SEMTECH

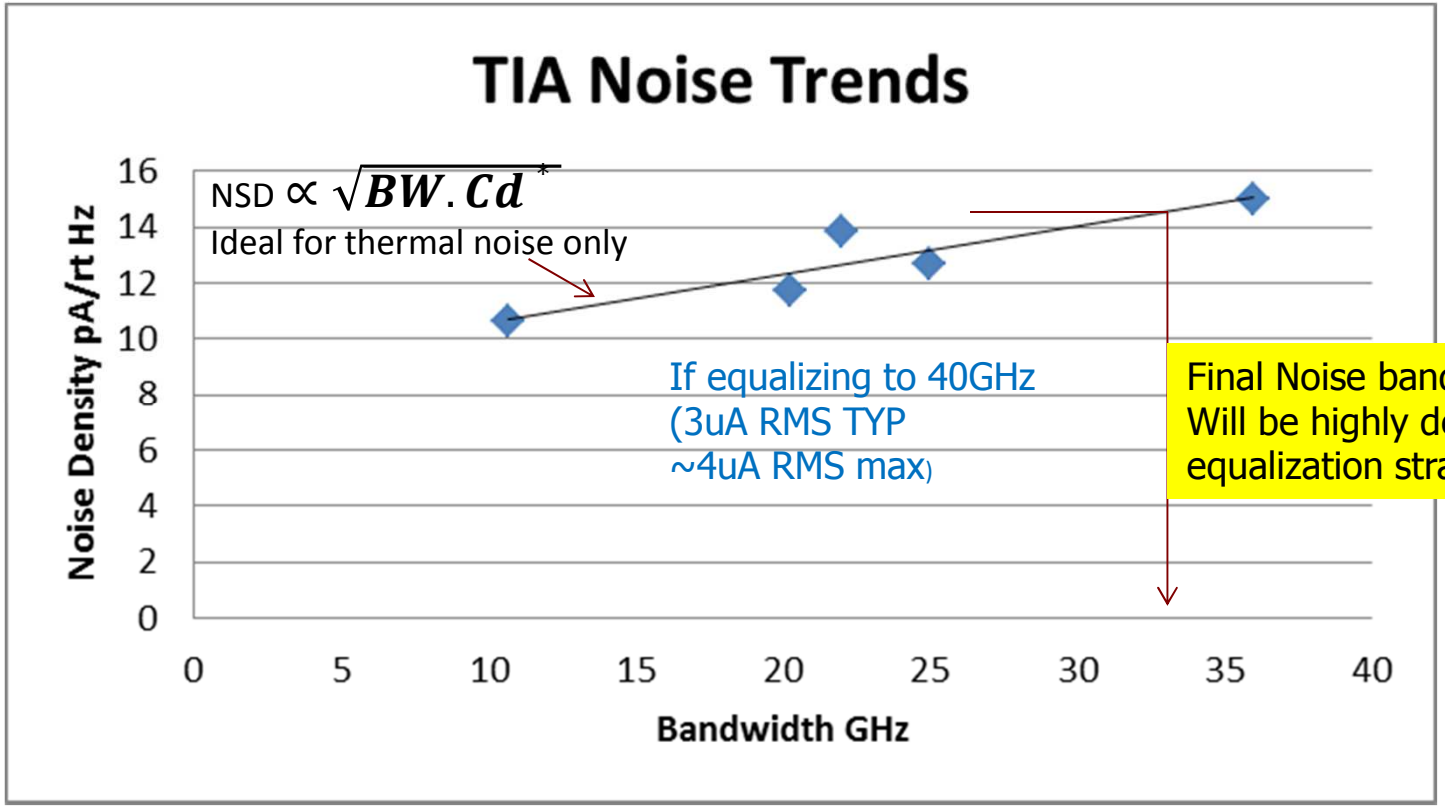
100Gb/s/Lambda PAM4: Component Perspective

Alan Tipper Sept 2014

Supporters

- Vipul Bhatt, Inphi
- David Brown, Semtech
- Keith Conroy, MultiPhy
- Neal Neslusan MultiPhy
- Jeff Maki , Juniper
- Winston May, Neo Photonics
- Ram Rao, Oclaro
- Bharat Tailor Semtech
- Francois Tremblay, Semtech
- Ed Ulrichs, Source Photonics
- Brian Welch, Luxtera

Receiver Noise Trend



Current Rx development is tracking the $\sqrt{BW.Cd}$ trend from a well established 10G baseline so we should target a 4uA RMS for TIA Noise post EQ

