Evaluation of fixed vs adaptive pre-emphasis for 100G per lambda optical link

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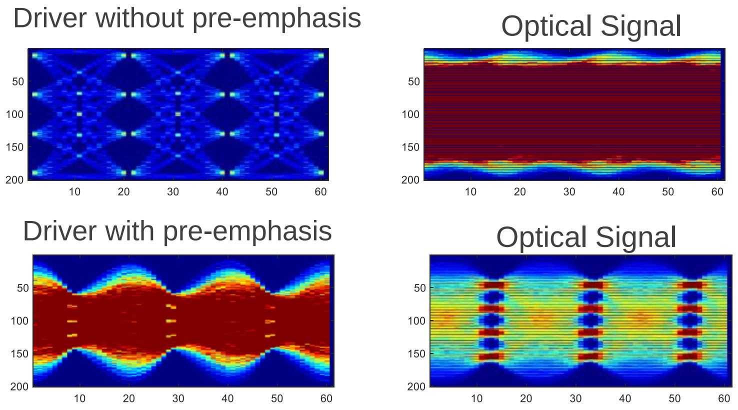
Background

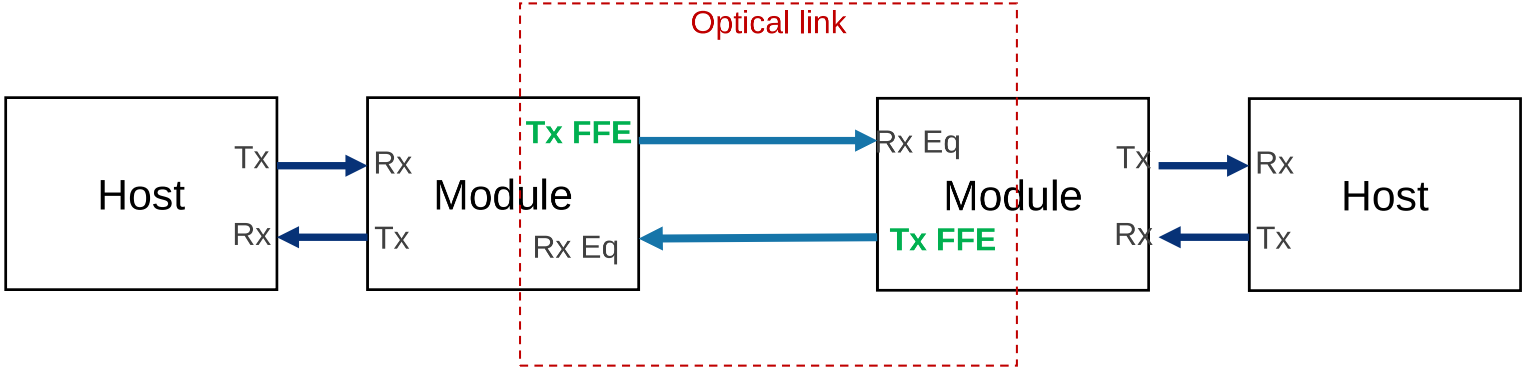
- The reaches of MMF channels have been reducing as data rate increases.
  - New methods are needed to serve markets required higher speed over 100m MMF channels.
    - Better equalization, more powerful low-latency FECs,…
- Recent presentations [1-3] evaluated options to achieve reaches ≥75 based on link model simulations and experiments.
  - Link parameters such as transmitter equalization with at least 3 taps, receiver equalization using at least 9 taps, RIN<-133 dB/Hz, Spectral Width < 0.6 nm, among others are needed.
- Models indicate that optimization of the transmitter equalizer could be impactful
  - Optimization requires to adapt to channel variations and implies some degree of training which is not supported in current MMF PMDs.
  - Options for transmitter trainer being considered in T11.2 Fibre Channel PI-8 [4].
    - However, potential advantages not quantified yet.
- This contribution evaluates potential advantages of using adaptive Tx equalization relative to fixed Tx equalization schemes

Pre-emphasis in MMF channels

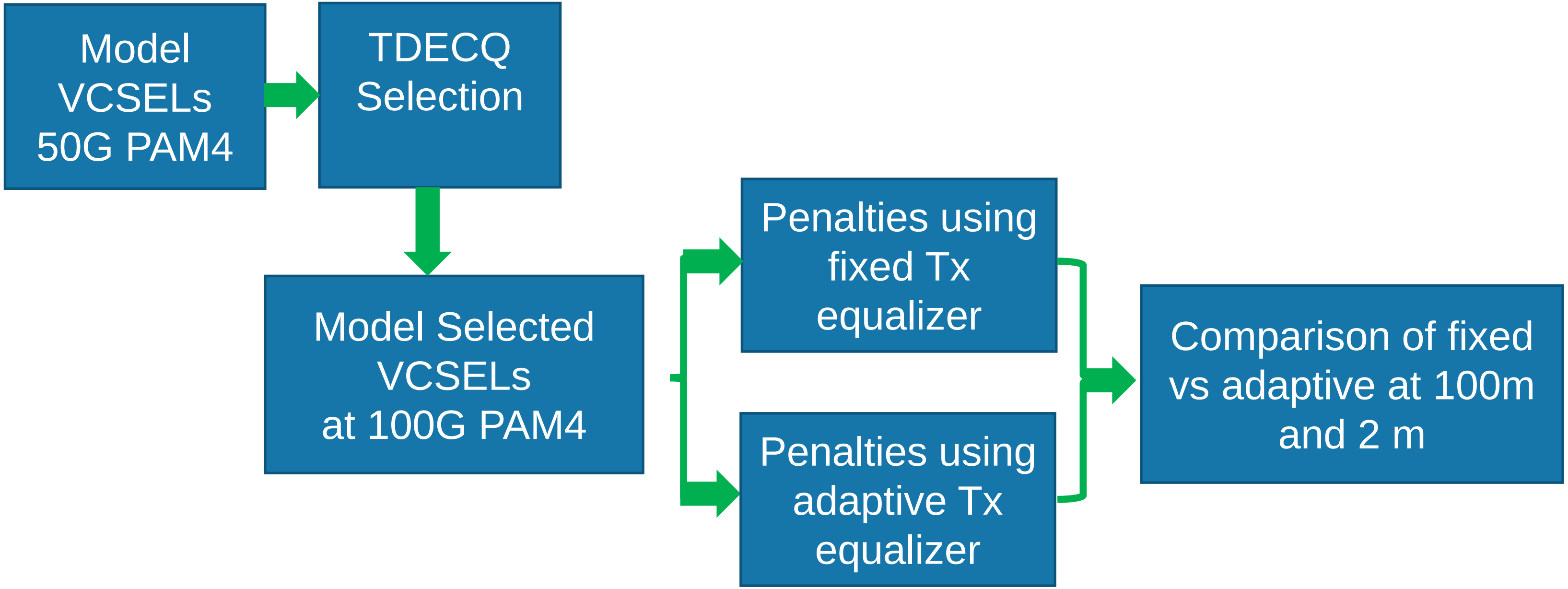
- This presentation focuses in the Tx equalization of the optical link.
  - A Tx equalizer of 3 taps is used here
    - $(c_{-1},1,c_1)$



