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Clarifications on Transmitter Constellation Closure (TCC) and Extended TCC (ETCC) as the Transmitter Quality Metric (TQM) for Coherent Transmitters

in correspondence to Comment #259

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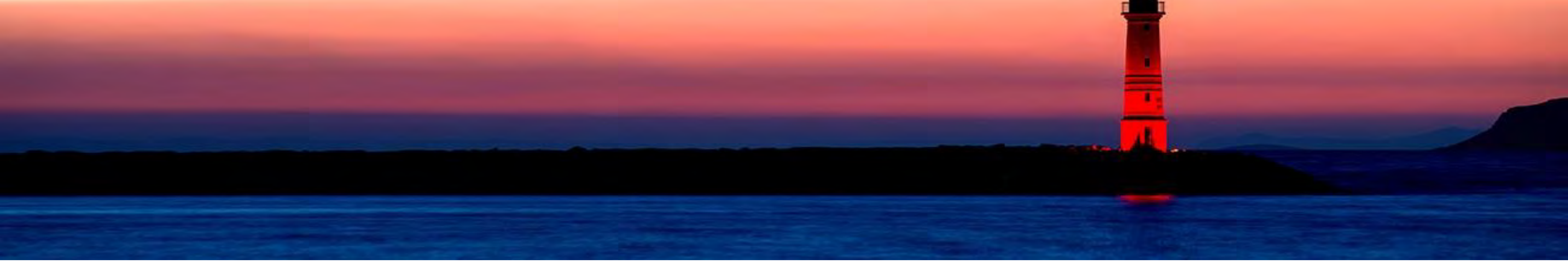


TQM considered by IEEE 802.3dj

- According to dambrosia_3dj_optx_01_240829, IEEE 802.3dj is considering:

Calculate TQM Calculation for 800GBASE-LR1, 800GBASE-ER1-20, 800GBAS-ER1, as: TQM = $\Delta RSNR_{tx}$, Tx-only RSNR penalty (Renamed as "Extended TCC") in dB (normative with a maximum specification)

- We have also stated that

(1) "Calculation of the TCC provides the Tx-only RSNR penalty ($\Delta RSNR_{tx}$) seen by the TQM reference receiver."

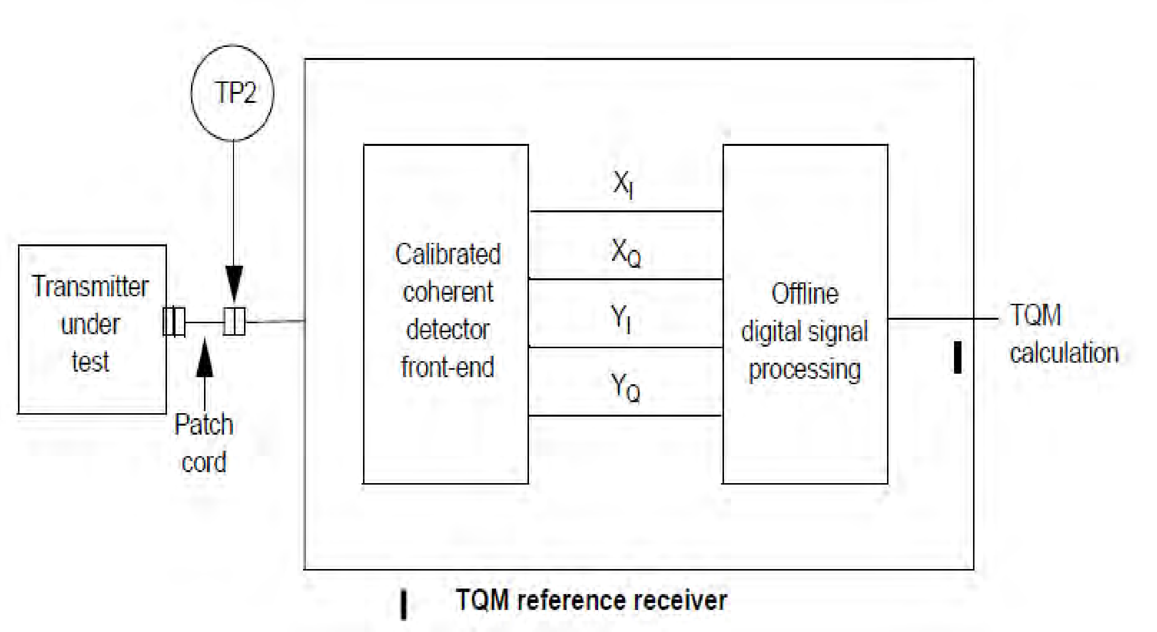
(2) "The ETCC specification can be generically represented by a BER-vs-TCC waterfall mask, i.e., "X dB TCC @ BER being Y decades (e.g., 0/1/2) lower than BERref.", similar to that reported in fan_3dj_02a_2407 and oif2024.422.00.