* Cd = Detector capacitance

Bottom Up 2km budget: Rx line up

- RMS Noise = 4uA
- Ideal OMA(11-00)=-9.2dBm @10^{-3} and 0.6A/W
- Demux loss 2dB
  - Ref: www.ieee802.org/3/ba/public/jul08/paatzsch_01_0708
    - <1.5dB loss for LAN WDM TFF filters
- Rx Penalties
  - 5% Linearity 1dB (see appendix 2)
  - Residual frequency response & reflections 1dB (after EQ)
- TDP
  - 2dB as per multiple previous presentations e.g Cole_2bs_01a_0714
- At input to demux, min OMA(11-00)=-5.2dBm @10^{-3}
  - -7.2dBm at input to Rx
  - At 10^{-5} we would need -4.4dBm pre-demux and -6.4dBm at the detector
- 10^{-3} BER is consistent with bhatt_3bs_010714 sensitivities
  - -5.3dBm OMA11-00 but more powerful FEC than .bj will be necessary
  - TX Power = 1.6mW average (pre mux)

Ideal SNR

$$BER = \frac{3}{8} erfc\left(\frac{OMA_{11-00}}{6\sqrt{2}\sigma}\right)$$

$$\sim 10^{-3} \text{ for } \frac{OMA_{11-00}}{\sigma} = 18$$

$$\sim 10^{-5} \text{ for } \frac{OMA_{11-00}}{\sigma} = 25$$

Status of Recent Experimental Data

- Stassar_3bs_01_0714
  - **1E-3 BER at -7.5dBm average with 6dB ER OMA(11-00) = -6.7dBm**
  - Using 40Gb/s grade components
- Mazzini_01a_0814_smf
  - 1E-3 BER at -5.5dBm OMA
  - Using 40Gb/s grade components
  - 1E-5 not demonstrated
- Bhatt_3bs_010714
  - 1E-3 not achievable (using error counting rather than Q)
  - 22GHz Tx bandwidth

Using legacy components without Tx pre-emphasis the best result so far is within 0.5dB of the proposed RXOMA Min.
Legacy TIAs typically have 25-30 pA/rt Hz noise – room for improvement

Bottom Up 2km Budget: Straw Poll of EA Modulator vendors

- We asked a group of Modulator suppliers: What are the trade offs between :
  - (a) 56Gbaud PAM4 EA with >1mW average output and 6dB ER?
  - (b) 56Gbaud PAM4 EA with >3mW average output and 6dB ER?
- Vendor responses:
  - Vendor A - *We do not think (b) EA with >3mW average output can be achieved, so (a) EA with >1mW average output will be the only viable option.*
  - Vendor B - *I don't think 3mW average power work for EML if it means the average power which is coupled into SMF. 6dB extinction ratio may be feasible if EML driver has a kind of non-linearity compensation.*
  - *Vendor C 3mW is achievable*
  - *More responses to come (vacation time has slowed down the response rate)*
- So far it looks like we need a low Tx power budget
  - Can't operate near class 1 limits
  - Lack of wide support for 3mW EAs
  - 3mW Tx Power may be prohibitive for SiP evolution – needs more study

Proposed Bottom Up Budget based on 1E-3 Raw BER

	Bhatt_3bs_01_0714 .bj KP4 FEC 1E-5 Raw BER	Cole_3bs_01_0714 BCH FEC 1E-3 Raw BER	Stassar_3bs_01_0714 .bj KP4 FEC 3E-4 Raw BER	Stassar_3bs_01_0714 .bj KP4 FEC 3E-4 Raw BER	1.6mW EA 4uA RMS Rx 1E-3 Raw BER 6dB ER
Tx source power dBmOMA(11-00)	2	1.5	0.8	5.8	2.8
Source power mW average	1.2	1.2	1.0	3.2	1.6
Mux loss	2.3	2	2	2	2
Post Mux OMA(11-00)	-0.3	-0.5	-1.2	3.8	0.8
Post Mux OMA(01-00)	-5.1	-5.5	-6	-1	-5.6
TDP dB	2.5	2	1	1	2
TXOMA-TDP(11-00)	-1.3	-2.7	-2.2	2.8	**-1.2**
TXOMA-TDP(01-00)	-6.1	-7.5	-7	-2	-6
Path Loss	4	5	4	4	4
RX in predemux dBm OMA(11-00)	-5.3	-7.7	-6.2	-1.2	**-5.2**
RX in dBm OMA(01-00)	-10.1	-12.5	-11	-6	-10.0
demux loss	2.3	2	2	2	2
RX in post demux dBm OMA(11-00)	-7.6	-9.7	-8.2	-3.2	-7.2
RX in post demux dBm OMA(01-00)	-12.4	-14.5	-13	-8	-12
Rx in dBm average at 6dB ER	-8.4	-10.5	-9.0	-4.0	-8.0
Source:Rx dynamic range	9.6	11.2	9	9	10

