Important Test Considerations for Generating Transmitter Specifications

IEEE P802.3db Short Reach Fiber Task Force Ad Hoc Telecon

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KEYSIGHT TECHNOLOGIES

Topics to discuss

- A quick review of the IEEE link budget method
  - The transmitter contribution to the link budget: OMA, ER, and Eye Closure penalty
- Eye closure metric for PAM4 systems: TDECQ
- Key lessons learned in IEEE and the evolution of TDECQ
- What represents the worst-case allowed receiver for 802.3 db and how that can impact transmitter test definitions
- Implications on receiver test

IEEE link budgets: Designed to allow interoperability

- Transmitter, channel, and receiver all considered as individual components of a communications system
- Each is specified so that when all three are combined you will achieve a working link
- Key issue: The specifications are defined based on a worst case scenario
- Example: A significant portion of the 6.9 dB link budget is consumed by penalties, the largest being TDECQ (max TDECQ at 4.5 dB)

Table 150–9—Illustrative link power budget

Parameter	OM3	OM4	OM5	Unit
Effective modal bandwidth at 850 nm (min)[a]	2000	4700		MHz·km
Effective modal bandwidth at 910 nm (min)[a]	1260	1980	3100	MHz·km
Power budget (for max TDECQ)	6.9			dB
Operating distance	0.5 to 70	0.5 to 100	0.5 to 150	m
Channel insertion loss[b]	1.7	1.8	2	dB
Allocation for penalties[c] (for max TDECQ)	4.9			dB
Additional insertion loss allowed	0.3	0.2	0	dB

[a]Per IEC 60793-2-10.
[b]The channel insertion loss is calculated using the maximum distance specified in Table 150–6 and cabled optical fiber attenuation of 3 dB/km at 850 nm plus an allocation for connection and splice loss given in 150.10.2.2.1.
[c]Link penalties are used for link budget calculations. They are not requirements and are not meant to be tested.

Transmitter ‘link budget’ specifications

WHAT IMPACTS RECEIVER SENSITIVITY?

- OMA and average launch power (absolute power)
- Extinction ratio (how much transmitter power is converted to modulation power)
- TDECQ: Measure the eye closure to estimate how much transmitter power is wasted due to eye closure
  - Measurement based on a virtual receiver
  - Virtual FFE to open the eye
  - Should simulate what a real receiver decision circuit would do
  - SER estimated from analysis of the post FFE waveform
- Minor specs for link budget: RIN, reflectance, SMSR…..

Table 150–7—Transmit characteristics

Description	Value	Unit
Signaling rate, each lane (range)	26.5625 ± 100 ppm	GBd
Modulation format	PAM4	—
Center wavelength (range), λ_1 for TxRx pair type TR Center wavelength (range), λ_2 for TxRx pair type RT	844 to 863 900 to 918	nm nm
RMS spectral width[a] (max) for TxRx pair type TR RMS spectral width[a] (max) for TxRx pair type RT	0.6 0.65	nm nm
Average launch power, each lane (max)	4	dBm
Average launch power, each lane (min)	–6.2	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	3	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min)[b]	–4.2	dBm
Launch power in OMA_{outer} minus TDECQ (min)	–5.6	dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	4.5	dB
TDECQ – $10\log_{10}(C_{eq})$[c], each lane (max)	4.5	dB
Average launch power of OFF transmitter, each lane (max)	–30	dBm
Extinction ratio, each lane (min)	3	dB
Transmitter transition time, each lane (max)	31	ps
$RIN_{12}OMA$ (max)	–128	dB/Hz
Optical return loss tolerance (max)	12	dB
Encircled flux[d]	≥ 86% at 19 µm ≤ 30% at 4.5 µm	—

[a]RMS spectral width is the standard deviation of the spectrum.
[b]Even if the TDECQ < 1.4 dB, the OMA (min) must exceed this value.
[c]C_{eq} is a coefficient defined in 121.8.5.3, which accounts for the reference equalizer noise enhancement.
[d]If measured into type A1a.2, type A1a.3, or type A1a.4, 50 µm fiber, in accordance with IEC 61280-1-4.

