KEYSIGHT

Physical measurements for TDECQ versus SER

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- Bell Huang and Brain Tian affiliated with Tac-GenRay

Background: TDECQ range compresses at high SER

- Transmitters that had a wide range of TDECQ (1.3 to > 6dB) measured at the common SER of 4.8e-4 (802.3bs, cd, cu, db) have a much narrower range of TDECQ as the target SER is increased
- 0.5 to 2.5 dB
- Typical spec limit for TDECQ is 3.5 dB (how much of the link budget is allocated to transmitter eye closure and dispersion)

Background: TDECQ range compresses at high SER

Leyba and Le Cheminant: TDECQ versus high SER Limits:

https://grouper.ieee.org/groups/802/3/dj/public/adhoc/optics/0623_OPTX/leyba_3dj_optx_01a_230629.pdf

As SER increases, TDECQ range compresses. Does this represent behavior in real systems? Would two transmitters that have different TDECQ at low SER, but similar TDECQ at high SER yield similar receiver sensitivities observed at the high SER?

Liu and Fan: Study on the dependence of TDECQ on SER

https://grouper.ieee.org/groups/802/3/dj/public/adhoc/optics/0823_OPTX/liu_3dj_optx_01a_230829.pdf

Answers ‘yes’ to the above questions. Shows “that the dependence of TDECQ on symbol error rate (SER) is different for different optical transmitter types, and a “worse” transmitter at low SER can become a “better” transmitter at high SER. Some physical explanations are also provided. Overall, TDECQ is expected to continue to be a viable performance metric for PAM4 at high SER”.

This presentation furthers the work by examining the behavior of physical transmitters and receivers operating at high SER values to document correlation between TDECQ and receiver sensitivity

Collect PAM4 transmitters with a wide range of TDECQ performance

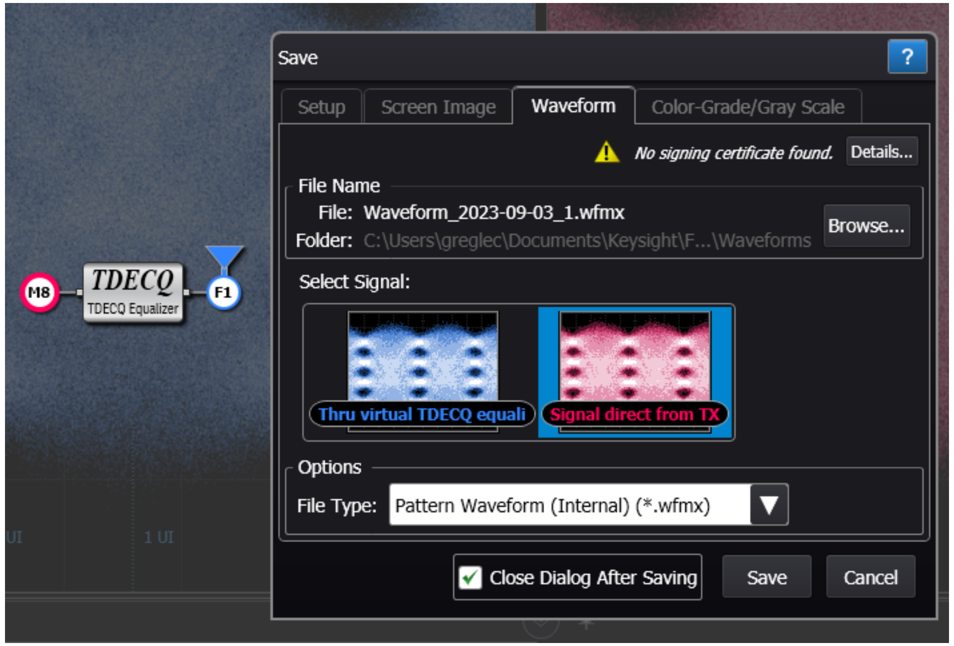
- Assume the TDECQ compression phenomenon is independent of the data rate, so we consider transmitters operating at any rate, but 53 Gbaud and 100+ Gbaud transmitters are preferred. Single-mode preferred, but multimode are also considered
- To demonstrate clear results, it is useful to have a wide range of transmitters in terms of TDECQ values (when measured at the common SER limit of 4.8e-4 using the 802.3cd reference receiver preset)
- Example: 1.5 dB, 2.5 dB, 3.5 dB. The TDECQ values do not need to be specific values, (bad transmitters are difficult to find)

Determine receiver sensitivity using the transmitters

- Connect each transmitter to a typical receiver. (We do not know much about what is inside the receivers and what equalization capability exists)
- Transmitter observed through very short, mid or long span fibers all provide useful information.
- The receiver sensitivity plot over a wide range of power into the receiver is useful. However we need a high-resolution analysis for the input power levels that result in SERs in the 5e-4 to 1e-2 range.
- Record the receiver input power for SER at 5e-4, 1e-3, 5e-3 (or whatever range is easily achieved, approaching the lowest power that yields a valid SER result)
- Record the waveform (discussed later)
- Repeat the process for each transmitter

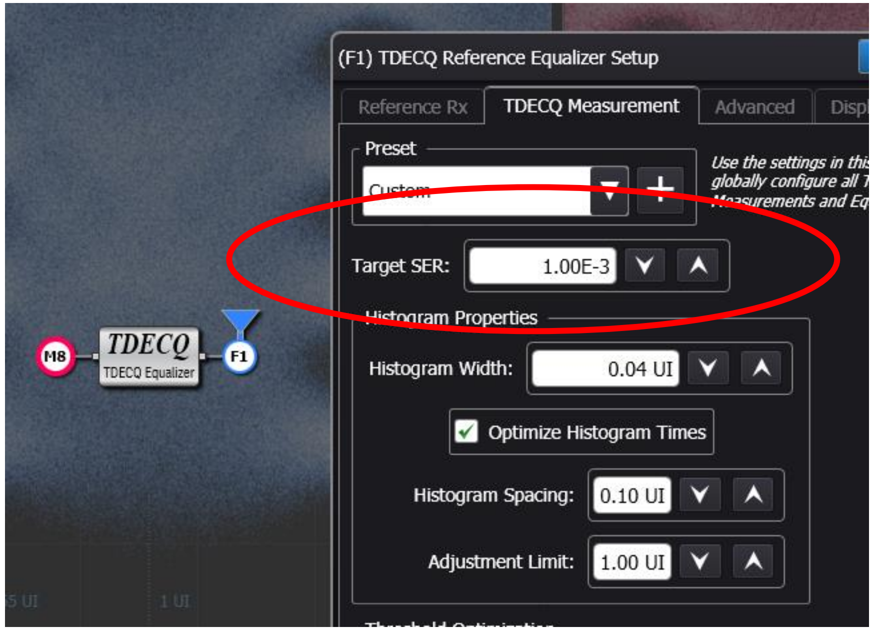
Record the waveforms

- Save the waveform file at the time the receiver sensitivity measurements are made. This allows additional TDECQ analysis with adjustments to the target SER as well as different equalizer lengths without having to measure the transmitter additional times. (Example: File/Save/Waveform and select the .wfmx file type)
- Be sure to select the waveform at the input to the TDECQ reference receiver (such as CH1 or M8) and not the output function of the TDECQ reference receiver (such as F1)



