Ideal SNR Penalties

400 Gb/s Ethernet Task Force

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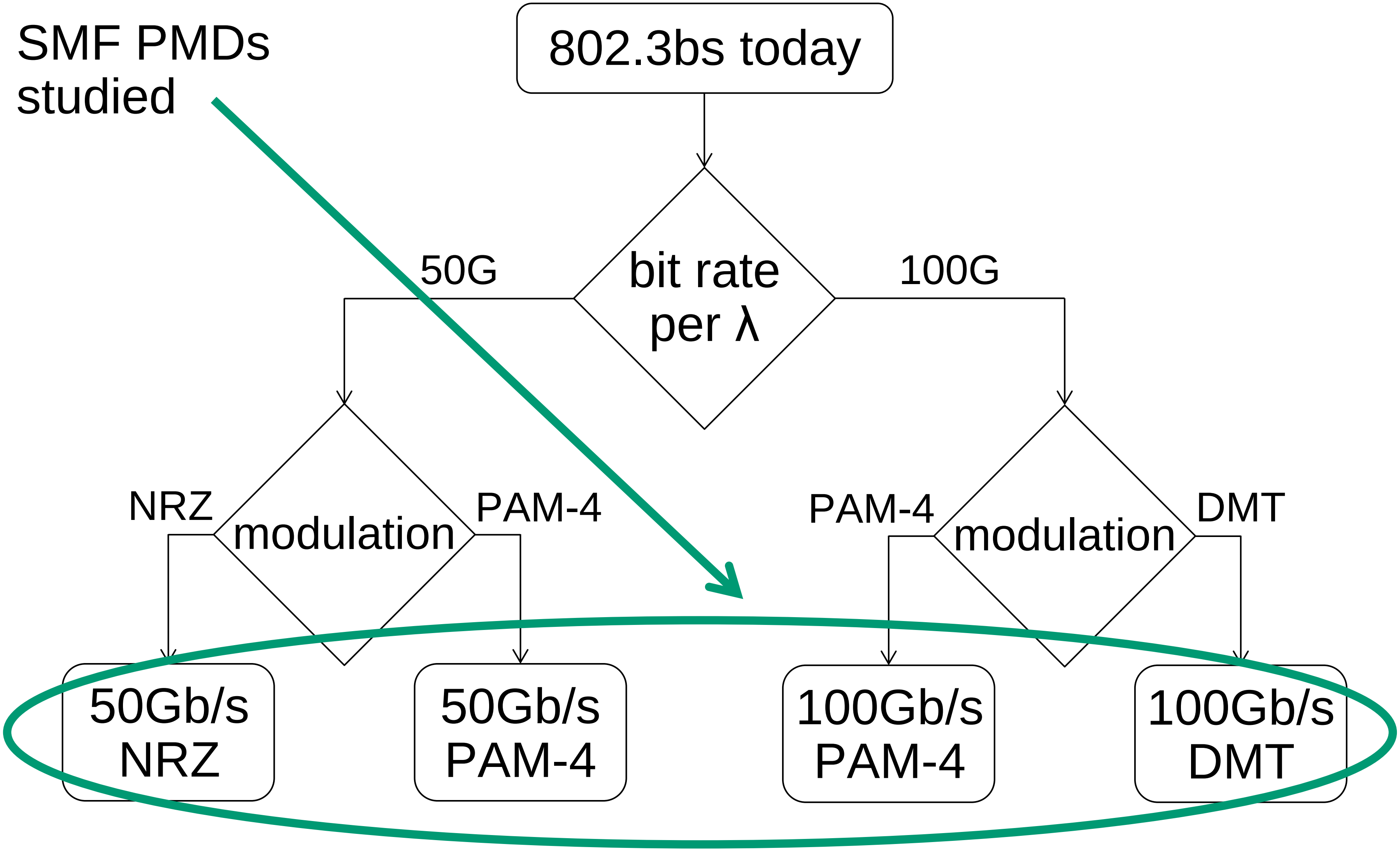
Duplex SMF & PSM4 PMDs Decision Tree

SMF PMDs studied



Introduction

- Bit Rate = Channels * Baud Rate * Bits/Baud
  - Channels = fiber pairs * lambdas * polarizations * I & Qs
  - Baud Rate: limited by B_{NQ} (Nyquist)
  - Bits/Baud: limited by SNR (Shannon)
- Ex.1: 10GBASE-LR, -SR (1λ, 1 fiber pair)

