400GBASE-ZR EVM Pass/Fail Criteria

Yi Weng, Konstantin Kuzmin, and Winston Way

NeoPhotonics

Supporters

Joerg Pfeifle, Keysight

Klaus Engenhardt, Multilane

Keith Conroy, Acacia

Dave Lewis, Lumentum

Hideki Isono, Fujitsu

Eric Maniloff, Ciena

Steve Trowbridge, Nokia

Introduction

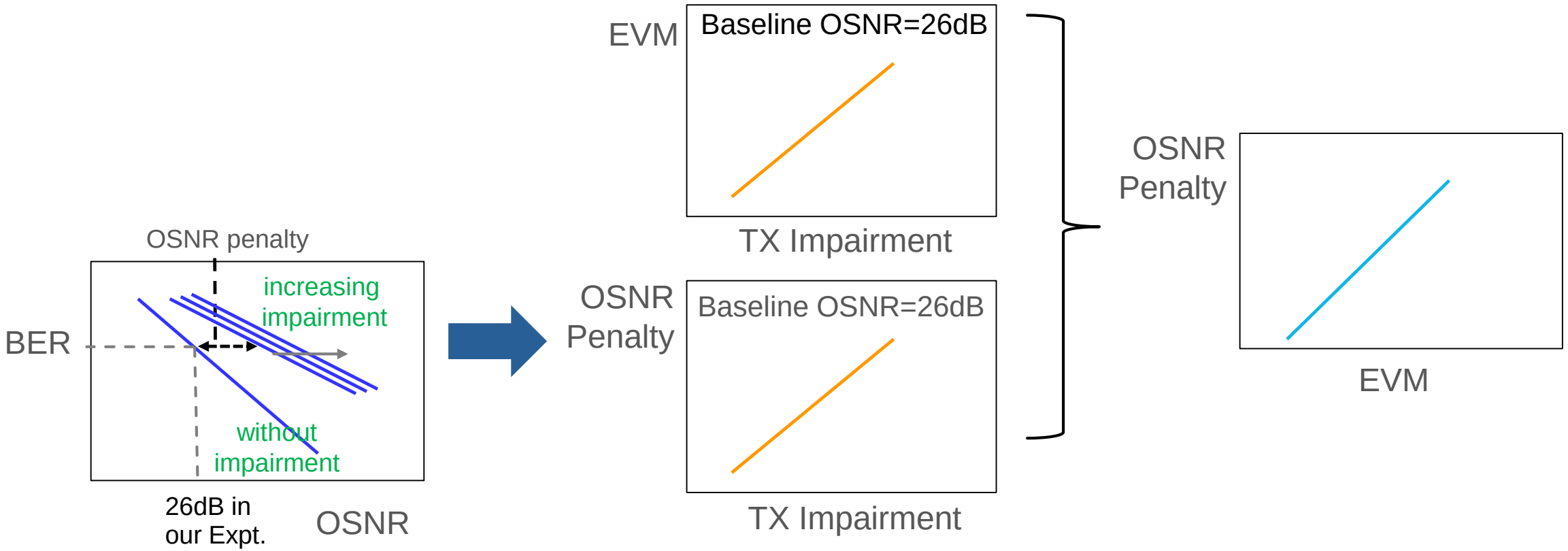
We carried out experiments to clarify the following points:

- Correlation between the measured EVM and 400GBASE-ZR TX impairments
- Propose the pass/fail EVM criteria for 400GBase-ZR

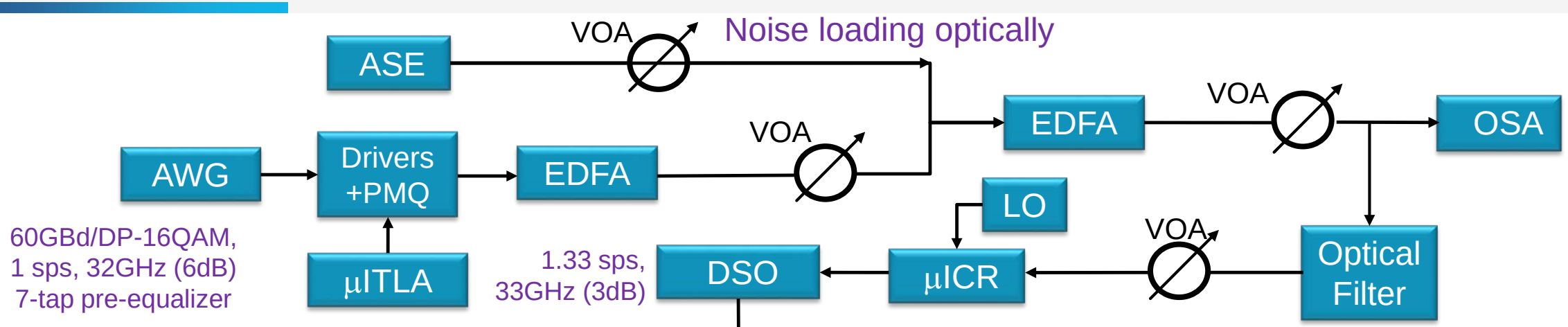
Procedure in Obtaining OSNR Penalty as a function of EVM

