Proposed test plan and actions towards an appropriate definition of EVM for 400GBASE-ZR

Fabio Pittalà, Peter Stassar, Huawei

IEEE P802.3ct Task Force, December 2019

Introduction

- EVM_{RMS} has been included in the in-force Recommendation ITU-T G.698.2 as the metric to define the quality of a 100 Gb/s DP-DQPSK transmitter.
  - It contains also the definition of a reference receiver.

- IEEE P802.3ct™/D1.1 has adopted the EVM_{RMS} definition used in the in-force Recommendation ITU-T G.698.2.

- Work on laboratory measurements investigating the suitability of EVM_{RMS} as the transmitter quality metric also for a DP-16QAM transmitter has been reported in IEEE802.3ct.

- The definition of EVM_{RMS} as a suitable metric for a DP-16QAM transmitter in 80 km 400 Gb/s applications in P802.3cw has to be established including the definition of a reference receiver.

Useful Documents and Previous Contributions

- *ITU-T G698.2: Amplified multichannel dense wavelength division multiplexing applications*
  - It contains the **Maximum EVM** definition and the reference receiver characteristics for the 100Gb/s DP-DQPSK signal.
- The Ad Hoc presentation *anslow_3cn_01_181025*, and the meeting presentations *anslow_3ct_02_0319* (Vancouver) and *pittala_3ct_01a_0719* (Vienna), report:
  - Measurement results on EVM_{RMS} for DP-DQPSK (considered by ITU-T Q6/15 when the EVM_{RMS} limits were defined for 100 Gb/s application codes contained in *Rec. ITU-T G.698.2*);
  - Measurement results on EVM_{RMS} for DP-16QAM.
- The Ad Hoc presentation way_3ct_01b_1119 reports EVM_{RMS} for DP-16QAM measurement results based on a different test plan and receiver based on test equipment and offline processing.
- The following presentations give an introduction on the processing steps required to calculate the EVM_{RMS} and on the reference script developed in ITU-T by Q6/15 members:
  - ITU session at OFC'18 (San Diego, March 2018), *Specifications for coherent 100 Gbit/s DP-DQPSK optical interfaces in a revision of ITU-T G.698.2*;
  - ITU session at OFC'19 (San Diego, March 2019), *Coherent Multi-Vendor Interoperable Specifications in Recommendation ITU-T G.698.2*;
  - Ad Hoc presentations *lecheminant_3cn_01_190207* and *lecheminant_3ct_01_190509*.

EVM Definition Differences in OIF, ITU-T and IEEE 802.3

Definition	Draft OIF 400ZR IA (oif2017.245.14) DP-16QAM	Draft Revised Rec. ITU-T G.698.2 DP-16QAM	a) In-force Rec. ITU-T G.698.2 b) Draft IEEE P802.3ct™/D1.1 DP-QPSK
EVM_{RMS} Normalization	peak ref. vector	peak ref. vector	1
Amplitude of the noise for each quadrature	$A_{RMS} = \sqrt{\frac{0.814 \cdot R_{symbol}}{10^{\frac{OSNR(193.6)}{10}} \cdot 12.5}}$		$A_{RMS} = \sqrt{\frac{1.466 \cdot R_{symbol}}{10^{\frac{OSNR(193.6)}{10}} \cdot 12.5}}$
	ONSR = OSNR Tolerance = 26dB	OSNR(193.6) = Minimum OSNR at reference point Rs referenced to 193.6 THz	
		OSNR(193.6) = TBD	a) OSNR(193.6) = 24dB b) OSNR(193.6) [amp.] = 19.5dB

