Block Error Ratio Measurements for PMD Receive Lane

(comment #180)

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Jan 9, 2025

Outline

1. Analysis of the error ratio tests in 174A.6.1.3 & 174A.6.1.4 with correlated errors

2. Proposal for a similar error ratio test, for an individual lane of a multi-lane PMD (Draft 1.3 comment #180)

Cl **174A** *SC* **174A.6.1.4** *P* **665** *L* **24** # 180

Brown, Matt — Alphawave Semi

Comment Type **T** *Comment Status* **X**

The block error ratio test method in 174A.6.x.x provides a means to constrain the block error ratio due to a single lane by constraining the error histogram to be below a limit curve. This is overly conservative and does not provide a single metric for optical and electrical waterfall curves.

SuggestedRemedy

An effective block error ratio metric for a single lane on a multi-lane PMD is required. A contribution with proposal will be provided.

Proposed Response *Response Status* **O**

Background

- Considerations for 802.3dj error ratio allocation
  - Multiple inter-sublayer links (ISLs) adding errors to the same codeword
  - Error correlation from MLSD/DFE
  - RS FEC Interleaving
  - Inner FEC and convolutional interleaving

- Methods of testing error ratio compliance based on PMA-based measurement (see Receiver Performance Evaluation)
  - 174A.6.1.3: Error mask test
  - 174A.6.1.4: Block error ratio method

PMA block error histogram

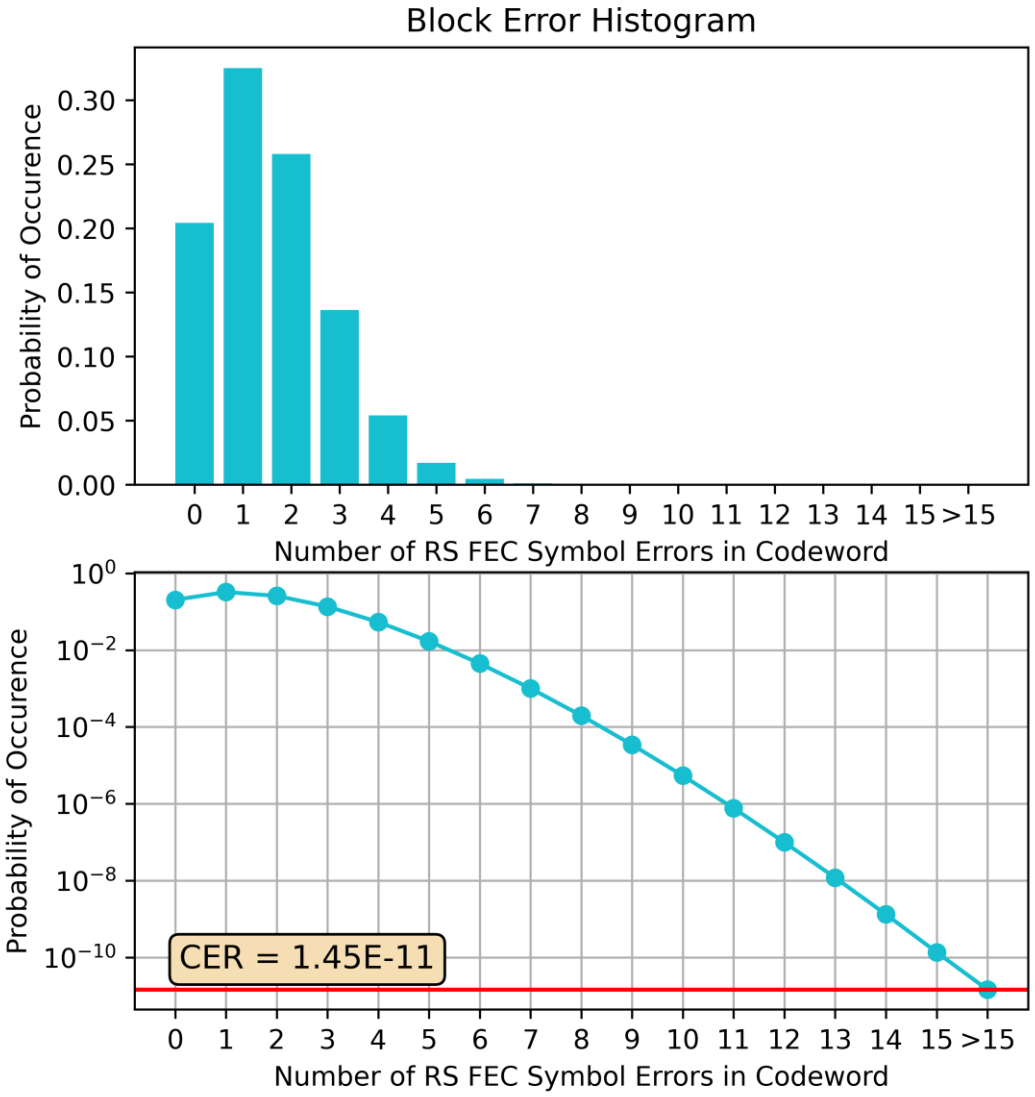
Random error assumption:

