TDECQ Part 1
Making Accurate and Repeatable Compliance Measurements

TDECQ Overview

TDECQ is the acronym used to describe “transmitter dispersion and eye closure quaternary”. This is a power penalty metric that describes how much extra power is required from a transmitter, relative to an ideal transmitter, to compensate for both non-ideal transmitter waveforms and the impact of chromatic dispersion. It is similar to the transmitter dispersion penalty (TDP) metric used in NRZ optical communications standards. It was developed in the IEEE 802.3bs standard and improved in the IEEE 802.3cd standard. It is a convenient way to specify the performance of a PAM4 transmitter, as it aggregates many transmitter attributes into a single metric, and the metric directly indicates the impact a transmitter’s imperfections will have on overall system-level performance.

TDECQ is a convenient way to specify the performance of a PAM4 transmitter, as it aggregates many transmitter attributes into a single metric that indicates the impact of a transmitter’s imperfections will have on overall system-level performance.

N1092x 26/53 GBd PAM4 Optical Ref Rcvr (1, 2, or 4 channels)

N1078A 16/32/64 GBd Optical Clock Recovery

Optical DUT
**TDECQ Definitions**

TDECQ effectively is a symbol-error-ratio (SER) based measurement that compares a physical transmitter device under test (DUT) to a virtual ideal transmitter. The DUT waveform is acquired with an oscilloscope that is configured as a virtual PAM4 receiver with a 5-tap feed-forward equalizer. Virtual Gaussian noise is added to the waveform and the SER of the DUT is mathematically estimated. The noise is increased until a target SER, on the order of 1e-4 (standard dependent), is observed. The tap values of the virtual receiver equalizer are automatically optimized to improve the DUT waveform to allow the maximum amount of added noise for the target SER. The virtual ideal transmitter, with the same optical modulation amplitude (OMA) as the DUT, is also subjected to added noise. Generally, more noise can be added to the virtual transmitter than the DUT to observe the target SER. The ratio of the two added noise values represents the DUT power penalty and is the PAM4 equivalent of the legacy TDP measurement used for NRZ transmitters.

**TDECQ Measurement Setup**

The TDECQ measurement is defined by IEEE 802.3bs and IEEE 802.3cd and is configured in the Keysight FlexDCA sampling oscilloscope interface as follows (verify the DCA-X frame + module or DCA-M calibrations are valid):

A. Mode: Select Eye/Mask mode

B. Acquisition: In the Setup/Acquisition menu enable Pattern Lock, enable “Acquire Entire Pattern”, set Samples/UI to “Automatic”, and enable “Wrap Waveform”

C. Channel: In the channel menu, choose the correct wavelength, enable SIRC and select the correct reference filter from the dropdown list (being careful to select a TDECQ configuration and not an NRZ filter). For example, the correct filter setting for 400GBASE-DR4 is labeled “53.125 GBd TDECQ (26.56 GHz)”. 

D. Equalizer: In the Measure/Waveform Signal Processing/Signal Processing menu, pull down the TDECQ equalizer block, assign the DUT waveform to the equalizer input and drag a function color to the equalizer output as shown below:

1. Click on the TDECQ equalizer block to open the TDECQ Reference Equalizer setup dialog.
2. Start by selecting the Taps tab on the left. In the preset menu, choose the correct standard (802.3cd preset recommended). See screen shot below.
E. Measurement: Select Measure/Eye Mask/PAM/TDECQ and apply the measurement to the function assigned to the TDECQ equalizer output. The DCA will acquire the waveform (approximately 5 seconds required with N1092), optimize the equalizer tap settings (about 5 seconds), and report the TDECQ value.

The reported TDECQ value is the effective power penalty for the DUT, indicating the extra power required, relative to an ideal transmitter, to overcome waveform impairments.

**Best Practices for Accurate TDECQ Measurements**

The TDECQ measurement has been optimized for use with the compliant SSPRQ test pattern. TDECQ can be performed on shorter patterns. However, short patterns are typically less complex than the SSPRQ pattern and are likely to yield optimistic results. Also, the TDECQ measurement process requires OMA and computes this from the pattern. SSPRQ has long runs of logic 0 and 3 levels, enabling an accurate OMA measurement. Shorter patterns may yield a less accurate OMA value, resulting in a less accurate TDECQ analysis.
A single SSPRQ pattern acquisition is sufficient for an accurate TDECQ measurement. To achieve sufficient sample populations if shorter patterns are used (note, shorter patterns are not compliant), increase the Samples/UI rather than acquiring additional patterns. This approach enables all acquired samples to be considered when the equalizer is being optimized. For example, if the test pattern used is PRBS13Q (8191 symbols) instead of SSPRQ (65535 symbols), at least 8x the Samples/UI should be used.

