TDECQ ANALYSIS FOR 100G VCSEL CHANNELs

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IEEE P802.3db 100 Gb/s, 200Gb/s, and 400 Gb/s Short Reach Fiber Task Force
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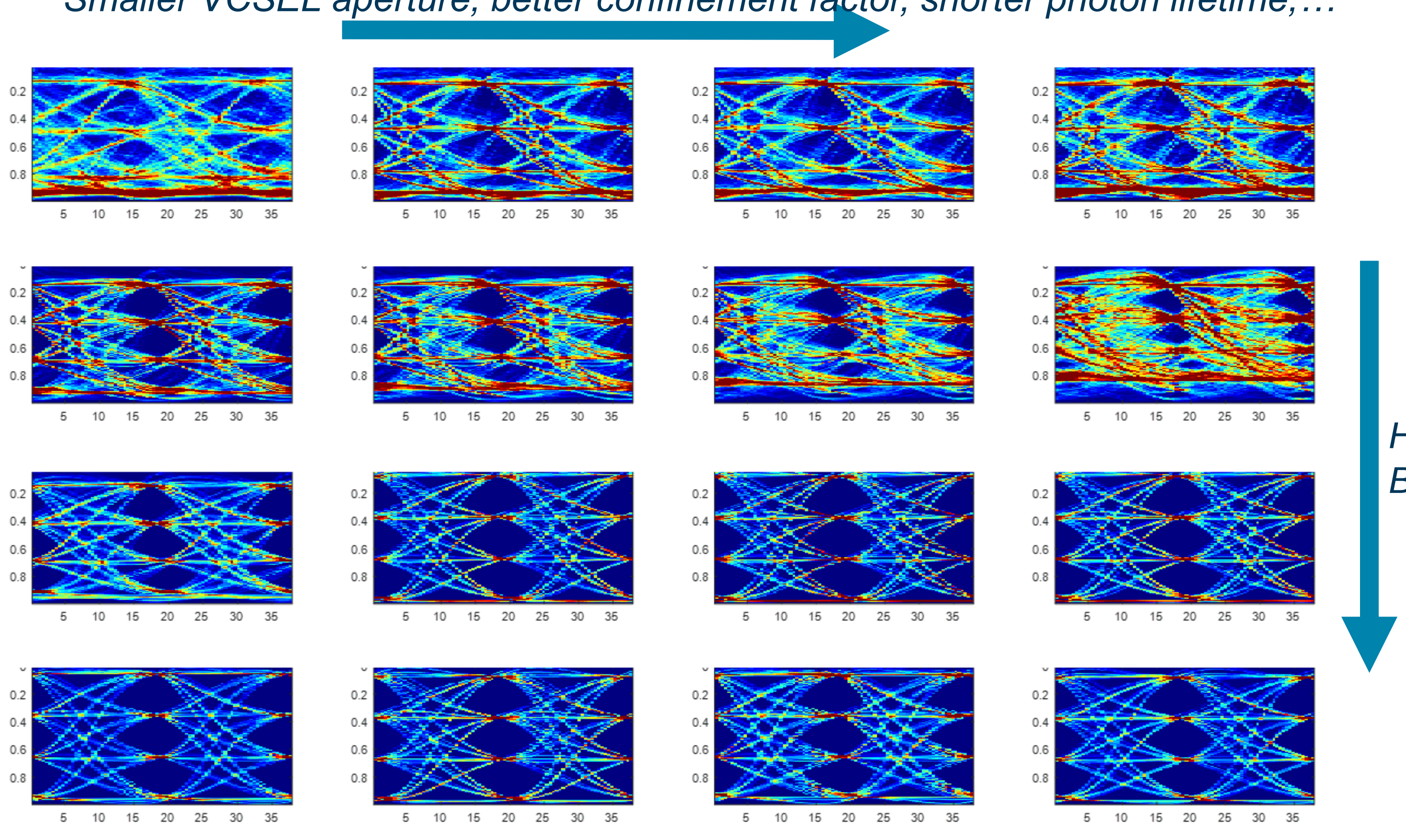
Background and Objectives

- VCSEL simulations are presented in support of the development of 100m SR and 50m VR PMD specifications for MMF channels operating at 100G/lambda.
- Some of the topics addressed:
  - Minimum number of taps for 50m and 100m
  - Bandwidth vs. TDECQ
  - Transmitter equalization and overshoot limits
  - Consideration for TDECQ adjustment threshold
  - RIN impact on TDECQ
- Yield and interoperability discussions based on simulation results:
  - Considerations for transmission equalization and overshoot
  - Better VCSEL yield or less complex receiver for 50m VR

VCSEL Simulation parameters

- Initial population of 100’s of VCSELs.
- The selection method for this presentation is mainly based on bandwidth.
- VCSEL parameters considered: aperture size, confinement factor, photon lifetime, bias current among others cause changes in bandwidth, eye opening and skew.

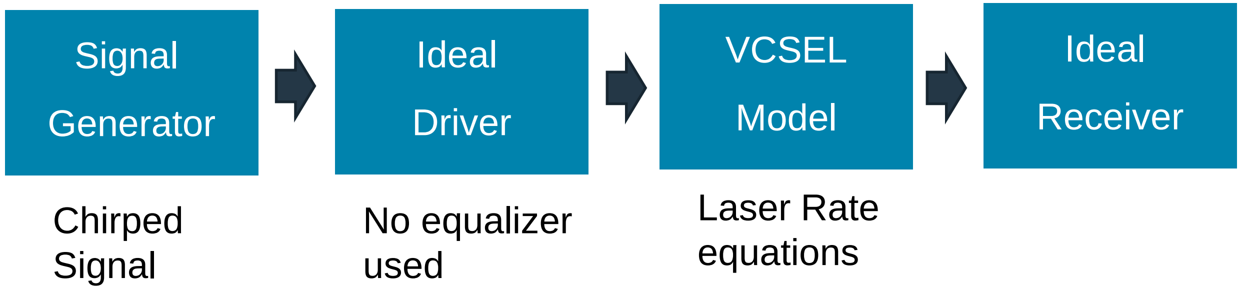
Smaller VCSEL aperture, better confinement factor, shorter photon lifetime,…

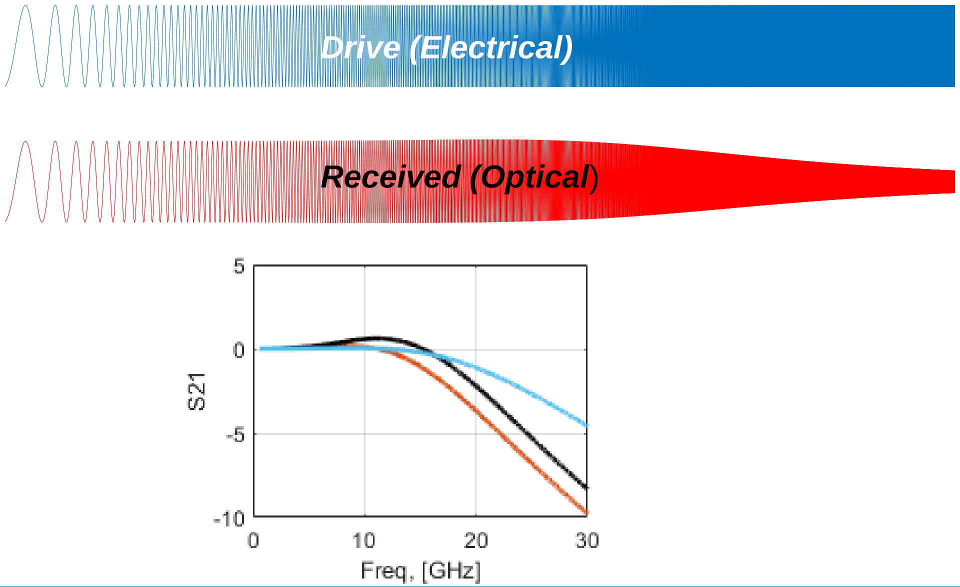


Higher Bias current

VCSEL Frequency Response Characterization

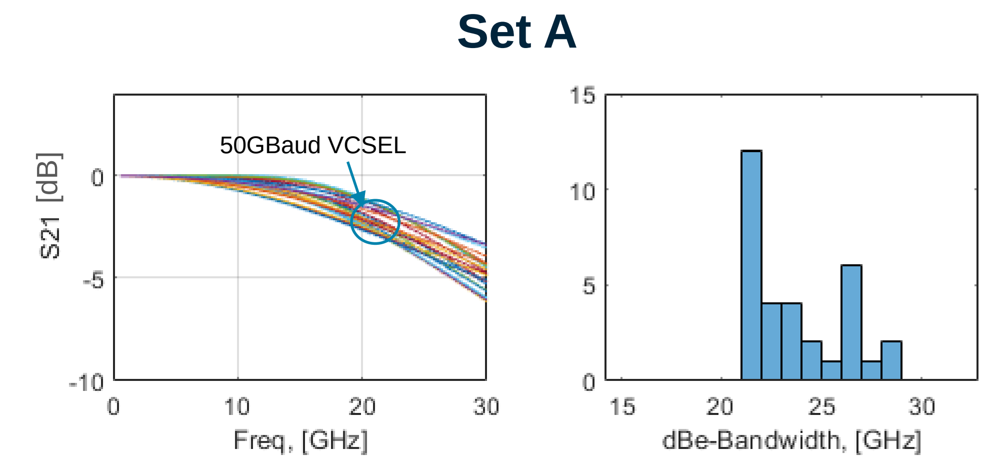
- Laser rate equations includes the interaction between optical and electrical carriers and cavities modes.
  - temporal resolution ≈250 fs for all simulations
- Bandwidth characterization (small gain S21) used chirped signal
- TDECQ evaluated for 5, 7, 9, 11 taps using SSPRQ
- Intended to populate critical areas in the 2-D TDECQ map (dawe_3cd_01a_0318.pdf)