(impairments in both polarizations)

- **Anslow_3ct_02_0319 used 34Gbaud/DP-16QAM at OSNR=23dB (for a 63Gbaud digital noise loading) to show that OSNR penalty is proportional to EVM**
- **In this experiment, we used 60Gbaud/DP-16QAM at OSNR=26dB (optical noise loading). OSNR=26dB is consistent with what has been proposed in the baseline (stassar_3ct_02-0719)**



Experiment Setup



Offline DSP

1. Keysight DSP (Lecheminant_3ct_01_190509): for measuring EVM_m, where EVM_m uses the **peak** ref. vector for normalization

2. State-of-the-art DSP: for obtaining "BER vs OSNR", and quantitative estimate of various impairments

Calibrated TX impairments (including I-Q skew, quadrature error, imbalance, and DC-offset) are generated in the optical coherent transmitter

Initial TX and RX impairments are negligible

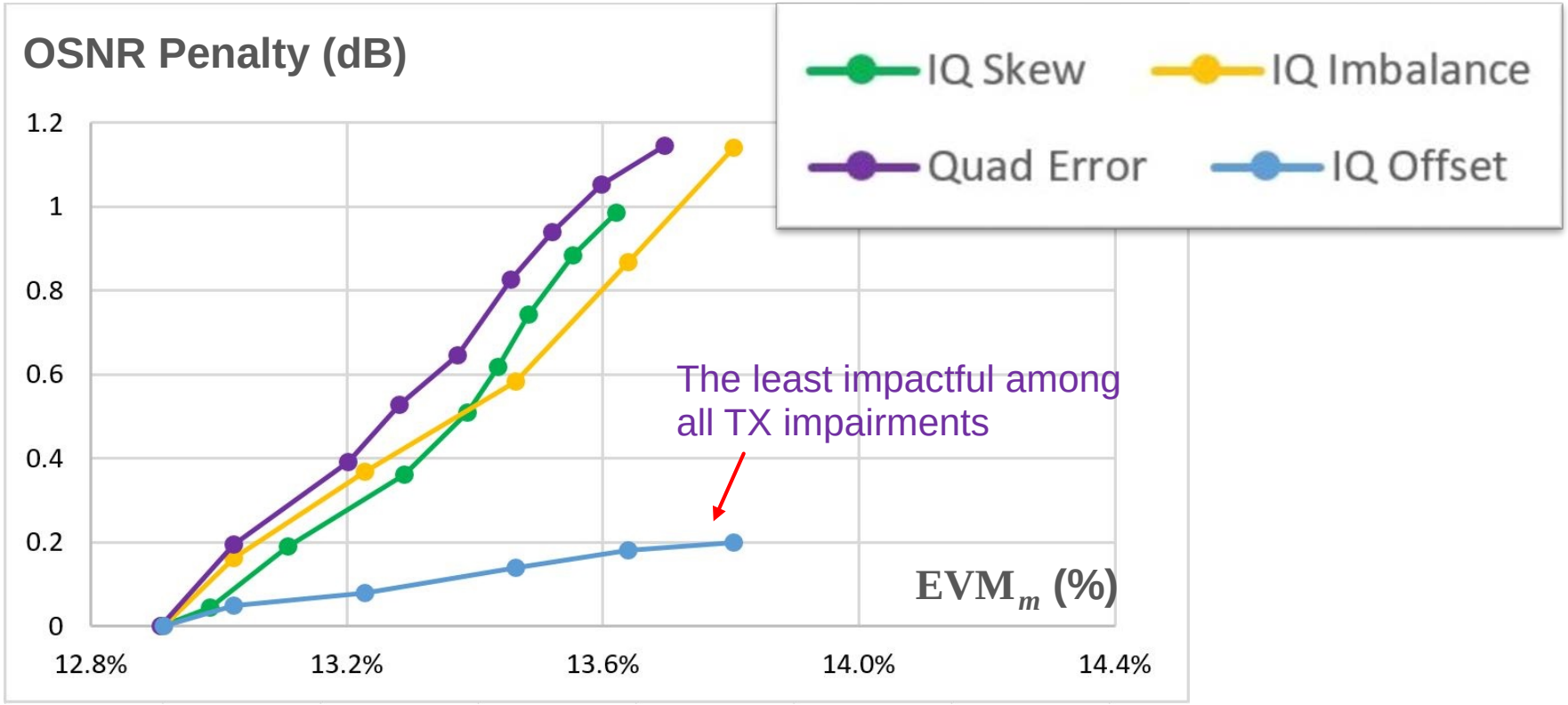
- **Coherent TX**

Tx Impairment	IQ Offset (dB)	Quad Error (deg)	IQ Imbalance (dB)	IQ Skew (ps)
X	-77.4	0.05	-0.04	-0.01
Y	-75.6	-0.04	-0.06	0.02

- **Coherent RX**

Rx Impairment	IQ Offset (dB)	Quad Error (deg)	IQ Imbalance (dB)	IQ Skew (ps)
X	-98.0	0.06	-0.03	0.02
Y	-96.2	0.1	-0.06	0.03

OSNR Penalty vs EVM_m: Comparing the slopes of four TX impairments



Similar trend as shown in Anslow_3ct_02_0319. The differences are that we used:
(a) OSNR=26 instead of 23 dB (hence a lower EVM_m at the starting point)