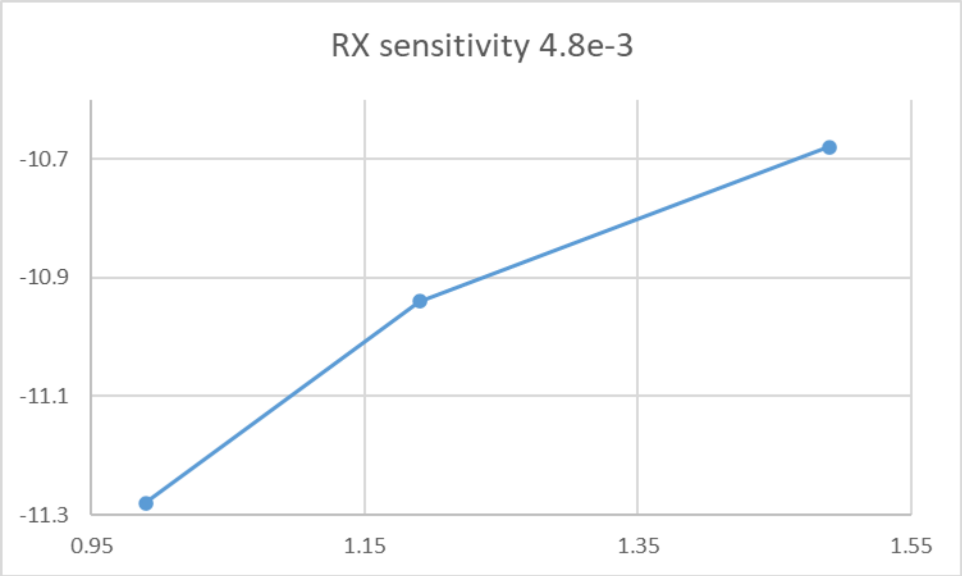
Determining TDECQ at different values of SER

- The TDECQ virtual receiver is easily adjusted to allow different target SER’s
  - If we determine receiver sensitivity at 5e-4, 1e-4, 5e-3 we need to determine TDECQ at the same 3 values
  - Adjust the SER to observe the TDECQ value at each setting
    - All TDECQ values can be determined from one waveform (stop acquisition to get stable results)
    - There is no need to re-acquire the waveform to generate new TDECQ values. This can also be done on a saved waveform (loaded back into the test instrument)
    - Record the virtual equalizer settings used (e.g. 5 taps etc.)



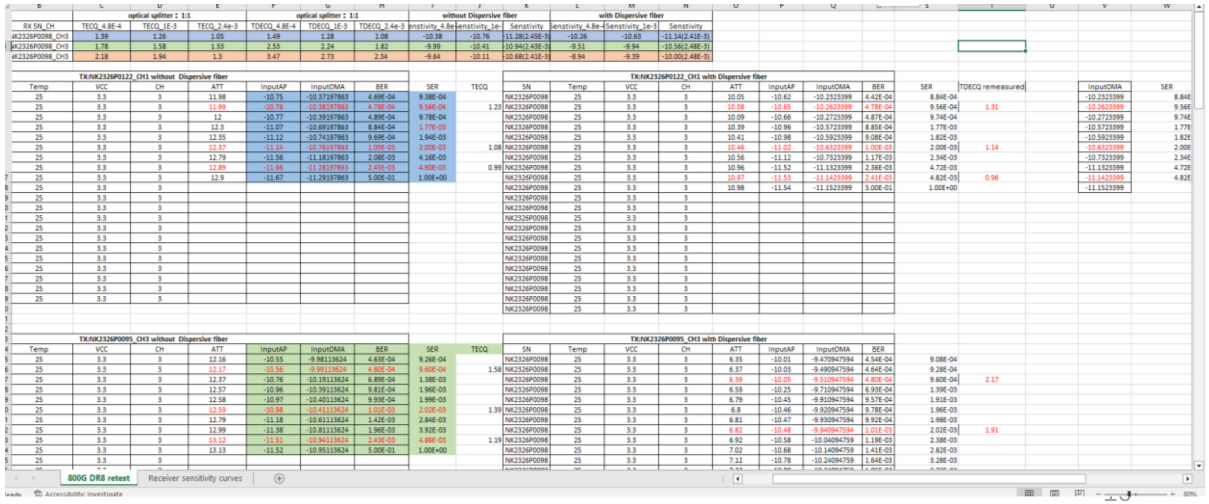
Correlating TDECQ and receiver sensitivity

- For each transmitter, we will have receiver sensitivity values at several SER limits
- For each transmitter we will have TDECQ values at the same SER limits
- We then plot receiver sensitivity versus TDECQ for each transmitter. There will be one plot for each SER limit
  - Example if there are three transmitters, we have one plot of Receiver sensitivity versus the three TDECQ values for the SER limit at 5e-4, one plot for SER limit of 1e-3, one plot for SER limit 5e-3



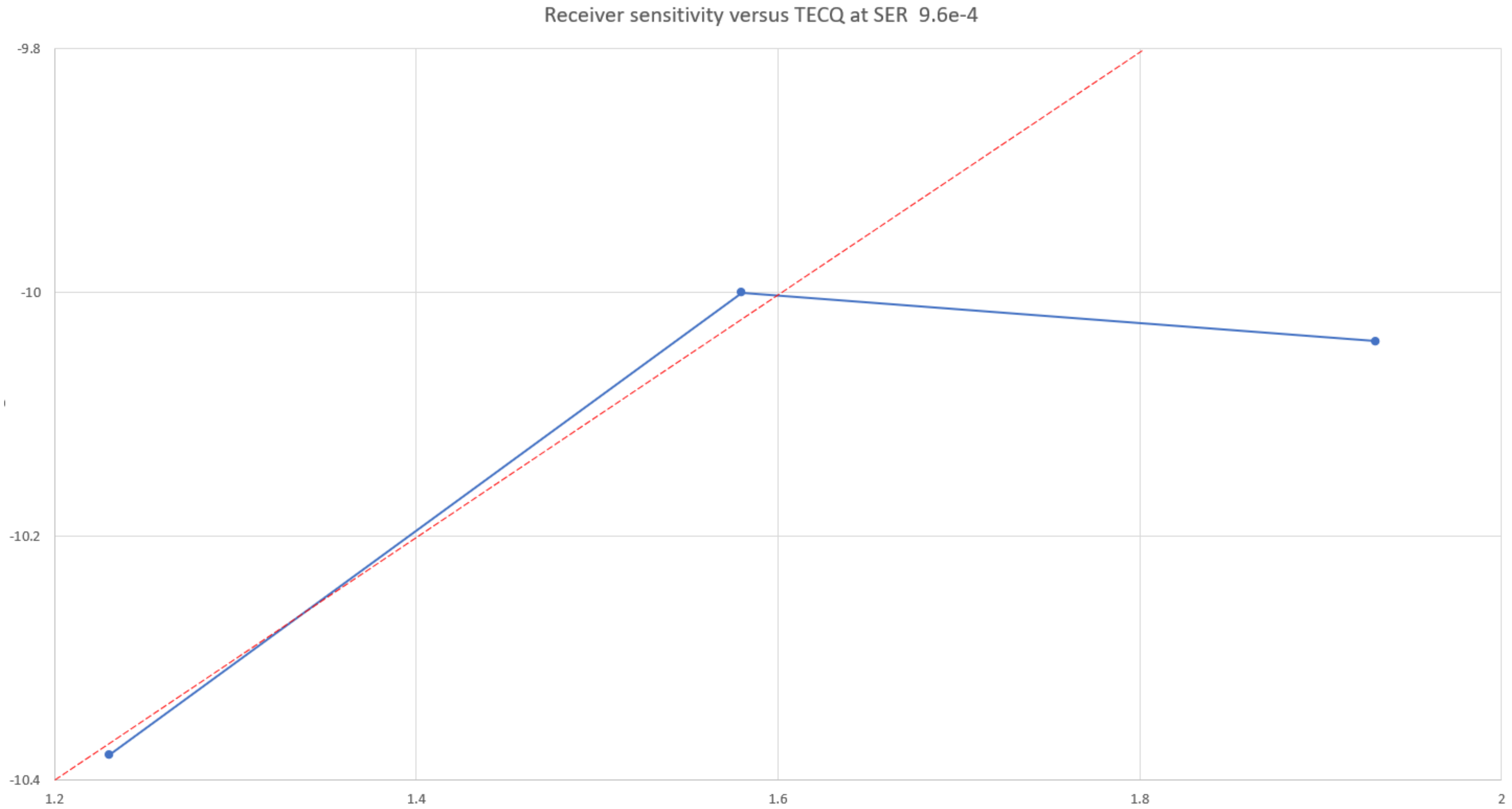
Individuals affiliated with three transceiver companies volunteered to contribute experimental results