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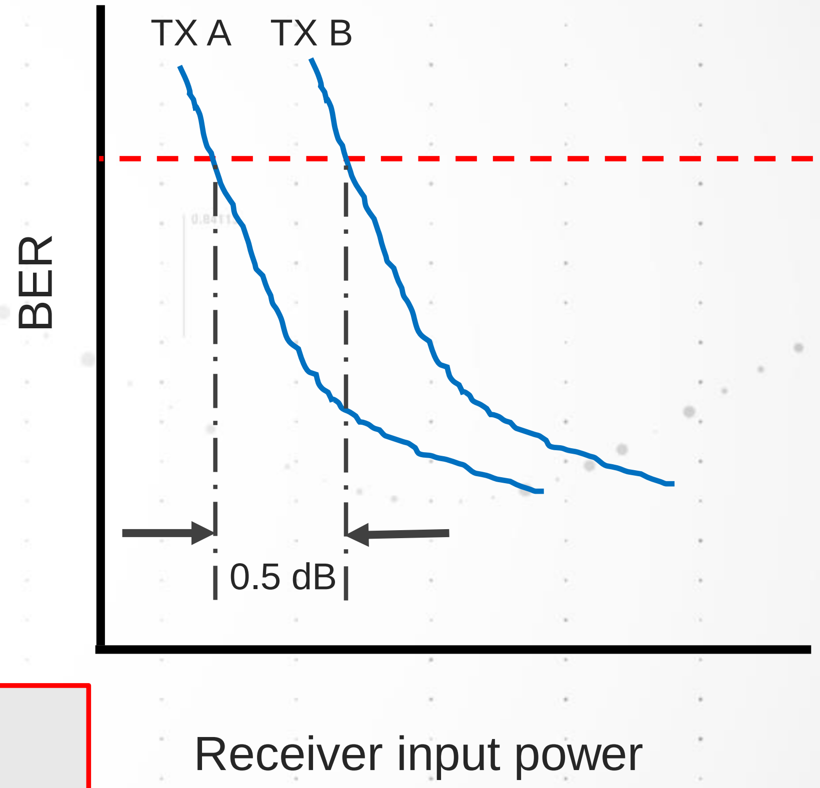
A practical view of TDECQ

- Definition: How much extra power is required from the transmitter, relative to an ideal transmitter, to compensate for the eye closure
- TDECQ should predict relative shifts in receiver sensitivity at the system level due to TX eye quality
- If transmitter A has a TDECQ of 2.7 dB and transmitter B has a TDECQ of 3.2 dB, <u>when these are connected to a real receiver,</u> sensitivity curves should be separated by 0.5 dB (3.2 – 2.7) at uncorrected SER limit



Key Point: This works well when the virtual receiver used for TDECQ analysis correctly emulates the physical receiver used in the sensitivity measurements