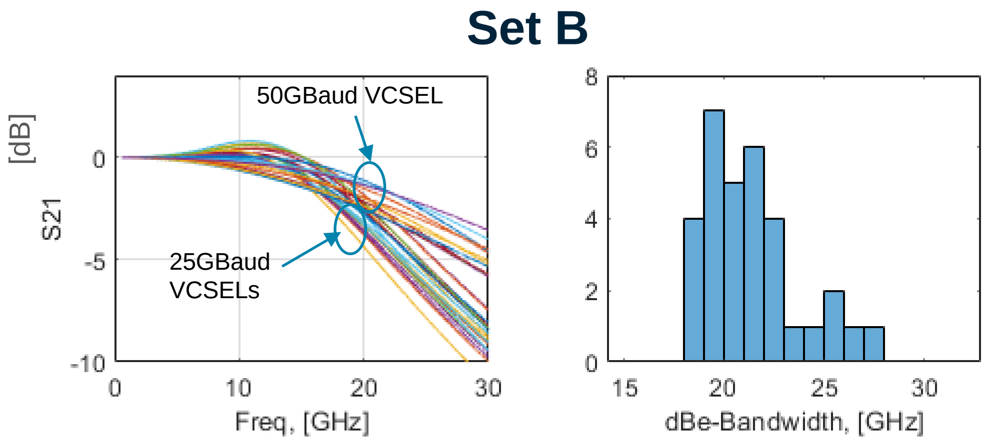




VCSEL Populations S21 parameters

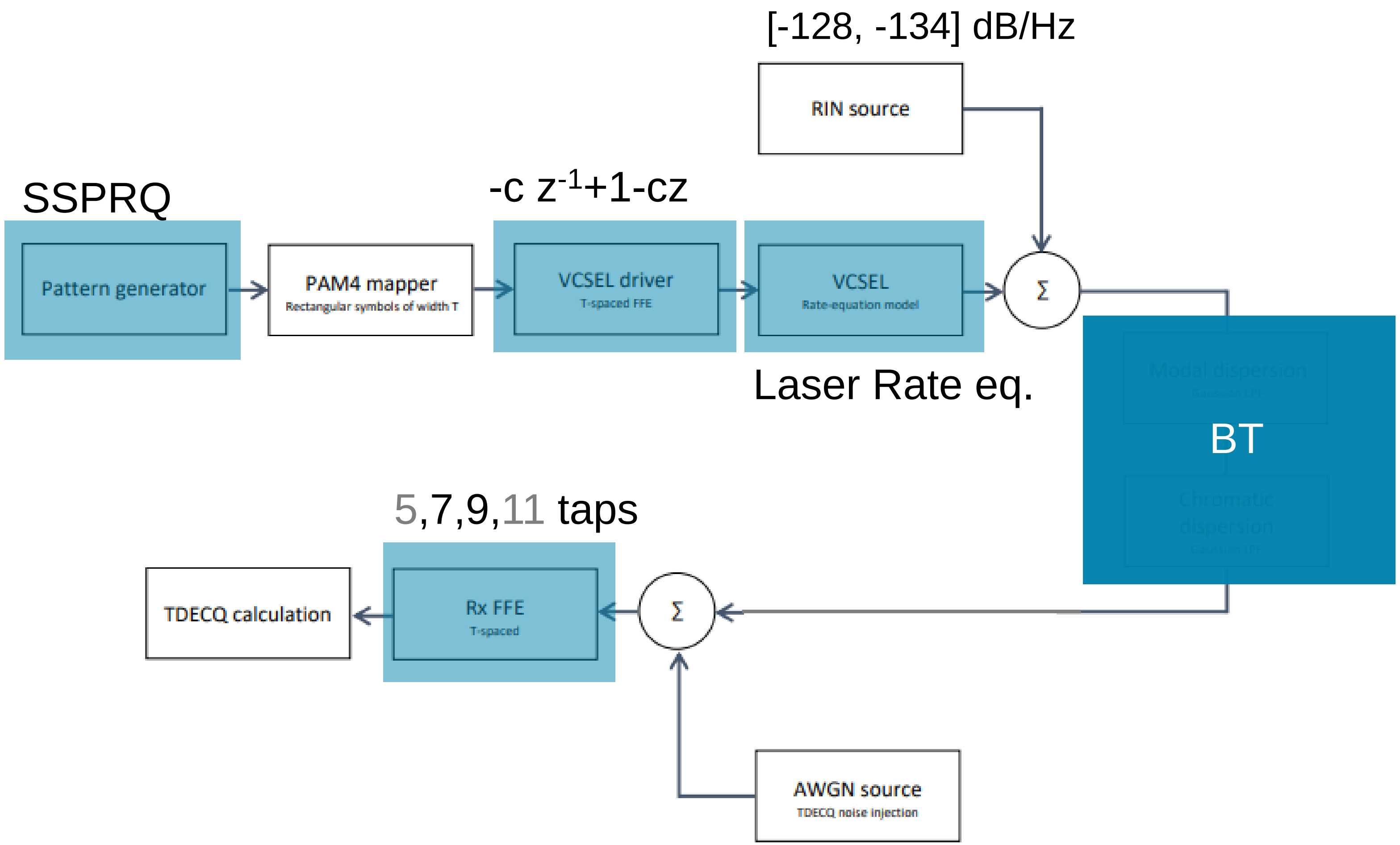
- Simulated VCSELs for 50G and 100G applications
  - Each set comprises 32 VCSELs
  - Each set's VCSELs were equalized using three c values, 0.15, 0.2, and 0.25 producing a total of 96 lasers per set.
- For each population represent, we use several RIN_OMAs
  - A range from -128 dB/Hz to -134 dB/Hz
- This presentation focus on Set A and RIN -131 dB/Hz
  - Used an electrical driver with 20-80 rise time between 11.75 ps to 12.25 ps
  - For some parts of this analysis we also used VCSELs from Set B





For bandwidth calculation c=0

Channel and TDECQ Modeling



Utilized Bessel Thomson filters:
-100m OM4: 15GHz
-50m OM4: 21GHz

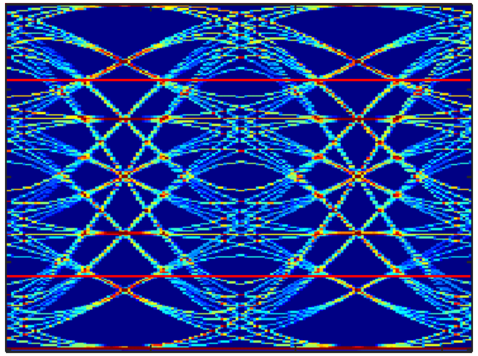
Based on ingham_3db_adhoc_01a_062520.pdf

VCSEL Model Assumptions

- Driver signal assumes Gaussian impulse response.
  - No CTLE used
- The VCSEL model can simulate the coupling of VCSEL modes to fiber modes.
- However, for this analysis we replaced the fiber and Rx by the TDECQ filter with bandwidth of 15GHz for 100m and 21GHz for 50m.
  - Therefore the VCSEL modes were combined before the filter