- Three 100G EMLs, back to back, and through 2km and 10 km fiber
- Three 100G FR4 transmitters (fiber span not reported)
- Three 100G FR4 transmitters (10km span)
- Three 100G SR8 transmitters (back to back)
- All TDECQ measurements made with the common 5-tap FFE reference equalizer except where noted

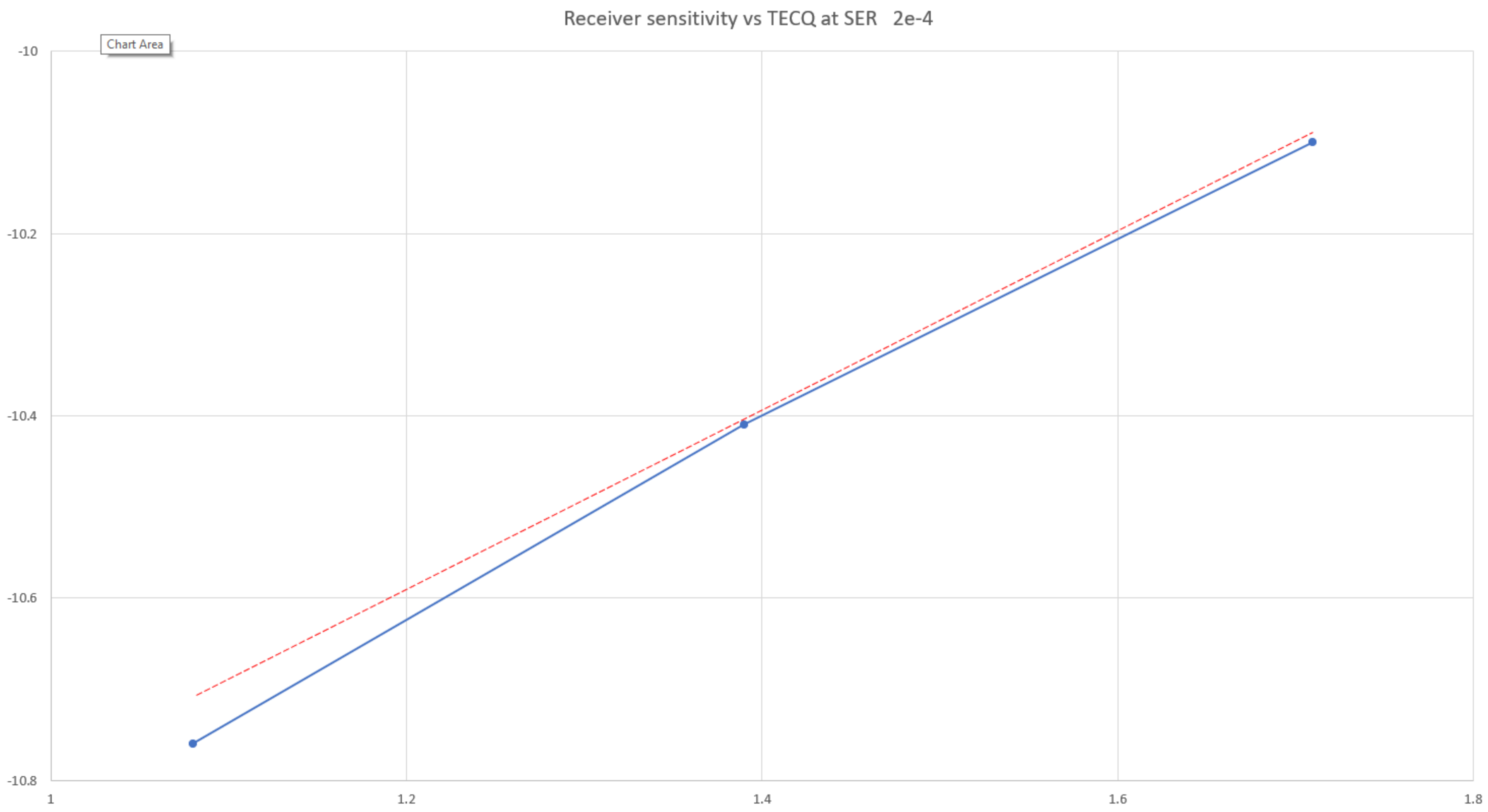


Experiment 1: Three 100G EML's (53 Gbaud) direct connection to the receiver (TECQ)

- Receiver sensitivity (dBm) versus TECQ (dB)
- SER at 9.6 e-4
- Red line indicates ideal 1 dB : 1dB correlation
- At "original" SER of 4.8e-4 TECQ values 1.4, 1.8, 2.2 dB reduced to plotted values of 1.2, 1.5, 1.9 at SER 9.8e-4
- TECQ based on 802.3cd 5-tap FFE