100G experiments from [5]



Evaluation Methodology

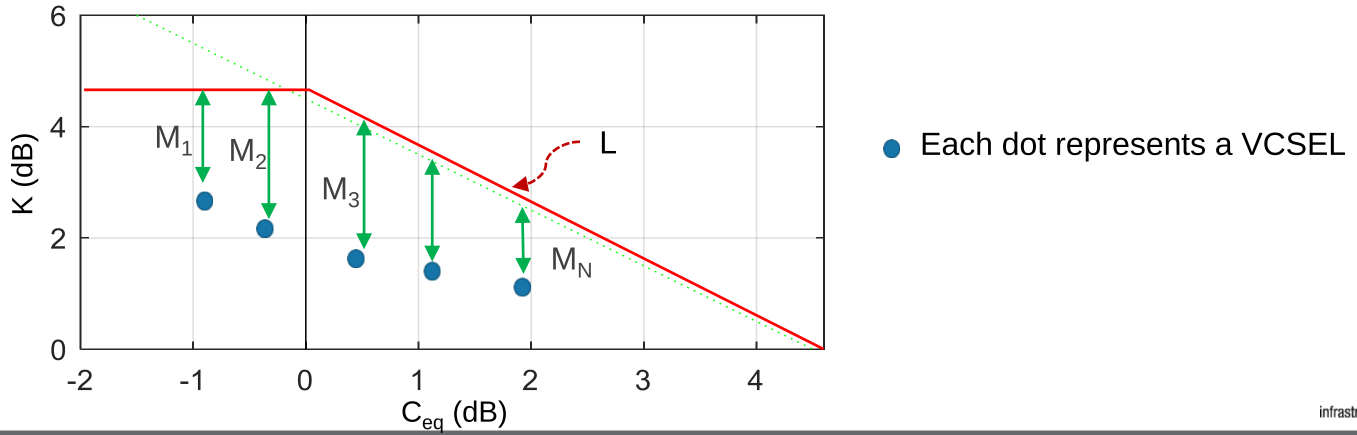


Methodology to Select VCSEL Population

- A set of VCSELs were simulated using laser rate equations at two symbol rates
  - Initially, 1200 VCSELs of 26.5625 GBaud (50Gbps PAM-4 802.3 cm)
    - Random variation in VCSEL parameters such as bias, carrier and photon lifetime, cavity reflectance, among others (see backup slide for more information)
    - RIN not included in initial estimation
  - Selected subset 440 VCSELs that “passed” TDECQ
- The selected subset was modeled at 53.125 GBaud (for 100G PAM4 802.3 db).
  - Different transmitter equalization scheme applied
    - Additional 10 VCSELs outliers (non passing and non-equalizable) eliminated. Population =425 VCSEL
  - Fixed*: { (-0.1 1 -0.1) ,(-0.3 1 -0.3) , (-0.4 1 -0.4) }*
  - Adaptive $(c_{-1}\ 1\ \ c_1)$, adaptive, where the absolute values of c_i are capped at values ranged from 0.3 to 0.4. Results shown in this presentation, are capped at 0.4.
- The difference in dispersion penalties between fixed and adaptive approach were compared

Methodology to Quantify Differences

- A modified TDECQ metric used
  - TDECQ is defined for 5 Taps and bandwidth based on 100m channel bandwidth,
  - Here relaxed requirements to allow for 9 taps and channel bandwidths or arbitrary length (e.g., 2m and 100m OM4)
- TDECQ is separated in main components to facilitate comparison
  - TDECQ (dB) = K (dB) + C_{eq} (dB) as used in [6].
  - where K represents non-equalizable impairments (noise, distortion, eye tilt,…) and C_{eq} the noise enhancement.
- Margins of K relative to a penalty limit, L, were computed as follows
  - The limit, L is equal to min(4.5 dB - C_{eq} (dB) ,4.5dB)
  - The margin, M, is equal to L-K



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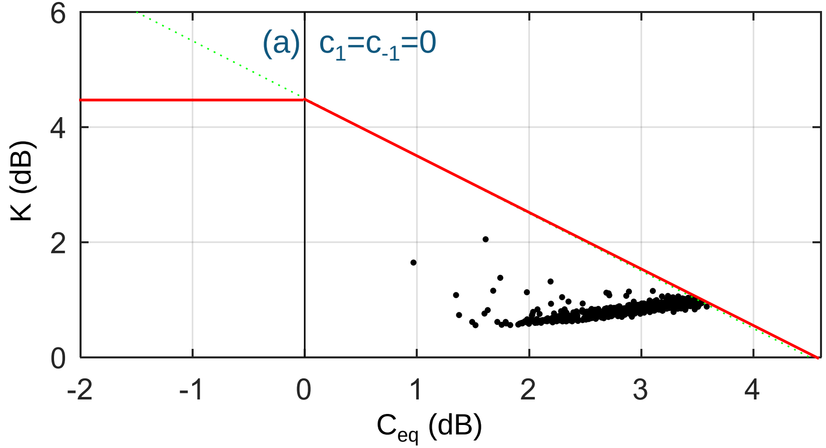
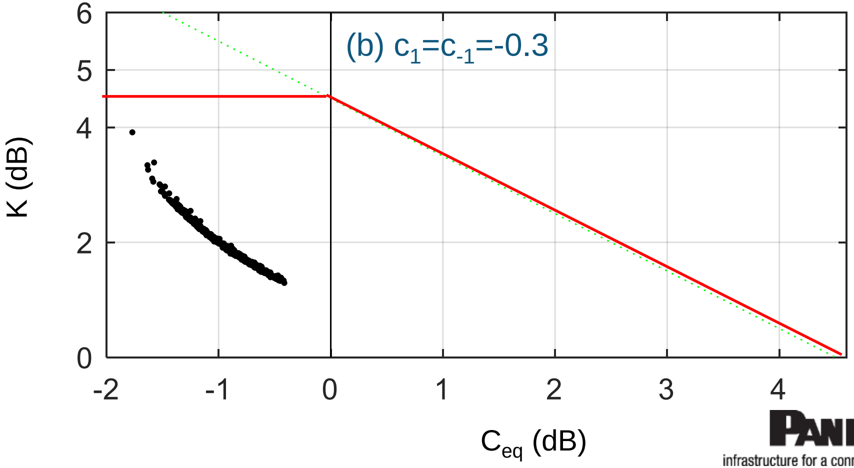
VCSEL Population