- In the presentation, clarifications on TCC and ETCC as the TQM for coherent transmitters are provided.

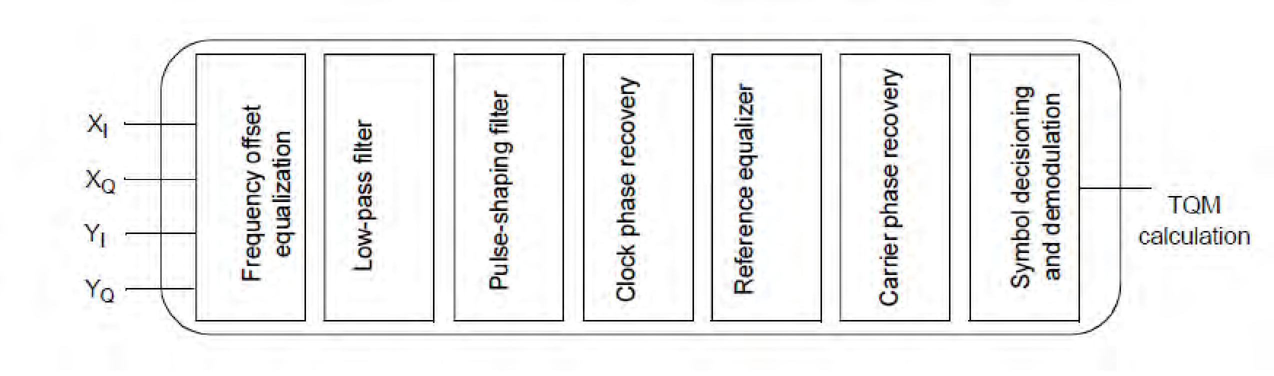
The TCC Test Method (digital/virtual noise loading)