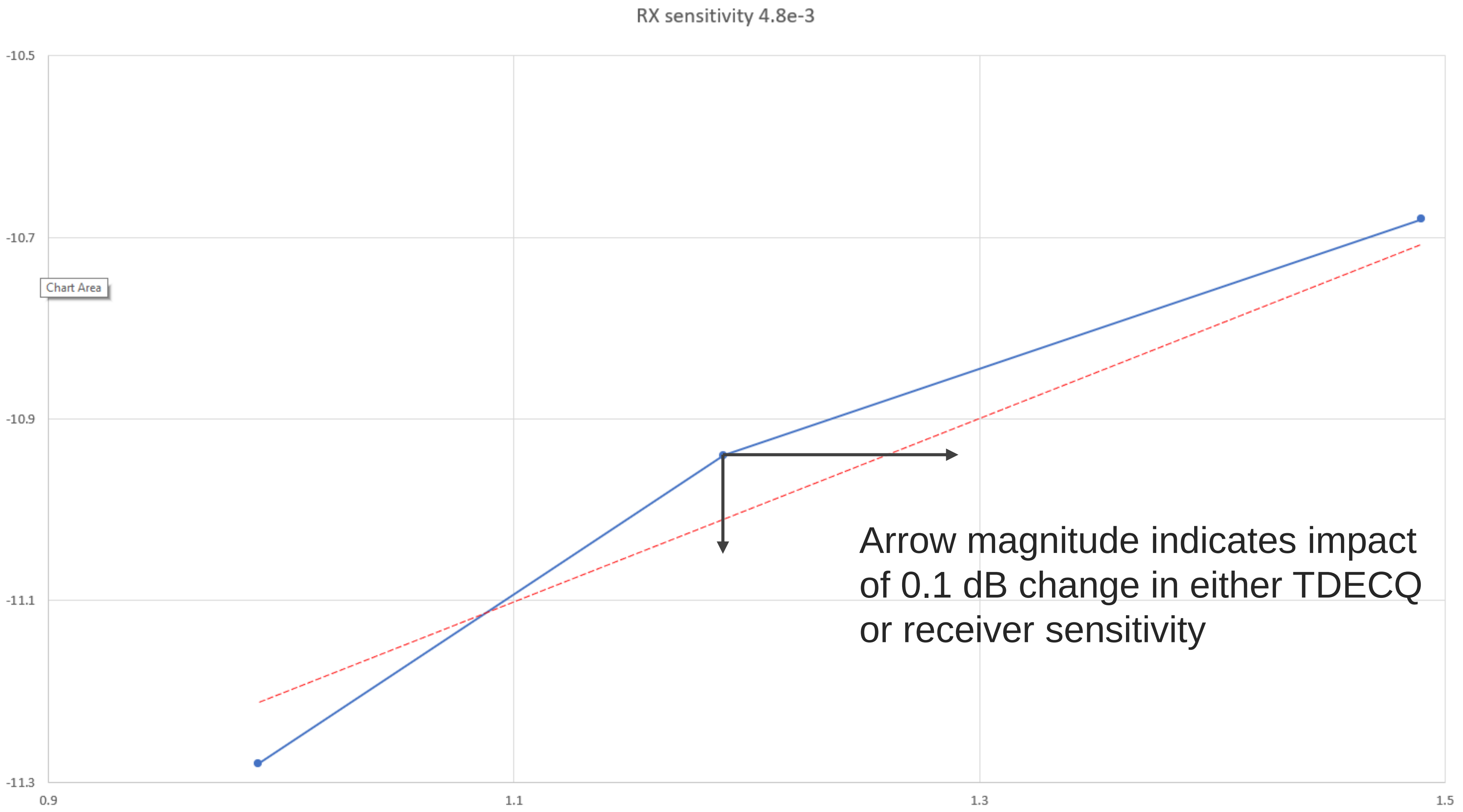


Receiver sensitivity vs TECQ at SER 2e-3



Receiver sensitivity versus TECQ at SER 4.8 e-3

Receiver goes unlocked ~ -11.3 dBm OMA, highest observable SER 4.8e-3



Experiment 2: Three 100G EML's (53 Gbaud) through 2 km (1 TX) and 10 km (2 TX) to the receiver (TDECQ)

- Receiver sensitivity versus TDECQ