Proposed Test Plan for 400GBASE-ZR Standardization Work

Measurements setups

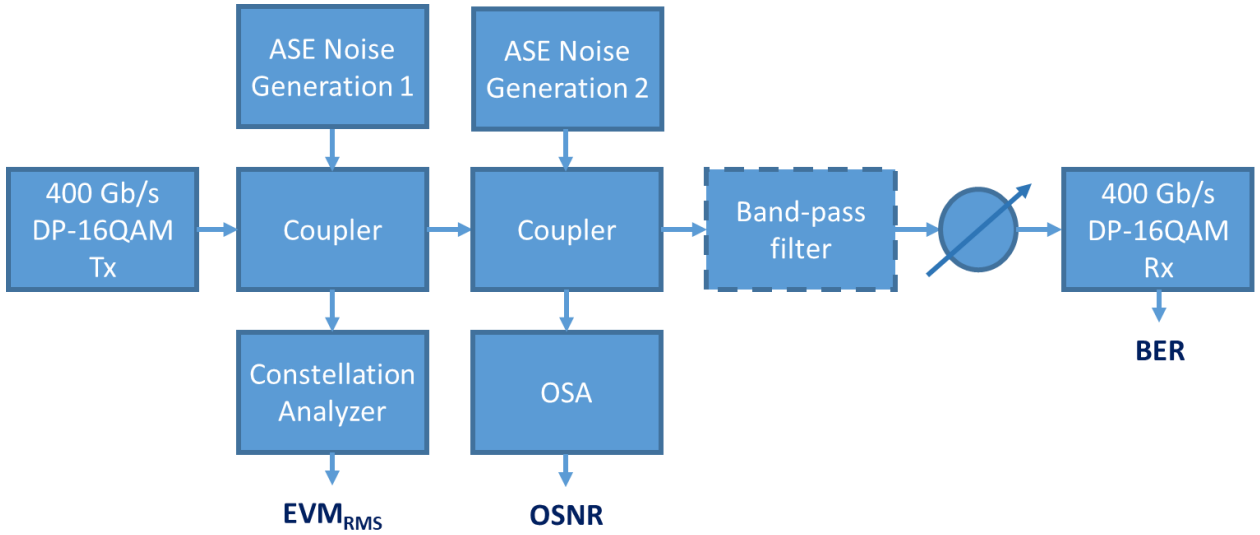


Fig. 1 Measurement setup for OSNR penalty vs EVM for non-equalizable noise like impairment.

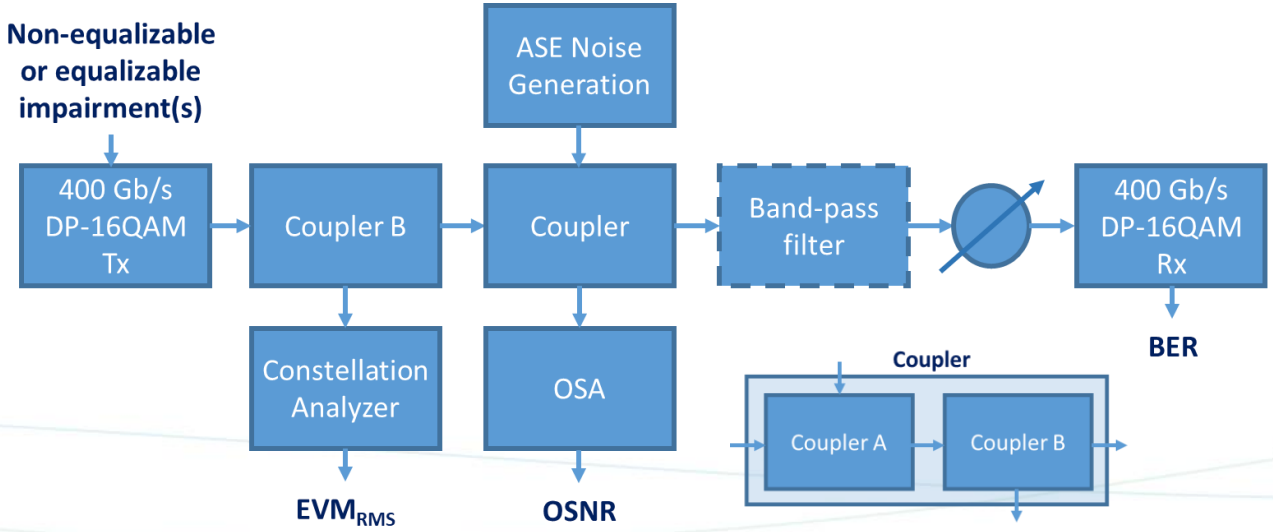


Fig. 2 Measurement setup for OSNR penalty vs EVM for non-equalizable (circle-like noise) or equalizable impairment(s).