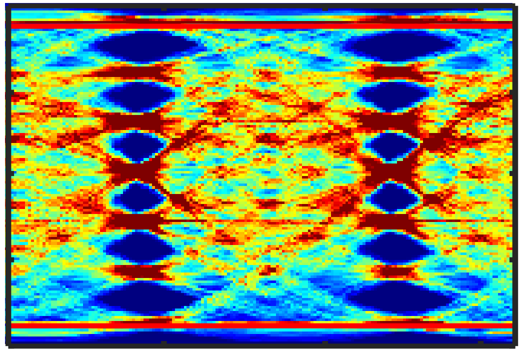
Example for 100G Channel

Driver Signal



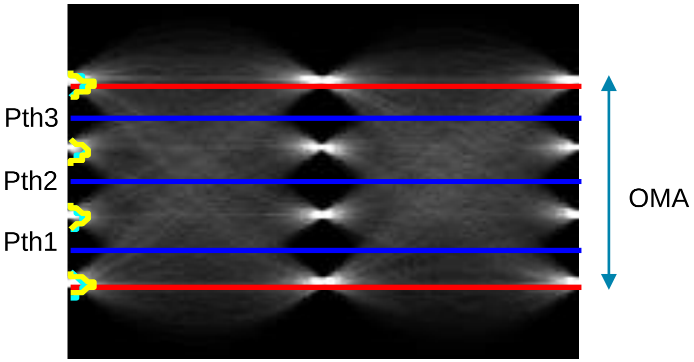
20-80% Rise time=12 ± 0.25 ps c=0.15-0.2

Optical Signal



TDECQ Filter 15GHz
No equalizer

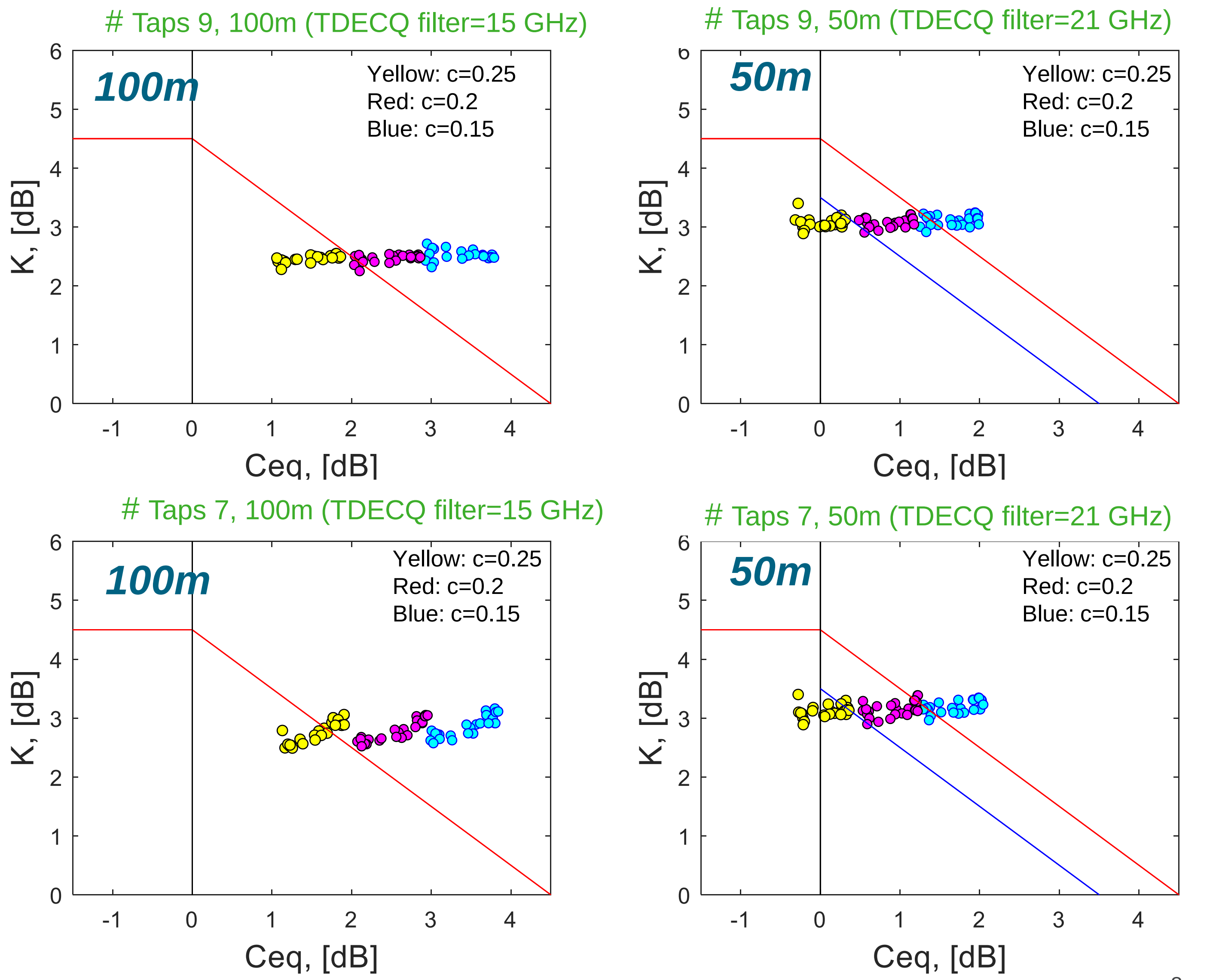
Received Signal



9 Tap Equalizer
TDECQ =4.9 dB, Kd=2.9 dB (see next slide)

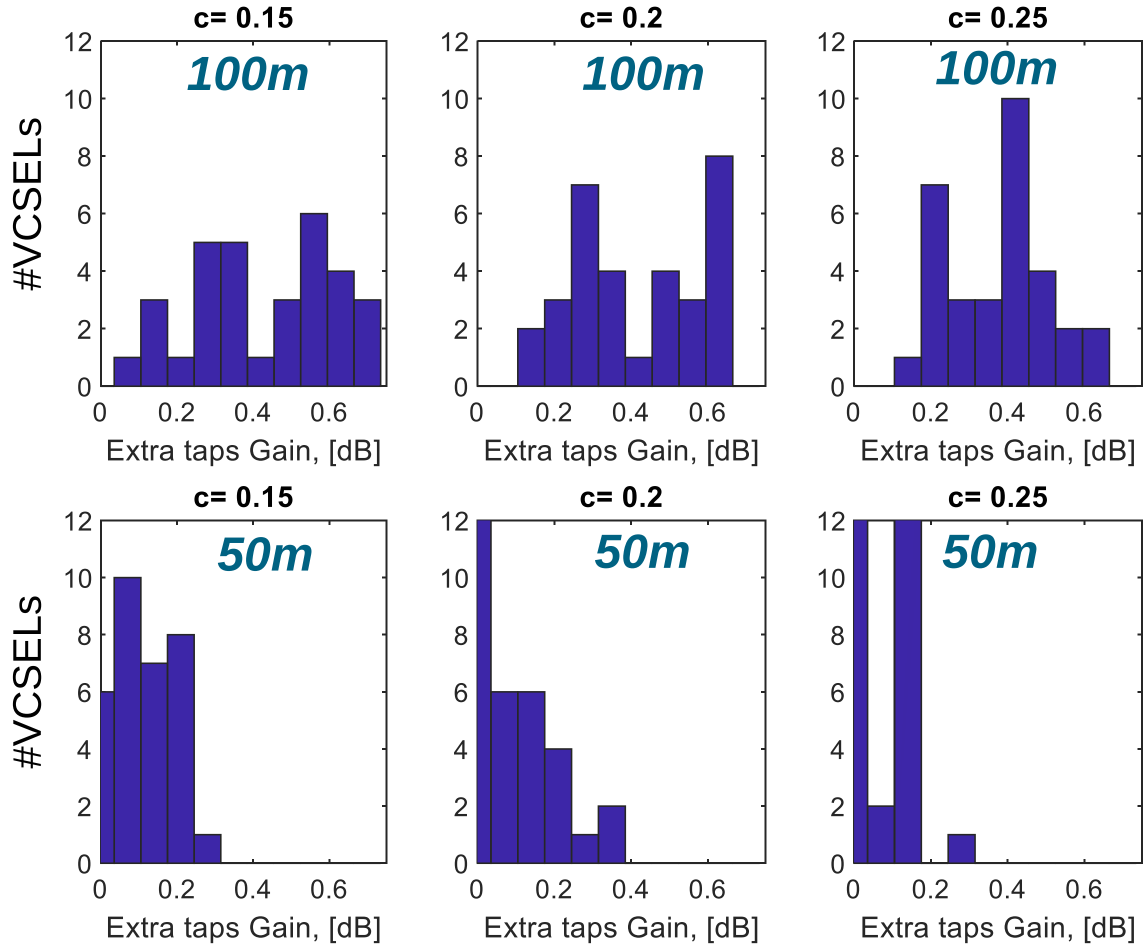
TDECQ results for 100m and 50m OM4

- Each circle represents a VCSEL. The colors represent the transmitter tap value.
  - c = 0.15, 0.2, 0.25
  - Red diagonal line for TDECQ of 4.5 dB
  - Blue diagonal line for TDECQ of 3.5 dB
  - Assumed RIN OMA = -131 dB/Hz
  - Set A used
- This evaluation indicates that at least 9 tap equalizers are needed for 100m and c=0.25
- For 50m, 9 or 7 taps could be potentially used for VCSELs with c=0.2 and c=0.25.
  - However, 9 taps can improve margins and yields



