Proposed updates to TDECQ calculations for improved robustness and repeatability

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KEYSIGHT TECHNOLOGIES

Comparing TDECQ measurement stability for T and T/2 equalizer tap spacing

– At the last SMF ad hoc call, T/2 tap spacing was identified as a possible source of TDECQ measurement repeatability problems

  - We need to avoid possible implementations that provide lower TDECQ penalties for the wrong reasons

– As an example, instrumentation noise (known as the σ_S term in the TDECQ mathematics) was used to exhibit how the noise gain variability of a T/2 spaced equalizer can improperly bias the measurement result

– Unfortunately, the ensuing discussion then focused on oscilloscope noise and skewed responses away from the original measurement repeatability problem

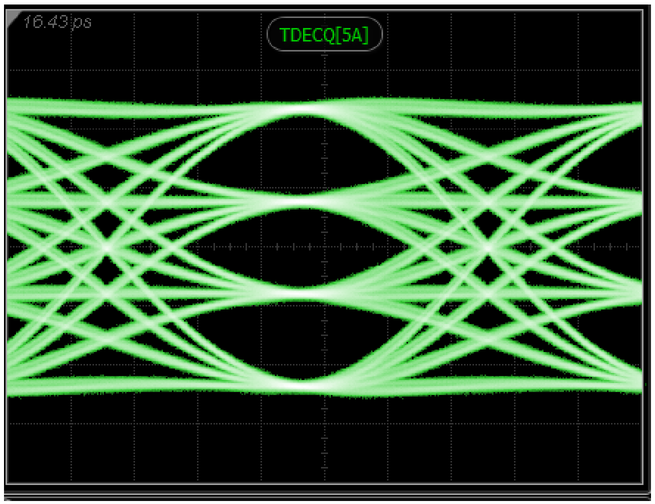
– The overall TDECQ measurement problem is manifest for other scenarios that are completely independent of instrumentation noise

The need to specify an optimization method

- The original TDECQ methodology specified that taps are “optimized for TDECQ,” without specifying how.
- Because there are many trade secrets and patents surrounding equalizer tap optimizations, care should be taken to avoid implementation specific variations in TDECQ (vendor A versus vendor B) or requiring methods that are not in the public domain.
- Keysight proposed MMSE (minimum mean-square error) for tap optimization along with a change to a T-spaced equalizer. The MMSE change was accepted, but the change to T-spaced was rejected.
- MMSE is insufficient for T/2 spaced equalization, so further specification is required.

Example of MMSE with T/2

The equalizer on the left was optimized with straight MMSE. It has a larger eye opening but also has worse TDECQ because of an increased noise gain (smaller C_{eq})

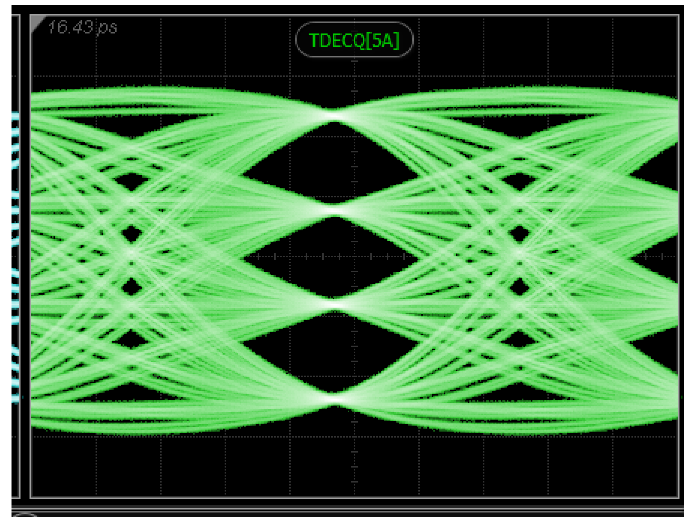


Tap Values:

0.049362, -0.180165, 1.430913, -0.357259, 0.050296

Measurement		Current
Eye 1/2 Width (1.0E-6)	F1	21.19 ps
Eye 1/2 Height (1.0E-6)	F1	133.2 µW
TDECQ	F1	1.47 dB

$C_{eq} = 0.557$



Tap Values:

-0.125905, 0.196675, 1.028602, -0.009174, -0.102636

Measurement		Current
Eye 1/2 Width (1.0E-6)	F1	15.85 ps
Eye 1/2 Height (1.0E-6)	F1	132.2 µW
TDECQ	F1	1.27 dB