The measurement setup in Fig. 1 (for noise like impairment) and the one in Fig. 2 (for non-equalizable or equalizable impairments) should be used to determine following parameters:

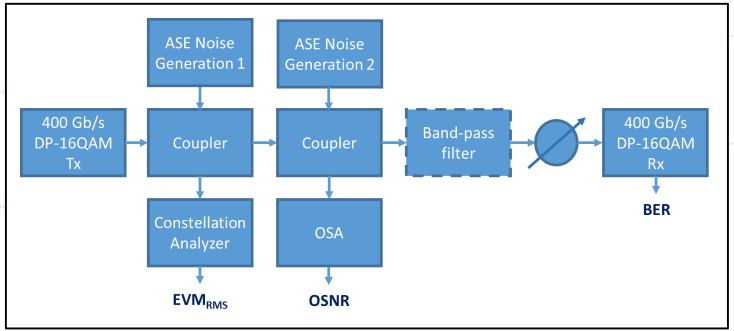
- I-Q offset (IEEE Draft P802.3ct/D1.1 - 154.8.10);
- Quadrature error;
- I-Q imbalance;
- I-Q skew (IEEE Draft P802.3ct/D1.1 - 154.8.4);
- non-equalizable impairment like circle-like noise (zero mean noise with fix magnitude and incremental phase) as shown in *anslow_3cn_01_181025*;
- non-equalizable noise like impairment.

Proposed Test Plan for 400GBASE-ZR Standardization Work

Measurements based on setup in Fig. 1

If measuring non-equalizable noise-like impairment using the setup in Fig. 1 the following steps are used:

1) Without ASE noise generation 1, adjust the ASE noise generation 2, to get the considered pre-FEC BER of 1.25e-2; then first EVM_{RMS} and OSNR values are measured (EVM_0, $OSNR_0$).
2) a) Introducing ASE noise generation 1 and measure EVM_{RMS} (EVM_1), the pre-FEC BER is changed (not 1.25e-2 anymore), b) then adjust the ASE noise generation 2, to set pre-FEC BER at 1.25e-2 again, then turn-off ASE noise generation 1 and then the second OSNR value is measured ($OSNR_1$), the OSNR penalty is ($OSNR_1$-$OSNR_0$).
3) Change the ASE noise generation 1, and repeat the step 2), more EVM_{RMS} and OSNR values are measured.
4) The curve of OSNR penalty versus EVM_{RMS} is obtained.



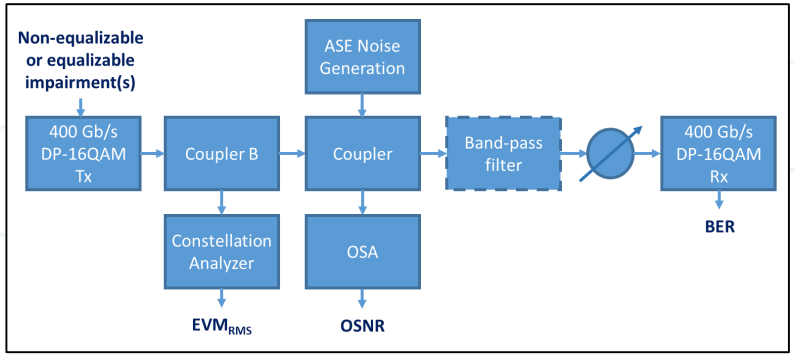
Proposed Test Plan for 400GBASE-ZR Standardization Work

Measurements based on setup in Fig. 2

It is preferred that measurements are obtained independently for each parameter, i.e as the effect of varying one parameter is being measured the other parameters remain unchanged.