(b) 60 instead of 34 Gbaud
(c) The peak (instead of average) reference vector for normalization and also the latest Keysight script

Measured EVM_m and OSNR penalty versus TX impairments

TX impairment	Value	Measured EVM_m	Measured OSNR penalty
(a) IQ skew in both pol	0.75 ps	13.29%	0.36 dB
(b) IQ imbalance in both pol	1 dB	13.64%	0.84 dB
(c) IQ quad error in both pol	5°	13.37%	0.63 dB
(d) IQ DC offset in both pol	-26dB	13.23%	0.08 dB
(a)+(b)+(c)+(d) [measured]		15.0%	1.82 dB

1.91 dB (direct sum)

These results show that the penalties caused by the 4 impairments are additive!

To reduce testing effort, the effect of IQ DC offset can be included in the overall EVM test (like TDP or TDECQ), and no separate test is necessary

Theoretically, EVM can be translated to pre-FEC BER

Amplified

- OSNR ≤ 26dB @ BER= 1.25e-2

via Eq. (1) →

OSNR ≤ 26dB @ EVM_m =15.7%

$$BER = \frac{\left(1 - M^{-\frac{1}{2}}\right)}{\frac{1}{2}\log_2 M} \cdot erfc\left[\sqrt{\frac{3/2}{(M-1)\cdot(k\cdot EVM_m)^2}}\right]$$

M = 16, $k^2 = 9/5$ for 16QAM

Assumptions: (1) AWGN, (2) data-aided, (3) EVM_m

Eq. (1)

Ref: IEEE PTL 2012, Vol. 24, No. 1, pp. 61-63.
and correction in [9] of ICTON 2012 Mo.B1.5.

Note: $EVM_a = (\sqrt{9/5})\cdot EVM_m$ for 16QAM
where EVM_a uses average reference vector for normalization