- Selected VCSEL's in TDECQ plane
  - Symbol Rate 26.5625 Gbaud
  - Receiver BW=13.2813 GHz
  - Channel BW =11.2 GHz
  - RIN not included

Without Tx pre-emphasis

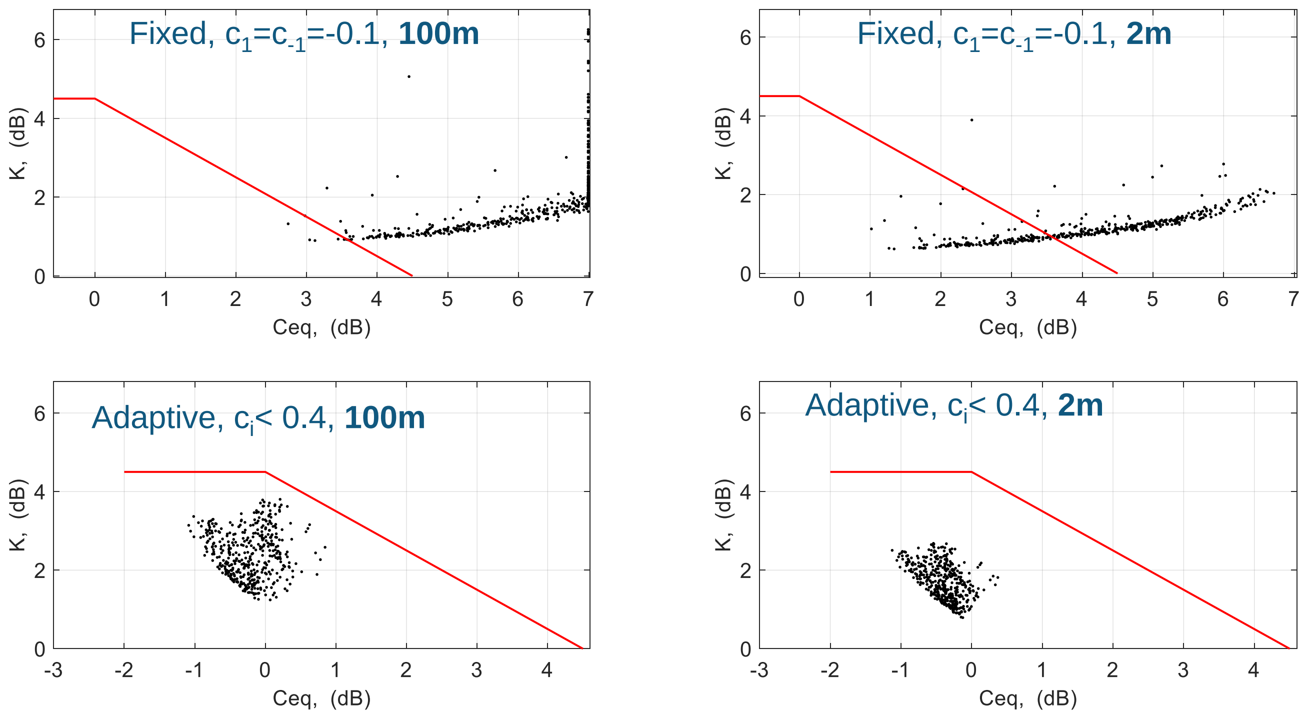