- PAM-4 symbol errors are independent
- Each PAM-4 symbol error has one bit error

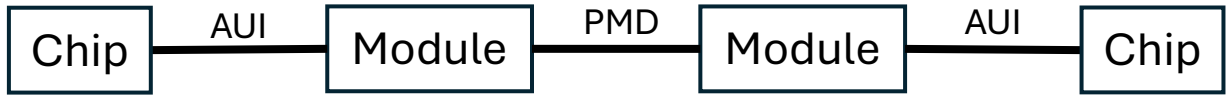
$$RSSER = 1 - (1 - 2BER)^5$$

$$H(k) = \frac{n!}{k!\,(n-k)!} RSSER^k (1 - RSSER)^{n-k}$$

Frame loss ratio for entire PHY	Codeword error ratio for entire PHY	BER for entire PHY (BER_{total})
6×10^{-11}	1.45×10^{-11}	2.92×10^{-4}



Model of an optical PHY as a three-part link



BER allocation: 0.32×10^{-4} 2.28×10^{-4} 0.32×10^{-4}

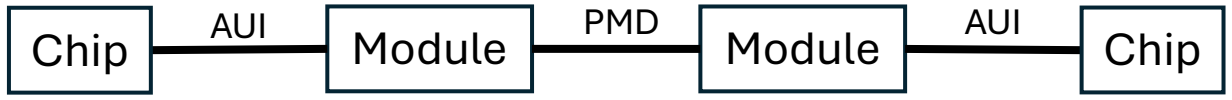
***This example is based on Table 174A-1 below. In this example, the allocation for both C2C and C2M links are lumped into one AUI for simplicity of the example.**

Table 174A–1—Error ratio allocations for optical PHYs

Sublayer or interface	Frame loss ratio for entire PHY	Codeword error ratio for entire PHY	BER for entire PHY (BER_{total})	BER per sublayer in a PHY
xAUI-n C2C[a]	6×10^{-11}	1.45×10^{-11}	2.92×10^{-4}	0.08×10^{-4}
xAUI-n C2M				0.24×10^{-4}
PMD-to-PMD				2.28×10^{-4}
xAUI-n C2M				0.24×10^{-4}
xAUI-n C2C				0.08×10^{-4}

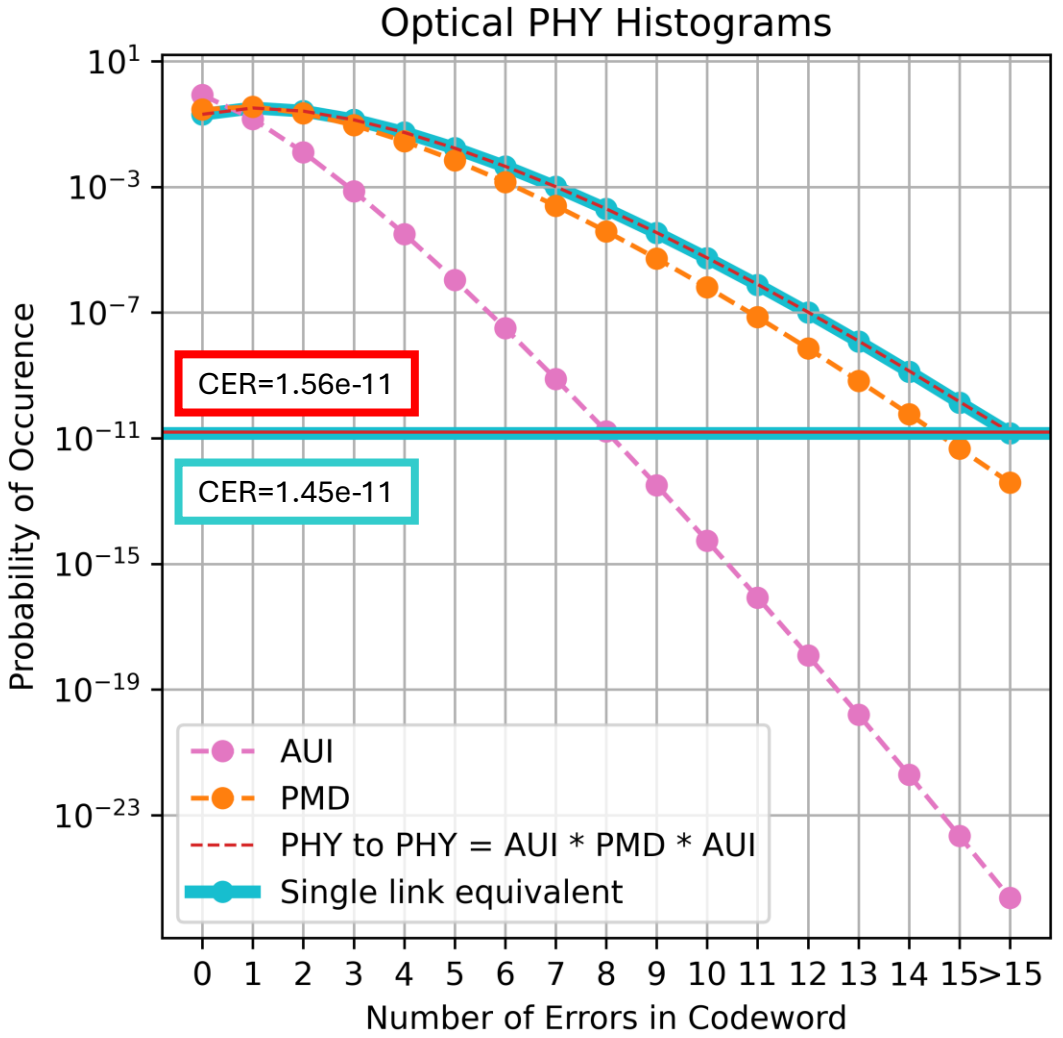
[a] If the PMD is a type defined in Clause 180, Clause 181, Clause 182, or Clause 183 (i.e., 200 Gb/s per lane), and xXAUI-n C2C is a type defined in Annex 120D (i.e., 50 Gb/s per lane) or Annex 120F (i.e., 100 Gb/s per lane), the xXAUI-n C2C is expected to meet at the BER allocations in this table.