Key lessons learned in IEEE

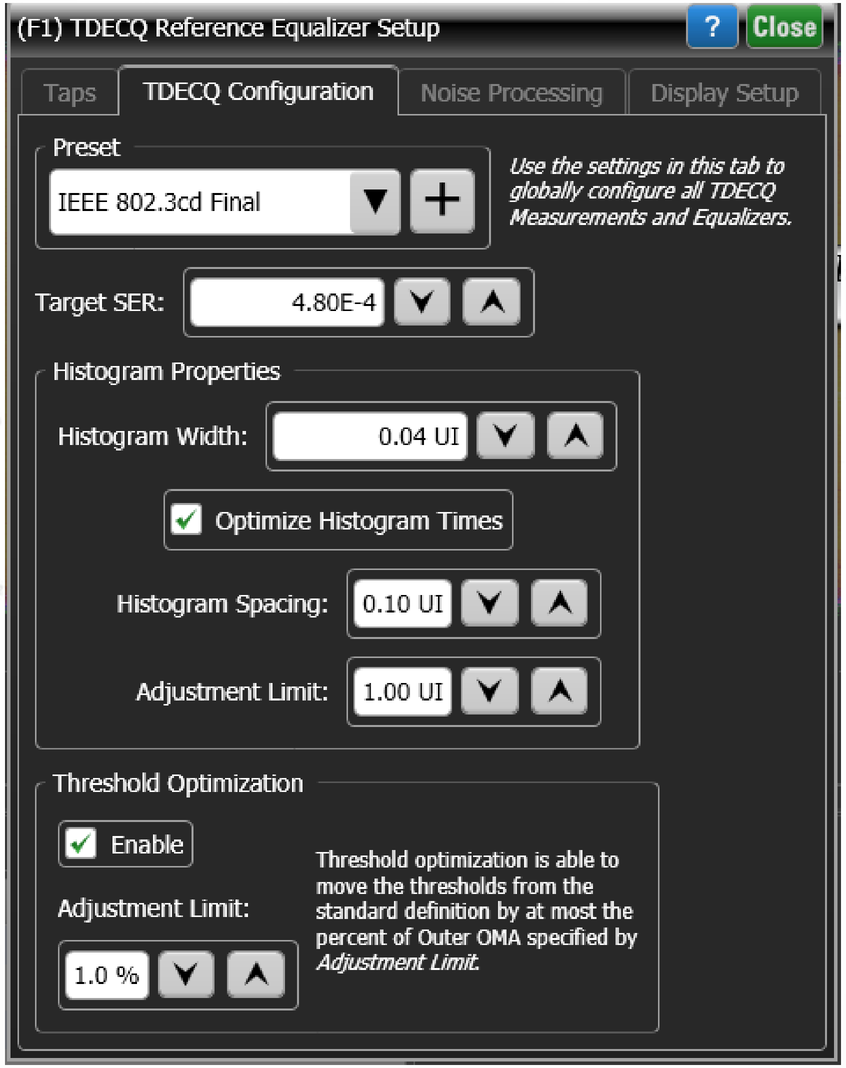
- The virtual receiver used to measure TDECQ needs to simulate how real receivers operate
- There were several iterations to get to a final definition of the TDECQ virtual receiver
- Current definitions:
  - 5 tap T-spaced FFE optimized to minimize TDECQ
  - Measurements made over an 0.1 UI span
  - Decision thresholds allowed to deviate from ideal linear positions by 1% of OMA
  - Nyquist (half baud) bandwidth

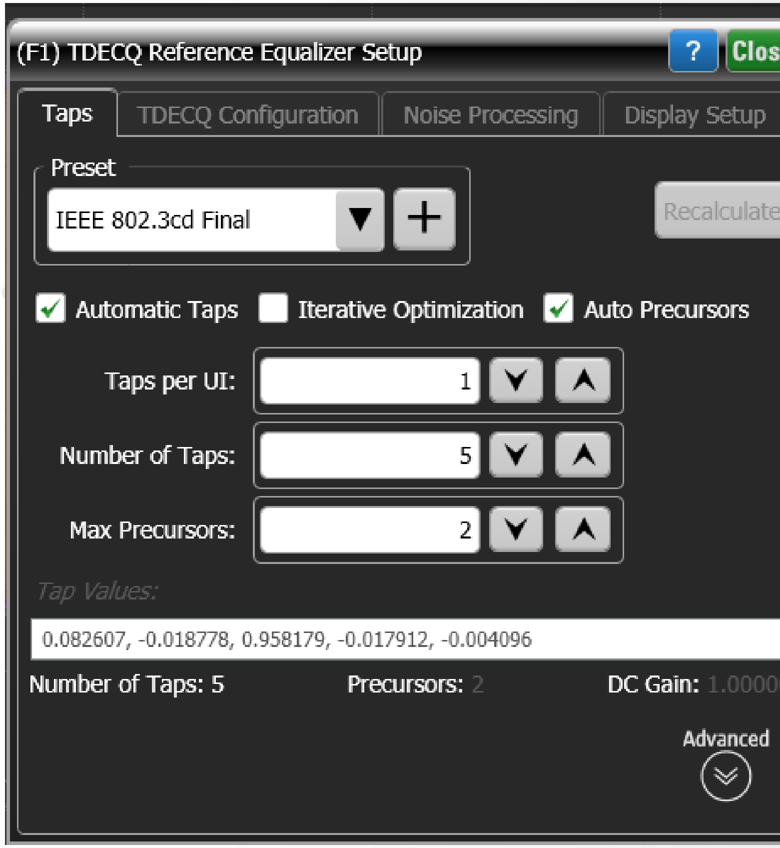
Key question: What represents the worst case physical receiver we believe will be used in 802.3 db systems? Is it the same as was defined in 802.3 cd?

