Penalties dB	0.2	1.8	1.3	1.8	1.4
RX Sens. OMA post- DeMux v. LR4 dBm	-10.8	-13.0	-14.2	-15.7	-16.1

400G 10km Duplex SMF PMDs Comparison

400G 10km - LR4 specs 4x25G NRZ No FEC MOD & DML	8x50G NRZ BCH FEC MOD	8x50G PAM-4 BCH FEC MOD DML	4x100G PAM-4 BCH FEC MOD	4x100G DMT-K BCH FEC 25G DML	
TX OMA delta (pre-Mux) dB	1.3	1.5	1.1	2.3	2.6
RX Sens. delta (post-DeMux) dB	-2.2	-3.4	-4.9	-5.3	
Total delta dB	3.5	4.9	4.5	7.2	7.9

Every RX Sens. delta is idealized, incomplete, and optimistic

Optical Specifications of SMF PMDs Study

Thank you