Measurement Metrics for Interoperable Transmitters

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Overview

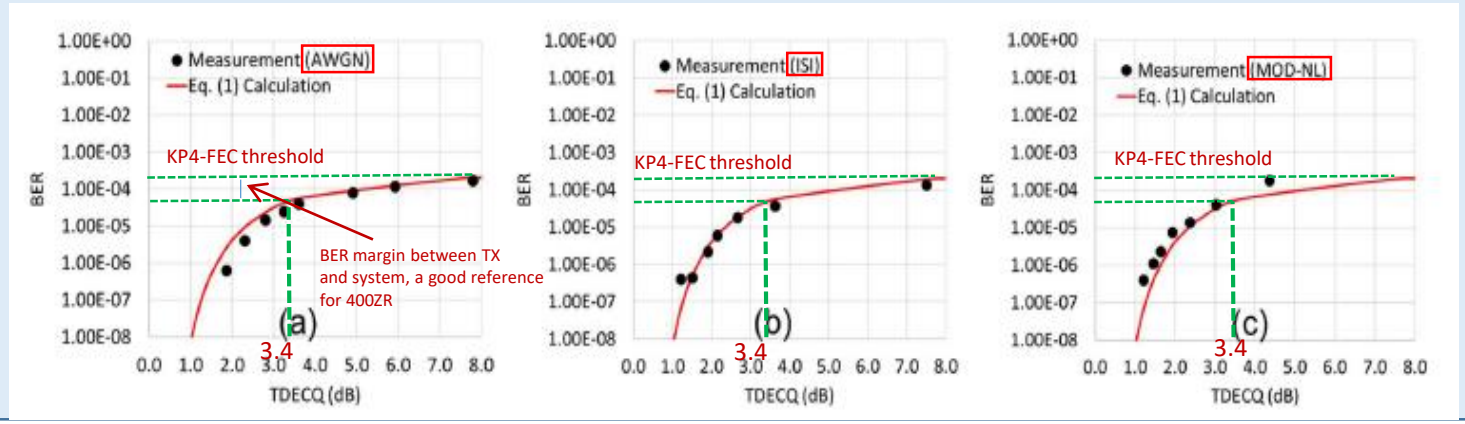
- EVM was proposed to quantify the quality of a 400GBase-ZR transmitter
- Objective is to provide a single measurement that correlates to the transmitter under tests performance
  - Transmitter EVM measured by a well-defined constellation analyzer (which includes a well-defined reference receiver)
  - Transmitter BER measured by the same constellation analyzer
    - BER in this case is a measurement of the transmitter, not the system
- Pre-FEC BER measurements are fast and easily implemented
- Either measurement with reference receiver is intended as a design verification test, not production

Measurement Metrics for Interoperable Transmitters- A Review

- Due to the slow BER measurement of an error rate < 1e-12 for NRZ OOK 10Gb/s, an alternative fast measurement metric was needed
  - ❑ **Eye Mask** – Discarded due to poor correlation with BER
  - ❑ **TDP** (Transmitter and Dispersion Penalty) – Discarded due to the slow measurement and expensive equipment: requires a reference transmitter, a reference receiver, and a BERT.
  - ❑ **TDEC** (Transmitter and Dispersion Eye Closure)- Uses a sampling scope instead of a BERT.
- PAM4 (50Gb/s, 100Gb/s and beyond)
  - ❑ **TDECQ** (Transmitter and Dispersion Eye Closure Quaternary)- Same setup as TDEC, except adding a 5-tap T-spaced FFE equalizer. It correlates well with BER for various transmitter impairments (see 3 cases below). Also, a clear threshold for pass/fail (e.g., TECQ≤3.4dB for 400GBase-DR4 and –FR4).

$$BER = \frac{3}{8} erfc\left(\frac{Q_T}{\sqrt{2}} \cdot \sqrt{\frac{TDECQ^2}{TDECQ^2 - 1}}\right)$$

(Acacia, W3G.3, OFC2020)



A useful transmitter quality metric (1) correlates well with BER for all transmitter impairments, (2) is inexpensive, and (3) has a clear pass/fail threshold