With Tx pre-emphasis

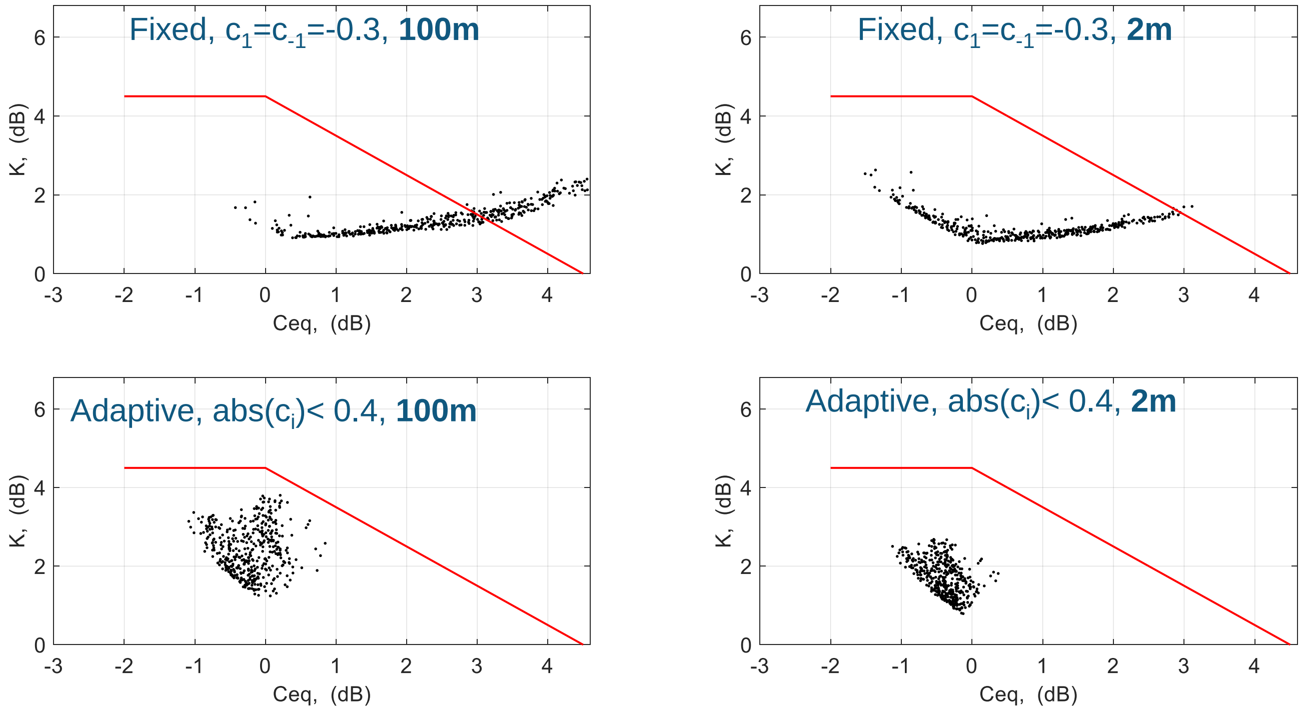


Results

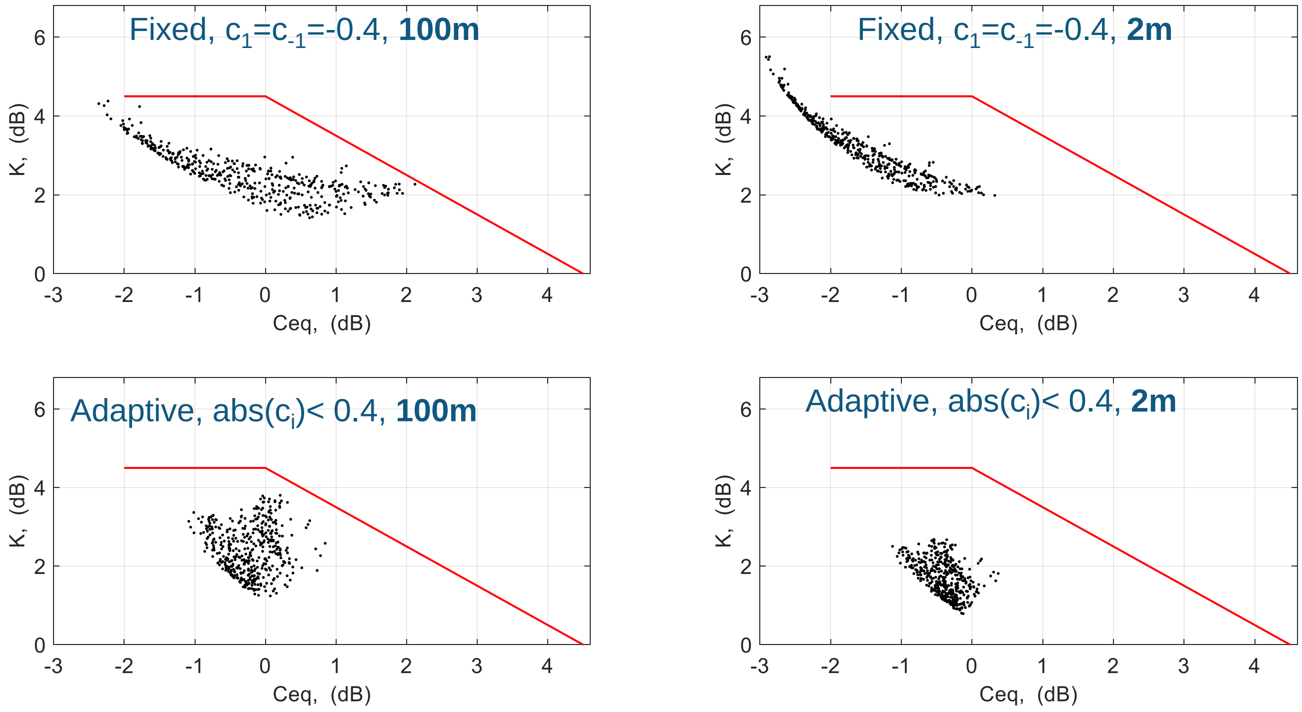
Fixed vs Adaptive at 100G: Results for low Tx Eq.



