

Development of extended transmitter constellation closure (ETCC) as a new coherent Tx quality metric

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Motivation for a Tx quality metric

- Current specification methodology for coherent optics only accounts for a lumped Tx/Rx implementation penalty
 - Specified as an OSNR tolerance and typically tested with same-vendor Tx/Rx pairing
 - No separation between Tx and Rx performances
- There are many Tx specs for individual impairments, which the Rx design needs to be able to handle, however:
 - Worst-case values are assumed **not** to occur concurrently

Additional normative measure of **transmitter-induced performance penalty** is needed to ensure sufficient overall transmitter performance

Example Tx optical spec table from 800ZR (excerpt)

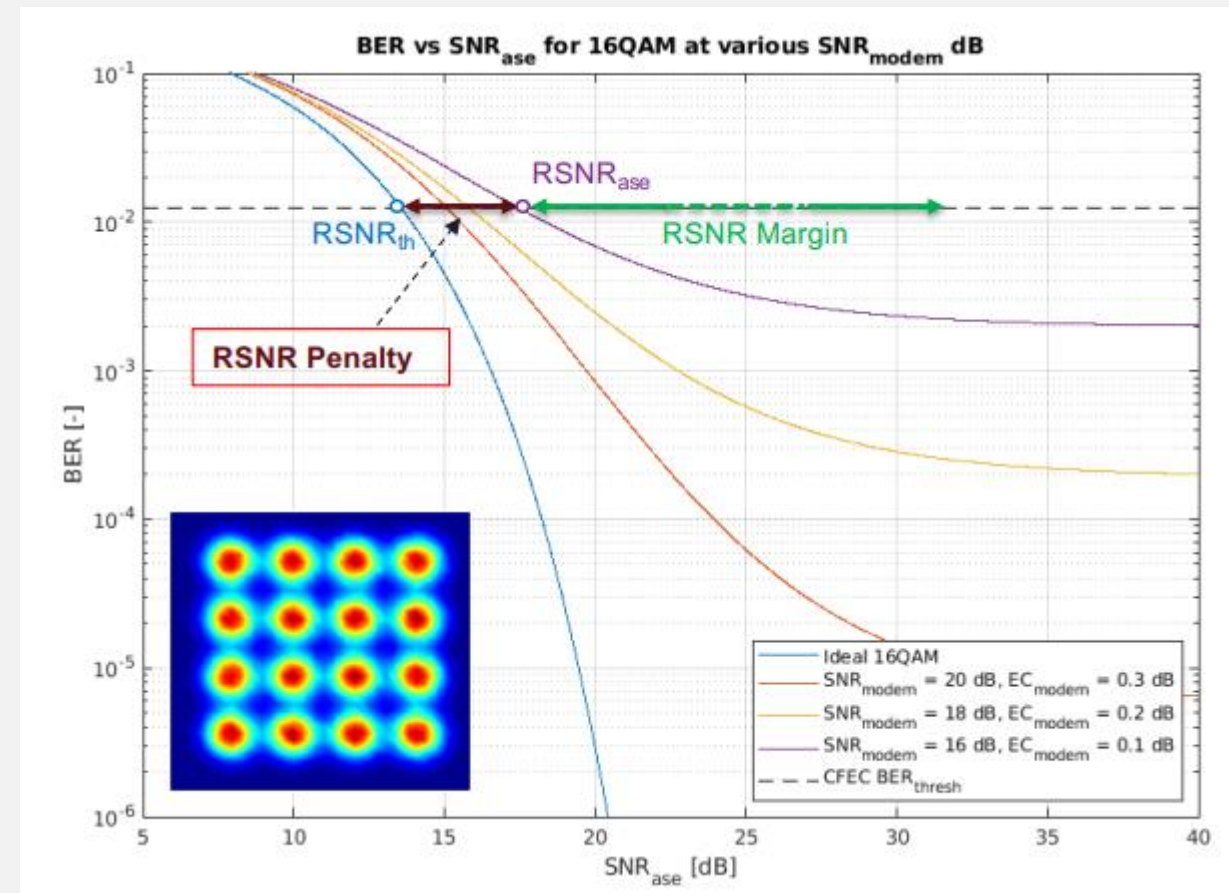
Ref	Parameter	Unit	Min	Max	Conditions/Comments
6.1.250	Transmitter polarization dependent power	dB		1.5	Power difference between X and Y polarization.
6.1.260	X-Y Skew	ps		5	
6.1.270a	DC I-Q offset (mean per polarization)	dB		-26	See definition and equation in 6.4.7
6.1.270b	I-Q instantaneous offset	dB		-20	Same formula definition as 6.1.270a, however, any averaging period shall be $\leq 1\mu s$ to be consistent with the timescales of Rx DSP operations. Specification applies at any point in time. Allows for modulator bias controls/errors.
6.1.271	Mean I-Q amplitude imbalance	dB		1	
6.1.272	I-Q phase error	deg	-5	+5	
6.1.273	I-Q skew	ps		0.75	