TDECQ improvements vs number of taps and c

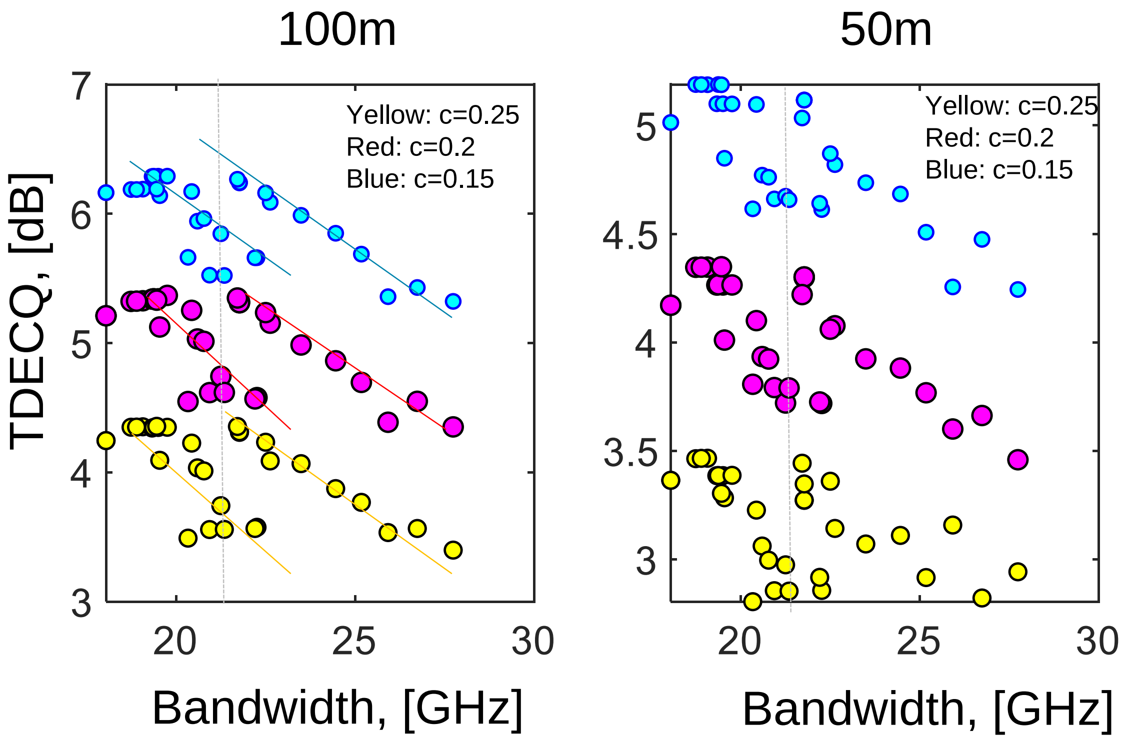
- For 100m, using 9 taps instead of 7 taps reduces TDECQ up to 0.8 dB
- For 50m, using 9 taps instead of 7 taps reduced TDECQ up to 0.4 dB
- For 50m 9 taps allow to tighten the limits of TDECQ to 3.5 dB (using c=0.25).
- This can reduce receiver requirements for 50m VR PMD and the transceiver cost
- For 100m there are marginal benefits for using 11 taps.
  - The max. improvement for c=0.15 observed ≈0.25 dB
  - The max. improvement for c=0.2 observed ≈0.12 dB
  - The max. improvement for c=0.25 observed ≈0.05 dB



See backup slide for K improvements

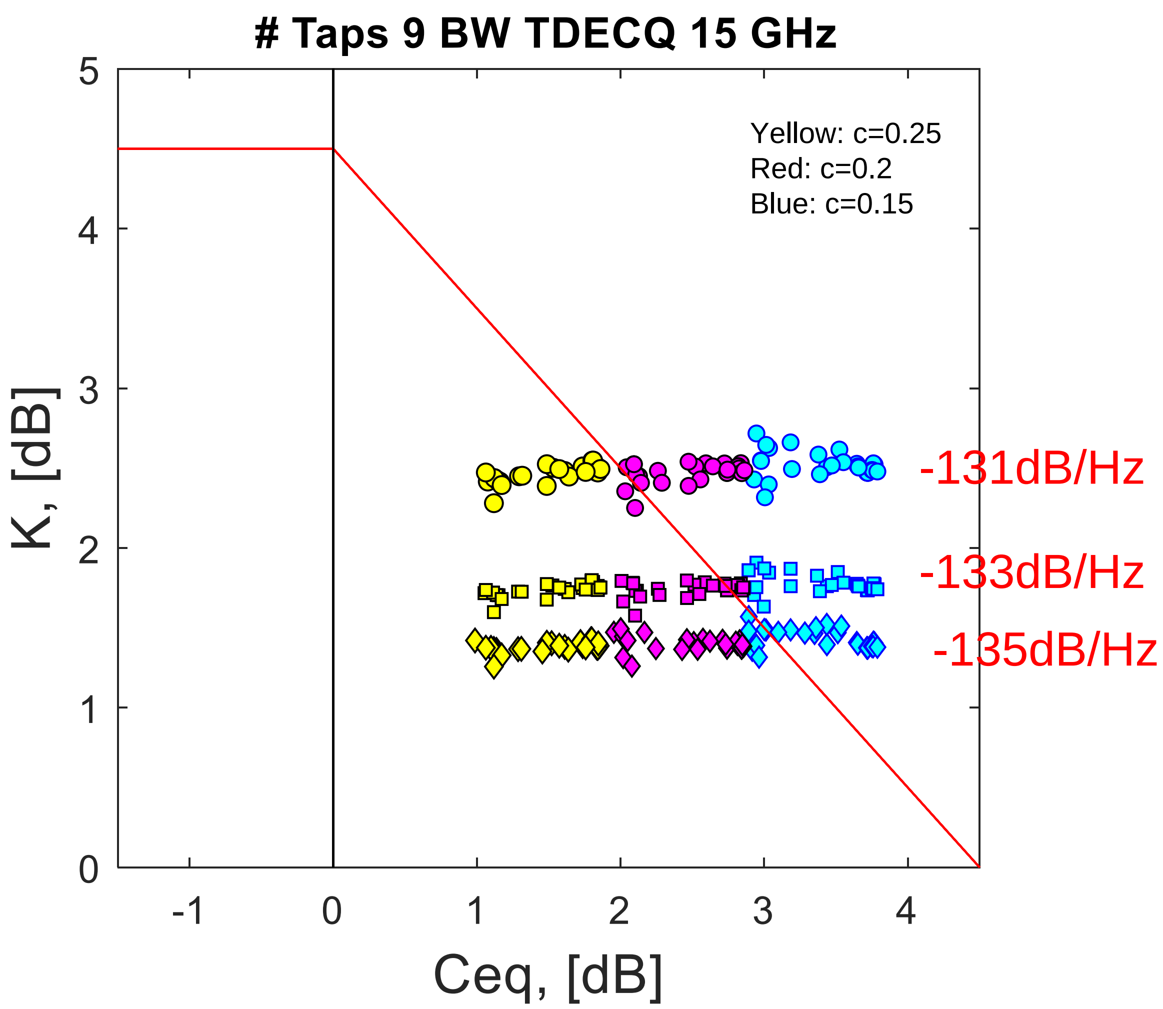
VCSEL Bandwidth vs TDECQ for various Tx equalizers

- Transmitter equalization reduce significantly the TDECQ values
- For the modeled VCSELs the Slope, TDECQ vs BW ≈0.16 dB/GHz