- SER at 9.6 e-4
- Red line indicates ideal 1 dB : 1dB correlation
- (At "original" SER of 4.8e-4 TECQ values 1.5, 2.5, and 3.5 dB
- TDECQ based on 802.3cd 5-tap FFE
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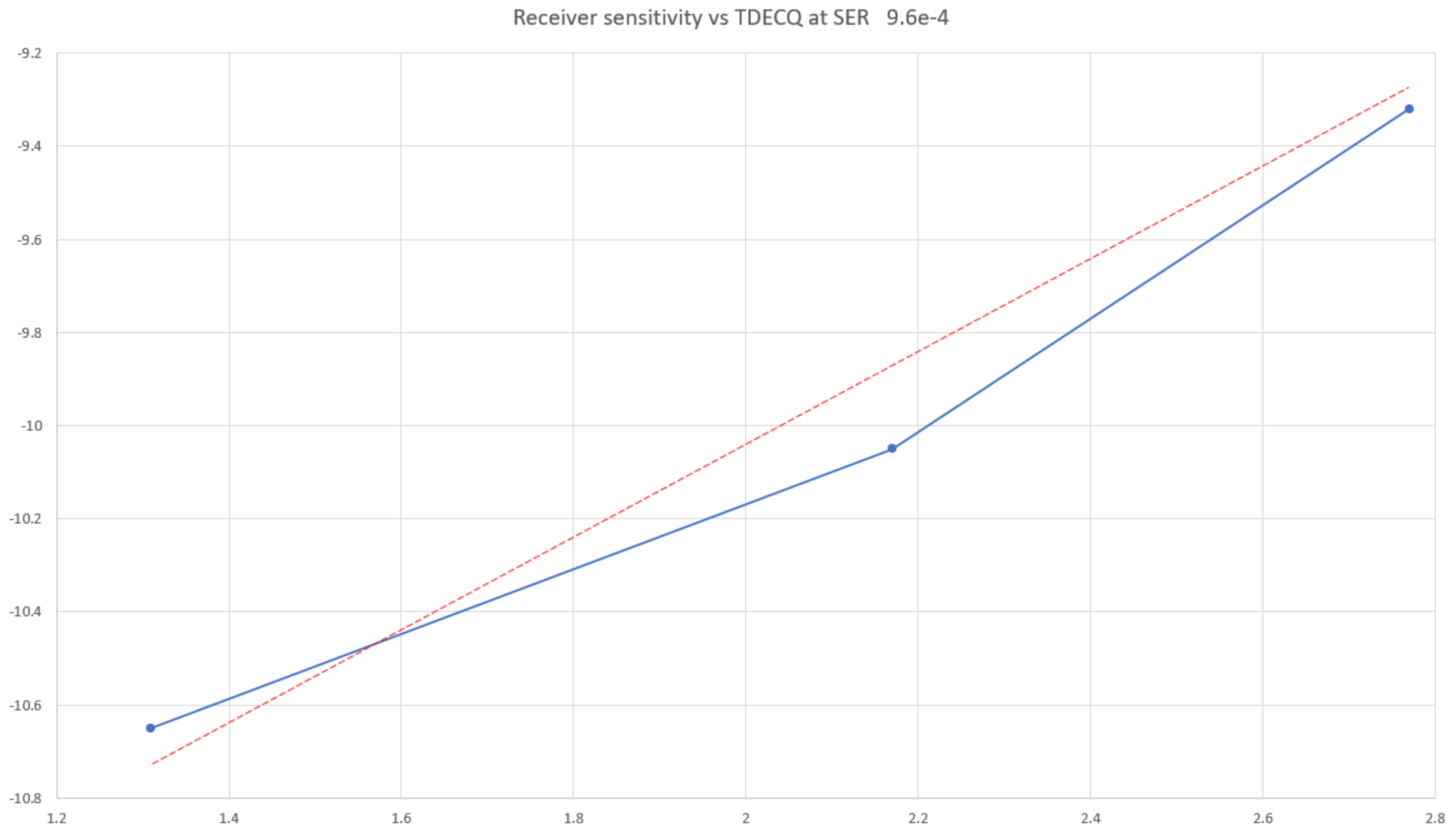
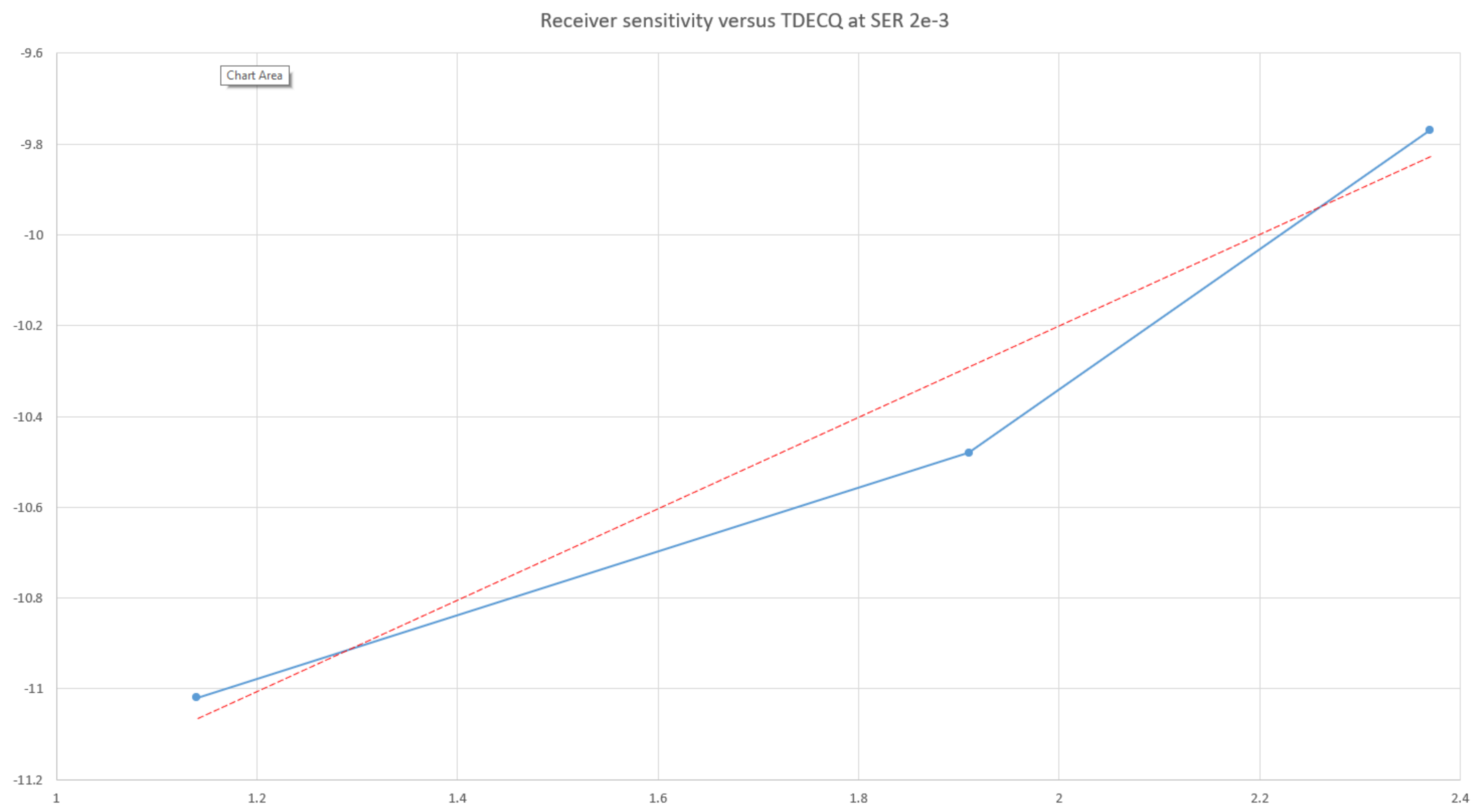
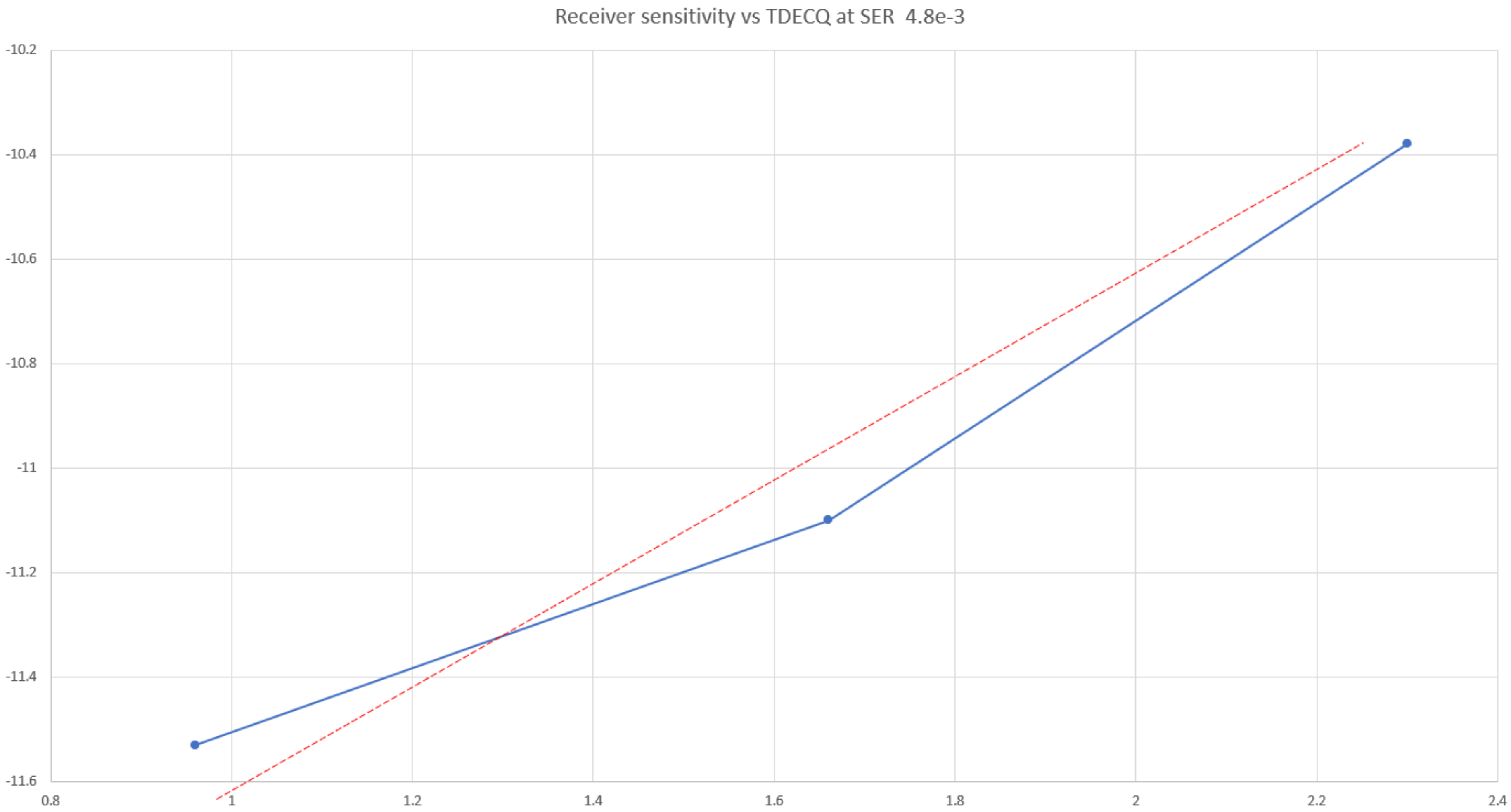