Fixed vs Adaptive at 100G: Results

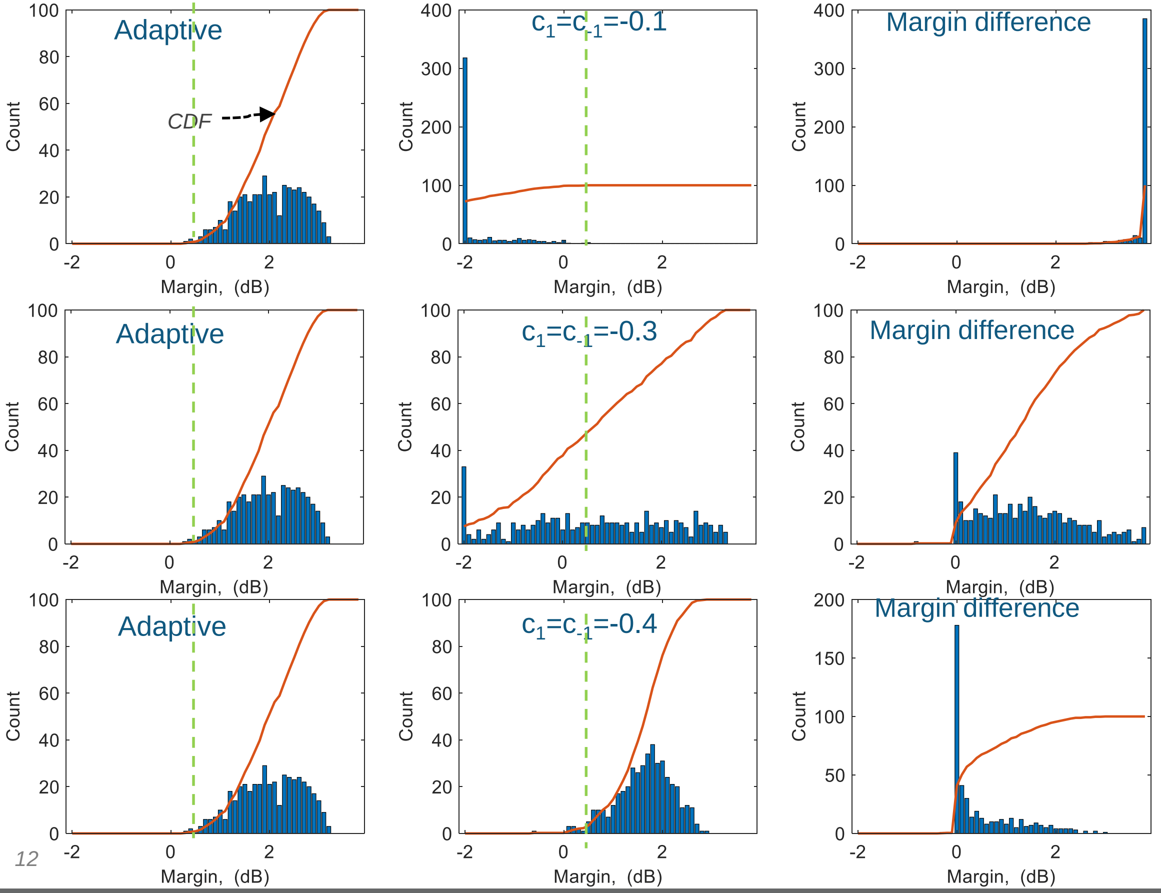


Fixed vs Adaptive at 100G: Results for high Tx Eq.



Margin Comparison 100G at 100 m, adaptive vs fixed

Tx equalizer (c_{-1}1,c_1), c_i are capped at 0.4 for adaptive



- Results for 100m show the advantages of adaptive over fixed equalization schemes.
  - For c_1=c_{-1}=-0.1, the advantage is near 4 dB for almost 100% of the VCSELs
  - For c_1=c_{-1}=-0.3, the advantage is near >1 dB for ≈65% or the VCSELs
  - For c_1=c_{-1}=-0.4, which correspond the adaptive equalizer cap, the advantages > 1 dB for 28% of the VCSELs and 0.5 dB for 33%
- As expected, the advantages reduce when the tap cap is equal to the fixed value but still important
  - >0.5 dB can help to allocate for RIN or other penalties.
  - The advantages are higher when considering channel length variation as shown in the next slide

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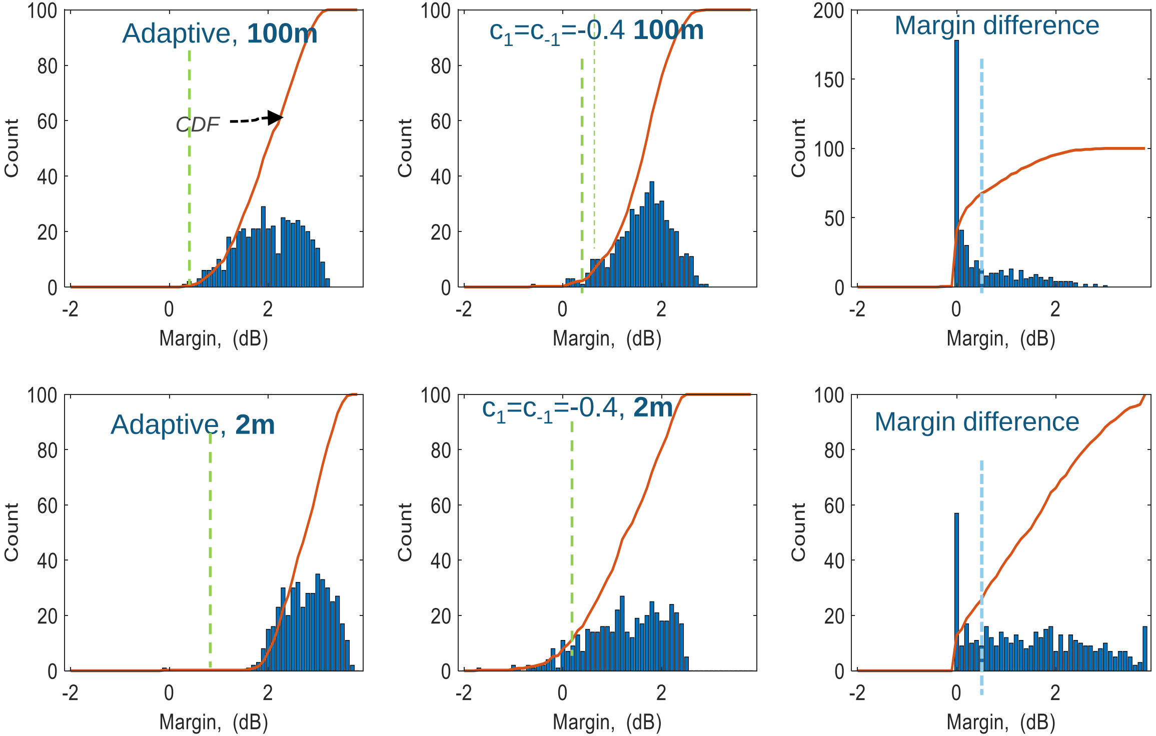
Margin Comparison 100G 100m and 2 m

Tx equalizer (c_{-1}1,c_1), c_i are capped at 0.4 for adaptive



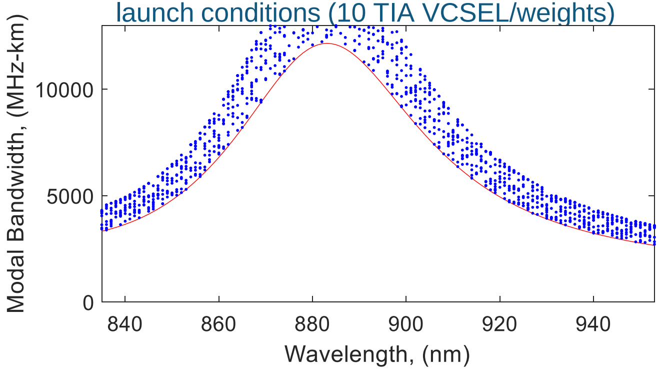
- When the channel length variation is included, a fixed pre-emphasis shows more disadvantages.
  - For example, the fixed equalizer using c_1=c_{-1}=0.4 over equalizes the channel for 2 m, producing failures for 10% of the VCSELs
  - This degradation is caused by overshoot and peaking of the driver which reduces the OMA signal.