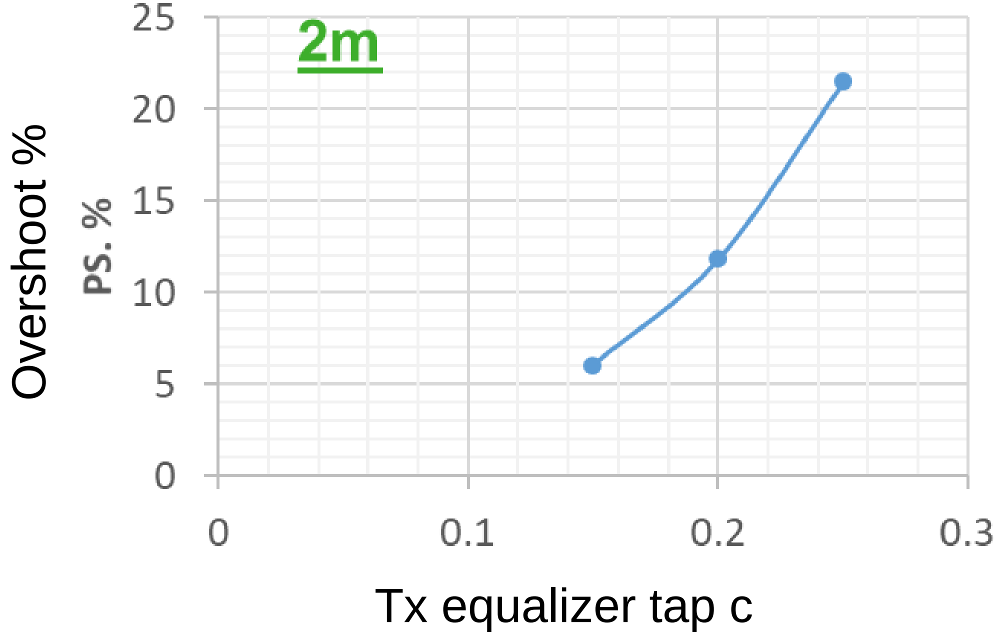
RIN OMA considerations

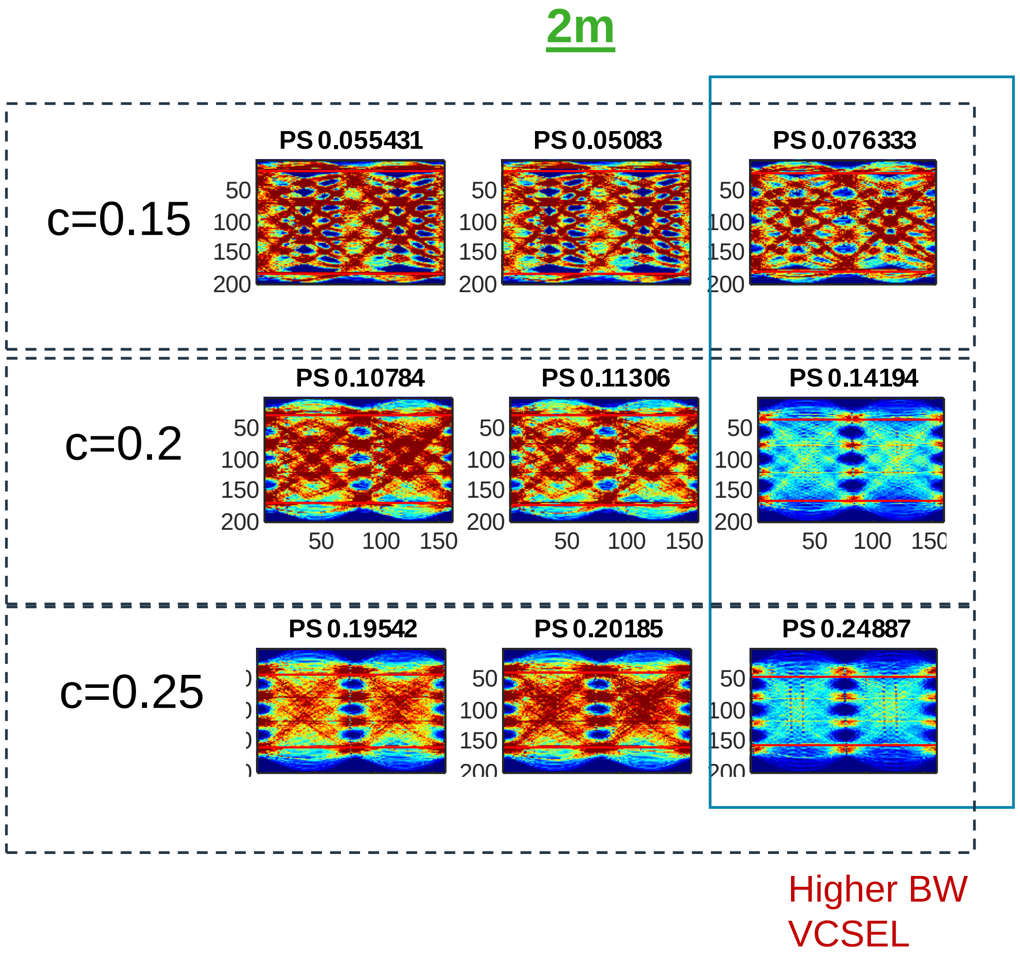
- Improving RIN 2-4 dBs significantly reduces TDECQ
- For RIN better than -133dB/Hz, VCSELs with c=0.2 and 0.25 meet TDECQ requirements for the 100m channel



Transmitter Equalization vs Overshoot

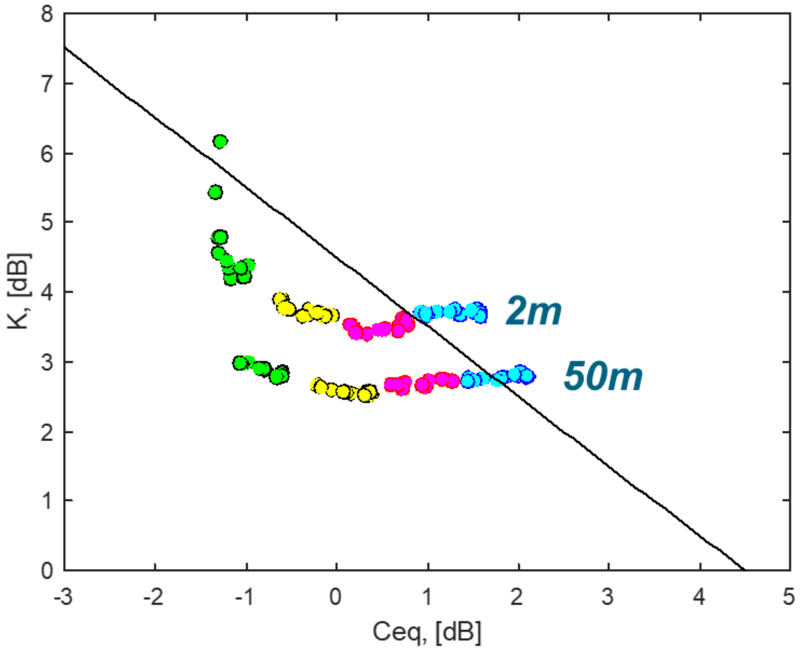
- Method described in annexes
- Overshoot at 2m for three levels of transmitter equalization was evaluated.
- The higher bandwidth VCSELs in the set required less pre-emphasis to open the eye.

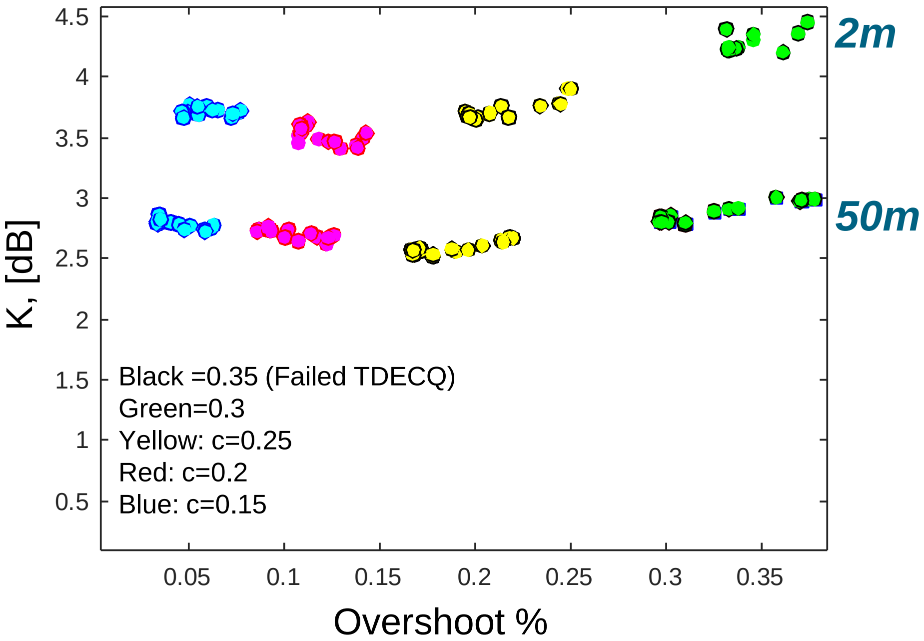




Transmitter Equalization Overshoot vs K

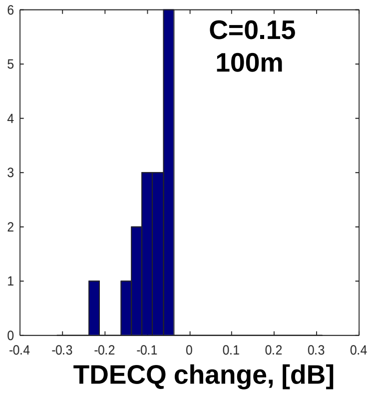
- In this simulation we compare overshoot of 2 vs 50m (9 tap equalizer) .
- High values of c can increase VCSEL yield.
- However, for the VCSELs with highest bandwidth using more pre-emphasis than needed produce overshoot issues.
  – A reasonable limit seems to be c<0.3.