Histogram convolution for multi-part links

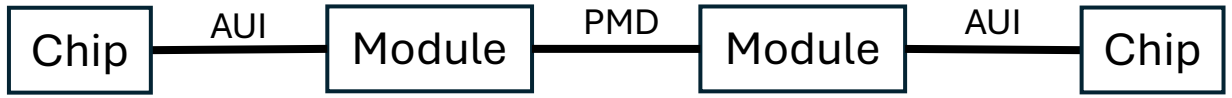


BER allocation: 0.32×10^{-4} 2.28×10^{-4} 0.32×10^{-4}

- End-to-end histogram can be estimated by convolving the individual histograms
  - Assumes that if one link adds *i* errors to a codeword, and another ISL adds *j* errors, this results in *i+j* errors total
  - Does not consider that errors could fall in same RS FEC symbol

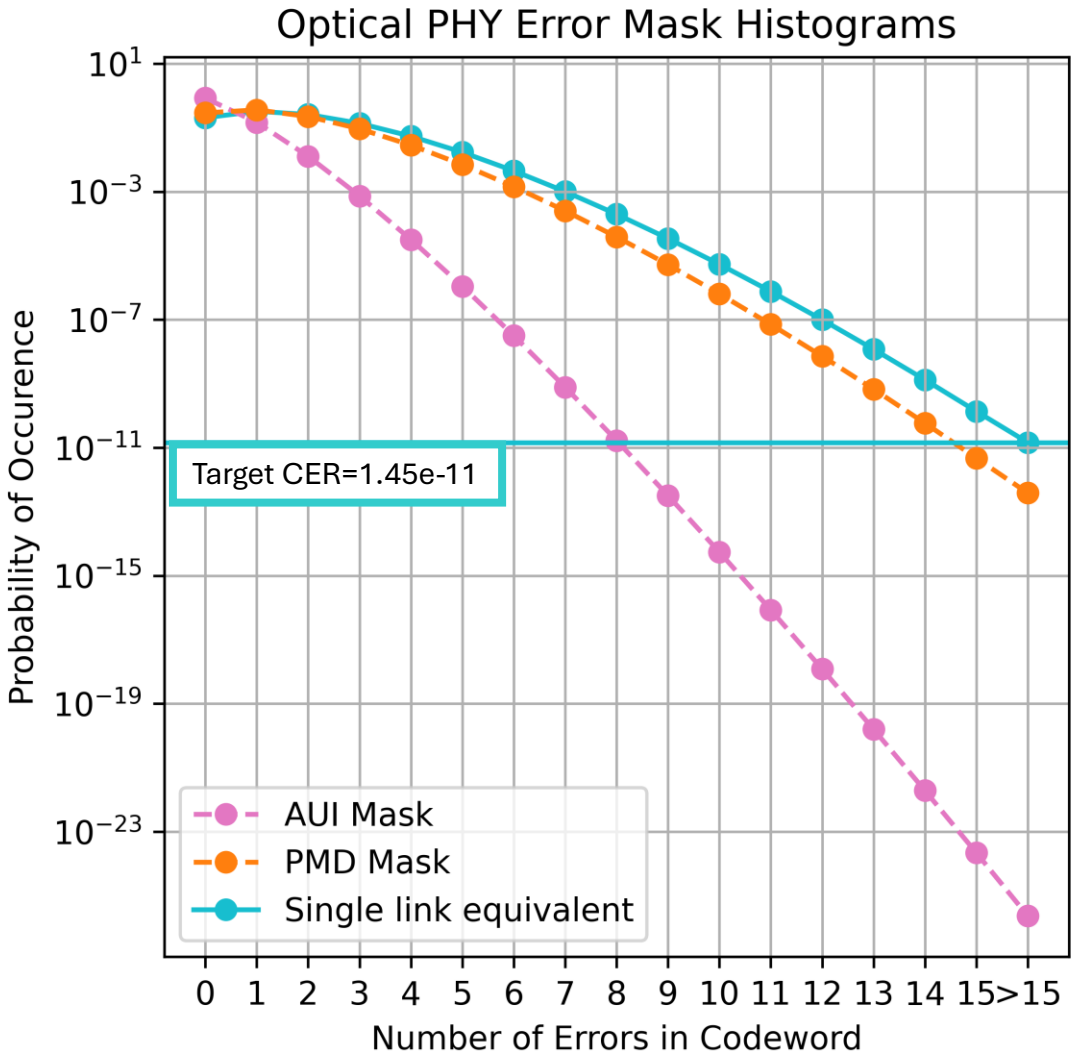


Error mask test