Using IQ offset as an example the procedure is:

1) Adjust the ASE noise generation, to get the considered pre-FEC BER of 1.25e-2; then first EVM_{RMS} and OSNR values are measured (EVM_0, $OSNR_0$).
2) a) Modify the transmitter to give a certain value of IQ offset and b) measure EVM_{RMS} (EVM_1), the pre-FEC BER is changed (not 1.25e-2 anymore), then adjust the ASE noise generation, to set pre-FEC BER at 1.25e-2 again, then the second OSNR value is measured ($OSNR_1$), the OSNR penalty is ($OSNR_1$-$OSNR_0$).
3) Modify the transmitter to give a certain value of IQ offset and repeat the b) part of step 2), more EVM_{RMS} and OSNR values are measured.
4) The curve of OSNR penalty versus EVM_{RMS} is obtained.



Proposed Test Plan for 400GBASE-ZR Standardization Work

Evaluate Suitability of EVM_{RMS} metric for DP-16QAM

Step 1:

1) Generate OSNR penalty versus EVM_{RMS} plots containing noise like impairments and deterministic impairments (as example circular impairment) using the setups as shown in Fig. 1 and Fig. 2. The two plots should lie on top of each other.
2) Introduce a 3rd line for an individual impairment like IQ offset, quadrature error, IQ imbalance (just one impairment at the time) which shows OSNR penalty vs uncompensated EVM_{RMS}.
3) Then check if the 3rd line for the particular impairment is very close to the other two lines. If this is the case we do not need to treat it as separate impairment and we would not need to compensate for it in the EVM calculation.
4) In case the 3rd line is sufficiently different to the other two lines then we will need to compensate for it (as it has happened for IQ-offset for 100 Gb/s DP-DQPSK transmitters).

Proposed Test Plan for 400GBASE-ZR Standardization Work

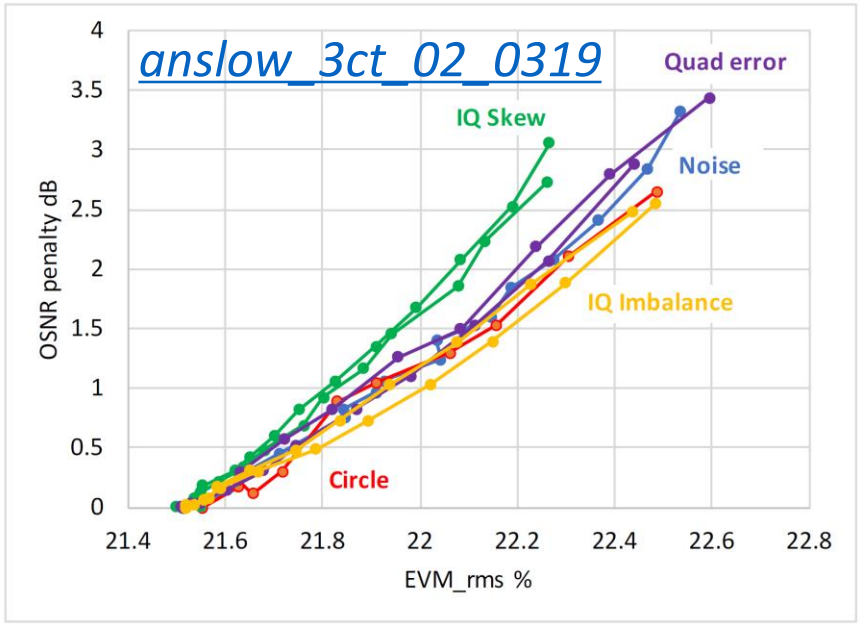
Evaluate Suitability of EVM_{RMS} metric for DP-16QAM

