Considerations for TECQ and TDECQ 200Gb/s transmitter lane specification and measurement

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Thanks to several who provided important insights on system design and its implications on transmitter specifications

- John Johnson
- Maxim Kuschnerov
- Gary Mak
- Matt Traverso
- Marco Mazzini
- Romesh Nandwana
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- Ali Ghiasi

IEEE link budgets: Designed to allow interoperability

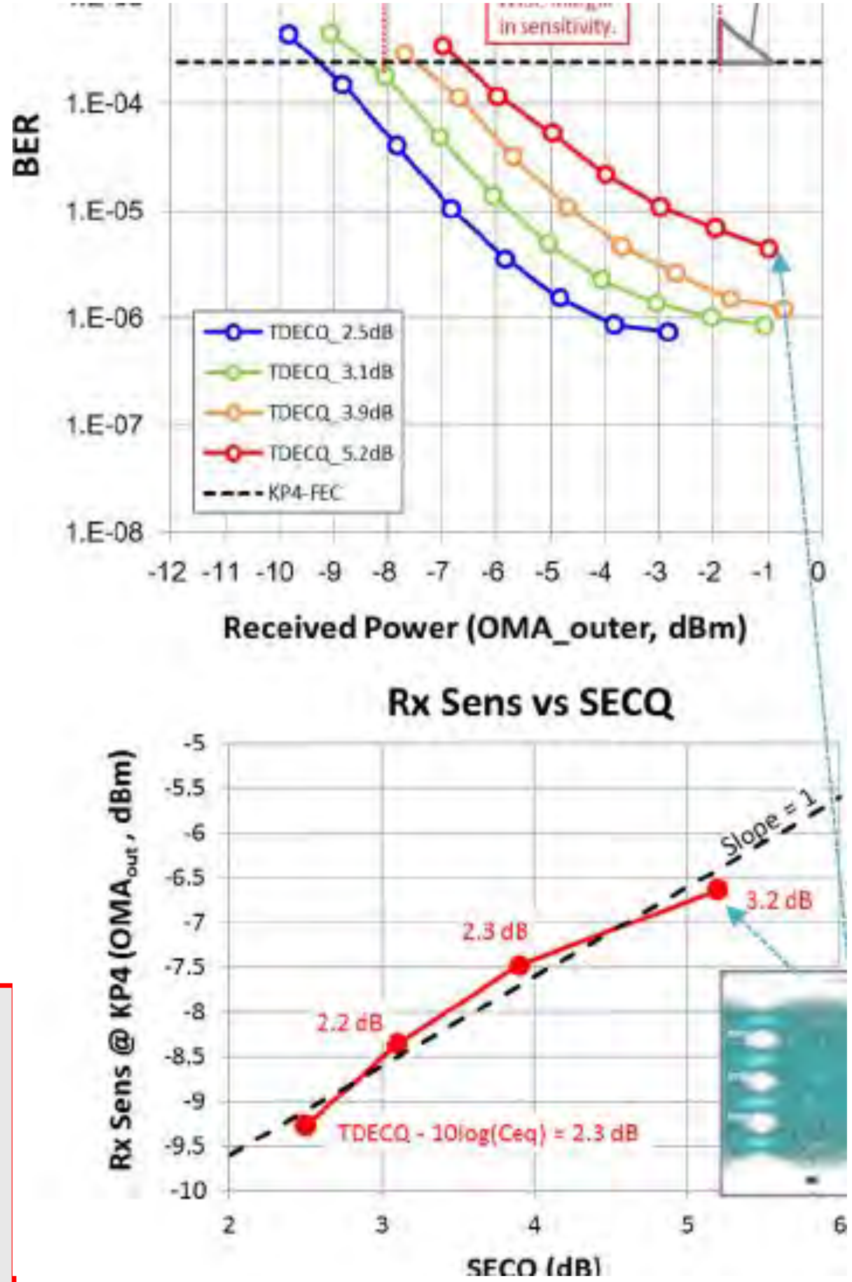
- TDECQ historically consumes a significant portion of the overall link budget
  - Example 400G FR4 and LR6:
  - 3.4 dB of the 7.8 dB link budget
- Transmitter, channel, and receiver all considered as individual components of a communications system
- Each is specified so that when all three are combined you will achieve a working link
- Key issues:
  - The transmitter is tested in the context of the receiver it will be used with
  - The specifications are defined based on a worst-case scenario which has historically bounded/defined the virtual reference receiver used in the TECQ/TDECQ metric

Table 151–9—400GBASE-FR4 and 400GBASE-LR4-6 illustrative link power budgets

Parameter	400GBASE-FR4	400GBASE-LR4-6	Unit
Power budget (for maximum TDECQ):	7.8	10.5	dB
Operating distance	2	6	km
Channel insertion loss[a]	4	5	dB
Maximum discrete reflectance[b]	–35[c]	–35[d]	dB
Allocation for penalties[e] (for maximum TDECQ):	3.8	4.2	dB
Additional insertion loss allowed[f]	0	1.3	dB