How do we get more margin? Detector Responsivity >>0.6A/W, higher than 1.6mW EA, Rx linearity <<5%

Note: stassar_3bs_01_0714 & Cole_3bs_01_0714
Did not quote mux/demux
Losses explicitly so 2dB has been assumed

Summary

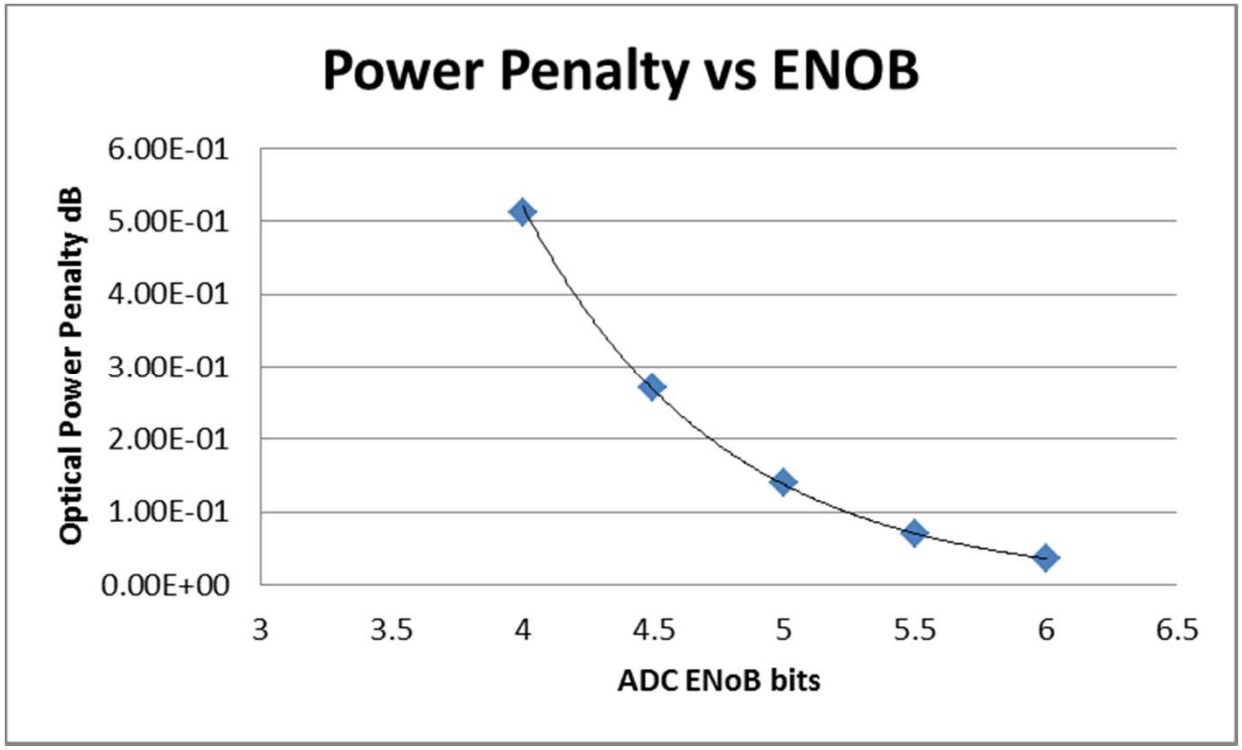
- Low Power EA Transmitters ~1.6mW Average will limit TX OMA
  - EA power vs detector responsivity trade off needs exploring
- Realistic integrated Noise is 4uA based on current Rx trends
  - Legacy devices are worse than this so some room for improvement
- FEC Needs to operate at 10^{-3} Raw BER
  - Experimental Results support 10^{-3} operation
- 2km Link budget can be closed with 2dB TDP & 2dB Rx penalties
  - TXOMA(11-00) - TDP > -1.2dBm
  - RXOMA > -5.2dBm
  - 4 wavelength solution appears feasible
- Noise bandwidth dependant upon choice of equalization
  - Analogue vs Digital EQ needs further study
- To build margin we need to examine:
  - Detector responsivity >>0.6A/W
  - Tx power >1.6mW
  - Rx Linearity <5%

Appendix1: RX Quantization Noise Penalty

Linear TIA with AGC
Input Referred Noise 4uA RMS
Min Input OMA(11-00) = -7.2dBm
0.6 A/W Detector