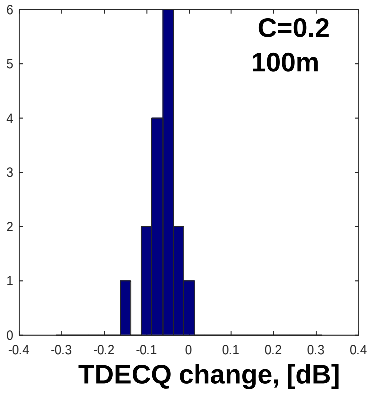


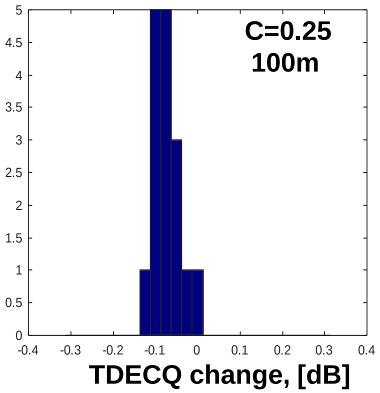


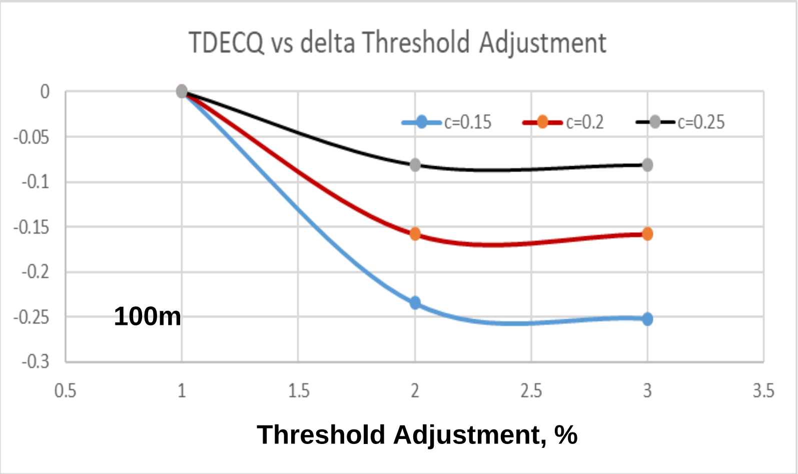
TDECQ vs Threshold Adjustment tolerances

- Relaxing the threshold adjustment tolerances can reduce TDECQ in some degree
- For the simulated VCSELs changing from ±1% OMA to ±2% can reduce up to 0.25 dB depending on the degree of the transmitter equalization.
- The adjustment effect for 50 m on TDECQ is smaller
  - around 30%-40% of the values shown for 100m

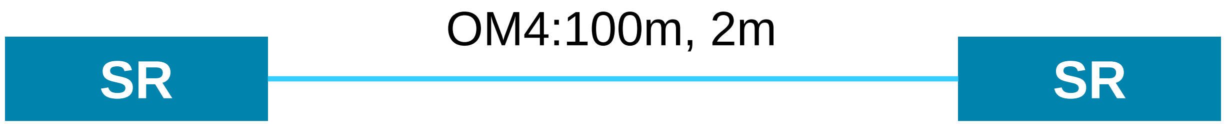




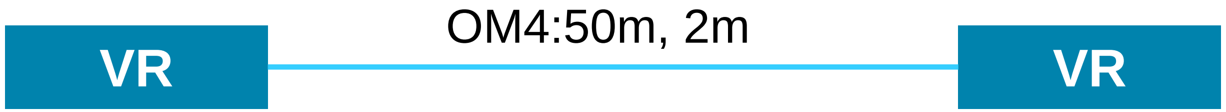




Options for SR and VR



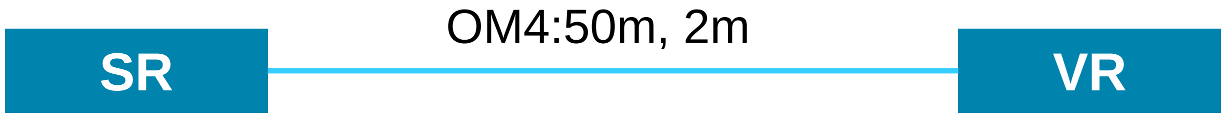
Some degree of Tx equalization is needed even for 25GHz VCSELs. The higher the pre-emphasis the better the eye for 100m but it can produce issues at 2 m (e.g, overshoot). Recommendation $0.2 \leq c \leq 0.3$



Lower bandwidth VCSEL could be used, e.g., 19 GHz VCSEL. The lower the bandwidth more pre-emphasis. There are options for cost reduction:

(I) Accept VCSEL with lower BW provided that the pre-emphasis does not add excessive overshoot, e.g. 25%

(II) Tightening TDECQ limits, to reduce complexity (and cost) of receivers



Depends on option selected for VR.
SR VCSEL needs to pass overshoot requirements for VR receiver. Overshoot or TECQ limits.

Discussion & Conclusions

- The analysis of simulated set of VCSELs with a bandwidth >20 GHz 100G/lambda indicates:
  - Tx equalization is needed even with high bandwidth VCSELs
    - C≥ 0.2 might be required
    - However, c>0.3 can be problematic at shorter distances due to signal overshoot.
  - The 100m OM4 link needs at least 9 taps and RIN_OMA<-131 dB/Hz as shown previously*
    - 11 taps can help to gain a quarter of dB
  - The 50m OM4 link requires at least seven taps for a TDECQ value of 4.5 dB
    - For reasonable TX equalization, TDECQ can be tightened to 3.5 dB using 9 taps
  - TDECQ reduction caused by changing threshold adj. from 1% to 2% is less than 0.25dB

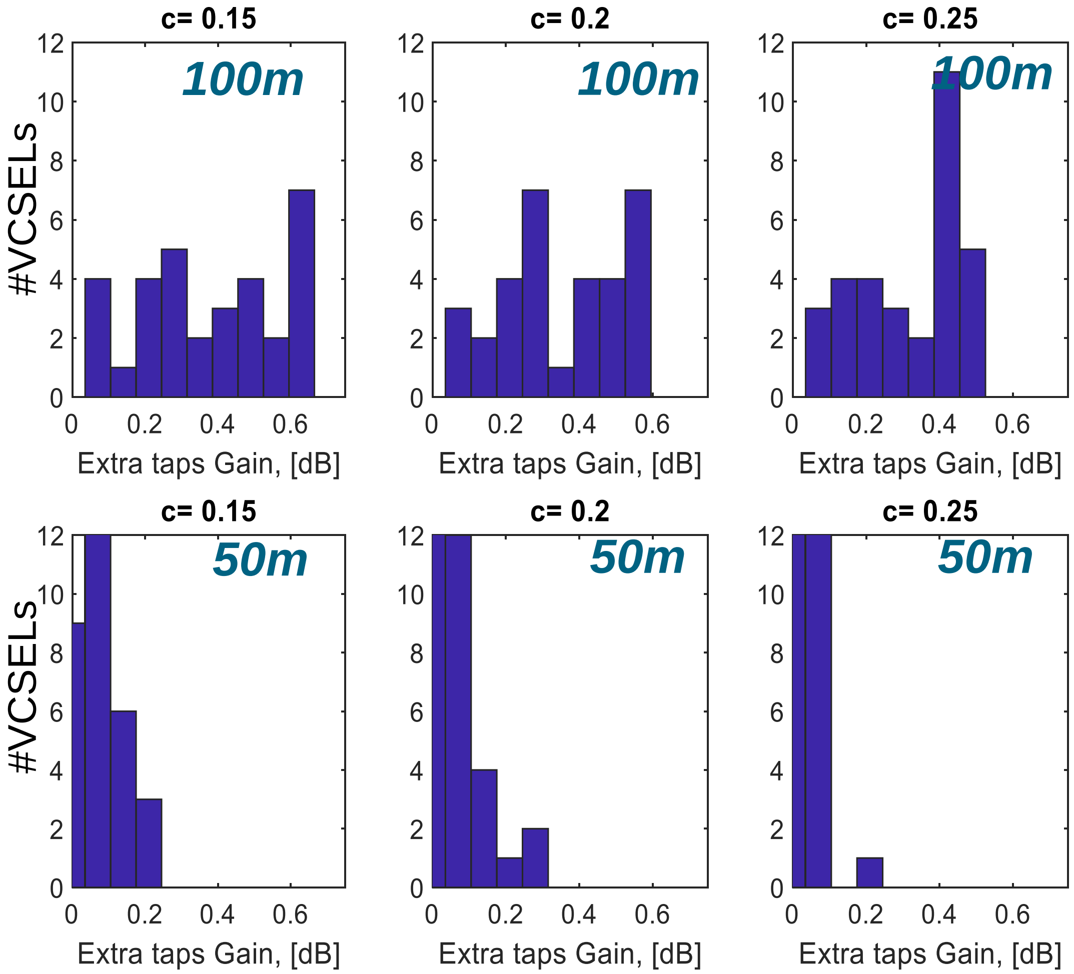
- VCSEL yield can be improved for 50m VR PMD.
  - Smaller bandwidths , e.g., 19 GHz might suffice
  - On the other hand, VCSEL TDECQ can be tightened to reduce receiver complexity