Measurement Metric for Interoperable Transmitters: 400GBase-ZR

- For 400GBase-ZR, BER measurement is instant due to a high pre-FEC BER threshold for RX (~1e-2) or for TX (~1e-3). Therefore, finding an alternative transmitter metric for interop seems redundant.
- Both transmitter EVM and BER measurement would require:
  - *Four pairs of balanced optical reference receivers and a real-time scope (i.e., Optical Constellation Analyzer)*
  - *A well-defined off-line DSP with proper low-pass filtering function and equalizers*
- EVM and BER have a good correlation assuming AWGN-like TX impairments through the equation below. However, this may not apply to non-noise-like transmitter impairments such as (1) IQ-offset, (2) polarization-dependent loss (PDL), or (3) driver and Mach-Zehnder modulator nonlinearities. In the future, adding probabilistic shaping also makes EVM not an accurate metric.

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

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

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

EVM_m: *EVM* normalized to the constellation maximum

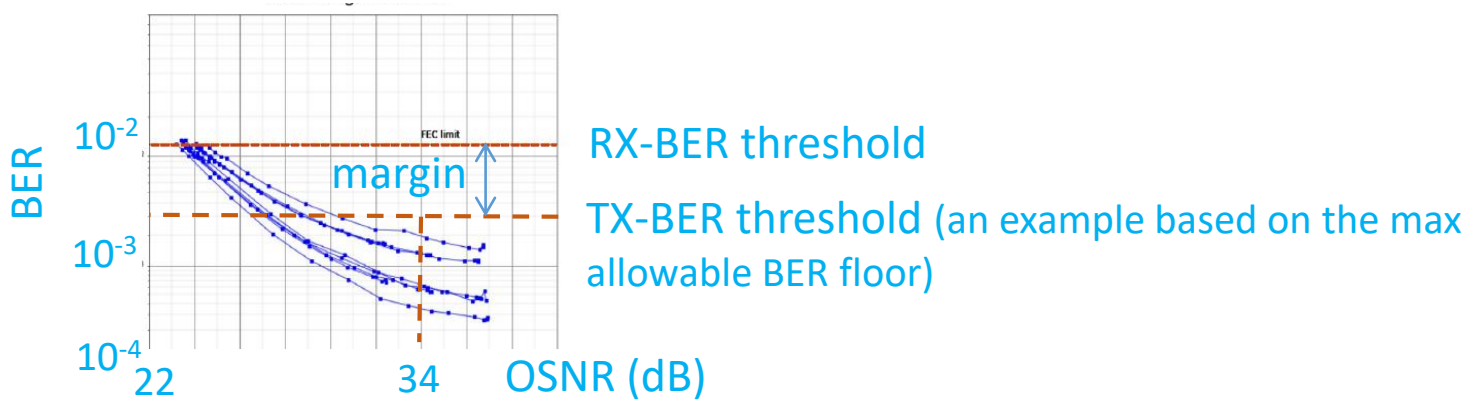
References:

1. IEEE Photonics Technology Letters, vol.24, No.1, pp.61-63. Also correction in [9] of ICTON 2012 Mo.B1.5.
2. way_3ct_01b_1119

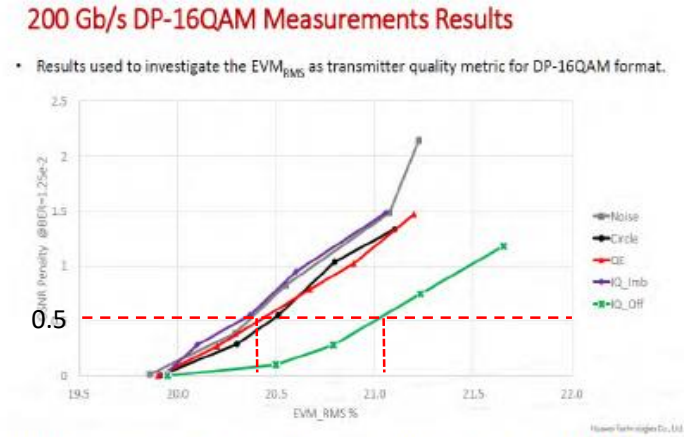
Single Pass/Fail Criterion (e.g., TDECQ ≤3.4dB for PAM4)

- **BER:** Similar to 400GBase-DR4/FR4 (see figures in slide 1), a lower value of BER (e.g., 3e-3) than the end-to-end pre-FEC threshold (1.25e-2) can be used at high OSNR (≥ 34dB).