The reference receiver is easy to modify

ALL POTENTIALLY INFLUENCE THE TDECQ VALUE

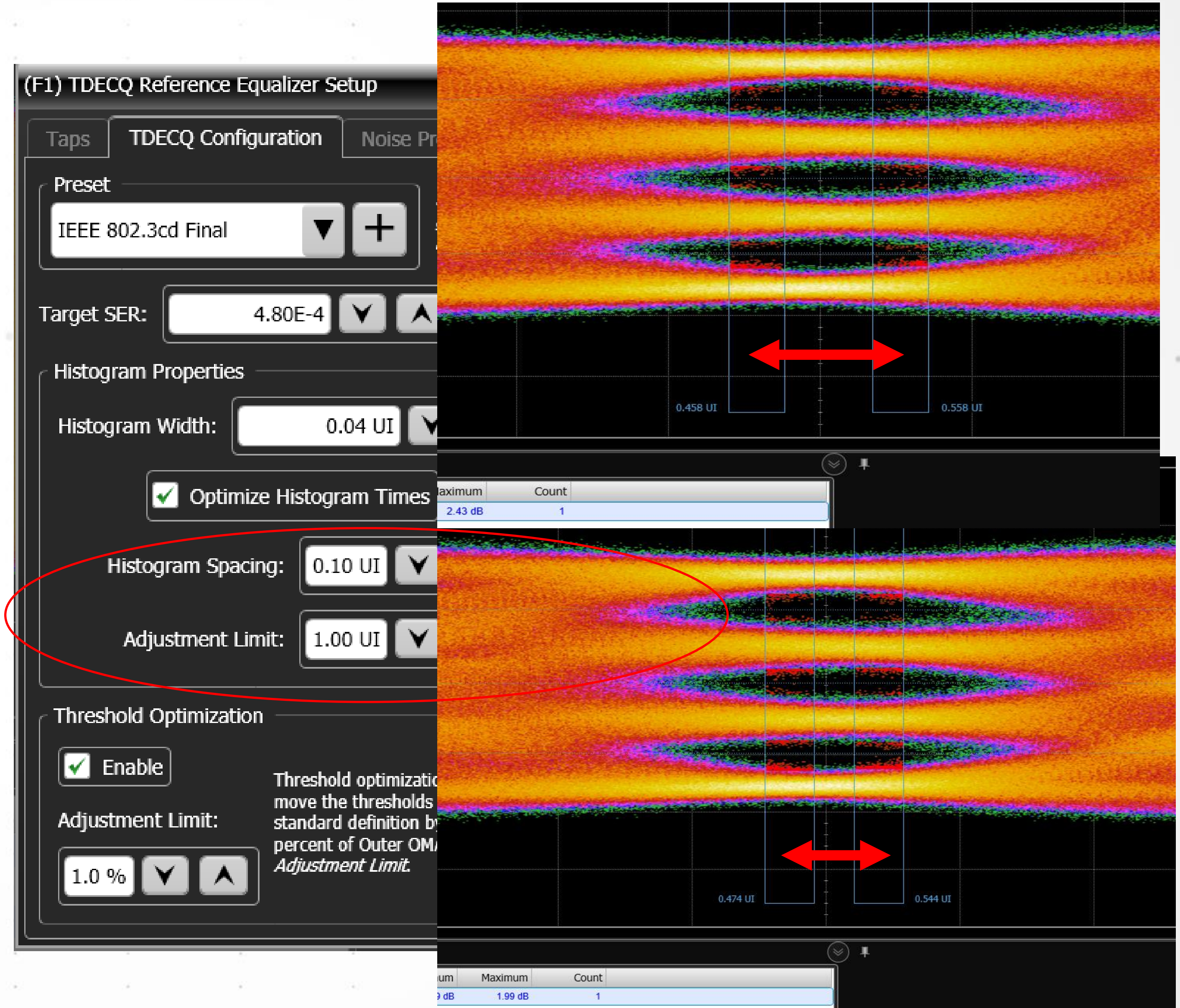
- Several parameters for the reference receiver are defined by IEEE.
- Easy to modify the reference receiver definition (but will no longer be IEEE compliant)





