TDECQ metric based on FFE+MLSE

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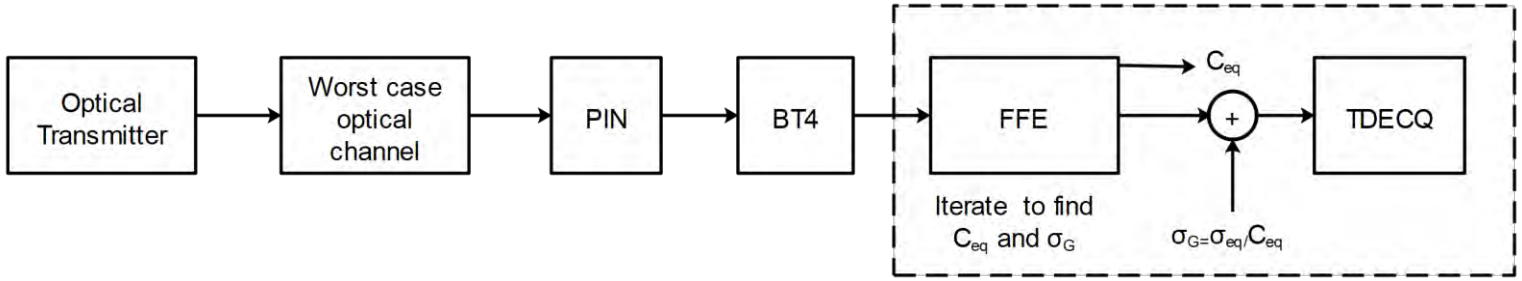
July 2023

IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force

Need for IMDD advanced equalization

- Advanced IMDD DSP is a prerequisite for a larger coverage of electrical and optical use cases at 100G and 200G per lane
- Advanced equalization is already being implemented for 100G SerDes and 200G optical PHYs
- FFE+MLSE has been proven superior for a variety of PAM4 use cases
  - ✓ **800G LR4** (better CD & PMD tolerance)
  - ✓ 100G **backplane** (improved insertion loss)
  - ✓ 100G & 200G **linear drive optics** (improved electrical insertion loss, CD, PMD)
  - ✓ 100G & 200G **CPO** (better CD & PMD tolerance)
- MLSE can be implemented with low complexity as reduced state sequence detector
- However, there is a lack of a transmitter quality metric for a FFE+MLSE receiver

Recap: Classical TDECQ definition



- A generic optical interconnect where a pattern is sent from an optical transmitter through a worst case optical channel to a test point is shown in Fig. 1 [IEEE Standard for Ethernet, IEEE Std. 802.3, 2018.].
- A TDECQ tester is connected to the test point. It consists of a reference receiver and a TDECQ algorithm
- The reference receiver converts the received optical signal to an electrical signal and filters it by a fourth order Bessel-Thomson (BT4) filter
- The TDECQ algorithm finds an optimal 5-tap feed-forward equalizer (FFE), given BT4 shaped receiver noise.
- The algorithm connected to the reference receiver finds the largest input referred receiver noise, σ_G, that causes a SER equal to the target (TSER) of 4.8×10^{-4} (KP4 FEC limit at 100G/lane PAM4)

TDECQ under discussion for 200G/lane PAM4

Longer FFE

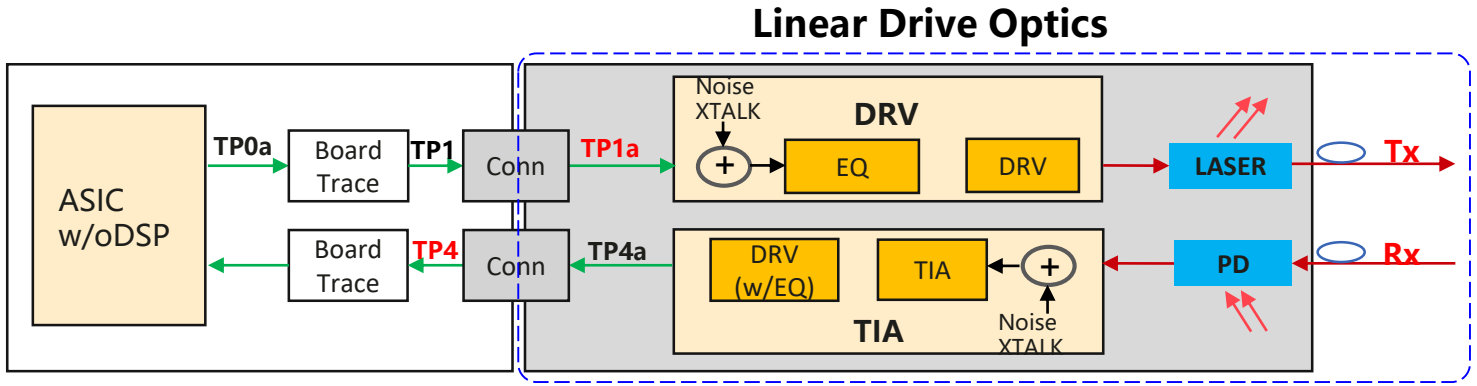
- For 200G PAM4 electrical and optical devices could be more bandwidth limited and have higher Xtalk and noise (rodes_3dj_01_2305)
- Due to increasing symbol rate, similar effects (e.g. reflections) might have an increasing inter-symbol interference (ISI)
- A 17-tap reference FFE equalizer was proposed in rodes_3dj_02b_2305
- At least 11 taps seemed viable in mi_3dj_01_2305 for the 800G FR4