[*] ingham_3db_adhoc_01a_062520.pdf , bhatt_100GSR_adhoc_01a_050720

Backup

K improvements vs number of taps and c

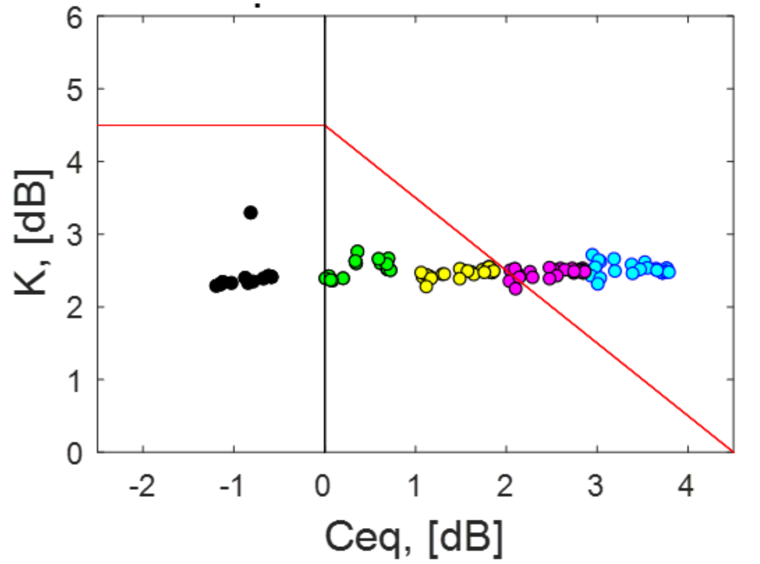
- For 100m, using 9 taps instead of 7 taps reduces TDECQ up to 0.8 dBs
- For 50m, using 9 taps instead of 7 taps reduced TDECQ up to 0.4 dB
- For 50 m 9 taps allow to tight the limits of TDECQ to 3.5 dB (using c=0.25).



Transmitter Equalization vs Overshoot

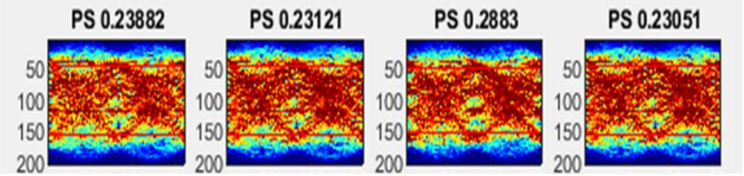
- Equalization using c>0.25 can help to reduce TDECQ.
- However, c>0.3 increase K for some VCSEL used in the short channel and also increases the overshoot.

Taps 9, 100m (TDECQ filter=15 GHz)

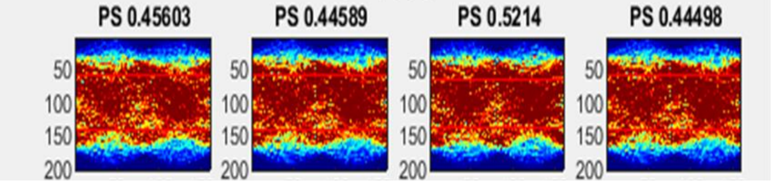


100m

C=0.3

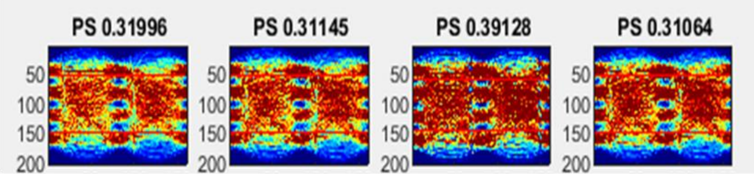


C=0.35

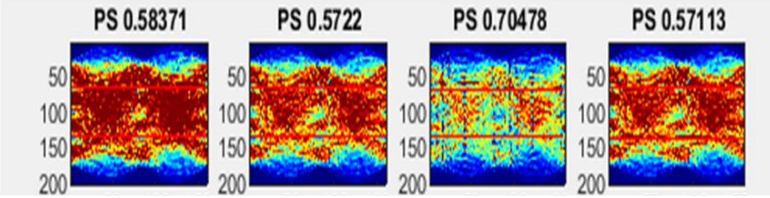


50m

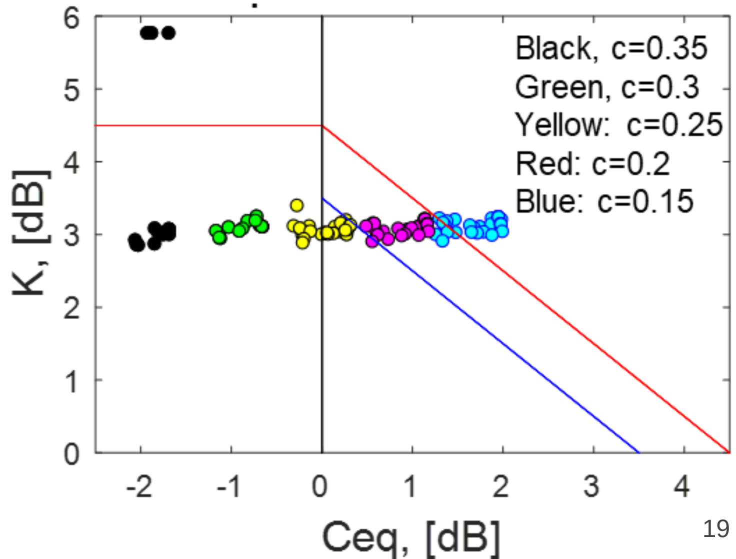
C=0.3



C=0.35

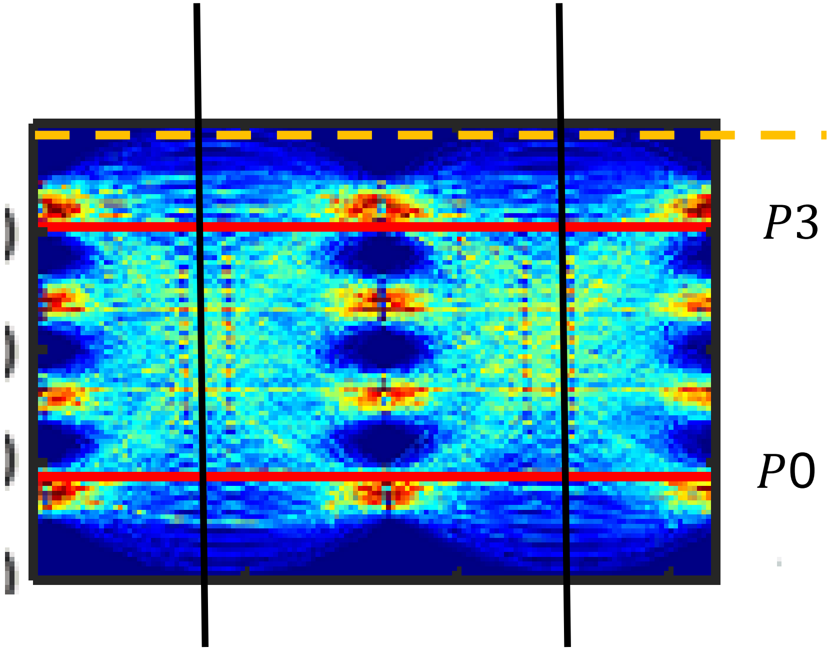


Taps 9, 50m (TDECQ filter=21 GHz)