- Taking into consideration the length variation, our overall evaluation using passing VCSELs, indicates that at least 40% of the cases see and improvement > 0.5dB ,
  - This improvement can impact on yields
  - From [2] that 0.5 dB can increase reaches in ~15 m, which can be significant for the switch-switch links

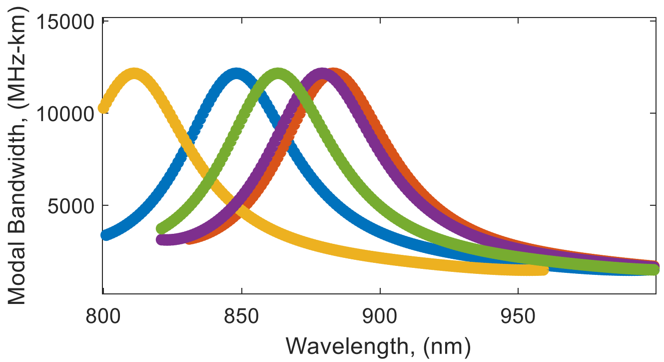
Why adaptive equalization?

- A lot of variability in MMF channels:
  - VCSELs properties and channel length as shown in previous slides
  - Impact of EMB on launch and wavelength of the VCSEL.
    - VCSELs most likely to see higher bandwidth that reported EMB which can exacerbate TX pre-emphasis
  - DMD tilt, left of right might need different weight is the Tx equalizer
- Modeling result shows adaptive equalization can produce higher margins ≥0.5 dB for ~40% of the VCSEL modeled.

EMB (red trace) is the worst value of 10 launch conditions (10 TIA VCSEL/weights)



EMB dependence on wavelength



Summary & Conclusions

- Compared adaptive vs. fixed Tx equalization for MMF optical link using VCSEL modeling and TDECQ based metric
- Results show margin and yield advantages
  - Adaptive Tx equalization can support more pre-emphasis without over equalizing shorter links and also more resilient to bandwidth variations due to launch condition & wavelength
  - Advantages of >0.5dB shown in results can increase reaches in >15 m for slower lasers,
- Proposed further investigation on performance advantages (reach and margins), yield and implementation cost
  - Additional margins can help in serving the switch-switch market better.
  - The estimation of yield improvement, if validated, can offset implementation cost
  - As proposed in a previous meeting, a collaboration with Fibre Channel T11.2 FC-PI8 could benefit both standards to achieve longer reaches or higher data rates.

Questions

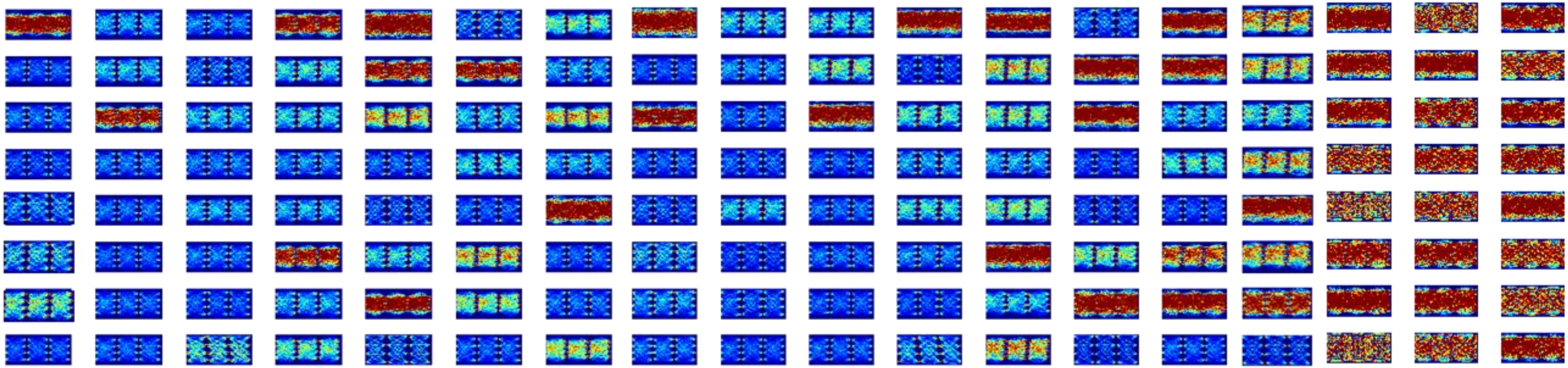
References

- [1] bhatt_100GSR_adhoc_01_050720
- [2] castro_100GSR_adhoc_01a_050720,
- [3] ingham_3db_adhoc_01a_062520
- [4] T11-2019-00225-v003 (Anil Mehta)
- [5] castro_100GSR_01a_0120
- [6] dawe_3cd_01b_0718

Backup

VCSEL simulation

- Initial population of 1200 VCSEL modeled using laser rate equations
  - Modeled VCSELs with up to 4 modes
  - Changed randomly parameters such as: bias Current, modulation current, cavity aperture, recombination factor, carrier lifetime, photon lifetime, saturation coefficient
- Selected subset that pass TDECQ (26.56GBaud PAM4).
- Modeled Penalties the selected subset at 100G (53.125GBaud PAM4)