Tx-only implementation penalty

Extended transmitter constellation closure (ETCC)

- New methodology under development within IEEE 802.3dj for 800GBASE-LR1/ER1/ER1-20 and ITU Q6/15 for 800G application codes in G.698.2
- Based on required signal-to-noise ratio (RSNR) at a given BER threshold
- The RSNR penalty for a given Tx/Rx combination (“modem”) can be measured
 - Difference in dB between $RSNR_{ase}$ and $RSNR_{th}$

If this measurement is done with a **defined reference receiver**, and its contribution to the penalty is de-embedded, the Tx-only RSNR penalty, i.e. ETCC, can be determined

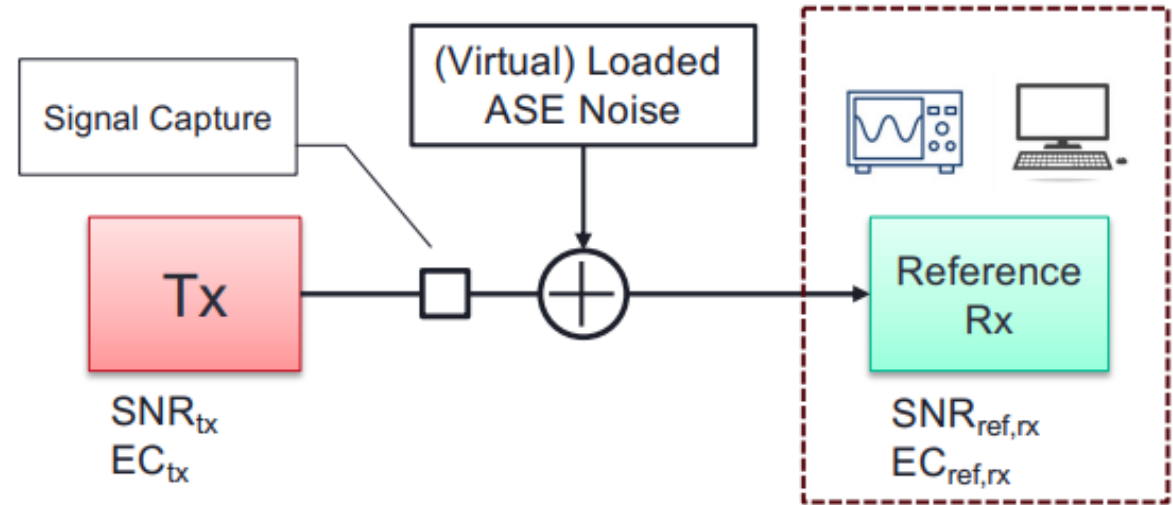


https://www.ieee802.org/3/dj/public/24_05/maniloff_3dj_02_2405.pdf

ETCC methodology

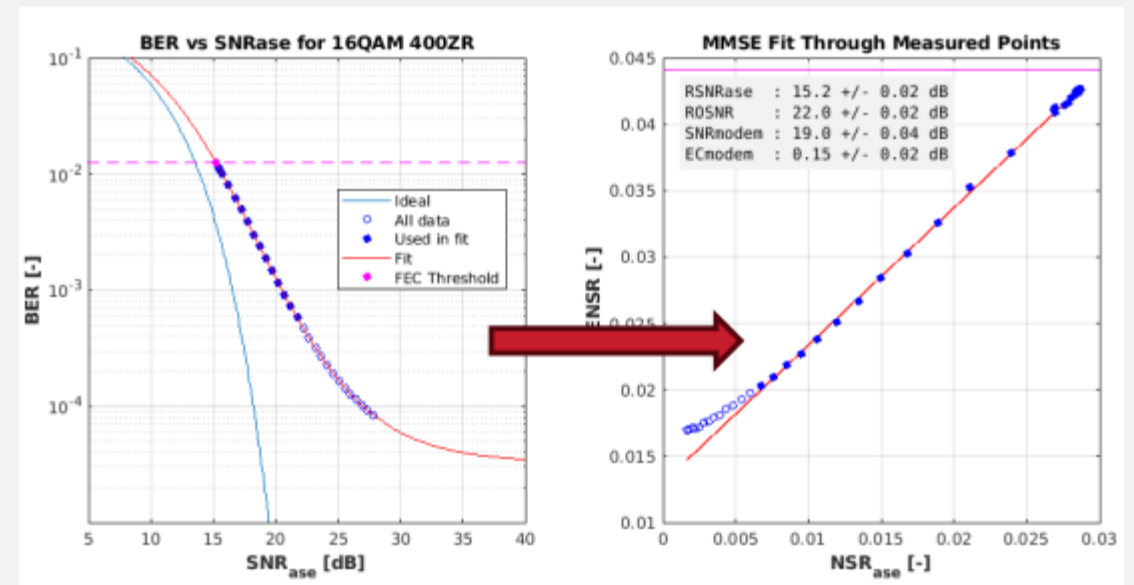
Virtual noise loading

- ETCC requires a single capture directly at the Tx output using a reference receiver
- The reference receiver comprises
 - A polarization-diverse coherent receiver with real-time sampling, specified bandwidth, min. ENOB, etc.
 - Calibration with max. allowed residuals
 - Offline digital signal processing for constellation recovery and bit error counting