Receiver sensitivity vs TDECQ at SER 2e-3



Receiver sensitivity versus TDECQ at SER 4.8 e-3

- TDECQ at 4.8e-4 for the three transmitters
  - 1.5, 2.5, 3.5
- TDECQ at 4.8e-3 for the same three transmitters
  - 1.0, 1.7, 2.3



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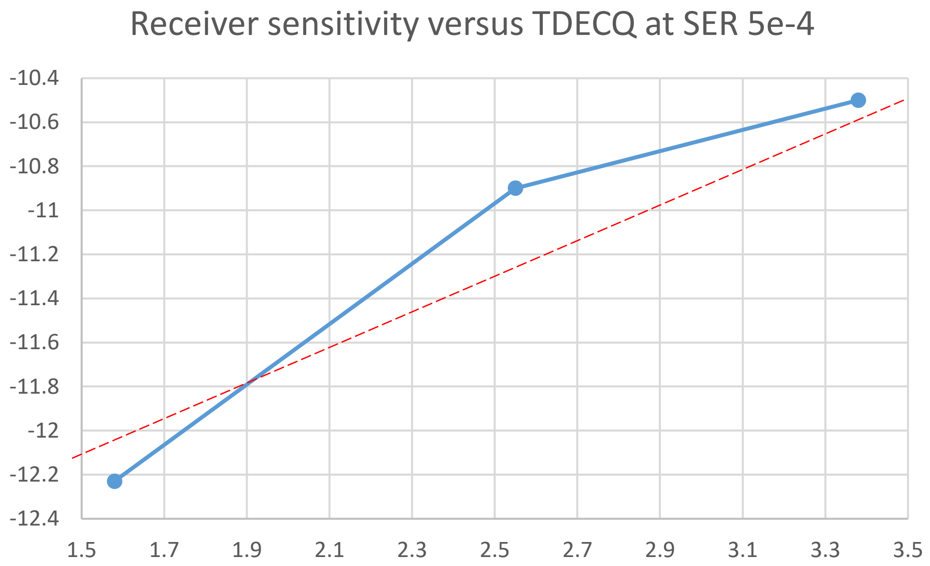
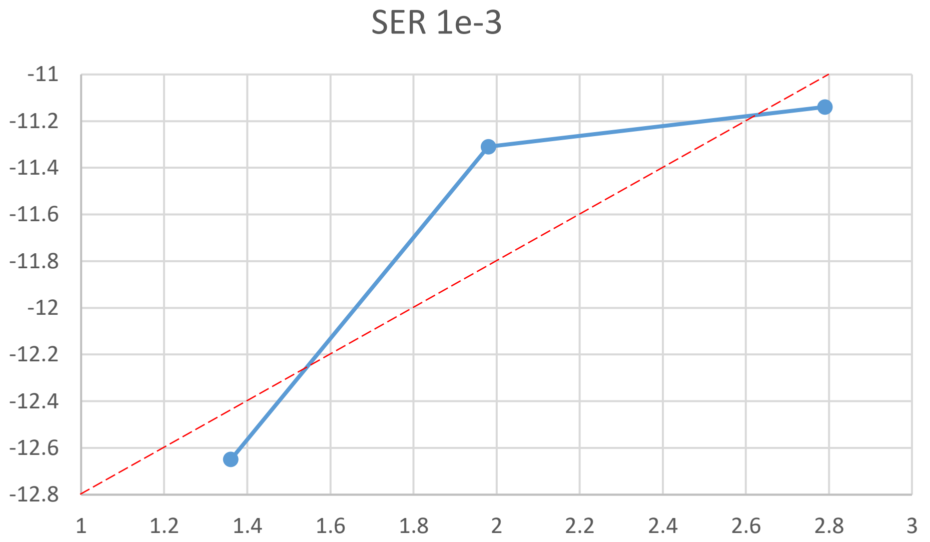
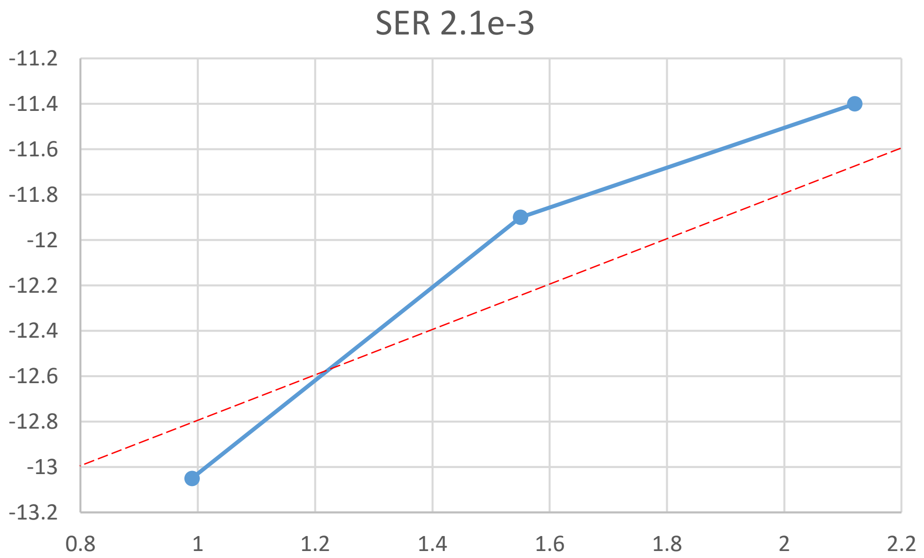
Experiment 3: Three FR4 EML transmitters with TDECQ range 1.5, 2.5, 3.5 (at SER 5e-4)