Reference: dambrosia_3dj_optx_01_240829

TQM Test Setup



Offline digital signal processing used for TQM calculation



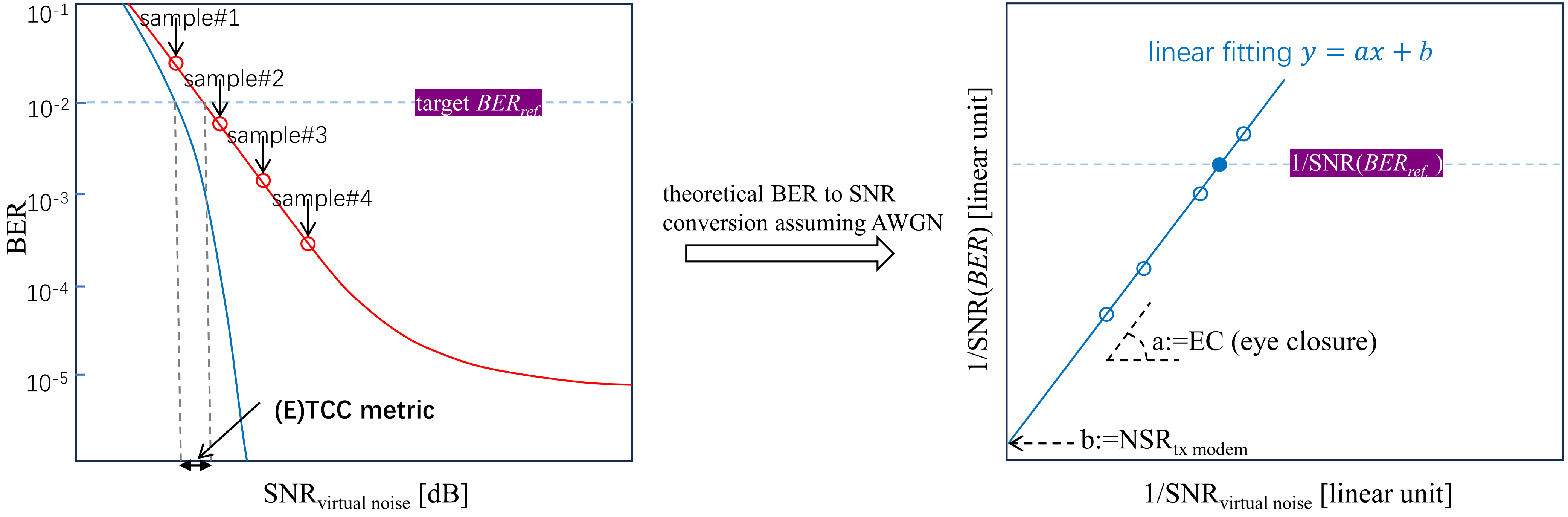
- More descriptions for each step can be found on Page 7 of fan_3dj_02a_2407.pdf.

$$\mathrm{TCC(dB)} = 10\log_{10}\left(\frac{\sigma_{\mathrm{ideal}}^2}{\sigma_{\mathrm{TUT}}^2 + \sigma_s^2}\right) + 10\log_{10}\left(\frac{p_{\mathrm{unfiltered}}}{p_{\mathrm{filtered}}}\right)$$

The essence of the extended TCC (ETCC) approach (1)

According to SG15-TD214/WP2 , the ETCC approach uses a 2-step process:

1. Sample the BER waterfall curve by sweeping virtual noise loadings in the linear (log scale) regime.
2. Transform both axes to noise-to-signal ratio, conduct linear fitting, and solve the required $\mathrm{SNR}_{\text{virtual noise}}$.



Comments on this approach:

- One can do fitting in the 1st step to extract required $\mathrm{SNR}_{\text{virtual noise}}$, so the 2nd step becomes unnecessary for pure TQM.
- The EC here is referred to as Eye Closure, but it actually reflects noise enhancement and many other factors. It is unlike *Ceq* in TDECQ, which is only determined by FFE frequency response. So, EC here is not as well defined as *Ceq* in TDECQ.
- Therefore, the EC and $\mathrm{NSR}_{\text{tx modem}}$ are at most informative terms, which only need to be specified optionally.

The essence of ETCC (2)