- The offline DSP is iteratively repeated for different levels of virtual loaded ASE Noise
- Procedure for de-embedding of reference Rx contribution to the measured penalty
- Fitting procedure to evaluate ETCC



Using Signal Capture, virtual noise loading is performed. This requires only a single Tx output capture.

https://www.ieee802.org/3/dj/public/24_05/maniloff_3dj_02_2405.pdf



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ETCC fitting procedure and calculation

$$ETCC = \Delta RSNR_{tx} = 10 \times \log_{10} \left(\frac{RSNR_{ase,tx}}{ESNR_{ref}} \right)$$

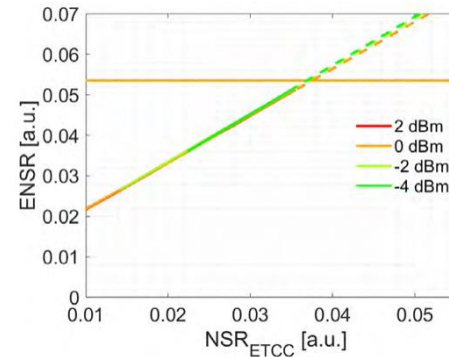
$$RSNR_{ase,tx} = \left((EC_{tx} \cdot ESNR_{ref})^{-1} - NSR_{tx} \right)^{-1}$$

EC_{tx} and NSR_{tx} are derived from a linear fit as

$$ENSR_i = a \times NSR_{ETCC,i} + b \text{ with}$$

$$EC_{tx} = a \text{ and } NSR_{tx} = \frac{b}{a}$$

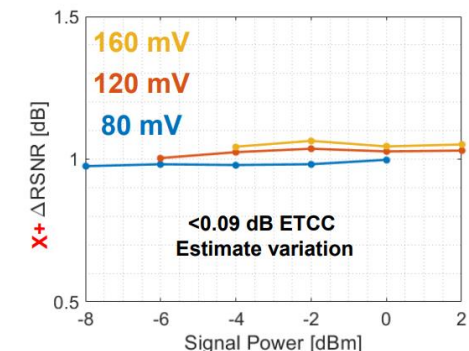
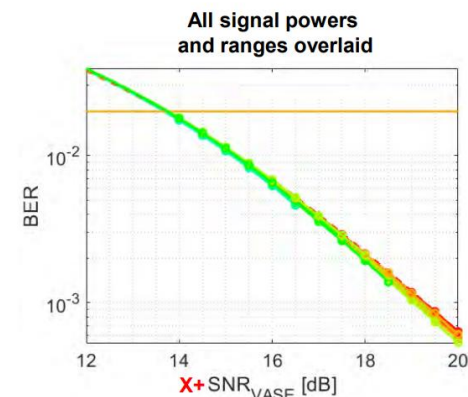
	BER_{ref}	$ESNR_{ref}$
800GBASE-LR1	1.1×10^{-2}	13.76 dB
800GBASE-ER1	2×10^{-2}	12.71 dB
800ZR	2×10^{-2}	12.71 dB
400ZR	1.25×10^{-2}	13.55 dB



De-embedding of reference receiver contribution is applied prior to fitting!