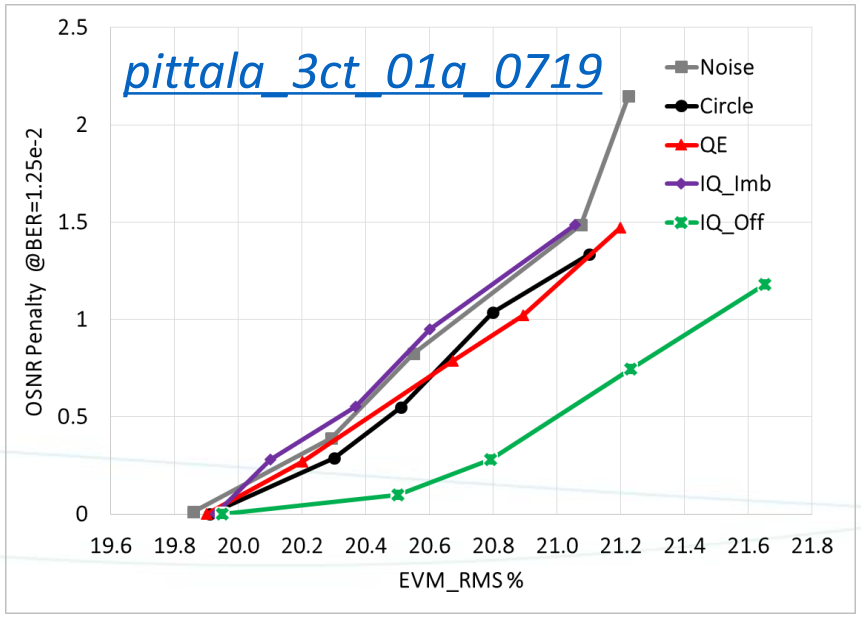
Step 2 (to be addressed after step 1 is completed).

Check the OSNR penalty for combination of impairments that remain compensated by the compensated EVM metric after step 1:

1) Generate OSNR penalty versus “compensated impairment(s)” plot(s) and define a suitable limit for the individual impairment. P802.3cw would need to discuss how to define those limits based on what the performance impact and current transmitter capability is.
2) Apply the combination of individual impairments with the limit defined in 1) and measure the associated OSNR penalty.
3) Establish whether the measured OSNR penalty is acceptable. In case it is not acceptable we need to re-define the limit for the individual impairment (back to 1)).

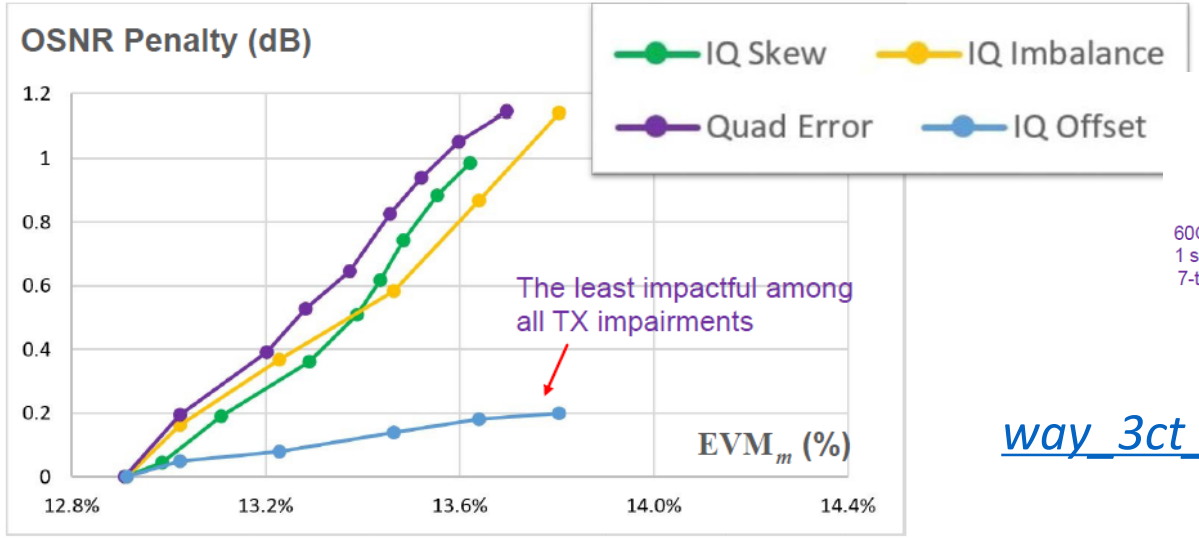
Current Achievements (1/2)