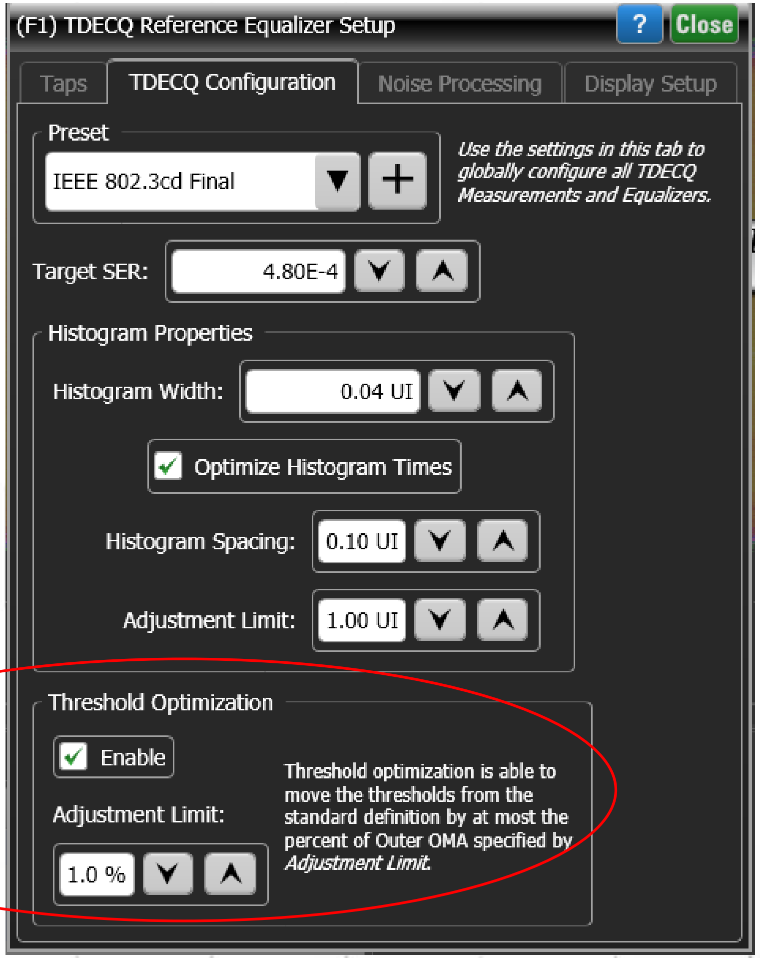
What region of the eye should define TDECQ?

- Waveform samples are collected in two histogram slices separated by 0.1 UI
- A reduced histogram spacing typically leads to a lower TDECQ value
  - This assumes that in a real system the receiver must be better at maintaining its sampling position in the eye center
- Example. At 0.1 UI spacing, TDECQ is 2.4 dB, at 0.07 UI spacing TDECQ is reduced to 2 dB



How tolerant is the receiver to nonlinearity?

- TDECQ decision thresholds can be adjusted from simple linear spacing
- Reduces TDECQ penalty for transmitters that are not ideally linear
- Current “1% of OMA” allowance seems to be sufficient for most transmitters today
- A higher deviation would require system receivers to tolerate more nonlinearity