Experimental Results

Note: SNR values shifted to maintain vendor confidentiality

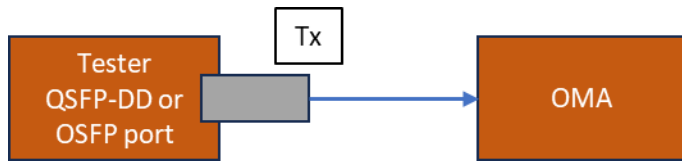


https://www.ieee802.org/3/dj/public/25_11/temprana_3dj_01_2511.pdf

OIF organized an 800ZR measurement plugfest prior to OFC

Dataset for validation of ETCC methodology

Transmitter waveform capture to support ETCC validation performed by Keysight



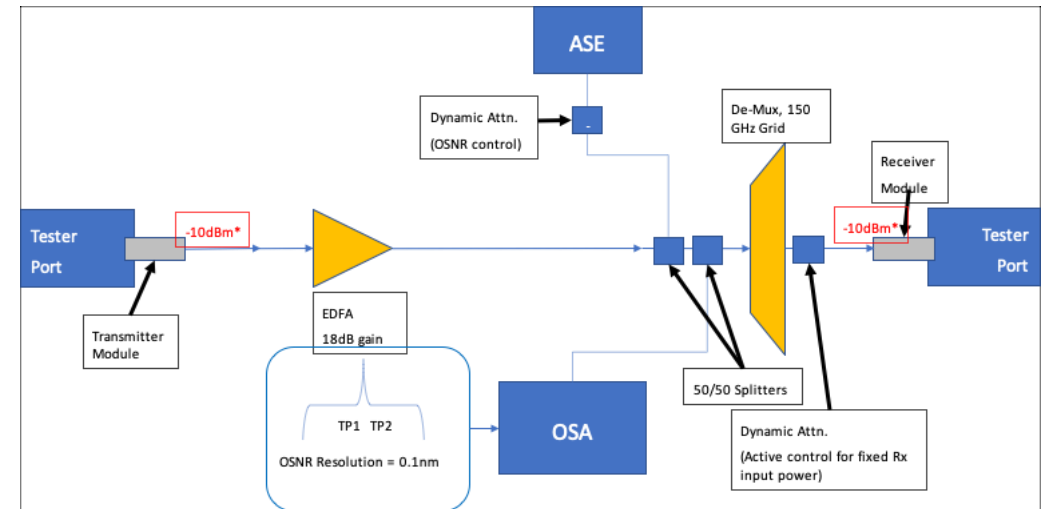
Optical modulation analyzer (OMA) fulfills all HW requirements on a reference receiver according to IEEE 802.3dj D3.0 draft

Tx waveform captures provided to industry for investigating reference receiver Offline-DSP

White paper available at OIF webpage:

<https://www.oiforum.com/documents/informative-documents/educational-demo-white-papers/>