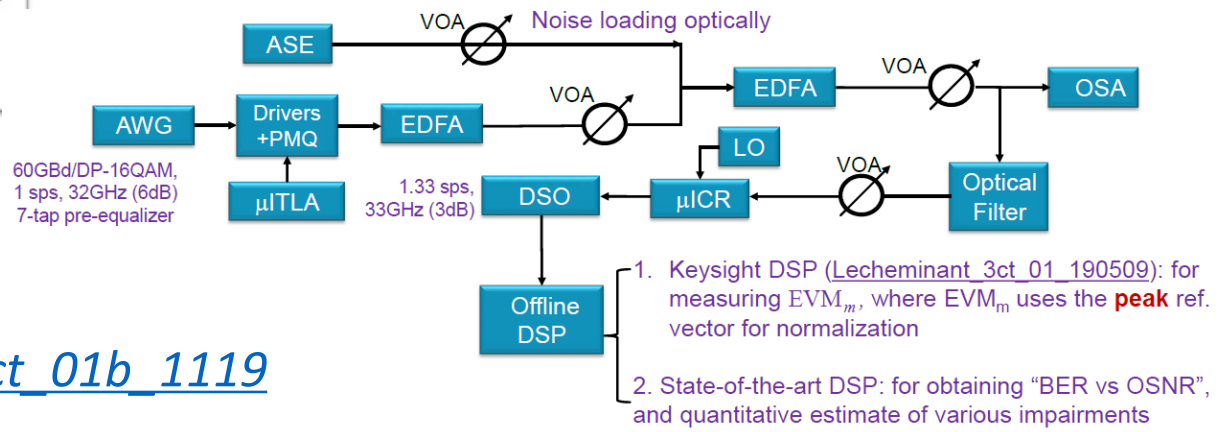




- The measurement results in *anslow_3ct_02_0319* and in *pittala_3ct_01a_0719* confirm that the transmitter quality metric used for DP-DQPSK in the in-force Recommendation ITU-T G.698.2 and in IEEE P802.3ct™/D1.1 is suitable also for DP-16QAM.
  - An EVM_{RMS} limit and a maximum allowable IQ offset still needs to be identified.
- However, the obtained curves are much steeper than those measured for DP-DQPSK:
  - In the results reported in anslow_3ct_02_0319, the EVM_{RMS} delta for 1 dB OSNR penalty is about 0.5%, starting EVM_{RMS} at about 21.5%, while in the results reported in *pittala_3ct_01a_0719* this is about 0.8% and the starting EVM_{RMS} is at about 20%.

Current Achievements (2/2)





way_3ct_01b_1119

- These measurement results are not directly comparable with those contained in *anslow_3ct_02_0319* and in *pittala_3ct_01a_0719* because a different test plan was considered:
  - missing non-equalizable impairments;
  - simultaneously tuning of OSNR and considered impairment;
  - use of a 7-tap pre-equalizer;
  - OSNR penalty based on offline processing;
  - different reference EVM script.
- However, there is indication that IQ-offset needs to be defined separately.

Next Steps

- **Use test plan proposed in slides 5-9.**
- Further study is required to identify the reason for this discrepancy between the measurement results reported in *anslow_3ct_02_0319* and in *pittala_3ct_01a_0719*.
  - An error in the reference script (developed in ITU-T by several Q6/15 members and used for testing) was found, the noise before calculating EVM_{RMS} was not properly added into the signal under test. **Re-processing of captured data or new measurements are required.**
- The measurement results in *anslow_3ct_02_0319* and in *pittala_3ct_01a_0719* show that the obtained curves are much steeper than those measured for DP-DQPSK.
  - The reference script has now been modified such that effect of noise (Minimum OSNR) is still considered when calculating the coefficients of the equalizer but the EVM_{RMS} is calculated on a constellation without additional noise. **Re-processing of captured data or new measurements are required.**
- **Make the reference script available to IEEE 802.3ct Task Force members.**
- **Perform measurements based on 400GBASE-ZR representative hardware.**
- **Note that this will be an iterative process, requiring inputs from multiple sources using different hardware.**

Thank You!