To increase Samples/UI go back to the Setup/Acquisition menu (see step A above) and choose “Manual” for Samples/UI. Rather than entering an integer value in the Samples/UI box, use the up arrow (circled in red in the screen shot below) to increase sample density. This allows FlexDCA to calculate the optimum next higher value of Samples/UI that results in a non-integer value. A non-integer value of Samples/UI results in a dense distribution of samples across the entire UI when the waveform is wrapped to create the eye diagram. That helps improve the accuracy and repeatability of measurement results.
It is a good measurement practice to verify that a valid pattern lock has been achieved. After executing a pattern lock, place the DCA into “oscilloscope mode” and confirm that the data pattern and not an eye diagram is observed:

![ Oscilloscope View Example ]

In this view, problems like excessive noise, jitter, or drift can be observed, which are often difficult to see when viewing the PAM4 eye.

The “iterative optimization” setting for optimization of the virtual equalizer is generally not used, as it requires extensive calculation time and yields a very small improvement in the TDECQ result.

![ Equalizer Setup Example ]

Specify Initial Tap Values
- Use Seed Taps
- Copy Current Taps

Seed taps for iterative optimization:
-0.250000, 1.500000, -0.250000, 0
If the TDECQ penalty is very large, the “iterative optimization” setting may yield an improvement that justifies the extra test time.

The TDECQ measurement is robust in the presence of instrumentation noise, as the oscilloscope channel noise is known and mathematically removed from the analysis. However, if signals are very small, oscilloscope noise may become significant and impair the ability of the DCA to construct the TDECQ measurement. An “SER?” value may be reported, indicating the presence of excessive noise. Large signals may also degrade TDECQ results, particularly when using very low noise channels like the N1092. When using the N1092, maintaining peak signal power levels at 1 mW or lower is advised for highest accuracy.

**Keysight TDECQ Solutions**

TDECQ measurements are easily performed with Keysight sampling oscilloscopes using FlexDCA Sampling Oscilloscope Software. The following lists example configurations:

86100D Oscilloscope mainframe

- Hardware option ETR (hardware option PTB recommended but not required)
- Flex DCA Firmware revision A.06.01 or higher
- Software package N1010100A or N1010200A. Feature-based software options 9FP or TFP could be used in place of the packages but are not recommended
- The following plug-in modules can be used
  - 86105D/86115D with options 281/282 and IRC (26 GBd and 53 GBd)
  - 86116C with options 025 and IRC (26 GBd and 53 GBd)
  - 86116C with options 041 and IRC (53 GBd)

N1000A oscilloscope mainframe

- Hardware option PLK (hardware options LOJ or LOJ + PTB are recommended but not required)
- N1010A FlexDCA Sampling Oscilloscope Software revision A.06.01 or newer and software package N1010100A or N1010200A
- The following plug-in modules can be used
  - 86105D/86115D with options 281/282 and IRC (26 GBd and 53 GBd)
  - 86116C with options 025 and IRC (26 GB and 53 GBd)
  - 86116C with options 041 and IRC (53 GBd)
N1092x DCA-M

- Hardware options PLK, LOJ, IRC and, for 26 GBd, option 168 (hardware option FS1 is recommended but not required)
- N1010A FlexDCA Sampling Oscilloscope Software revision A.06.01 loaded on a customer provided computer
- Software packages and options:
  - Recommended: Software package N1010100A or N1010200A loaded on the customer provided computer
  - Feature-based software options could be used in place of the software packages but are not recommended. Options 9TP or TTP can be loaded on the customer provided computer by the customer or option 9FP or TFP can be loaded on the DCA-M by Keysight

References

A. IEEE 802.3bs (TM): Standard for Ethernet Amendment: Media Access; Control Parameters, Physical Layers and Management Parameters for 200 Gb/s and 400 Gb/s Operation

B. IEEE P802.3cd Draft Standard for Ethernet Amendment: Media Access; Control Parameters, Physical Layers and Management Parameters for 50 Gb/s and 100 Gb/s Operation

C. J. King, D. Leyba, G. Le Cheminant, “TDECQ (Transmitter Dispersion Eye Closure Quaternary) Replaces Historic Eye-mask and TDP Test for 400 Gb/s PAM4 Optical Transmitters”, Optical Fiber Communications conference, March 2017

D. D. Leyba, G. Le Cheminant “Understanding Compliance Testing for PAM4 Optical Transmitters” Design Con 2018


F. IEEE Std 802.3bm(TM)-2015: Physical Layer Specifications and Management Parameters for 40 Gb/s and 100 Gb/s Operation over Fiber Optic Cables

Helpful DCA Documents

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