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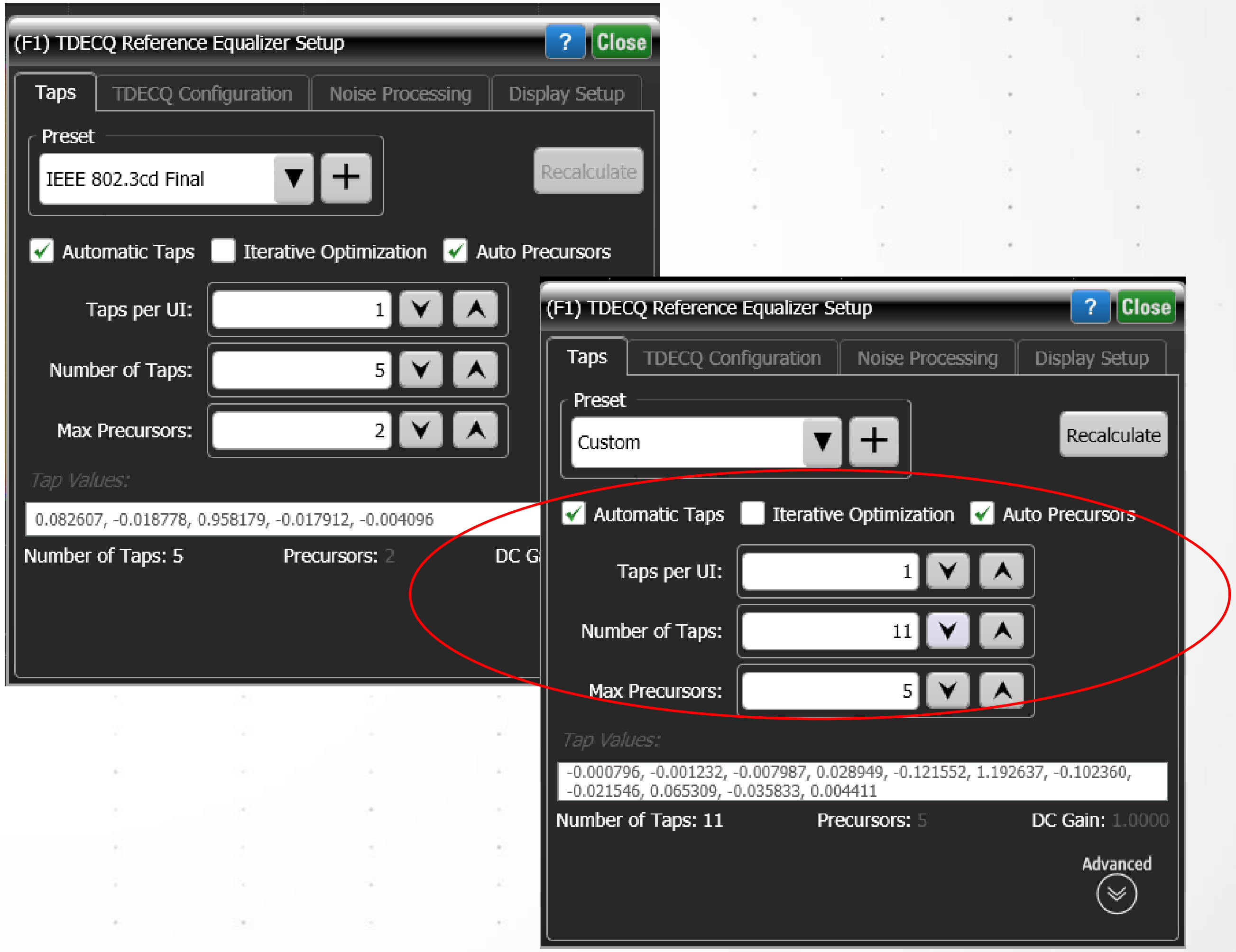
How complex should the equalizer be?

- Current IEEE TDECQ receiver uses a linear equalizer
  - 5 tap T spaced
  - Maximum 2 precursors
  - Both parameters adjustable (but not IEEE compliant if changed)
  - I have seen 0 to 0.3 dB improvement in TDECQ when going to a large number of tap values for the example waveforms I have
  - May see bigger improvement as data rates increase. Easy to verify