BER allocation: 0.32×10^{-4} 2.28×10^{-4} 0.32×10^{-4}

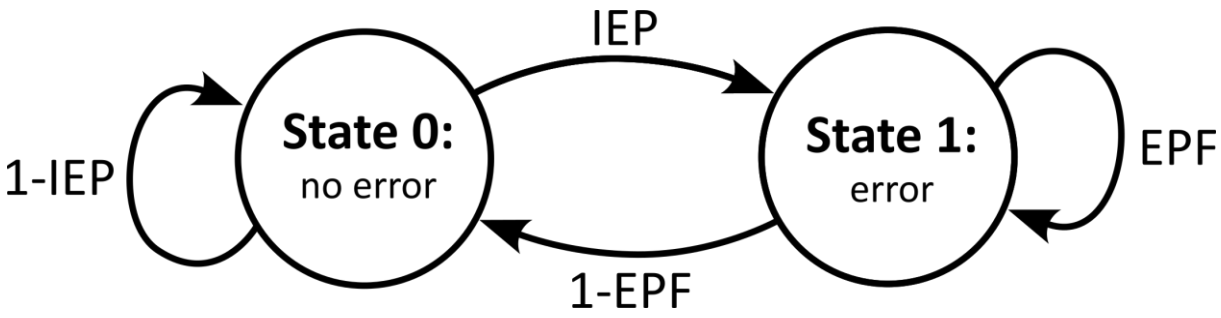
1. For each link, compute a histogram “mask” having the BER allocation assuming random errors
2. Ensure that the link’s measured histogram is lower in each of the bins (not including bin 0)



Error propagation factor (EPF) channel

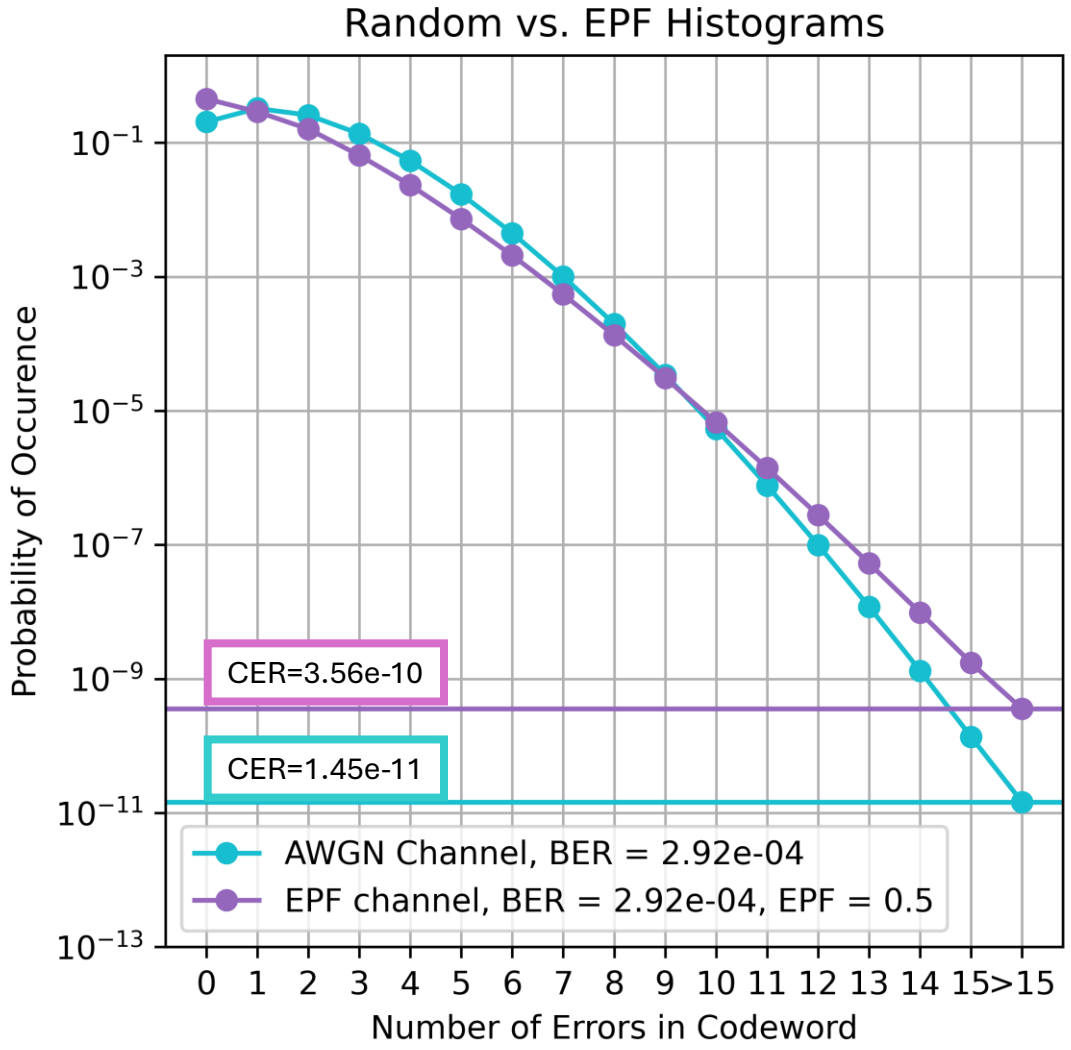
- If the channel is truly random, this test is accurate and has little margin, but what about with correlated errors?