  10Gb/s = 1 channel * 10GBaud * 1 bit/Baud
- Ex.2: 100GBASE-LR4, -SR4 (4λs or 4 fiber pairs)

  100Gb/s = 4 channels * 25GBaud * 1 bit/Baud
- Ex.3: 100G DP-QPSK Coherent (1λ, 1 fiber pair)

  100Gb/s = 4 channels * 25GBaud * 1 bit/Baud

  Ex. reference for analyzing I & Q as separate channels:

  J. Wozencraft, I. Jacobs, Principles of Communication Engineering, Wiley, New York, 1965, chapter 7.

Bits/Baud Examples

- NRZ: 1 bit/Baud
- PAM-M bits/Baud = log2(M)
  - M=2: 1 bit/Baud
  - M=4: 2 bits/Baud
- QAM-M bits/Baud = log2(√M)) = 0.5*log2(M)
  - M=4: 1 bit/Baud (i.e. M_I = 2, M_Q = 2)
  - M=16: 2 bits/Baud (i.e. M_I = 4, M_Q = 4)
- DMT-k QAM-M bits/Baud = log2(√M) = 0.5*log2(M)
  - k is the number of DMT sub-carriers
  - M=4: 1 bit/Baud (i.e. $M_{I\ K=1 \rightarrow k}$ = 2, $M_{Q\ K=1 \rightarrow k}$ = 2)
  - M=16: 2 bits/Baud (i.e. $M_{I\ K=1 \rightarrow k}$ = 4, $M_{Q\ K=1 \rightarrow k}$ = 4)

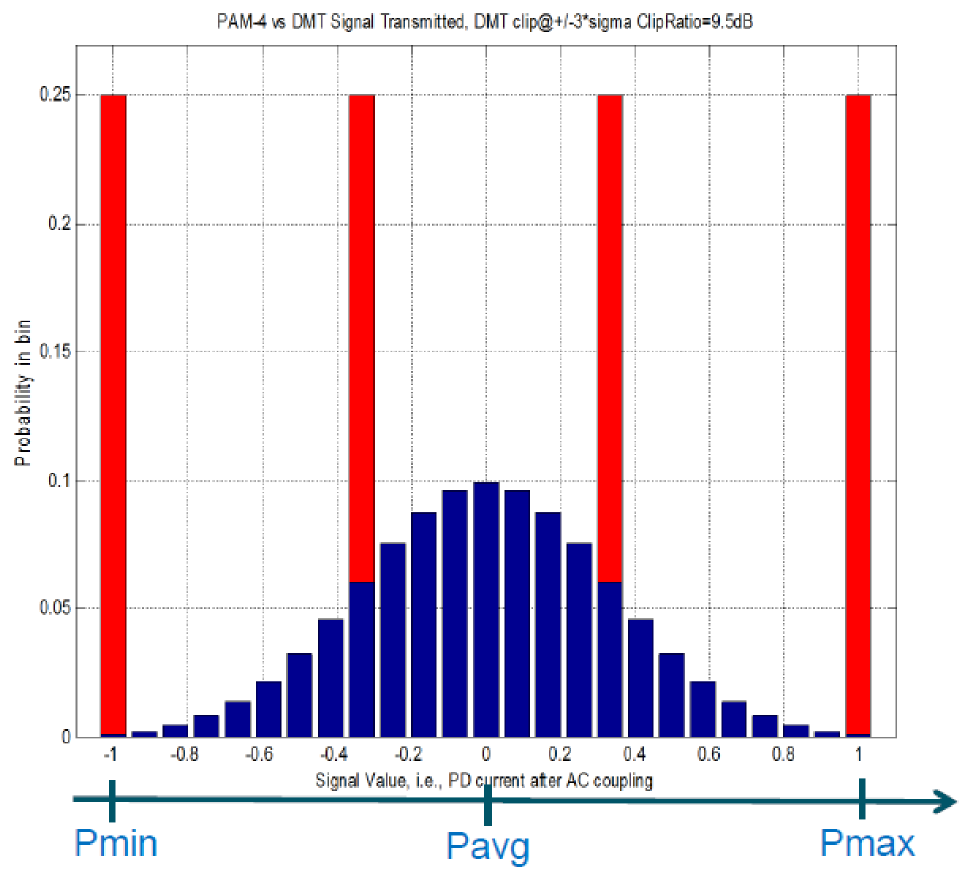
Bit Rate Examples

Modulation	Channels	Baud	Bits/Baud	Bit Rate
NRZ	1	2*BW	1	2*BW
PAM-4	1	2*BW	2	4*BW
QAM-16	2	BW	2	4*BW
DMT-k QAM-16	2*k	BW/k	2	4*BW