FFE+MLSE

- It was shown that a FFE+MLSE receiver has a higher CD and PMD tolerance for 200G/lane PAM4
- This can be relevant for the 800G LR4 PMD kuschnerov_3df_01b_221012, kuschnerov_3df_02a_221012

Advanced receiver implications at 100G/lane PAM4

Linear Drive Optics & CPO



- MLSE becomes a required subcomponent for 100G/lane SerDes to compensate for bandwidth limitations of the electrical channel
- Recently, linear drive optics were proposed using the LR SerDes IO to drive the electrical trace and the optical pluggable jointly
- Thus, direct drive (CPO) or linear drive applications (pluggable) based on 100G/lane might inherently use advanced FFE+MLSE receivers
- Viterbi algorithm (MLSE or MAP) generally can be used as hard decision or soft output

→ It is desired to have an advanced TDECQ metric for potential future use and standards

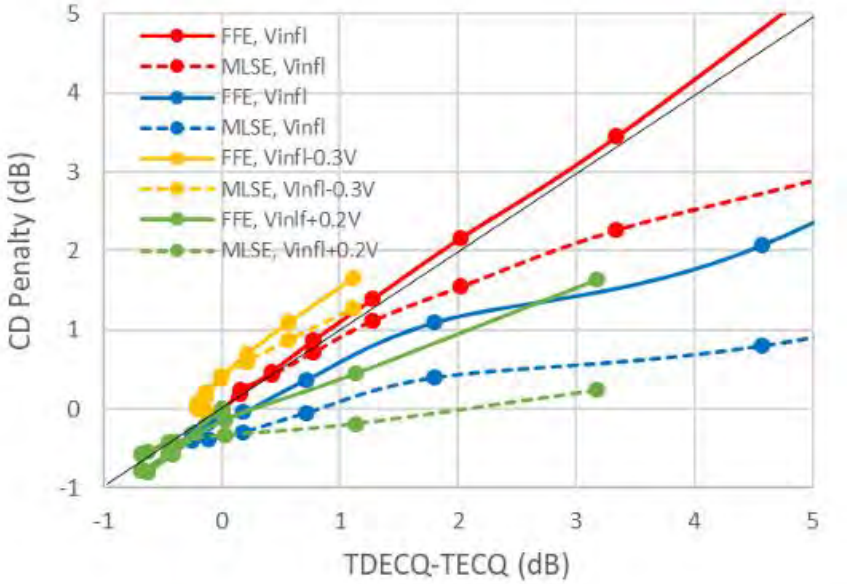
800G LR4: Need for a TDECQ metric update

- Overview of chirp & CD tolerance for 200G PAM4 is presented in johnson_3df_01a_221011
- FFE-based TDECQ overestimates the CD penalty for the MLSE based receiver
- The proposed LAN-WDM grid for 800G LR4 requires a CD tolerance from -28ps/nm:9.2ps/nm

TDECQ options for 800G LR4

1. Updated testing methodology with a limited ZDW range for testing (1305-1319nm) cole_3dj_01b_2305
2. Advanced TDECQ based on FFE+MLSE (this presentation)