Error propagation channel model (can model DFE or MLSD)

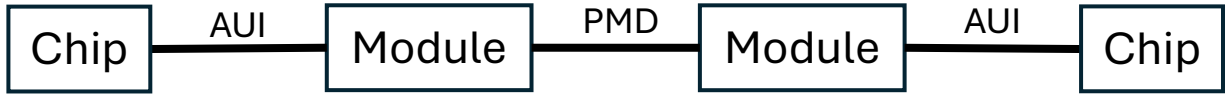


Statistical analysis of EPF Histograms:

M. Yang, S. Shahramian, H. Shakiba, H. Wong, P. Krotnev and A. C. Carusone, "Statistical BER Analysis of Wireline Links With Non-Binary Linear Block Codes Subject to DFE Error Propagation," in *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 67, no. 1, pp. 284-297, Jan. 2020, doi: 10.1109/TCSI.2019.2943569.



Error mask test for EPF channels

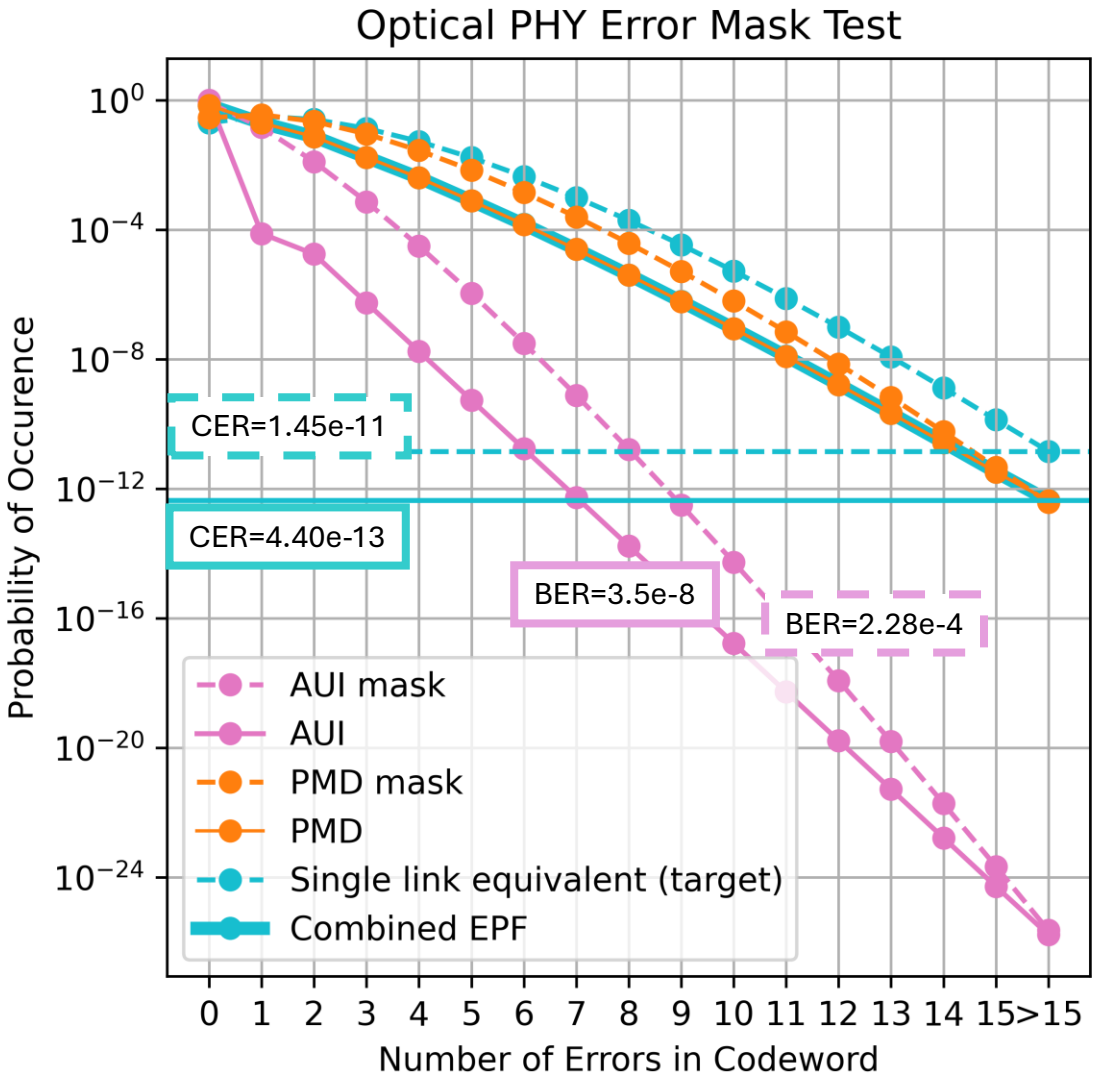


BER allocation: 0.32×10^{-4} 2.28×10^{-4} 0.32×10^{-4}

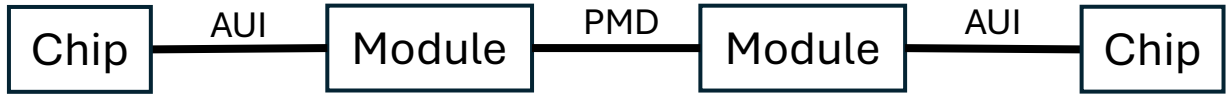
- Adding error correlation increases the slope of the histogram
- Error mask test is overly conservative in this case

The expected block error ratio is met if $H_m^{(i)}(k)$ (see 174A.6.1.1.3) are less than $H_{max}(k)$ for all k and i.

k>0



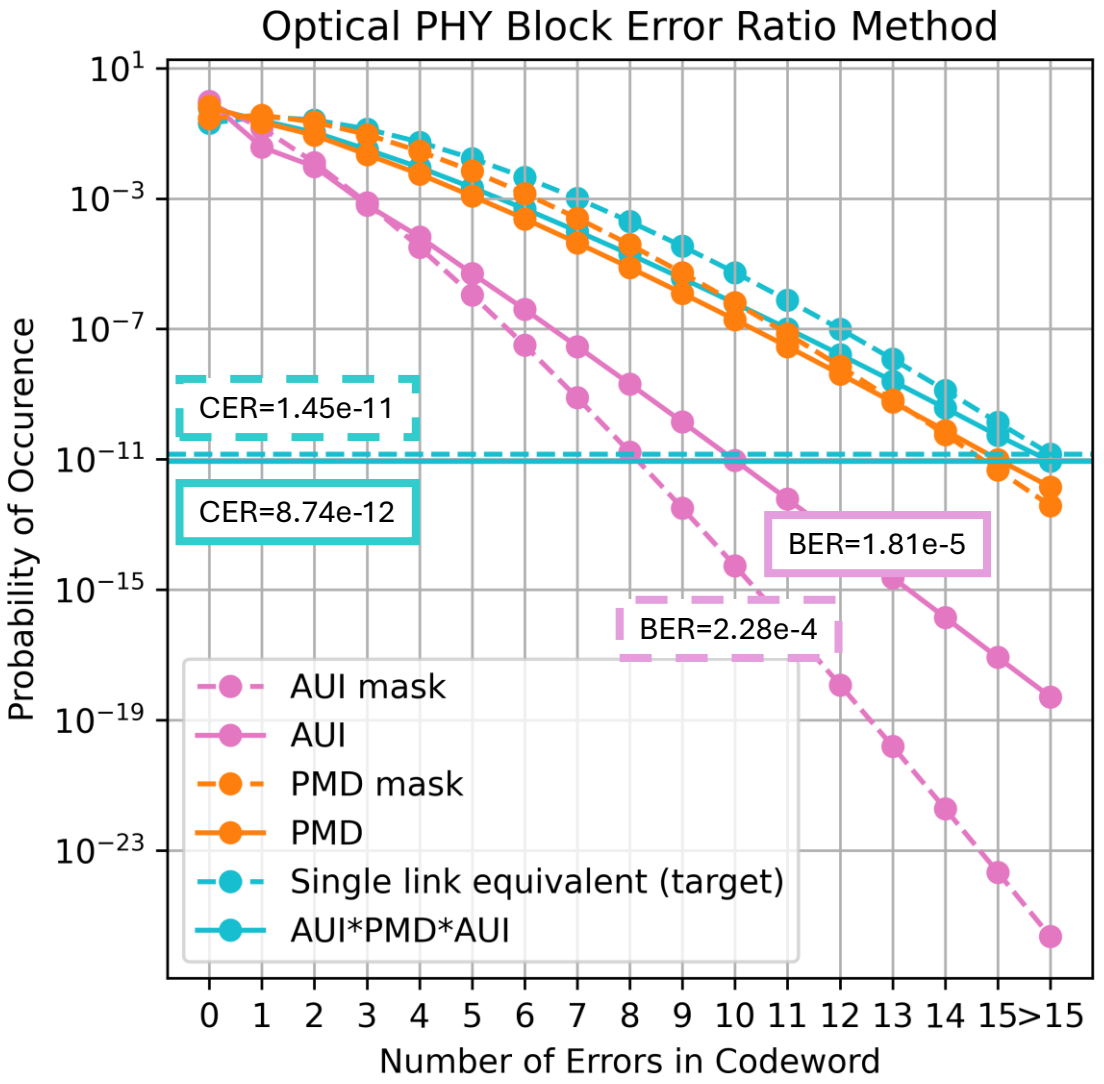
Block error ratio method for EPF channels



