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Reference Receiver Design for Transmitter Constellation Closure (TCC) as a Transmitter Quality Metric (TQM) for Coherent transmitters

Qirui Fan [1], Xiang Liu [1], and Tao Gui [2]

[1]Huawei Hong Kong Research Center, China; [2]Huawei, China

Transmitter quality metrics considered in Q6/15

Quote on the attached SG15-TD214/WP2 document of Liaison "ITU-T SG15 to IEEE 802.3: LS/r on B400G work and EVM":

" The TQMs considered during the recent Q6/15 meetings focused on two different approaches:

1. The extension of the error vector magnitude (EVM) as from current G.698.2 for compatibility with DP-16QAM constellations.

2. Approaches based on digital noise loading, referred during the meetings as transmitter constellation closure (TCC) and extended-TCC (ETCC), so named in this meeting and described in reference as Tx-only RSNR penalty in dB. The latter is a variation of the TCC which aims to enhance the accuracy of reference receiver performance estimation to better isolate the transmitter performance. For this purpose, it is proposed to describe the calibrated receiver not only as a noise source but also with an additional eye closure penalty term. "

Transmitter quality metrics considered in Q6/15 – cont'd

"Among the different options, Q6/15 is proposing to consider ETCC as the first option for a TQM for 800G applications. This is regarded as the most comprehensive option while not increasing the measurement effort due to the specified digital noise loading procedure. Final selection of the TQM will be however subject to future validation over data generated with the reference receiver to be agreed as from Section 2 of this document. Q6/15 also recognized that there have been no substantive contributions on DP-16QAM EVM over the last several years, and thus there seems to be no industry consensus to further develop this TQM. However, in the process of evaluating the performance ETCC for DP-16QAM, a read-out of EVM will be provided."

TCC Test Method (digital/virtual noise loading)

SG15-TD214/WP2 **provides a Pictorial representation of TCC test setup and TCC calculation procedures (see Figure 1)**

An ETCC example shown in SG15-TD214/WP2

SG15-TD214/WP2 **provides a Pictorial representation of data collection and parameter extraction during ASE noise loading experiment (see Figure 2)**

ETCC is proposed to describe the calibrated receiver not only as a noise source but also with an *additional eye closure penalty term* (the fitted slope of ENSR vs NSR$_{ase}$ curve).
The detailed ETCC math are well described in SG15-TD214/WP2

Reference Receiver DSP for 100G DP-DQPSK (ITU-T G.698.2 Annex A)

Annex A

Reference receiver characteristics for DP-DQPSK 100G

(This annex forms an integral part of this Recommendation.)

The reference receiver includes the following steps as defined in the EVM calculation in clause 7.2.12, except the first item:

– compensate for chromatic dispersion and differential group delay;
– demultiplex the two polarizations;
– remove the frequency offset between carrier laser and local oscillator;
– recover the carrier phase;
– retime and resample to one sample per symbol;
– compensate for IQ-offset;
– apply a 7-tap T-spaced FIR filter with the tap coefficients optimized for BER.

Reference Receiver for 800G (SG15-TD214/WP2)

“ During the Q6/15 Meeting in Montreal, a Breakout Group met to outline the functional blocks of a reference receiver including DSP steps for 800G DP-16QAM.

1. A coherent receiver frontend and a real-time sampling oscilloscope are used to acquire *Ix*, *Qx*, *Iy* and *Qy* waveforms.
2. A reference coherent receiver includes the following digital signal processing (DSP) steps:
   a) A preconditioning procedure to perform resampling to 2 samples per symbol and frequency offset equalization (FOE) of the test signal.
   b) A low-pass filter (LPF) to emulate the expected bandwidth limitation of the coherent receiver frontend.
   c) A predetermined pulse-shaping filter (PSF) to perform preliminary matched filtering attempting to match a typical transmitter (Tx) filter.
   d) A clock phase recovery algorithm to correct the timing of the oversampled signal.
   e) A reference equalizer based on a 2×2 multiple-input multiple-output (MIMO) filter with an adaptive T/2-spaced feed-forward equalizer (FFE), where T is the symbol period, for polarization demultiplexing and channel equalization.
   f) Carrier phase recovery.
   g) Symbol decisioning and demodulation.
3. Calculation of the TQM using the above reference receiver is carried out. The TQMs may be based on direct calculation or require virtual noise loading as detailed in Section 3 of this document.

Parameters of interest for the TQM, e.g., pre-FEC BER, electrical SNR, symbol error rate, should be part of the output of the reference receiver. ”

DSP parameters are open points.

Calibration of intrinsic receiver noise (from e.g. RX O/E)

The calibration of IMDD receiver noise level σ_s is a mature technology in use.

For TDECQ, σ_s is calibrated through a "Dark-Level Calibration" process according to Keysight's documentation, which is directly quoted here:

"When no light is present at an optical channel's input, the dark level calibration identifies internally generated offset signals (dark level) generated by the N7005A or N7004A optical-to-electrical converters and removes the offset during the measurement calculations.

…

A dark level calibration also measures the intrinsic noise of the channel and probe, which is important when making an accurate TDECQ measurement.