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. (A good example of the concept working well):
>
> https://grouper.ieee.org/groups/802/3/cd/public/July18/tamura_3cd_01c_0718.pdf

Key lessons learned in IEEE 802.3

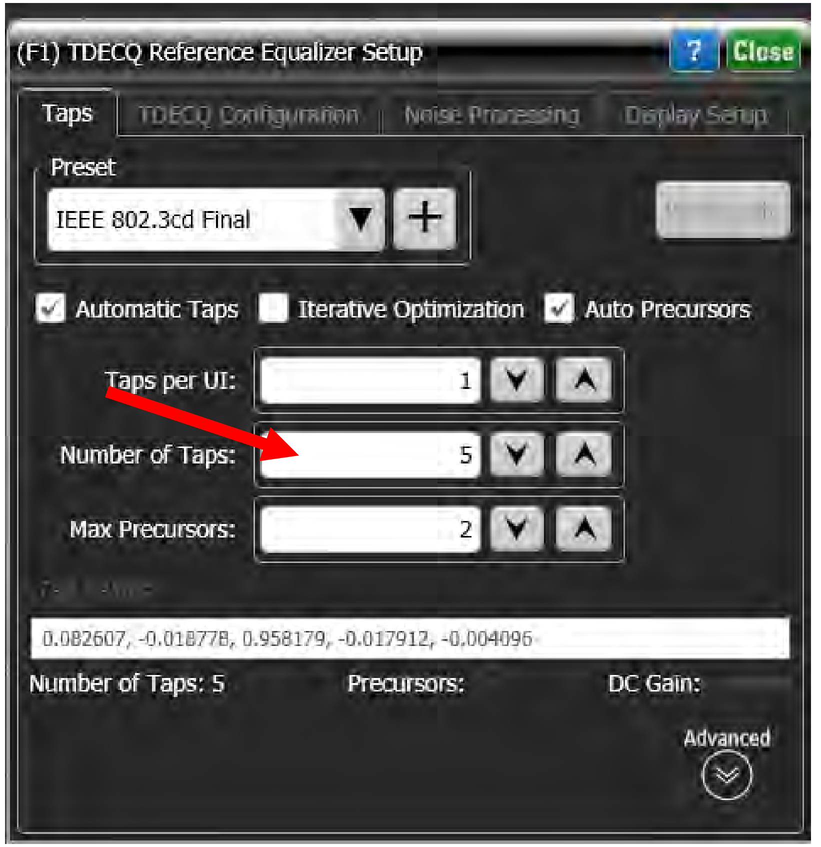
- There were several iterations to get to a final definition of the TDECQ virtual receiver
- Current definitions:
  - 5 tap T-spaced FFE optimized to minimize TDECQ (802.3db uses a 9 tap FFE)
  - Measurements made over an 0.1 UI span
  - Decision thresholds allowed to deviate from ideal linear positions by 1% of OMA (802.3db uses 2%)
  - Nyquist (half baud) bandwidth, fourth-order Bessel response

Key questions: What represents the worst-case physical receiver we believe will be used for 200 Gb/s lanes. What does worst-case really mean?

The following slides review what we *could do* and are not intended to dictate what we *should do*

The reference receiver is easy to modify from its current design

- Target SER
- Histogram width and spacing
- Decision threshold optimization
- FFE length and precursors