Unamplified

- TBD* ≤ ROP ≤ 0dBm @ BER= 1.25e-2

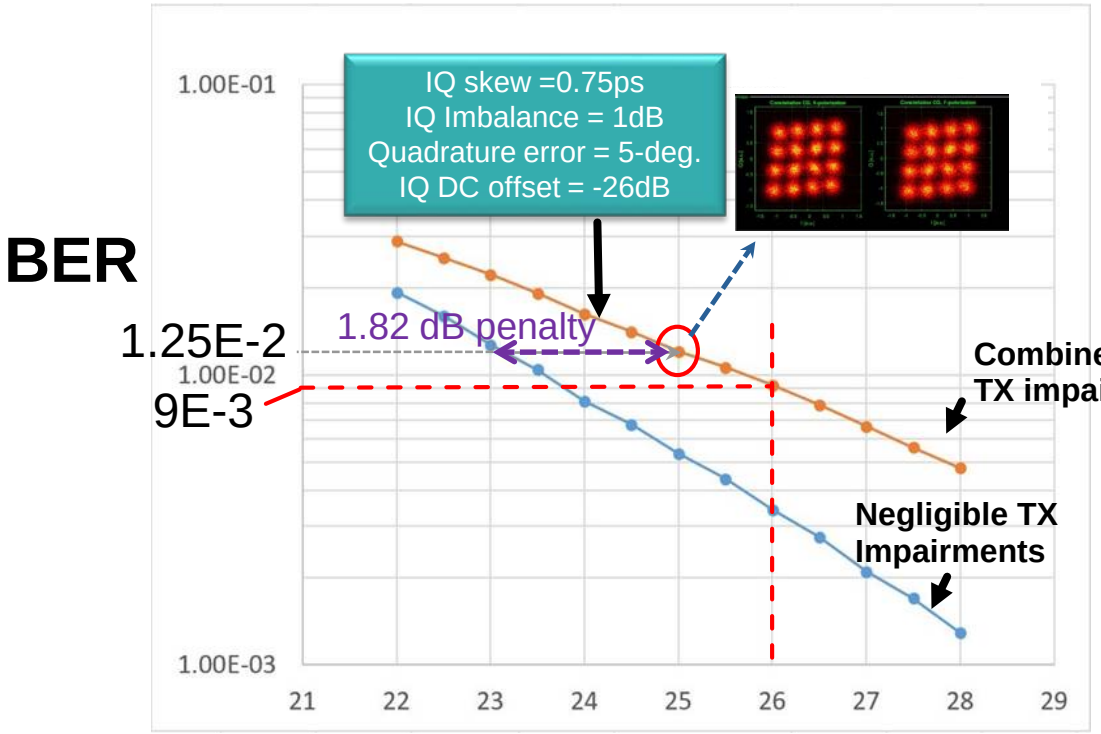
via Eq. (1) →

TBD* ≤ ROP ≤ 0dBm @ EVM_m =15.7%

*(*TBD= -20dBm in OIF 400ZR)*

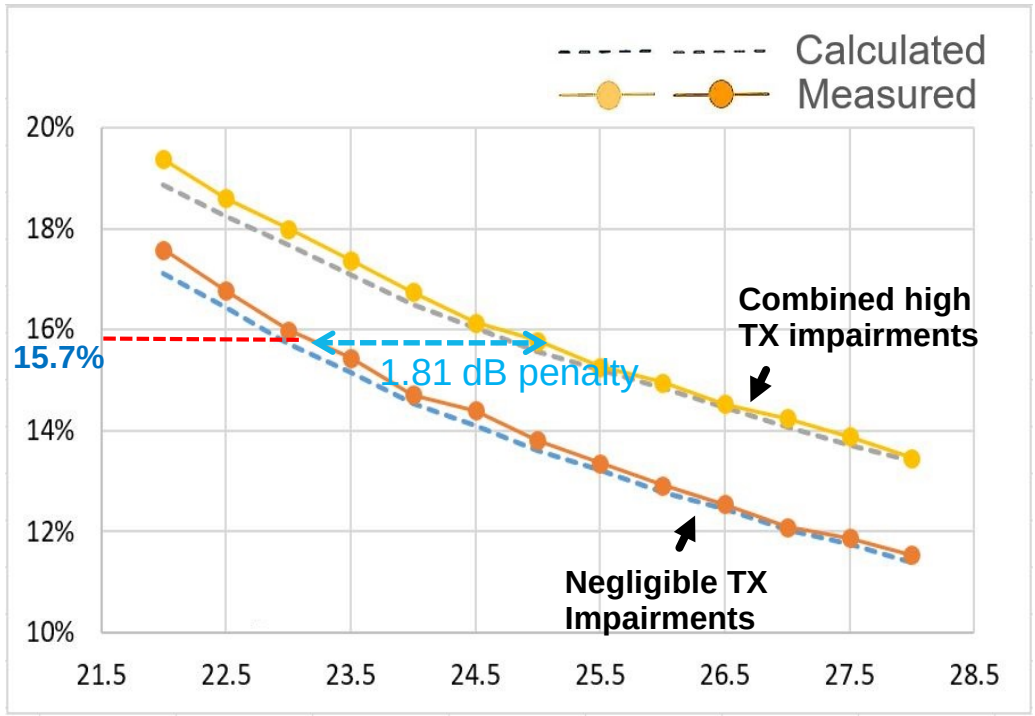
Measurement Verification: *[BER vs OSNR]* converted to *[EVM_m vs OSNR]*

with and without all 4 TX impairments



Dashed lines via Eq. (1)