Ref.: B. Guan and Y. Yin, Microsoft, "400ZR: A view from the "Clouds"", LightReading Optical Networking Digital Symposium, Feb 16 2021.



- **EVM:** Questionable because different transmitter impairments present different EVM thresholds (see explanation below). This is a serious issue because one does not know what TX impairment dominates. In addition, multiple measurement would be required for equalizable and non-equalizable TX impairments (pittala_3ct_01a_0120).



Initial measurement results on EVM$_{RMS}$ for DP-16QAM presented in https://www.ieee802.org/3/ct/public/19_07/pittala_3ct_01a_0719.pdf

For the same OSNR penalty of 0.5dB, for example, two different EVM thresholds can be seen for IQ-offset and the remaining group of noise-like parameters

Additional TX parameter that could behave differently from the noise-like group:

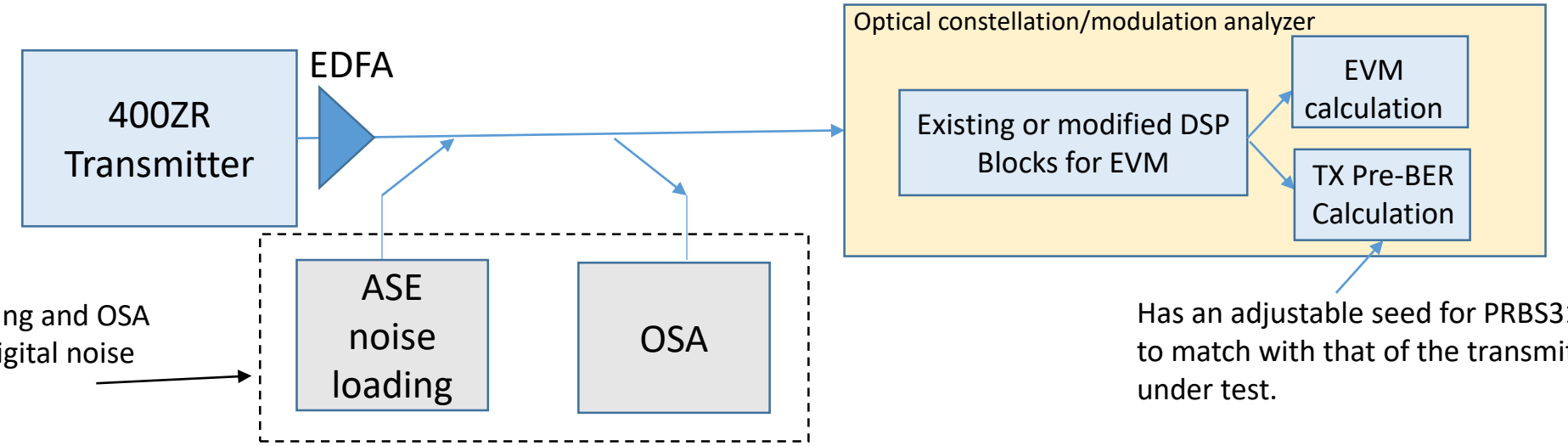
- PDL
- TX nonlinearity (driver, MZI)

One can use a single EVM threshold (e.g., a weighted average of different thresholds for different TX impairments) like TX-BER, but that threshold needs to be justified (not intuitively justifiable as TX-BER shown above)

Same Test Setup for TX-BER or EVM

Controlled parameters:

1. Reference Receiver with defined DSP blocks
2. LO optical power (TBD)
3. Received optical power (~0dBm)
4. OSNR (TX OSNR ≥ 34dB)