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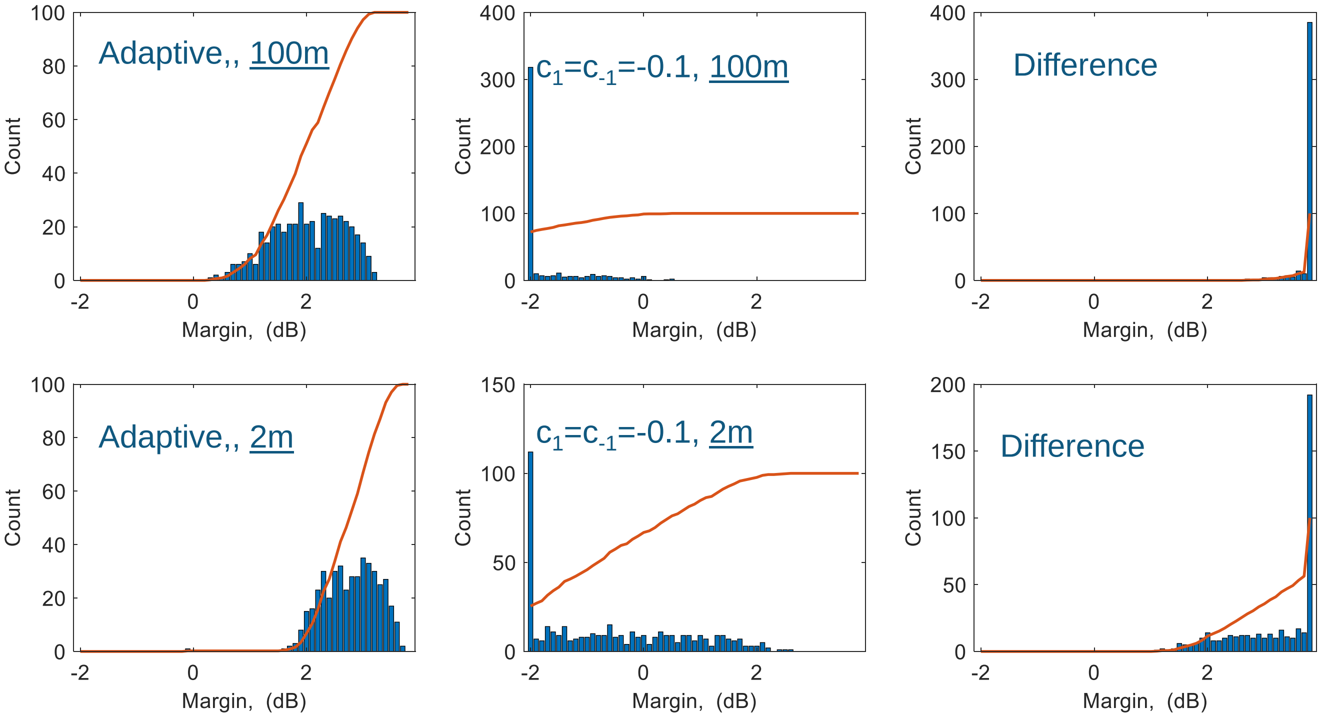
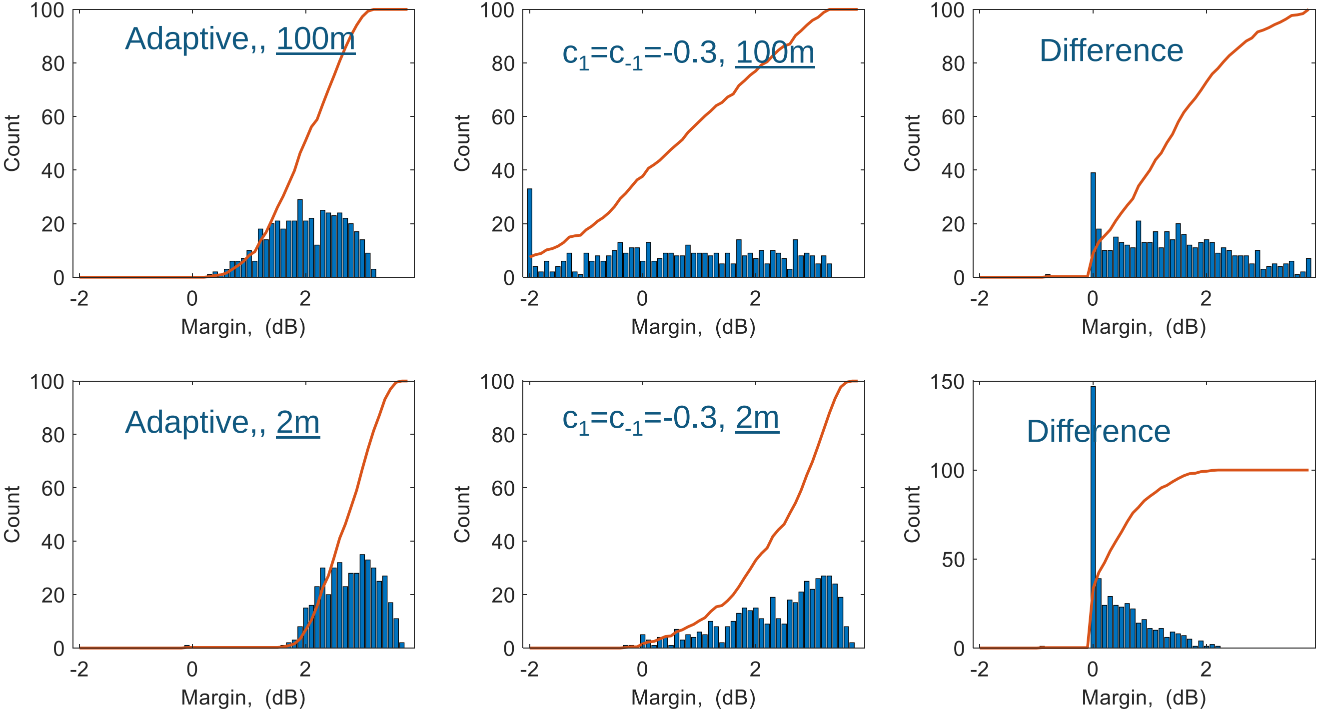
Margin Comparison