BER allocation: 0.32×10^{-4} 2.28×10^{-4} 0.32×10^{-4}

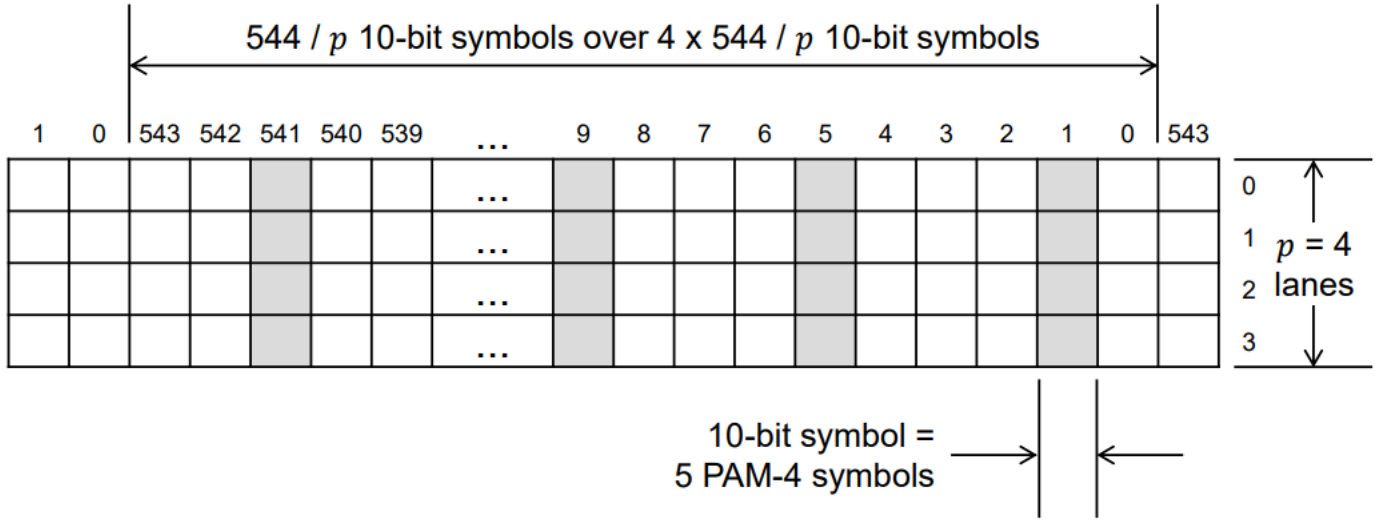
1. For each link, calculate random histogram with BER_{added}
2. Ensure that the measured histogram convolved with the BER_{added} histogram has CER less than 1.45e-11

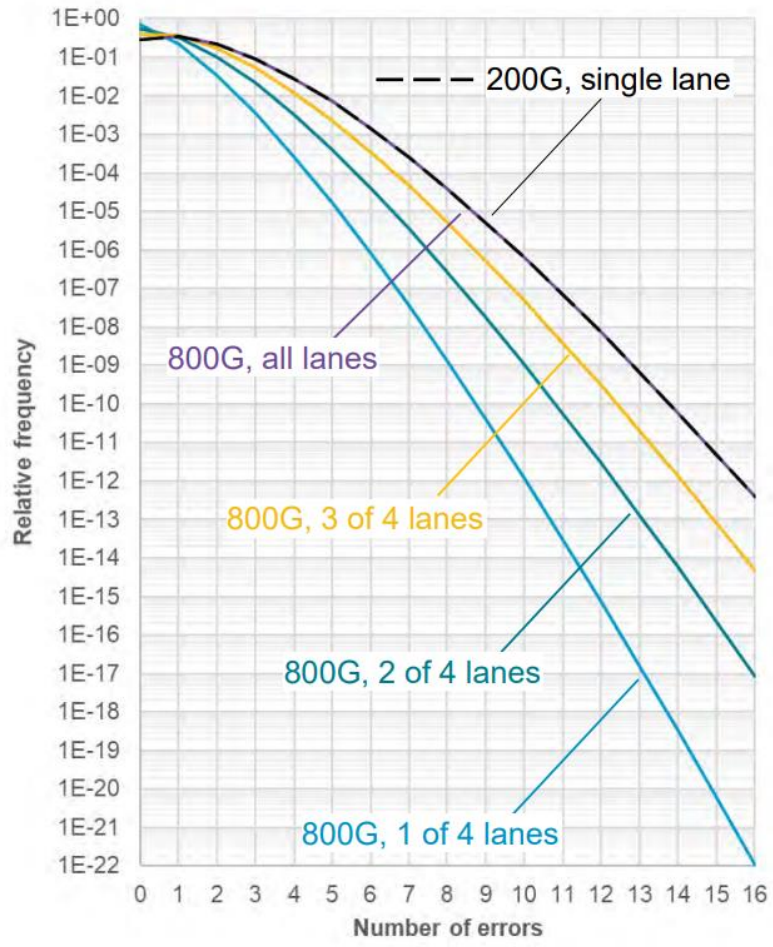
Although individual links exceed mask, combined links are still compliant, and with much less margin!