- 2.1e-3 highest observable SER



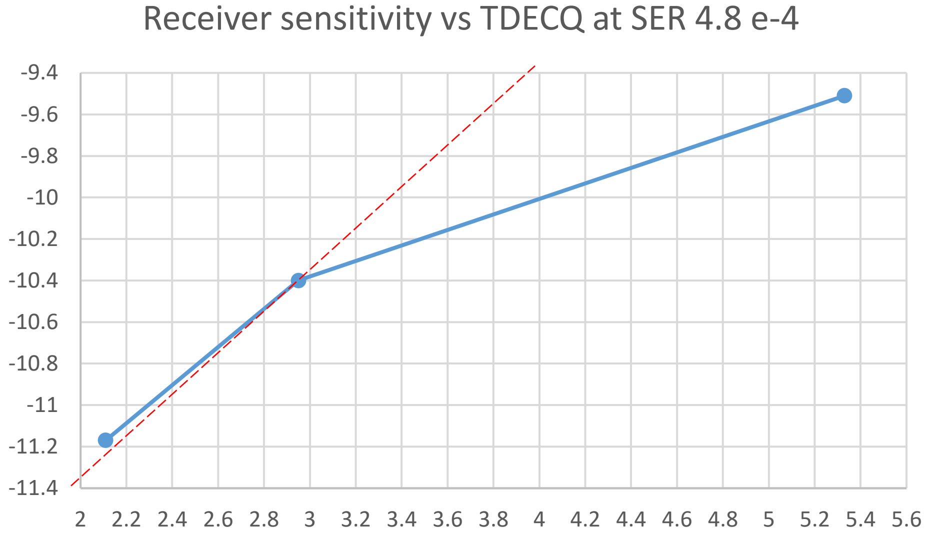


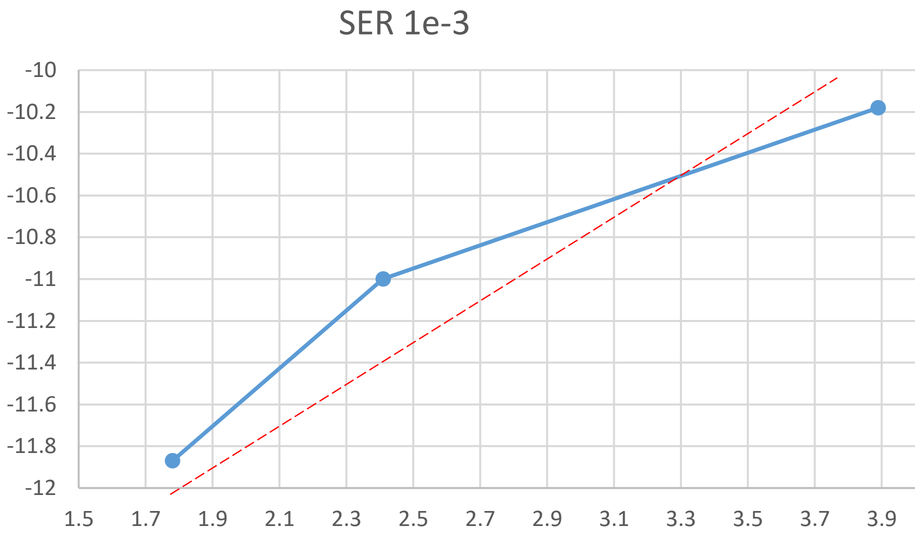


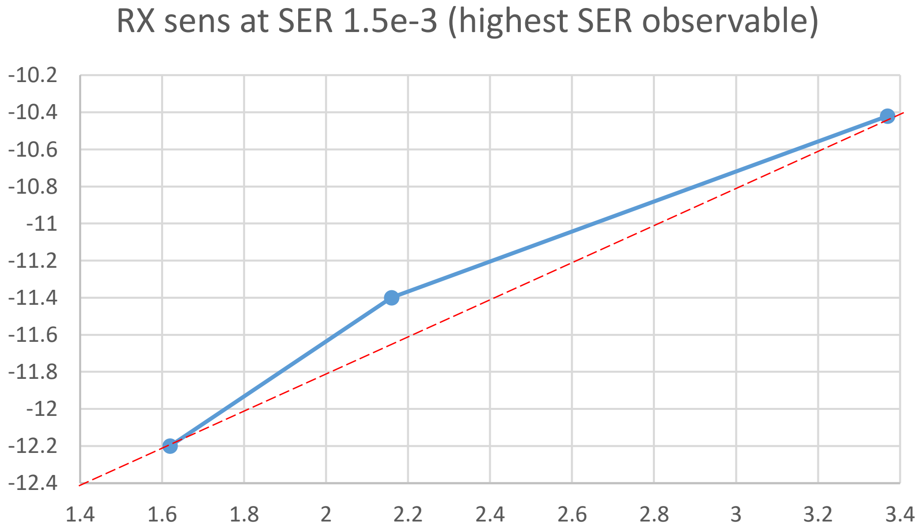
Experiment 4: 100G FR4 10km span

High TDECQ

- TDECQ as high as 5.6 dB (at SER 4.8e-4) achieves a working link
- Very good correlation at SER 1.5e-3 (highest observable SER)

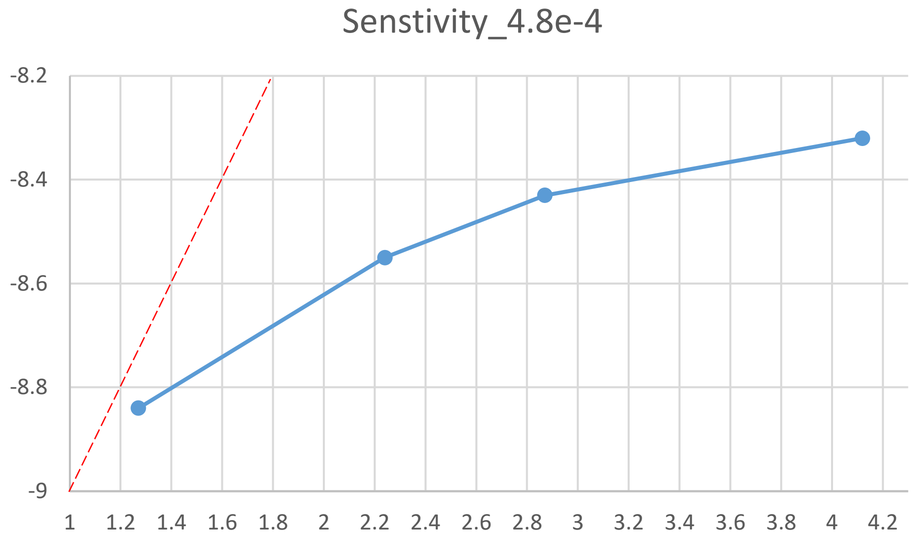


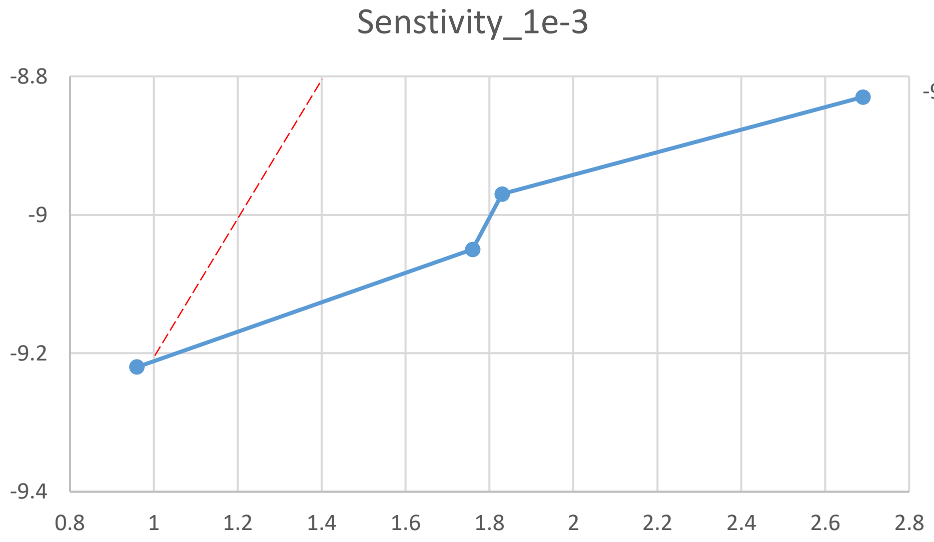


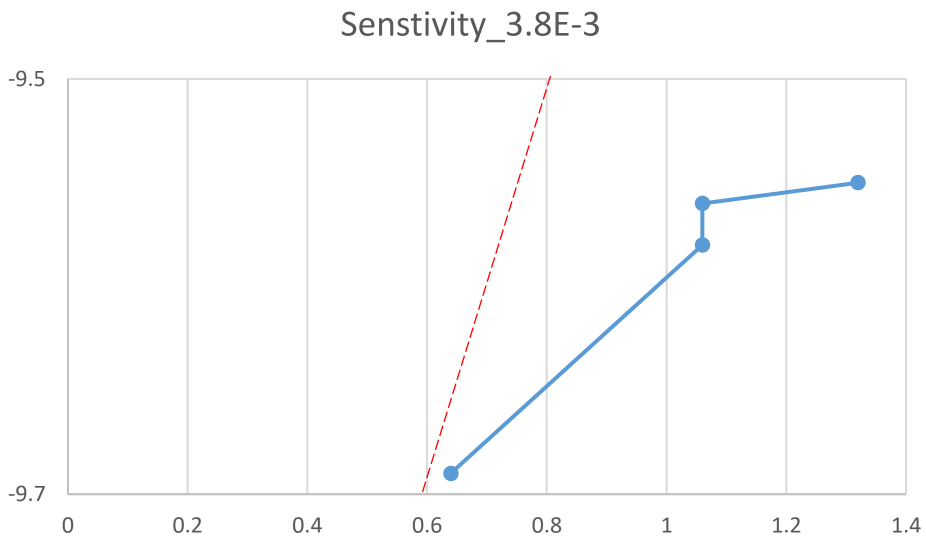


Experiment 5: Four multimode TX (53 Gbaud) direct to the receiver (TECQ)

- Receiver sensitivity versus TECQ
- SER at 4.8e-4, 1e-3, 3.8e-3 (break lock threshold)
- Red line indicates ideal 1 dB : 1dB correlation
- TDECQ based on 802.3db 9-tap FFE
- Receiver sensitivity only loosely correlated to TDECQ <u>for any SER</u>