Fixed, $c_1=c_{-1}=-0.1$, vs Adaptive capped 0.4



Margin Comparison

Fixed, $c_1=c_{-1}=-0.3$, vs Adaptive capped 0.4



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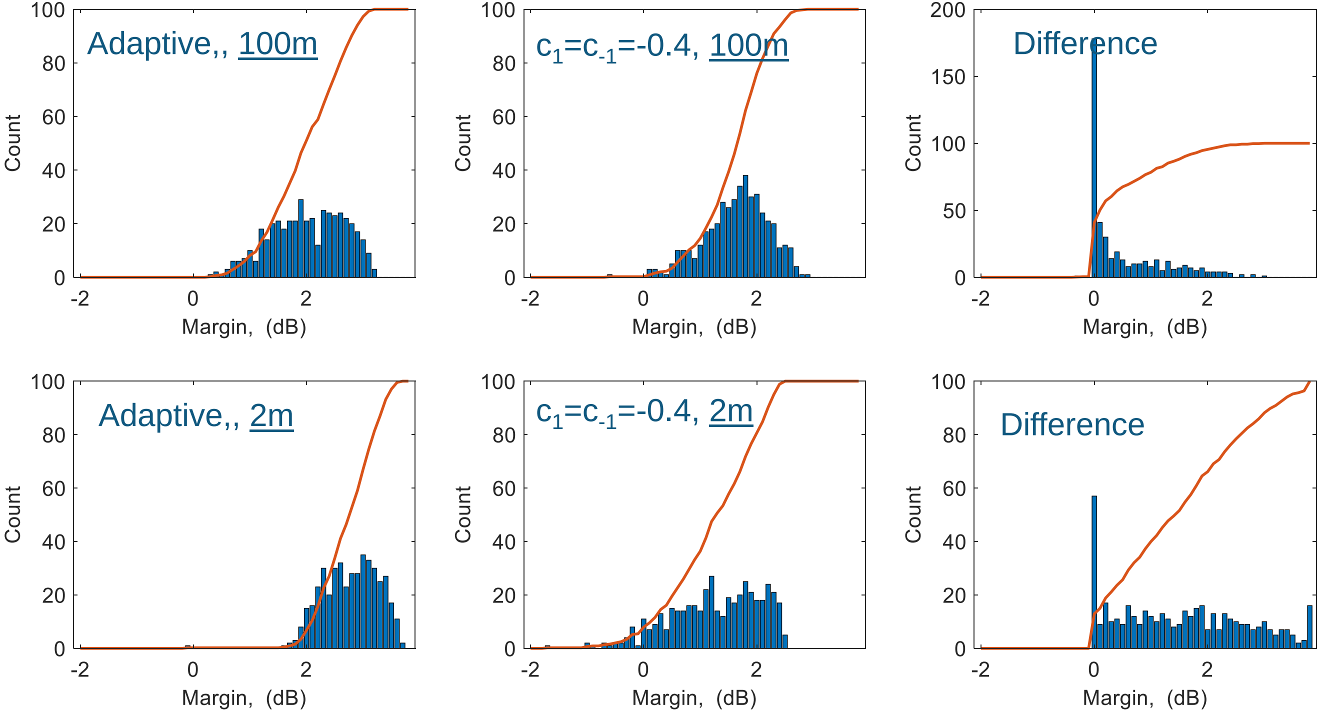
Margin Comparison

Fixed, $c_1=c_{-1}=-0.4$, vs Adaptive capped 0.4



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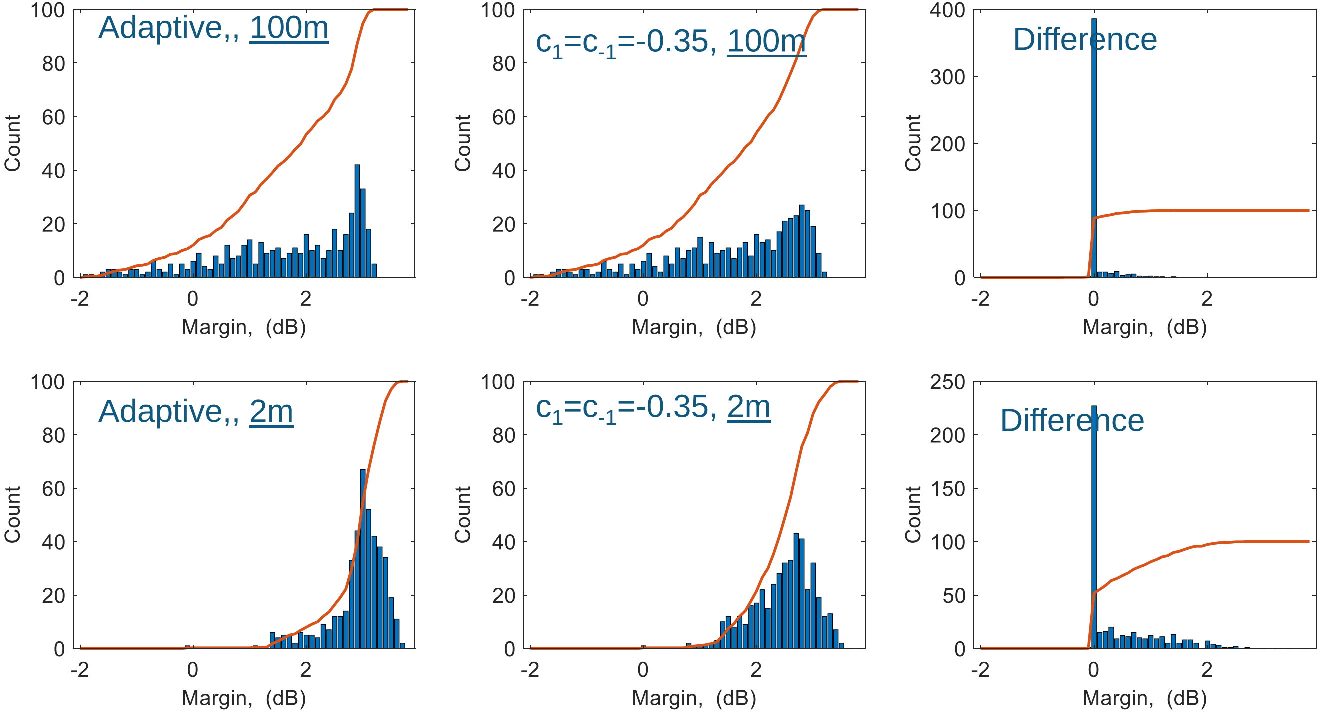
Margin Comparison

Fixed, $c_1 = c_{-1} = -0.35$, vs Adaptive capped 0.35



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Training time

Link Bring Up Times – 1

- 32GFC
  - LSN – 0.5 seconds
  - Optical Module Bring Up – 0 seconds
  - Link Training 1.5 seconds
  - Total – 2 seconds

- 64GFC
  - LSN – 0.5 second
  - Optical Module Bring Up – ? (2 Seconds Estimate)
  - Link Training – 3 seconds
  - Total = 5.5 seconds

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