Combining histograms across physical lanes

- So far, analysis have been simplified with single lane links and without FEC symbol interleaving
- With interleaving, histogram measurements are taken using shorter test blocks from each lane
- Histograms are convolved together to get combined affect of all lanes





Figures from: Receiver Performance Evaluation

Error ratio test for an individual lane in a multi-lane PMD

- Motivation: Comment #180 - An effective block error ratio metric for a single lane on a multi-lane PMD is required.
  - Allows us to plot waterfall curves for individual lanes

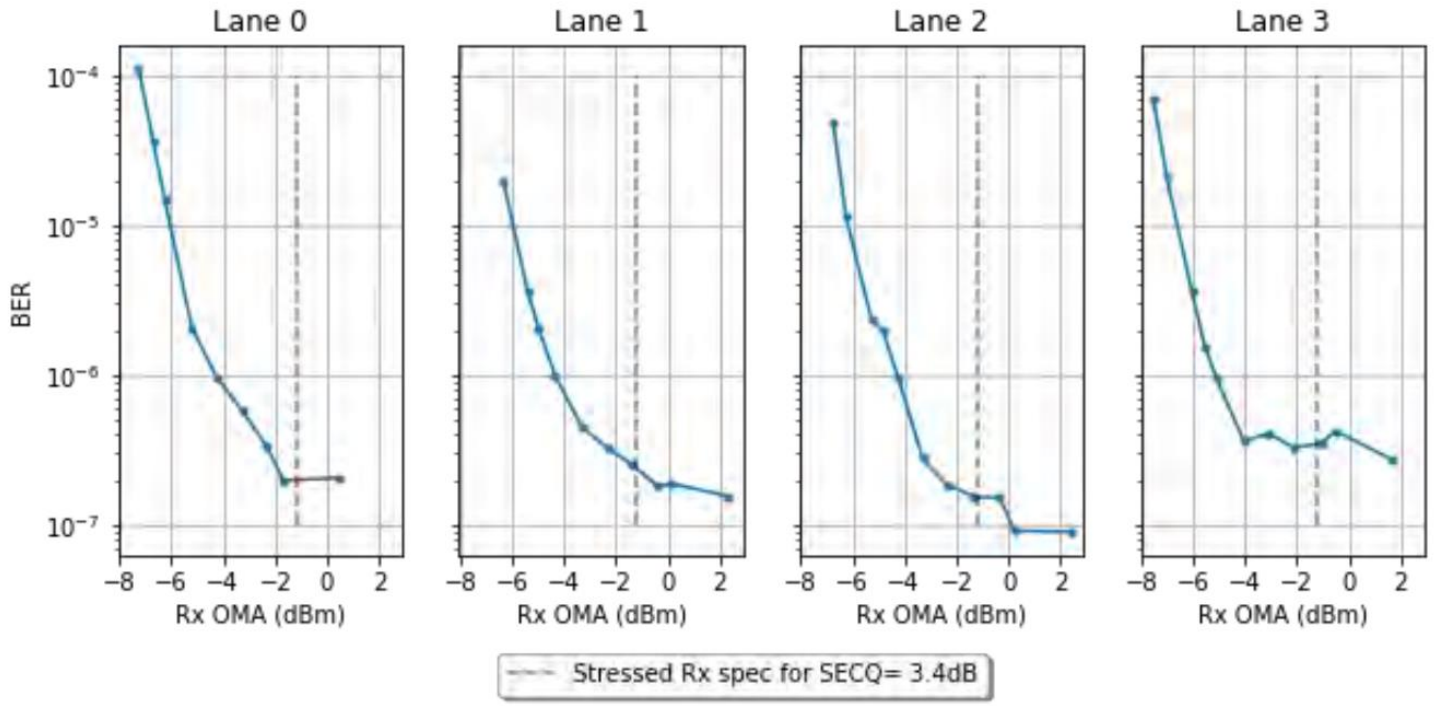


Figure from:

Transceiver Module Data in support of comments #396 and 397 against D1.2

Proposals

- Proposal for error ratio test on an individual lane in a multi-lane PMD:
  1. Measure a histogram for a test block of size 544/*p*
  2. Convolve together *p* identical copies of this histogram to yield a new histogram with test block length 544
     - This assumes that all lanes are identical to the lane under test
     - This models the effect of codewords being split across multiple lanes, and is different than simply extending the test block length to a full 544 over one lane
  3. Then this histogram can be used with the block error ratio method to calculate a CER estimate for a single lane
  - Each lane should individually meet the CER specification of 1.45e-11
- Other proposal:
  - Change 174A.6.1.3: Error mask test wording:

    "less than $H_{max}(k)$ for all i, and $k > 0$"

Conclusion

- Our statistical analysis shows that the error mask test may be conservative in the presence of correlated errors
- The block error ratio method is less conservative
- We propose a method for doing the block error ratio test on an individual lane in a multi-lane PMD

Thank you