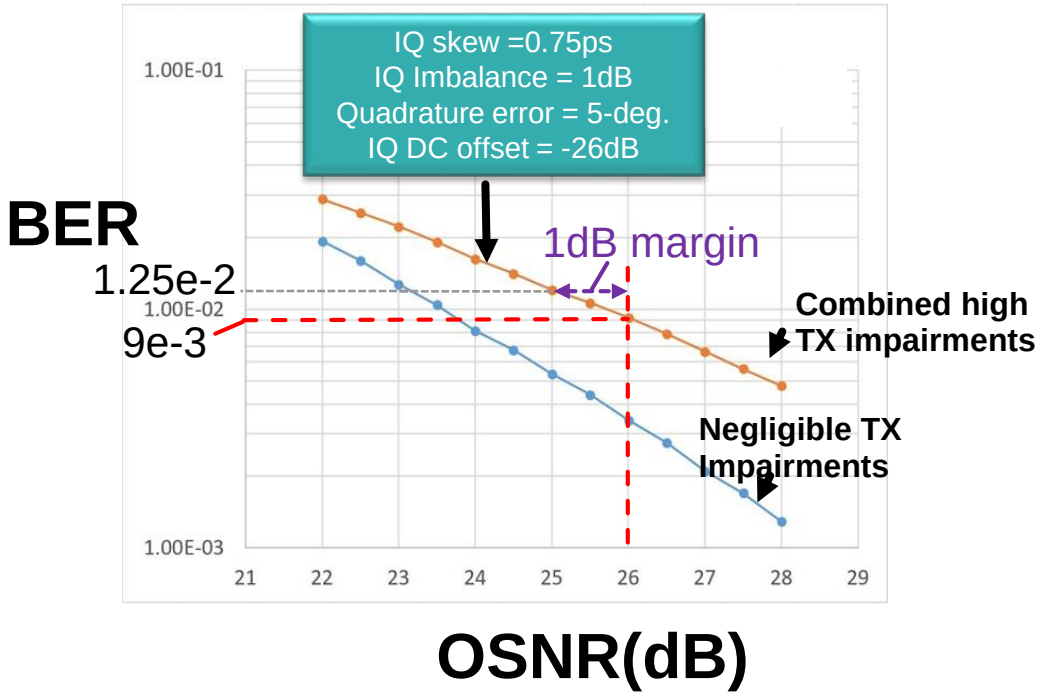
EVM_m (%)



The measured EVM matches quite well with the analytically converted EVM, even when the 4 combined high TX impairments are included

EVM Pass/Fail Criteria for Amplified Links

- Eq.(1) is proven to work well in converting BER to EVM, so we have proposed in OIF to use EVM_m =15.7% (corresponding to the CFEC threshold of BER=1.25e-2) as the pass/fail threshold when the OSNR is set at 26dB. However, in practice, a coherent receiver operating at a low received optical power (e.g., -12dBm) could incur up to ~1dB OSNR penalty. Therefore, we propose to slightly tighten up the pass/fail TX EVM_m to BER= 9e-3 at OSNR=26dB and leave ~1dB OSNR margin for receiver @ BER=1.25e-2 under the "worst-case" TX impairments (see figure below). The pass/fail BER= 9e-3 corresponds to an EVM_m = 14.8%.



EVM_m Pass/Fail Criteria for Unamplified Links

- EVM_m should be less than 15.7% for a received optical power (ROP) of TBD*~ 0 dBm

  *(*TBD= -20dBm in OIF 400ZR)*

Summary

- **TX for amplified links**

When 7-tap pre-equalization is applied in TX DSP, a pass/fail EVM_m ≤ 14.8% is proposed when the OSNR is set at 26dB. This leaves ~1dB OSNR margin for a coherent receiver @ BER=1.25e-2 when a TX has the “worst-case” impairments (the “worst-case” TX impairments are defined in Slides 10 and 11).

- **TX for unamplified links**

When 7-tap pre-equalization is applied in TX DSP, a pass/fail EVM_m ≤ 15.7% is proposed at TBD ≤ ROP ≤ 0dBm (“TBD” depends on the final baseline). Once the min ROP is decided, our industry can collectively decide whether there is a low risk to tighten the EVM spec also to 14.8%.

Thank You!