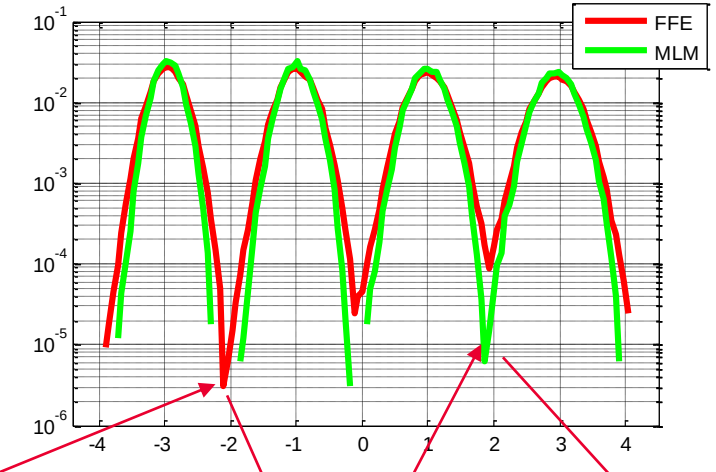
112.5Gbaud PAM4 EML

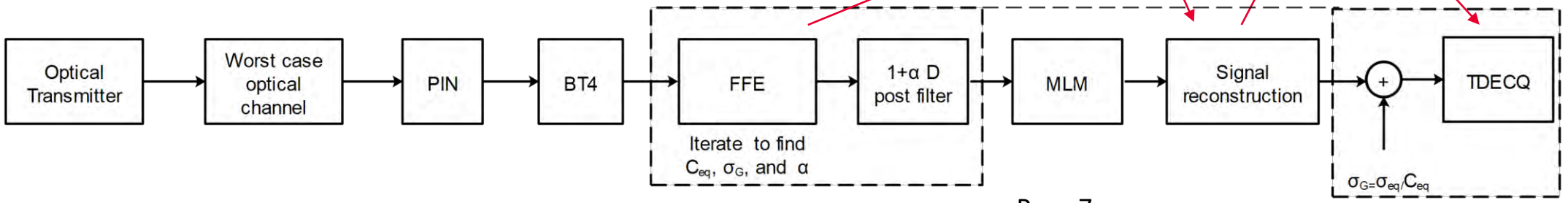


johnson_3df_01a_221011

TDECQ based on MLSE

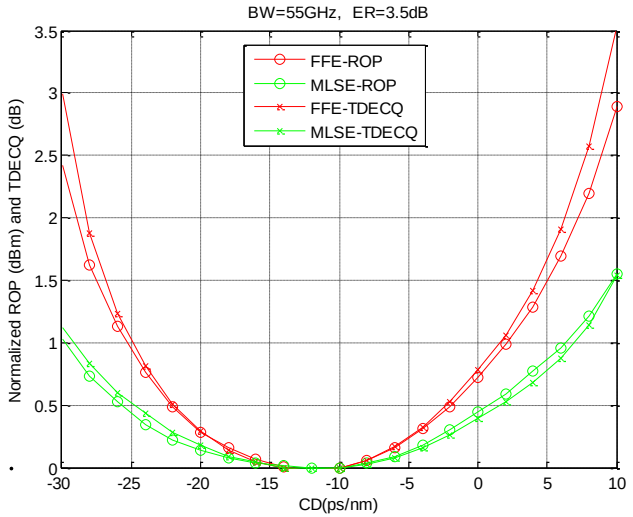
- A novel transmitter quality metric was developed for the FFE+MLSE receiver
- It includes the baseline system (ending with FFE) extended by a 2-tap post filter (1+αD), simplified MAP algorithm called MaxLogMAP (MLM), a signal reconstruction block, and TDECQ calculation
- The TDECQ calculation is almost identical to the FFE-based TDECQ calculation. The noise deviation (σ) search is applied to find sigma value that gives SER=TSER (target SER).