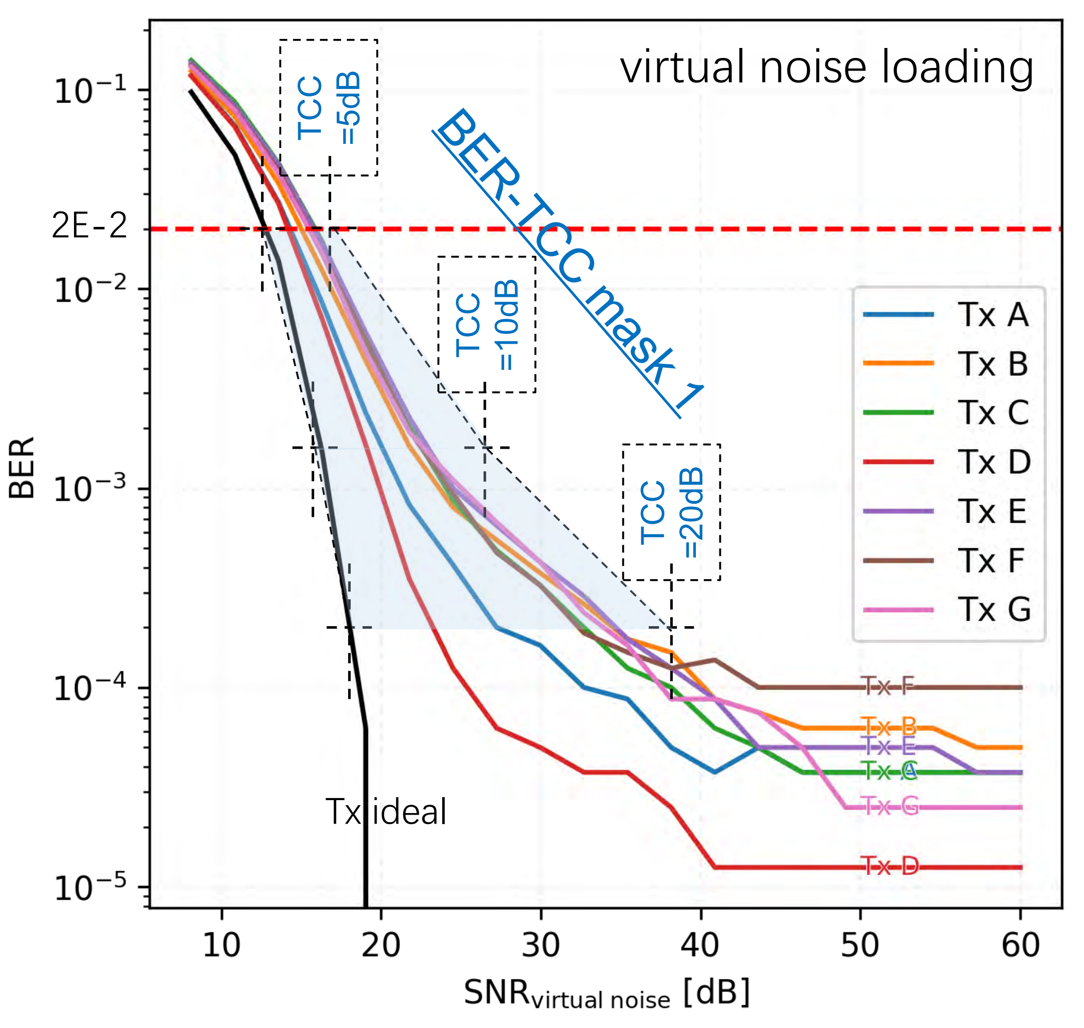
In maniloff_3dj_02_2405, it was commented that TCC assumes *EC*=1. This is not true. In fact, the effect of noise enhancements are implicitly embedded in TCC calculation. Specifically, TCC measures the loaded noise power at the input of reference equalizer, so that the equalizer enhanced noises are functioning in the measurement loop.

The reasons for the ETCC approach to be referred to as extended TCC are:

1. Its 2-parameter fitting explicitly characterizes the linear regime of the BER waterfall curve, which provides an indication of the error floor behavior (which may be valuable to end users).

2. $SNR_{virtual\ noise}@BER_{ref.}$ can be evaluated in extended ways. Besides noise searching, fitting or interpolation are also viable.

A simple specification of ETCC via the BER-TCC waterfall mask
(Based on fan_3dj_02a_2407 and oif2024.422.00)



Reference: fan_3dj_02a_2407
(adapted with additional annotations here for clarity)

- The BER-TCC waterfall curve is readily available during the TCC measurement.
- A simple ETCC specification via a BER-TCC waterfall mask can be used to confine the error floor behavior, e.g.,

BER	TCC mask 1*	TCC mask 2**
2E-2	≤5 dB	≤2.5 dB
2E-3	≤10 dB	≤5 dB
2E-4	≤20 dB	≤10 dB

(*: a loose mask example; **: a tight mask example)

- The BER-TCC waterfall mask can be readily defined as: [X, Y, Z]dB TCC @ BER=[1, 0.1, 0.01]×$BER_{ref.}$
- This specification approach is simple, illustrative and user friendly.