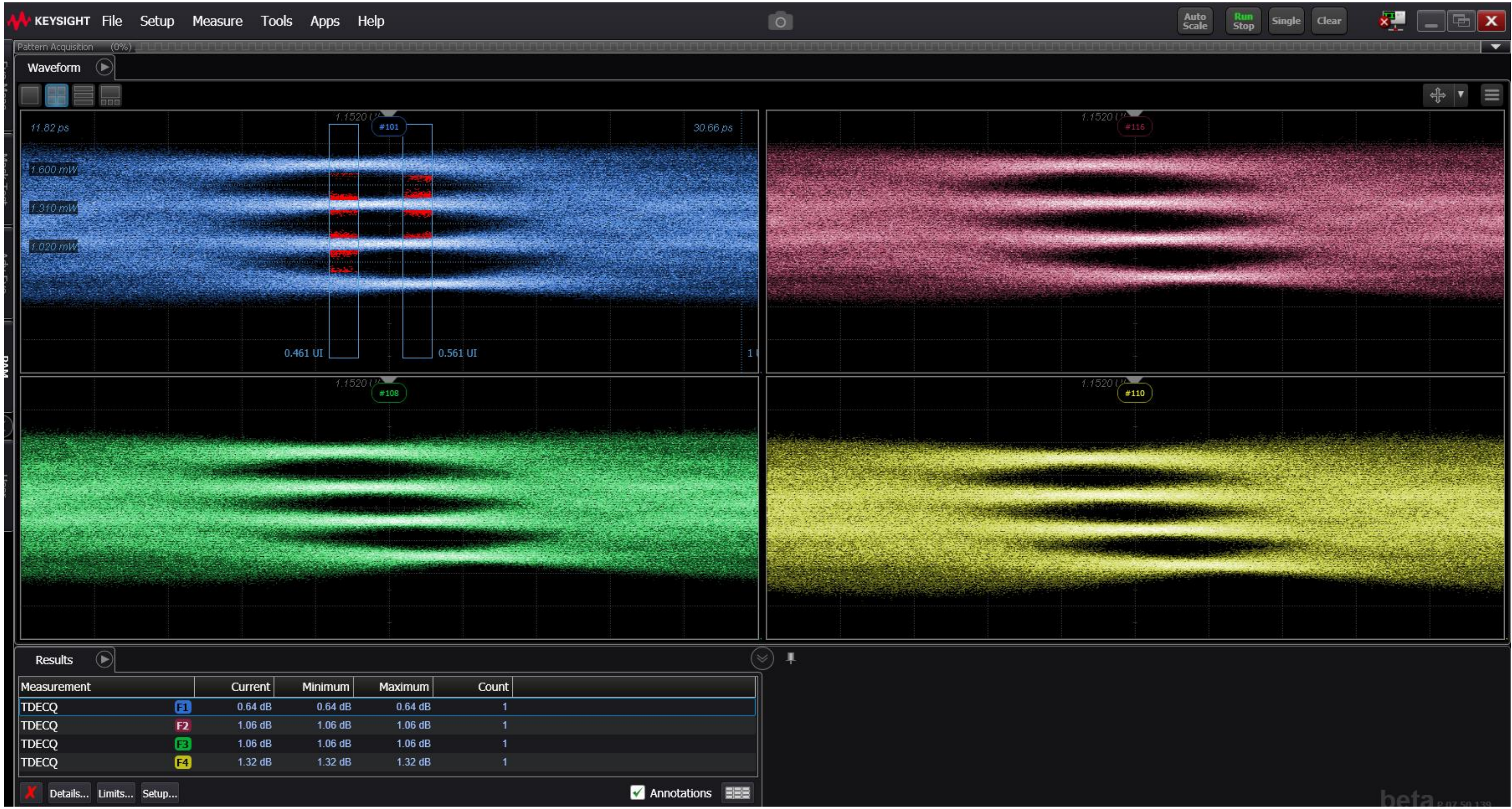




Eye diagrams imply a wide range of transmitter quality

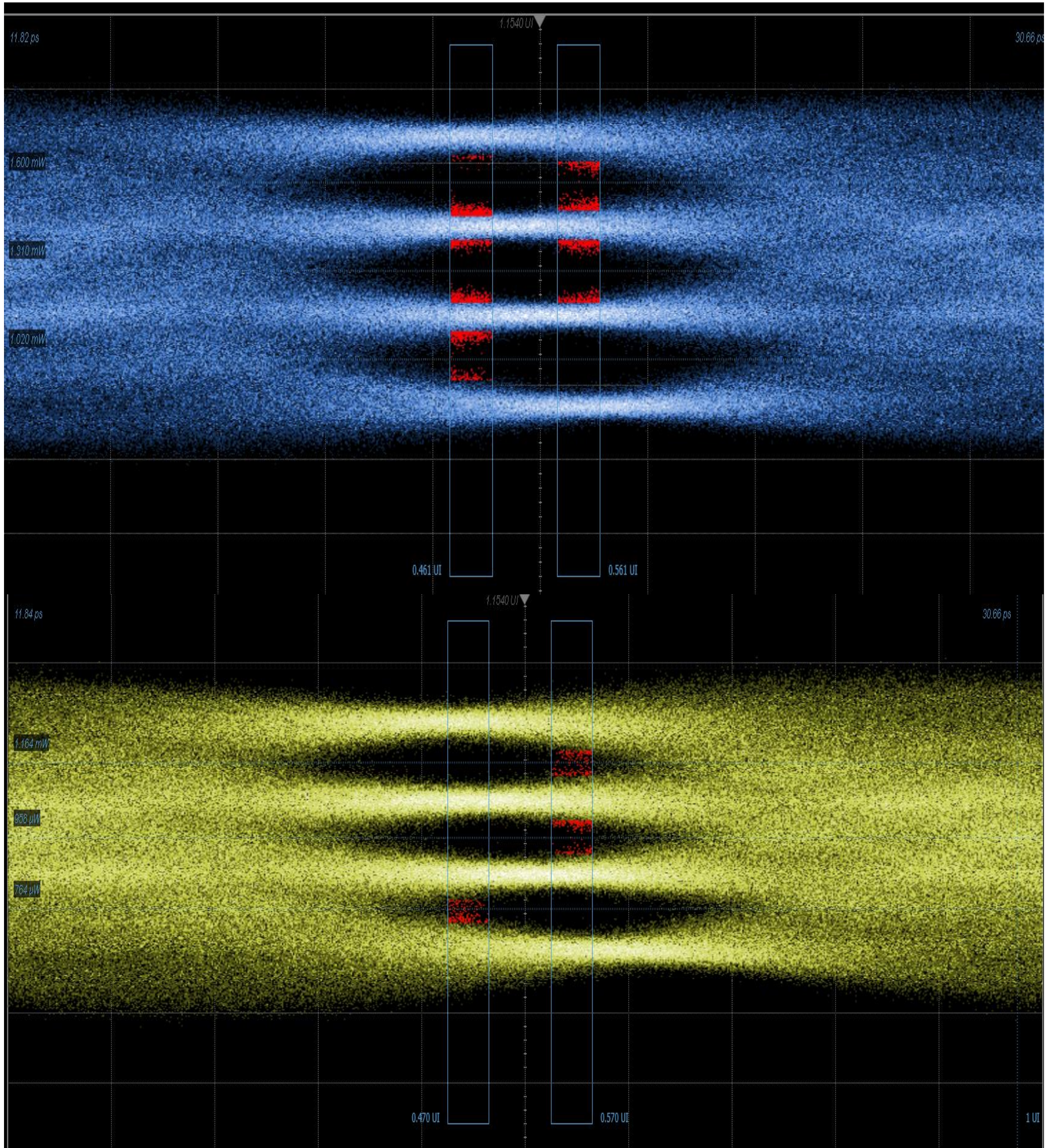
After TDECQ 9-tap FFE

- At SER 3.8e-3 a change of 0.64 to 1.32 dB in TDECQ corresponds to a change of only 0.14 dB in receiver sensitivity
- Eye quality is visibly different with almost no impact on receiver



Close up view of view of waveforms

- Supplier indicates the multimode receiver uses a different DSP than what is used in the single-mode receiver (experiment set #1)



Conclusions

- At high SER TDECQ is a good predictor a transmitters impact on link budget (often better correlation than at the common 4.8e-4 SER)
- What do we do for spec setting? This implies that a wide range of transmitter quality (as gauged by TDECQ) should result in operating links
- We have not proven experimentally what happens for SER above 5e-3
- Based on existing technology, the highest SER achievable was ~5e-3, often lower
  - As input power to the receiver was decreased any lower, the link failed (one example: CDR unlocked)
- Tests used simple FFE in TDECQ reference receiver. What's inside the real receivers? Do we need to update TDECQ reference receiver to align with current technology?

Thank you