Measurement of rOSNR for each Tx / Rx pairing performed by Exfo

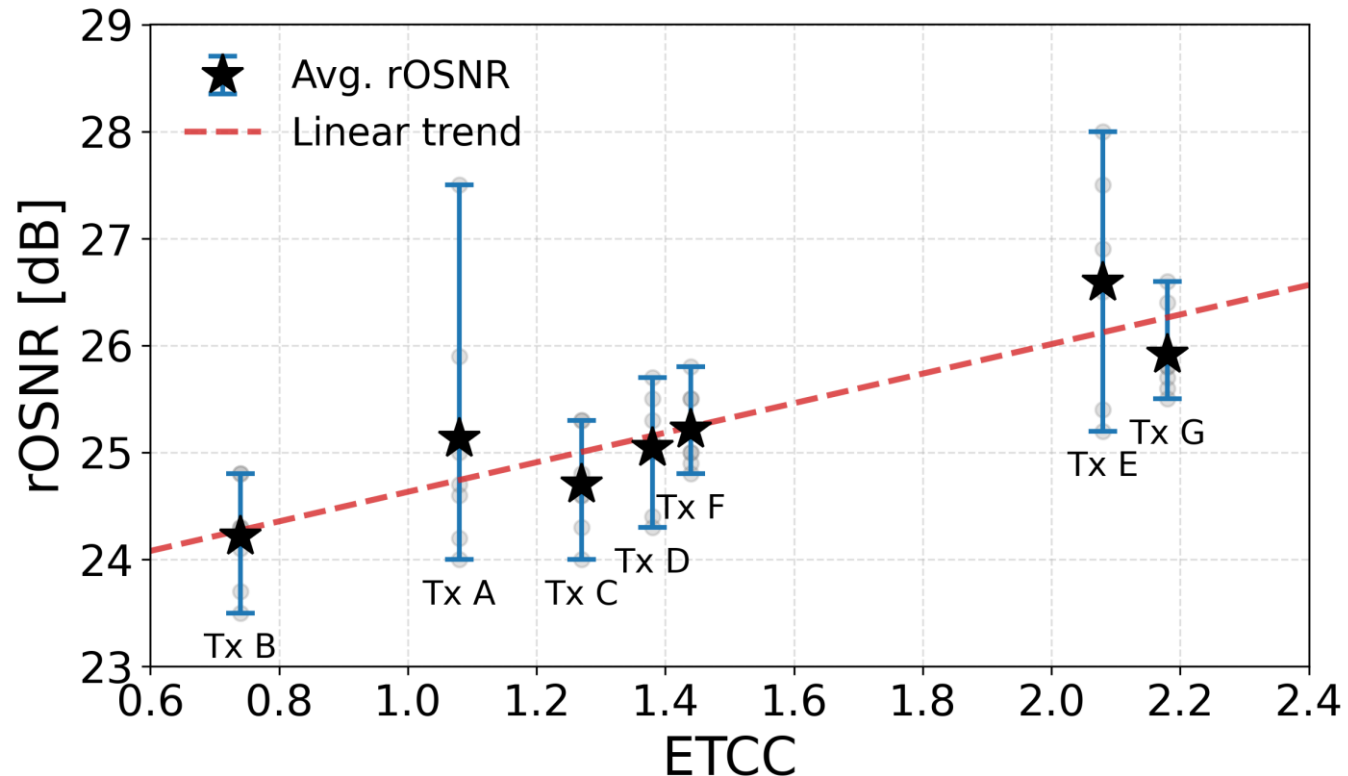


rOSNR results for each Tx / Rx pairing

EXFO OSA 193.700 THz		Tx							Average ROSNR for this Rx ↴
		Vendor A	Vendor B	Vendor C	Vendor D	Vendor E	Vendor F	Vendor G	
Rx	A	24.2	23.7	24.3	24.4	25.2	24.9	25.5	24.6
	B	24.6	24.3	24.6	25.3	26.9	25.0	25.8	25.2
	C	24.7	24.1	24.6	25.1	26.6	25.5	26.4	25.3
	D	25.0	24.3	24.8	25.0	26.5	25.0	25.7	25.2
	E	24.0	23.5	24.0	24.3	25.4	24.8	25.6	24.5
	F	25.9	24.8	25.3	25.7	27.5	25.8	26.6	25.9
	G	27.5	24.8	25.3	25.5	28.0	25.5	25.8	26.1
Average ROSNR for this Tx @ 193.700 THz ⇨		25.1	24.2	24.7	25.0	26.6	25.2	25.9	Single Vendor rOSNR of Rx

Use this as an indicator of Tx quality for ETCC validation

ETCC analysis of Tx waveform captures



- For each Tx, the min, max and avg. rOSNR across all 7 Rx is shown
- Offline processing of waveforms and ETCC calculation according to IEEE 802.3dj D3.0 draft
 - Acknowledgement to Acacia for providing the ETCC values
- ETCC correlates well with increase of average rOSNR

Summary and outlook

- To ensure interoperability Tx and Rx performances need to be separable
 - ETCC measures the Tx-only implementation penalty
- A tightly specified reference Rx is required to assess Tx performance
 - Current draft D3.0 of IEEE 802.3dj details reference Rx characteristics, calibration residuals, offline-DSP and receiver de-embedding for its coherent interfaces 800GBASE-LR1 and ER1
- OIF supports validation of ETCC methodology by conducting 800ZR measurement plugfest and sharing results
- Next steps:
 - Finalize ETCC methodology for 800G coherent interfaces
 - Investigate the transfer of this methodology for future 1.6T interfaces

Thank you