…

A new dark level calibration is recommended when the following occurs:

- ±5°C temperature change from the last calibration temperature
- 10 hours elapsed since last calibration
- Power is cycled "

✓ The above calibration procedure can be repeated 4x to fit coherent system. And σ_s is scaled to be that measured after LPF+PSF filtering for TCC.

Testing with the newest OIF datasets from OFC 2024

Applying the TCC reference receiver DSP to datasets measured at the OIF interoperation demo in OFC 2024

Test signal from transmitter A

Ideal signal without noise loading

see oif2024.422.00, slide 9

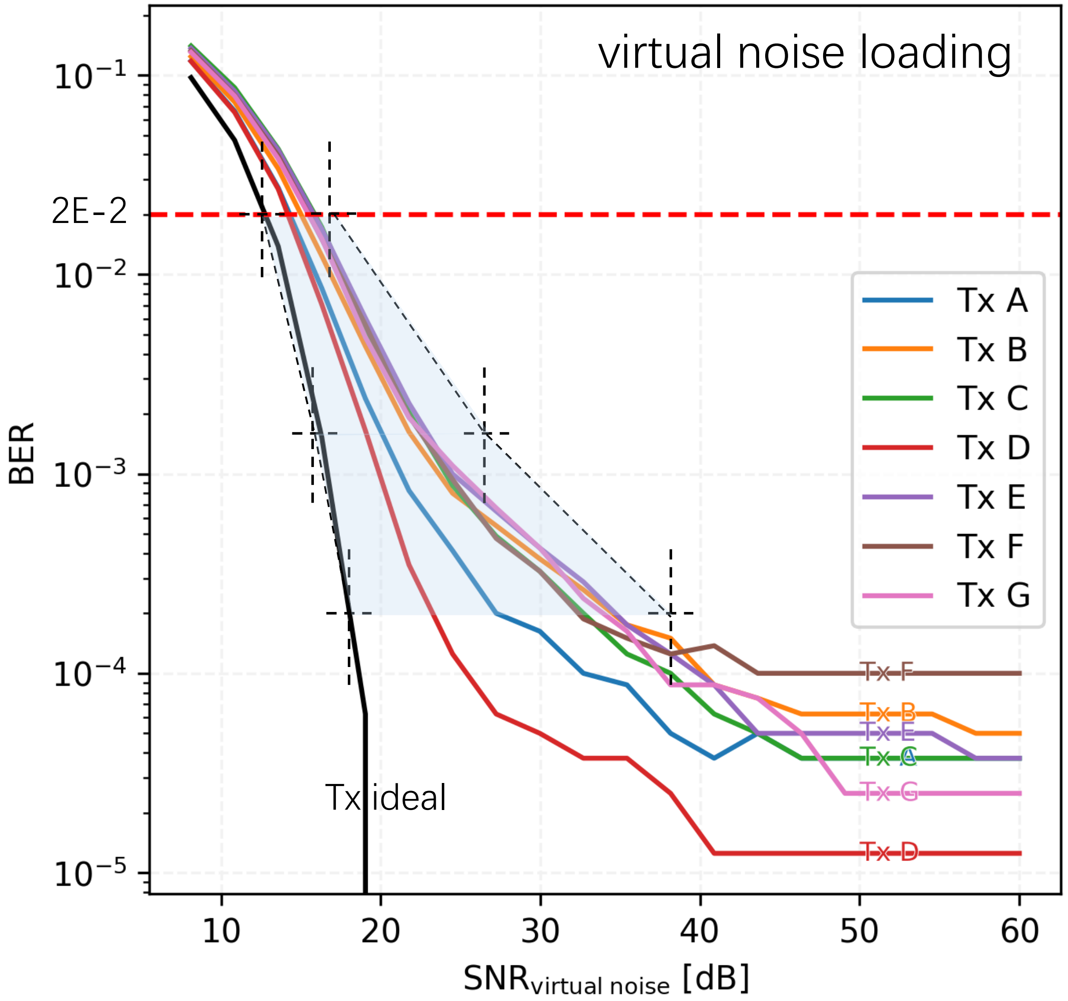
TCC vs. the measured rOSNR penalty

Based on the datasets measured at the OIF interoperation demo in OFC 2024

see oif2024.422.00, slide 10

- ✓ TCC measurements are in good agreement with those measured by the median performance receiver (Rx F)
- ✓ TCC with a well-defined reference receiver can be used as the TQM (as seen by typical coherent receivers)

Extending TCC to include BER waterfall masking



- Waterfall curve is readily available in TCC measurements.
- Additional specification based on BER waterfall masking can be used to confine the error floor, e.g.,

BER	TQM ($\Delta SNR_{virtual\ noise}$)
2E-2	**≤5 dB**
2E-3	≤10 dB
2E-4	≤20 dB

✓ The error floor can be confined by the TCC waterfall masking, i.e., "X dB $SNR_{virtual\ noise}$ penalty for BER Y decades-lower than BER_{ref}"

Concluding remarks

- We have summarized the discussions on the definition of the reference receiver for 800G and on (E)TCC-based transmitter quality metric (TQM).
- The TCC methodology can be readily extended by adding BER waterfall masking to confine the error floor.
- Further work is needed for complete specification of TQM including but limited to
  1. the detailed processing steps of the reference receiver and its parameters
  2. The choice of test pattern

Thank you!