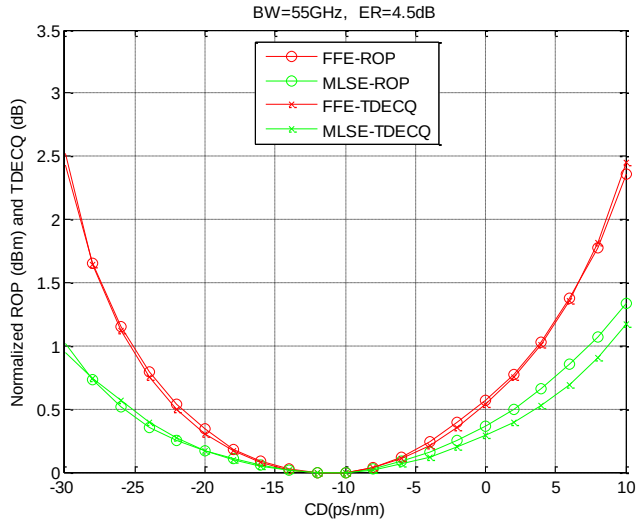


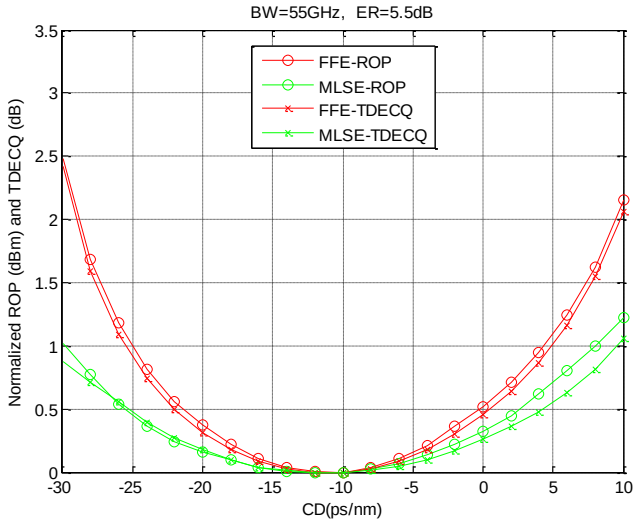


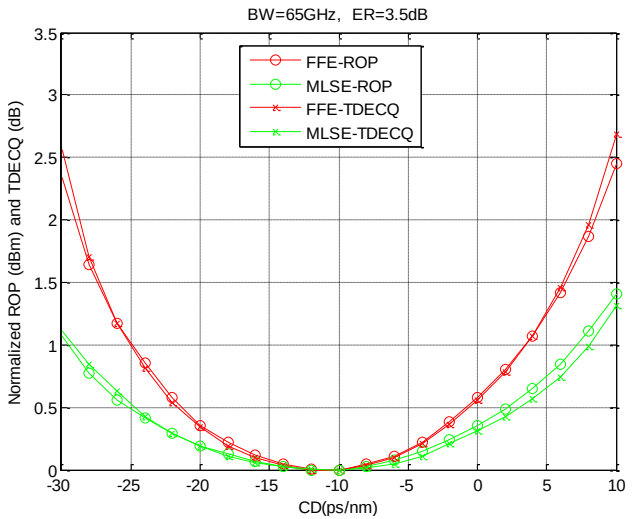
TDECQ metric comparison: FFE vs. FFE+MLSE

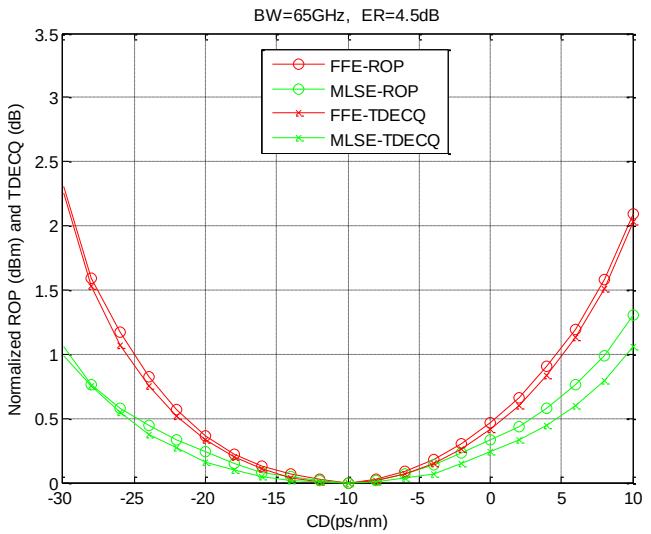
112Gbaud PAM4
TSER = 2*4.95e-3, 15-tap FFE
ER and components bandwidth varied

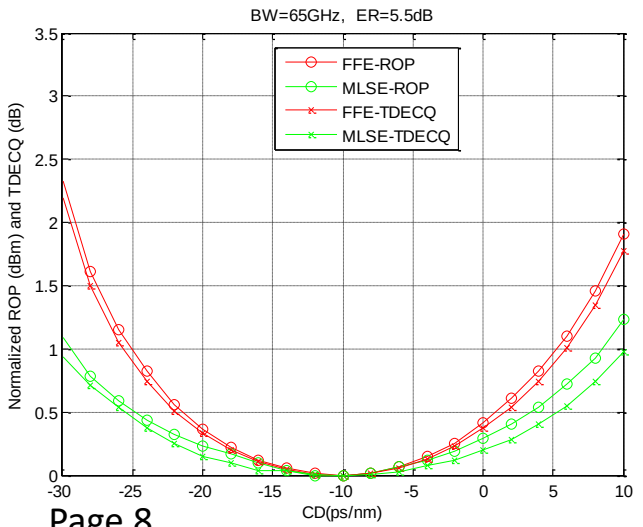












TDECQ estimation error

- TDECQ estimation at Pin=0dBm
- Maximum FFE TDECQ estimation error ~ 0.58 dB
- Maximum MLSE TDECQ estimation error 0.18 dB