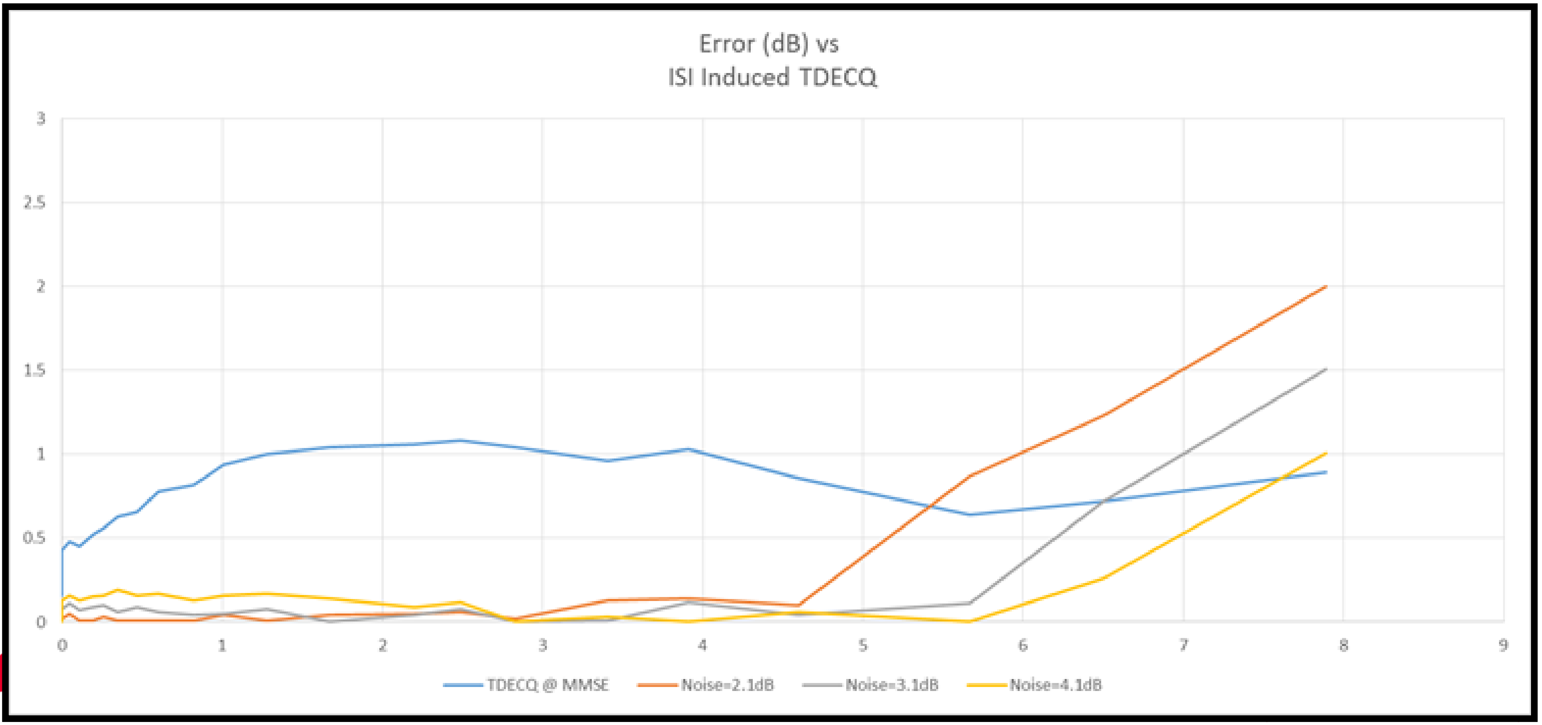
$C_{eq} = 0.907$

A TDECQ optimization method that supports the T/2 equalizer

- Keysight recommends keeping MMSE because it is well known and public domain, but with a minor modification to improve performance with T/2 equalizer.
- ‘Pre-loading’ a specific amount of noise to the transmitter waveform prior to optimizing the equalizer can significantly reduce the TDECQ error
- The following simulations consider how various pre-loaded noise values behave in the presence of both ISI induced TDECQ and noise induced TDECQ

TDECQ measurement error for ISI induced TDECQ

- Three values of 'pre-loaded' R term noise (blue trace is with no pre-loaded noise)
- R term definitions: Use 0.03*OMA, 0.024*OMA, and 0.019*OMA which corresponds to the amount of noise "R" that could be added by a receiver to transmitters with TDECQ values of 2.1 dB, 3.1 dB, and 4.1 dB, respectively.
- Conclusions from this chart:
  - Preloading noise results in much better TDECQ values
  - The amount of noise is of secondary importance for reasonable TDECQ values.



Conclusions

- TDECQ results for T/2 spaced equalizer are improved through pre-loading noise prior to optimization
- The amount of noise added is of secondary importance, but we recommend 0.0245 OMA
  - Works well for transmitters that do not have excessive TDECQ penalties (less than 5 dB).
  - Corresponds to the amount of noise that a receiver could add to a transmitter with 3.0 dB TDECQ.

Recommended changes to clause 121

- *Replacement for the fourth paragraph of 121.8.5.3:*

- *The reference equalizer (specified in 121.8.5.4) is applied to the waveform. The tap values are calculated as follows:*

- *1) Gaussian distributed white noise is added to the captured waveform. The noise should have an RMS value of 0.0245 * OMA, which corresponds to the amount of receiver noise that could be added to a transmitter with a TDECQ value of 3.0 dB.*

- *2) The equalizer taps are optimized for the minimum mean square error about the symbol levels (Pave – OMA/2), (Pave – OMA/6), (Pave+OMA/6), and (Pave+OMA/2), where the mean square error is calculated over the center 0.1 UI of the eye diagram.*

- *An eye diagram is formed from the equalized waveform. Note that this eye diagram does not include the noise that was added in step 1 above.*