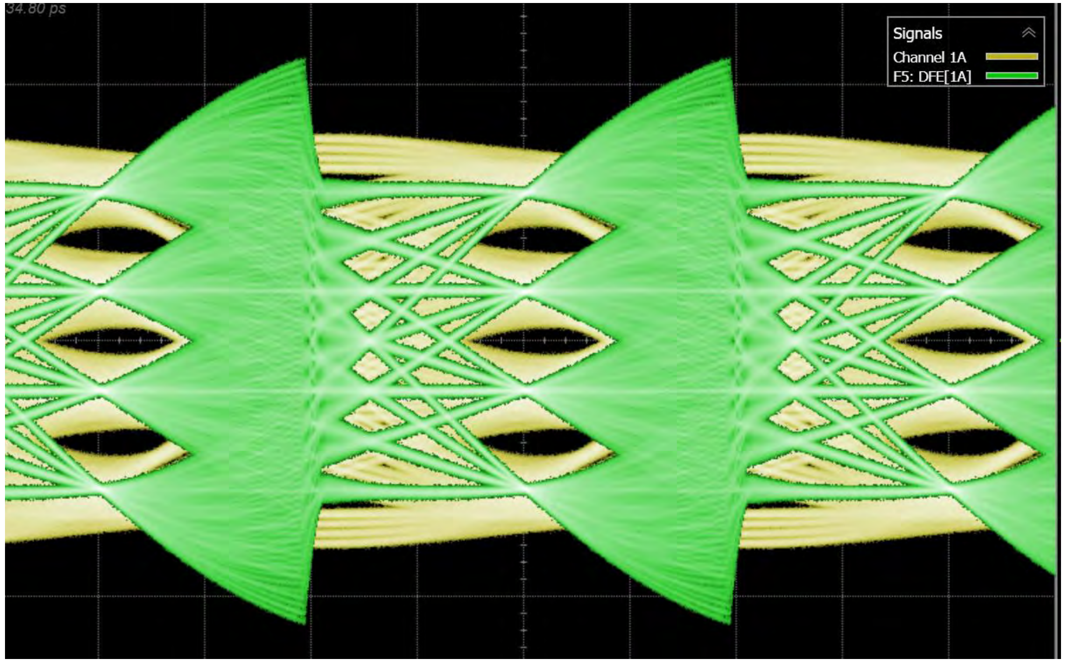


How complex should a 200 Gb/s TDECQ virtual equalizer be?

- 800G MSA uses a 21 tap FFE
- 802.3 db uses a 9 tap FFE
- DFE?
- MLSE?

DFE is likely feasible

- A physical DFE can be emulated to generate an effective eye diagram that TDECQ can be applied to
- Need to ensure that the penalty it predicts is similar to what real receivers provide
- May require some consideration on how OMA is determined, (fundamental to TDECQ analysis)
- The potential error propagation of the DFE may not be reflected in the TDECQ result



MLSE is likely feasible

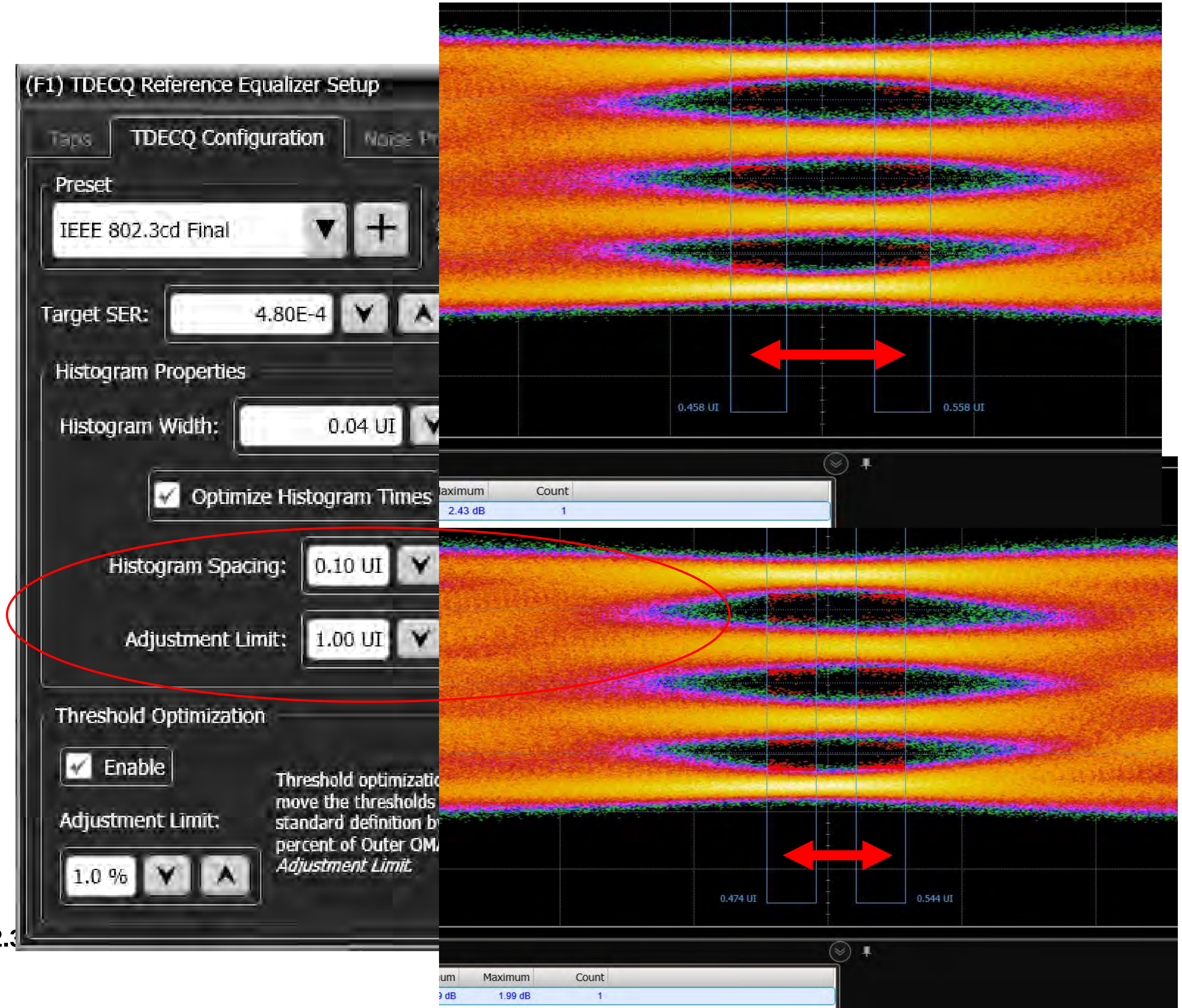
- This will be complex, but a first-level review indicates that an MLSE emulation in the TDECQ reference receiver is likely possible
- The work to do this is not trivial and would take significant time to prototype
- Requires that sample time optimization and threshold optimization no longer use “best” TDECQ as the optimization metric