Recommendation to explicitly define EQ optimization

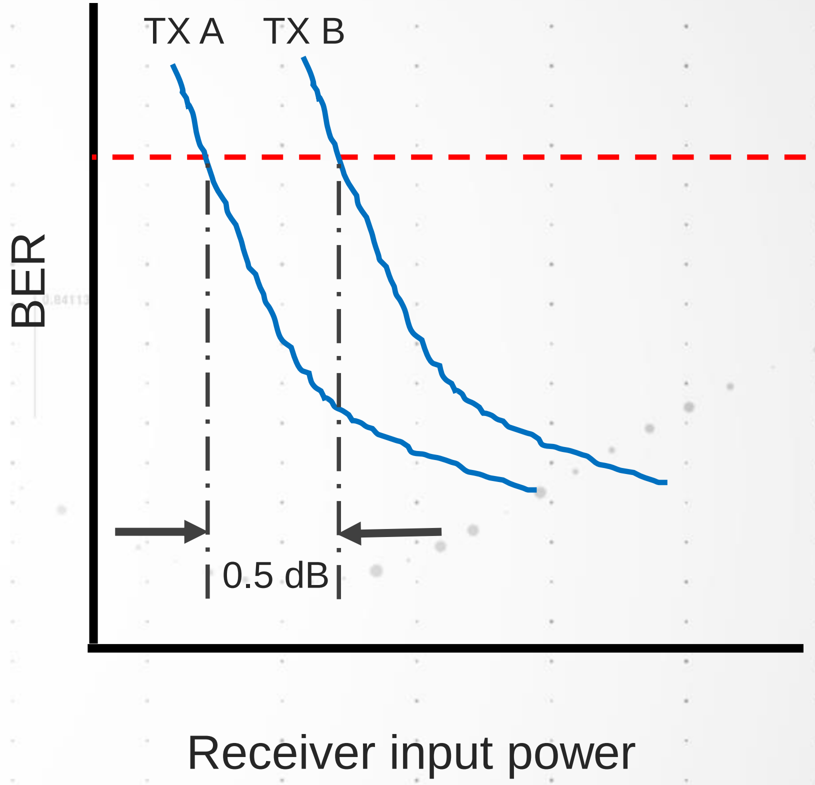
- The tap weights of the virtual equalizer are optimized as part of the TDECQ analysis
- Current IEEE optimization definition is open to interpretation and simply tries to minimize TDECQ
- Increases the likelihood of variability in test results across different T&M suppliers
- Our experience is that an optimization based on the TDECQ metric can lead to an EQ that is more complex/unrealistic versus what a real receiver would achieve, having lower computing power than the T&M system doing the analysis
- Recommendation: Optimize using a simple minimum mean square error of eye closure
  - MMSE was used for optimization in clause 68 (TWDP)
- We have done both and the typical benefit of the complex optimization is small
  - 0.1 to 0.2 dB, sometimes larger for very high penalties
  - MMSE optimization requires less than 5 seconds with good repeatability, complex method >60 seconds (with small improvement)

Dispersion: The ‘D’ in TDECQ

- In single-mode systems, TDECQ is performed with the transmitter observed through a fiber with the expected worst-case dispersion
- In multimode systems, TDECQ is observed with the observation bandwidth reduced to emulate the expected modal dispersion
- Anticipate the need to uniquely define the oscilloscope bandwidth for each span the standard will support

Keep the end goal in mind!

- Whatever is done to define the transmitter eye closure penalty test, it needs to accurately predict the link budget contribution
  - The end goal is to predict what the transmitter eye quality has on receiver sensitivity in a real system
- What do we believe should be expected for the worst case receiver in 802.3 db and how should it shape the TDECQ reference receiver definition?
- Remember: As you relax the burden on the transmitter with an 'easier' test, the receiver test needs to be modified in a complementary way. For example if the transmitter reference receiver is more tolerant of poor linearity, a stressed receiver test signal should incorporate more nonlinearity



Overshoot and undershoot

- NRZ specs historically use upper and lower eye-mask polygons to limit overshoot and undershoot
- 802.3 PAM4-based specs currently do not use an eye-mask, but still consider overshoot/undershoot
  - 802.3 cd used the TDECQ reference equalizer noise gain (Ceq) to infer overshoot
  - 802.3 cu implemented a direct measurement of overshoot and undershoot with a small percentage of samples allowed to exceed the spec limit
    - Measurement method and spec limits were developed through experimentation
- Both methods result in an efficient test process as metrics ‘drop out’ of the TDECQ waveform
  - No extra data is acquired as values are obtained through analysis of the TDECQ waveform.
- How big is the overshoot problem for 802.3db? We should not need to invent anything new but we may be required to modify the method or spec limit based on true TX and RX behavior

Thank you!