One error made in maniloff_3dj_02_2405 when comparing TCC with ETCC

Aside: Tx only RSNR Penalty vs TCC

- Tx only RSNR Penalty is related to TCC as follows:

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

$RSNR_{th} \neq RSNR_{ref}$!

$$= \frac{RNSR_{th}}{\left(\left(EC_{tx} \cdot ESNR_{ref}\right)^{-1} - NSR_{tx}\right)}$$

$$= \frac{EC_{tx} \cdot RNSR_{th}}{\left(RNSR_{th} - EC_{tx} \cdot NSR_{tx}\right)}$$

$$= \frac{EC_{tx} \cdot \sigma_{th}^2}{\left(\sigma_{th}^2 - EC_{tx} \cdot \sigma_{tx}^2\right)}$$

- Assuming no eye-closure, i.e. $EC_{tx} = 1$,

$$\Delta RSNR_{tx} = \frac{\sigma_{th}^2}{\sigma_{th}^2 - \sigma_{tx}^2} = \frac{\sigma_{th}^2}{\left(\sigma_{tx}^2 + \bar{\sigma}_{ase}^2 + \sigma_{ref,rx}^2\right) - \sigma_{tx}^2}$$

$$= \frac{\sigma_{th}^2}{\left(\sigma_{tx}^2 + \bar{\sigma}_{ase}^2 + \sigma_{ref,rx}^2\right) - \sigma_{tx}^2} = \frac{\sigma_{th}^2}{\bar{\sigma}_{ase}^2 + \sigma_{ref,rx}^2}$$

- Comparing the noise loading component of TCC to Tx only RSNR Penalty with $EC_{tx} = 1$:

$$\frac{\sigma_{th}^2}{\bar{\sigma}_{ase}^2 + \sigma_{ref,rx}^2} = \frac{\sigma_{ideal}^2}{\sigma_{TUT}^2 + \sigma_S^2}$$

Reference: OFC2024, TH2a.26

- Where:
  - σ_{th}^2, σ_{ideal}^2: Theoretical noise variance at the FEC threshold
  - σ_{tx}^2: Tx implementation noise variance
  - $\sigma_{ref,rx}^2$: Reference Rx implementation noise variance
  - $\bar{\sigma}_{ase}^2$, σ_{TUT}^2: Maximum tolerated (virtual) ASE noise variance at the input of the (Reference) Rx
  - $\sigma_{th}^2 = \sigma_{tx}^2 + \bar{\sigma}_{ase}^2 + \sigma_{ref,rx}^2$: The total noise variance at the FEC threshold in a (virtual) noise loading experiment is the sum of all the implementation- and (ASE) loading noise variances.

- In maniloff_3dj_02_2405, $ESNR_{ref}$ (the pre-FEC SNR@BER_{ref} for TUT) is incorrectly set to be equal to $ESNR_{th}$ (pre-FEC SNR@BER_{ref} for ideal Tx). Thus, the conclusion that TCC=ETCC only when EC_{tx}=1 is incorrect.

- In fact, $RSNR_{ase} \equiv \frac{S}{\sigma_{TUT}^2}$, so that

$$\Delta RSNR_{tx} = \frac{RSNR_{ase}}{RSNR_{th}} = \frac{\sigma_{th}^2}{\sigma_{ase}^2} \equiv \frac{\sigma_{ideal}^2}{\sigma_{TUT}^2}$$

  is valid for any EC_{tx}.

- Thus "TCC provides the Tx-only RSNR penalty ($\Delta RSNR_{tx}$) seen by the TQM reference receiver", and is equivalent to ETCC in term of assessing $\Delta RSNR_{tx}$.

- ETCC is regarded as the extended TCC because it extends beyond providing $\Delta RSNR_{tx}$, by providing two additional (informative) parameters, EC_{tx} and NSR_{tx}.

Concluding remarks

- We have presented the essences of the TCC and ETCC approaches.
- TCC provides the Tx-only RSNR penalty ($\Delta RSNR_{tx}$) seen by the TQM reference receiver.
- ETCC additionally provides the BER-$\Delta RSNR_{tx}$ slope information, which is valuable to indicate the error floor behavior.
- A simple and illustrative way to specify ETCC is to use the BER-TCC waterfall mask, which can also provide more information on the error floor behavior than just one slope.

Thank you!