Equalizer optimization

- The tap weights of the virtual equalizer are optimized as part of the TDECQ analysis
- Current optimization defined in Clause 121 effectively says that all possible tap weight combinations are valid, and all should be verified to determine the lowest possible TDECQ penalty
  - 802.3 db, with 9 FFE taps did not update clause 121, but acknowledged that more efficient methods of optimization are valid
- As we consider longer FFE's, and as we consider more forms of equalization, we will need to define efficient and well documented optimization methods

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" (2% for 802.3 db)
- A higher deviation would require system receivers to tolerate more nonlinearity

Are noise mechanisms modeled correctly?

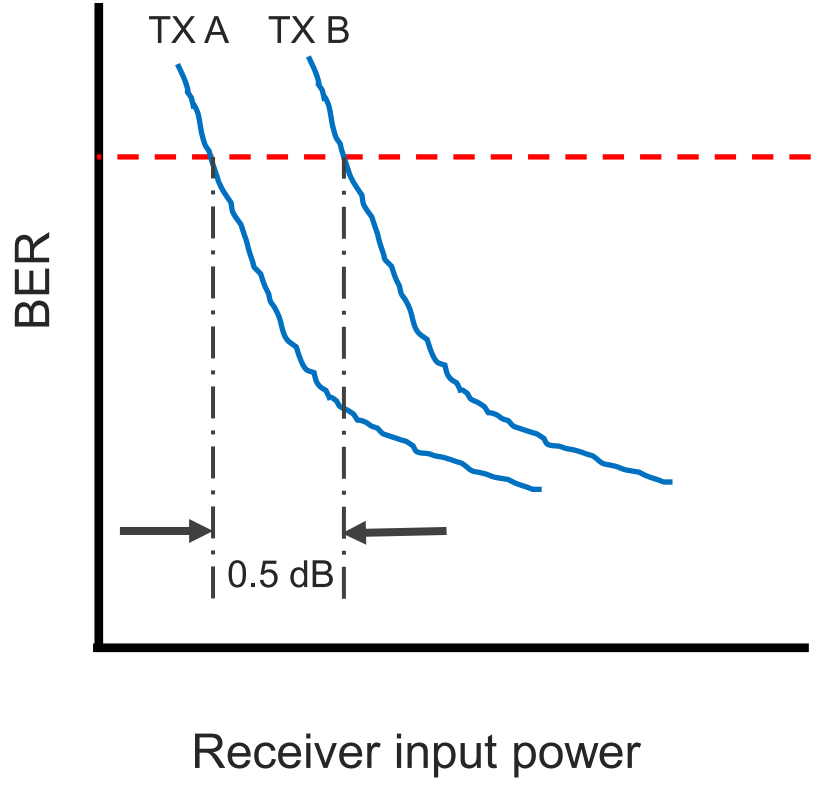
- If we go to higher SER limits, is the Gaussian noise model still valid? (The TDECQ penalty is assessed by adding Gaussian noise until the SER limit is reached)
- Consider other noise mechanisms that may become more significant as we go to 200 Gb/s per lane (RX TIA noise etc.)

Measurement channel frequency response

- As long as the TDECQ measurement uses a reasonable pattern length (e.g. SSPRQ at 2^16-1), the measurement can be 'pattern locked'
- This facilitates easy modification of the measurement channel frequency response
  - Fourth Order Bessel Thomson
  - Fourth Order Butterworth
    - Historically we use Bessel responses (constant group delay in passband) as they yield well behaved time domain responses. But a Butterworth response may better represent real receiver responses
  - Others?

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 for 200 Gb/s lanes 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 must 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.
- The TX spec limits may need revision to effectively balance the burden imposed on receivers with a more powerful reference RX



Thank you