Overshoot Method

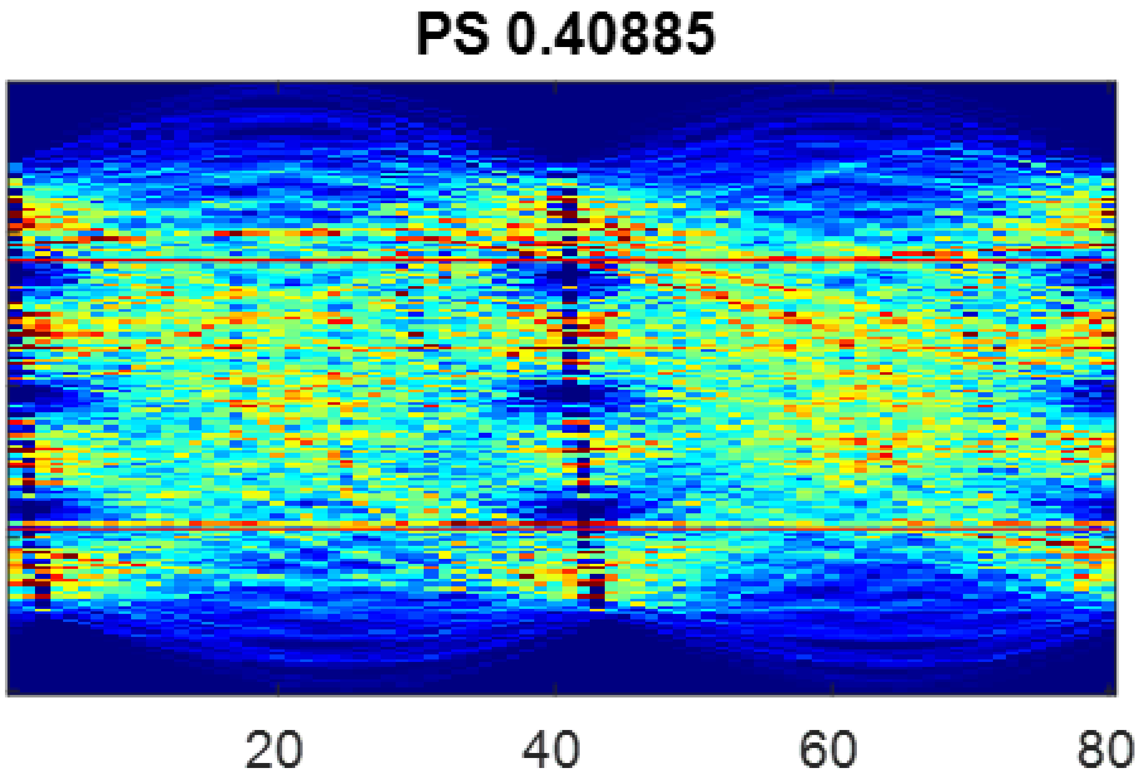
- Method described in zivny_3cu_01_032420 and its impact for SMF channels developed in 802.3 cu were evaluated in rodes_3cu_01_0320



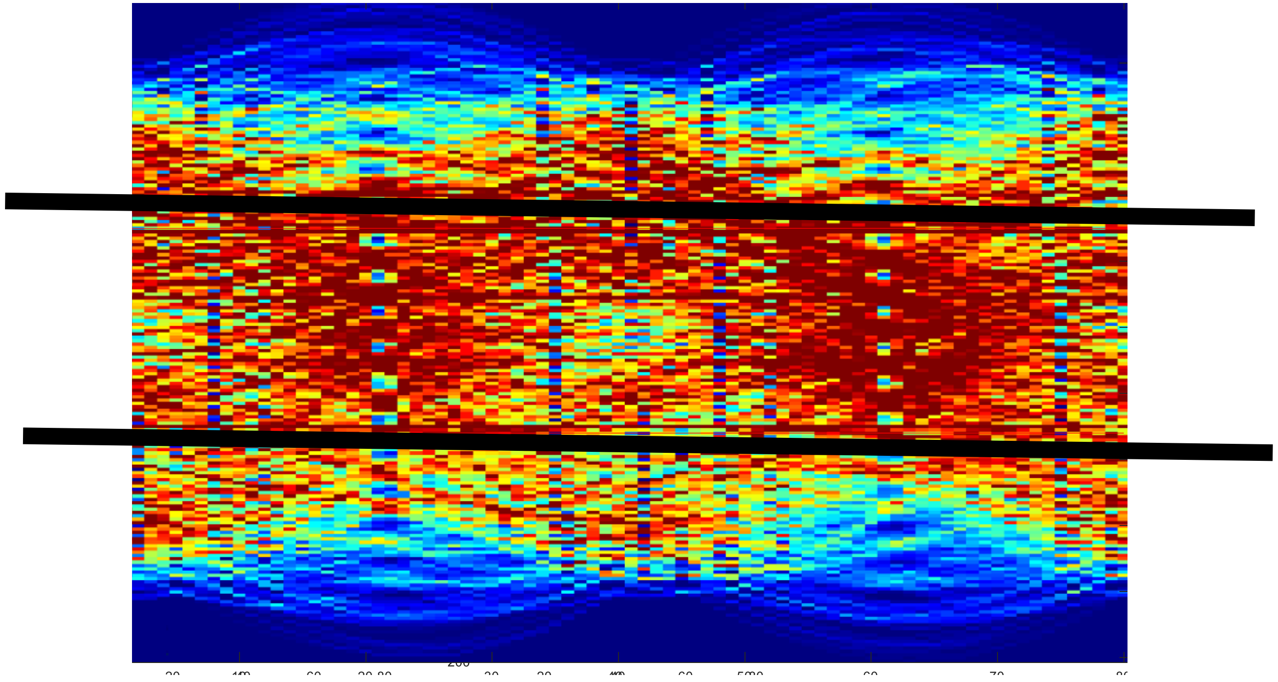
$$Overshoot = \frac{Pmax - P3}{P3 - P0} = \frac{Pmax - P3}{OMAouter}$$

Pmax computed for 1%, which means that 99% of the samples in a 1U have lower values than Pmax

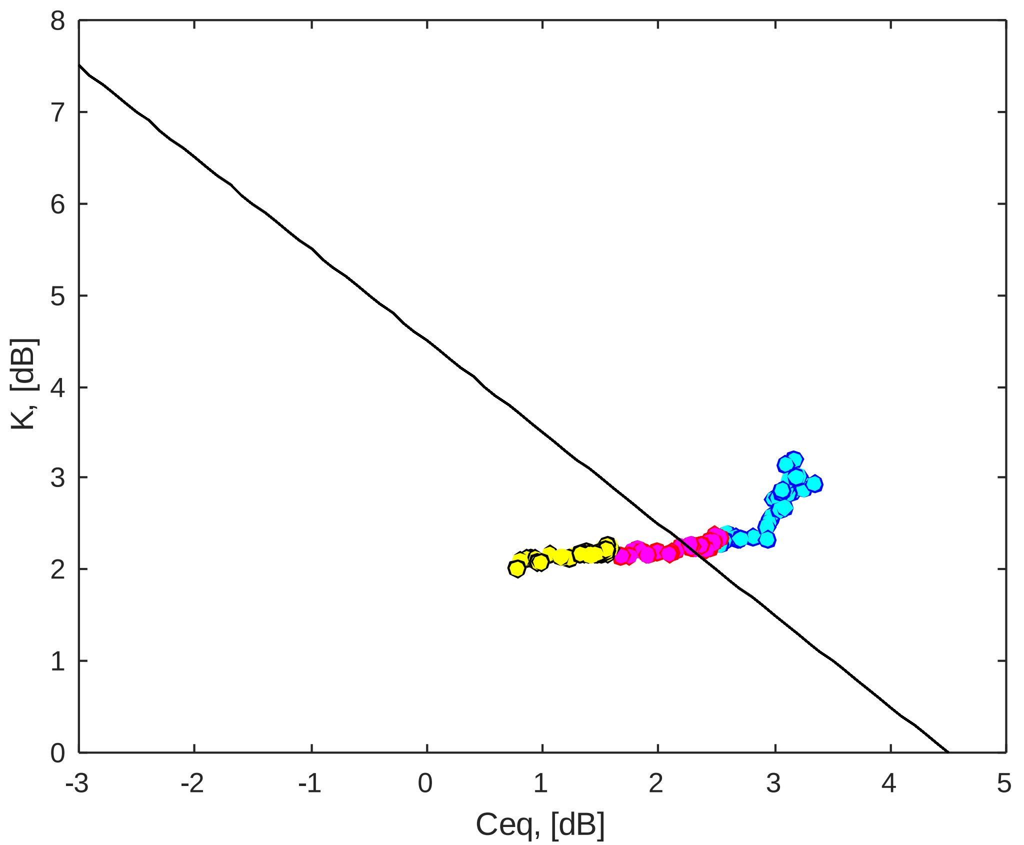
Overshoot examples



C=0.3 Ps 70%



C=0.35 Ps 70%



Running more simulation better resolution. Work to be shown in future contributions.