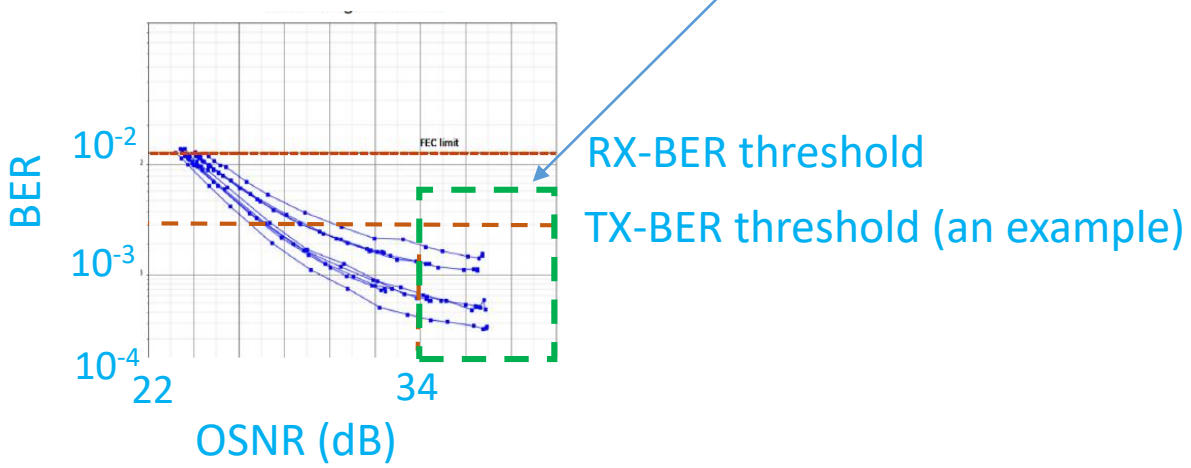
- Can the external ASE loading and OSA be replaced by calibrated digital noise loading in off-line DSP?

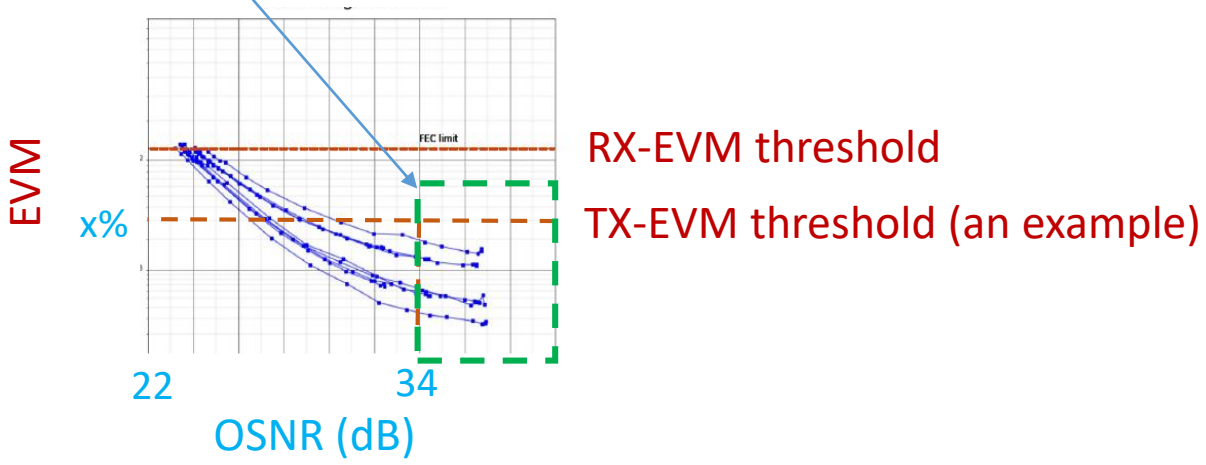
Has an adjustable seed for PRBS31 to match with that of the transmitter under test.

Since TX-BER and EVM use the same test setup, they can be measured to correlate or contrast each other for different transmitter impairments

Correlating TX-BER with EVM using existing multi-vendors' 400GBase-ZR transmitters and a common (reference) receiver

BER floors and EVM floors can be compared





Can use a typical 400GBase-ZR receiver to compare the results with those of a constellation analyzer with reference DSP

Conclusions

- EVM and BER can both be characterizations of transmitter quality assuming both can provide a simple threshold value for pass/fail
- Pre-FEC BER @ 400G can be measured very quickly
- Dispersion compensation is handled by receiver DSP
  - No need to include transmission fibers in the test setup to characterize transmitter pre-compensation
- Abstraction to EVM may create unnecessary design burdens that increase cost
  - e.g. artificially tight requirements for I-Q Offset (PDL and TX nonlinearities require more data)

Proposal:

(1) Proceed with plan to characterize EVM using representative transceiver implementations, but add TX-BER measurement to the test plan so that we can correlate or contrast the two TX measurement metrics

(2) Use multiple already inter-operable 400GBase-ZR transceivers to measure their TX-BER and EVM at OSNR ≥ 34dB and received optical power > 0dBm and compare