Total Input Referred Noise

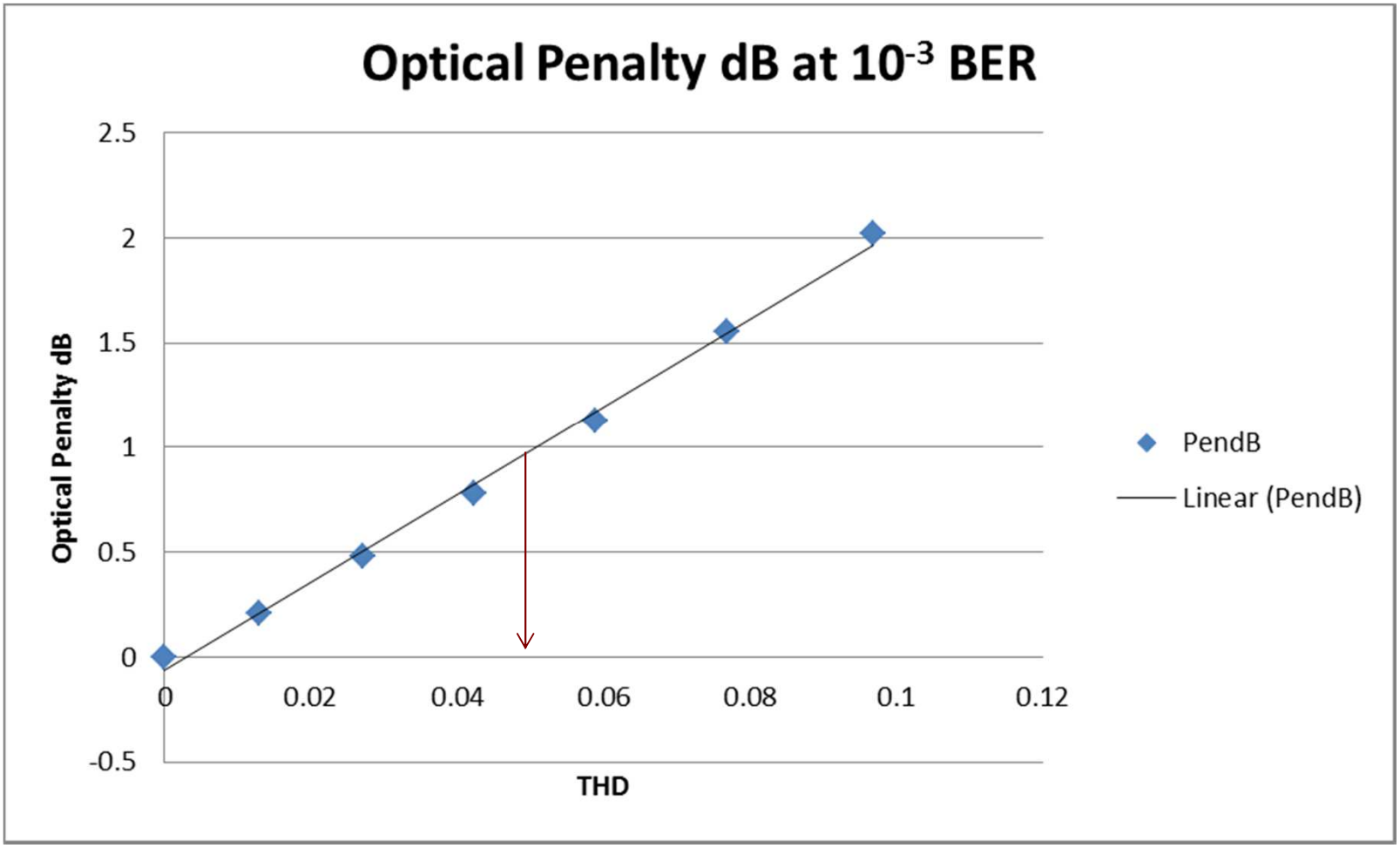
$$i_n^2 = i_{TIA}^2 + \frac{(Ipp^2)/8}{10^{\left(\frac{6.02ENoB+1.76}{10}\right)}}$$



For ENoB>5.5 bits RX quantization noise should not be significant if the AGC is matched to the ADC Input Range

Appendix 2: Simulated RX THD Penalty

56Gbaud PAM4, -140dB/Hz RIN, 2km SMF, 32GHz RX BW



<1dB Penalty for <5% THD

update to http://www.ieee802.org/3/100GNGOPTX/public/may12/tremblay_01a_0512_optx.pdf