- $BW = B_{NQ\_PAM\text{-}4} = B_{NQ\_QAM\text{-}16} = k * B_{NQ\_DMT\text{-}k\_QAM16}$
- QAM has 2 channels (I&Q) on one BW/2 sub-carrier
- DMT has k BW/k spaced sub-carriers (1st is BW/(2*k))
- DMT cyclic prefix overhead is ignored in these examples

DMT PAPR Penalty (Electrical) Reference

DMT TX 'SIGNAL VARIANCE' AND CLIPPING



- **Red = PAM-4 probability**
- **Blue = DMT example with moderate clipping at +/- 3*sigma**
  - 'Clipping ratio' = 9.5dB
- **Mean time to 'clipping' is about 370 Bauds, so average more than one clip per Block of N=512 Baud samples.**
  - Many blocks will have multiple clippings
- **The 'Signal Variance' (which is communication theory TX power) is 7 dB lower than that of PAM-4**
- **Note that the laser has the same peak-peak power range and equal average power**

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Will Bliss, Advanced Modulation, bliss_3bs_01_0714, p.13

SNR (Electrical) Examples

Modulation	S	N	SNR
NRZ	P	$2*BW*N_0$	$P/(2*BW*N_0)$
PAM-M	P	$2*BW*N_0$	$P/(2*BW*N_0)$
QAM-M	P/2	$BW*N_0$	$P/(2*BW*N_0)$
DMT-k QAM-M	$\beta_{PAPR}*P/(2*k)$	$(BW/k)*N_0$	$\beta_{PAPR}*P/(2*BW*N_0)$

- S & N are for single channel (I or Q for QAM and DMT)
- $BW = B_{NQ\_PAM-4} = B_{NQ\_QAM-16} = k * B_{NQ\_DMT-K\_QAM16}$
- N_0 = Noise Power Density (two sided)
- β_{PAPR} = DMT Peak to Average Power Ratio loss coeff.

PAM, QAM SNR Modulation Penalty

- All penalties on this and following pages are in dB optical
- PAM-M modulation penalty = 10*log10(M-1)
  - PAM-2 (NRZ) = 0 dB
  - PAM-4 = 4.8 dB
  - PAM-16 = 11.8 dB
- QAM-M modulation penalty = 10*log10(√M -1)
  - QAM-4 = 0 dB
  - QAM-16 = 4.8 dB
  - QAM-256 = 11.8 dB
- Modulation penalty decreases S in SNR therefore:
  - Reduces TX OMA of symbol eye

DMT SNR Modulation Penalty

- β_{PAPR} = DMT PAPR loss coeff. (see page 7)
  - $10*\log10(1/\sqrt{\beta_{PAPR}})$ @ +/- 3σ clipping = 3.5 dB
- DMT-k QAM-M mod. penalty = $10*\log10((\sqrt{M} -1)/\sqrt{\beta_{PAPR}})$
  - DMT-k QAM-4 = 0.0 + 3.5 = 3.5 dB
  - DMT-k QAM-16 = 4.8 + 3.5 = 8.3 dB
  - DMT-k QAM-256 = 11.8 + 3.5 = 14.3 dB
- Modulation penalty decreases S in SNR therefore:
  - Reduces TX OMA of symbol eye

SNR Bandwidth Penalty

- Bandwidth penalty = 5*log10(B_{SIG}/B_{REF})
  - 19G → 30G = 1.0 dB
  - 25G → 50G = 1.5 dB
  - 25G → 100G = 3.0 dB
- Bandwidth penalty increases N in SNR, therefore:
  - does not show up directly in normative specs.
  - decreases RX Sens. in spec. comparisons
- Ideal SNR penalty = modulation + bandwidth penalties

Ideal SNR Penalties of 100G PMDs

Modulation	λs	GBaud	BW GHz	Penalty dB
25G NRZ	4	25	12.5	0
50G NRZ	2	50	25	1.5
50G PAM-4	2	25	12.5	4.8
100G PAM-4	1	50	25	6.3
100G PAM-16	1	25	12.5	11.8
100G QAM-16	1	25	25	6.3
DMT-k QAM-16	1	25/k	25	9.8
DMT-k QAM-256	1	12.5/k	12.5	15.3

KR4, KP4, BCH FEC Gains: 2.6, 3.2, 3.8 dB, respectively

Ideal SNR Penalties

Thank you