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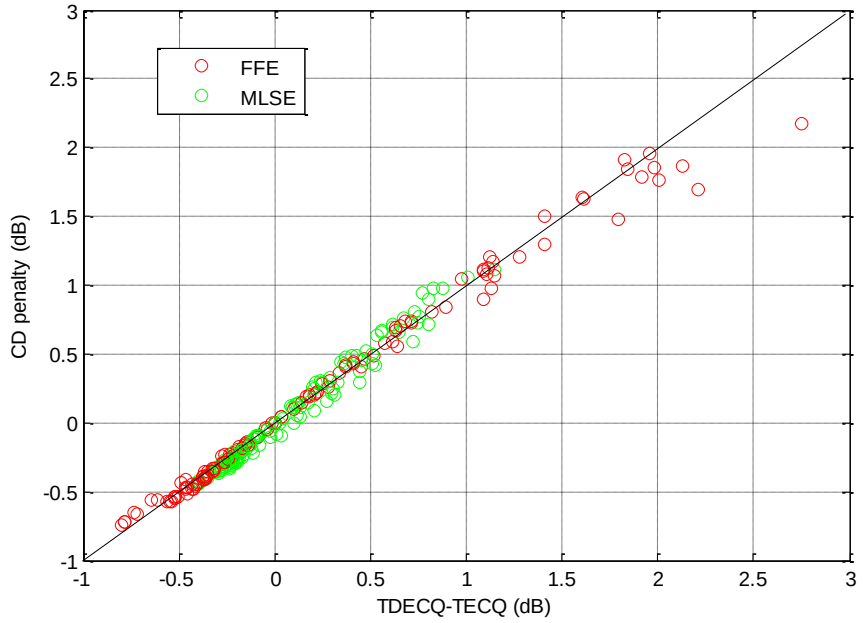

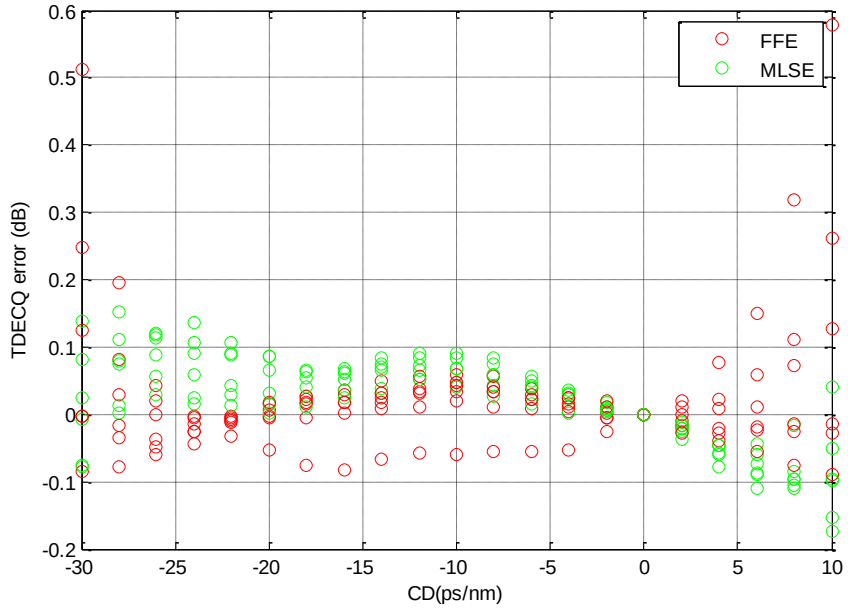

Conclusions

- The performance of a precise TDECQ metric based on the FFE+MLSE receiver was presented for 200G PAM4
- The method can be applied to both hard decision and soft output MLSE, PAMx modulation formats and MLSE with various tap numbers
- It can cover higher tolerances with respect to CD, PMD, low pass filtering for various use cases (800G LR4, linear drive optics, CPO) which are likely to use MLSE
- Approach can have broader appeal to other SDOs (e.g. OIF)
- 800G LR4 TDECQ can be implemented using either option:
  - ✓ FFE based TDECQ with reduced ZDW range for testing based on a statistical channel model / segmentation of the link using CD_Q
  - ✓ FFE+MLSE based TDECQ metric based on classical channel model
- New TDECQ metric can be provided to interested 3rd parties for a broader test coverage and evaluation

Thank you.