KEYSIGHT

TDECQ Calculation Method

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Addressing comments #94, #95, #96, #97, #98, #99, #100, #101, #102, and #103 against IEEE P802.3dj D3.1

Introduction

- Clause 180 received the most comments during the second standards association recirculation ballot for the IEEE 802.3dj project.
- Multiple concerns were raised regarding the TDECQ calculation method as currently defined by the spec.
- Given the timeline of the IEEE 802.3dj project, the CRG needs to build consensus around the TDECQ calculation method to avoid ending up with an incomplete intermediary measurement.
- This presentation proposes a complete re-write of the TDECQ calculation method that would address the following concerns:
    1. TDECQ does not require an eye diagram to be calculated.
    2. The current text describing the TDECQ calculation method is confusing and hard to follow.
    3. TDECQ combines the cumulative distribution functions of individual threshold to compute the symbol error rate instead of using the Q-function.
- The suggested remedy below shall replace the text in clause 180.9.6.4 starting from page 484 line 6 and ending on page 487 line 24 in draft 3.1.

Calculating TDECQ

TDECQ is calculated using the waveform equalized by the reference receiver described in 180.9.6.3 using optimized tap weights. TDECQ is relative to a target maximum Symbol Error Rate (SER_{target}) and is calculated as:

$$TDECQ = 10\log_{10}\left(\frac{\sigma_{ref}}{R}\right)$$

Where σ_{ref} is the noise RMS value that can be added at the input of a receiver to a signal with no impairments and equivalent OMA_{Outer} to the measured signal. It is calculated as:

$$\sigma_{ref} = \frac{OMA_{Outer}}{6Q_t}$$

Where Q_t is consistent with the target error rate and can be calculated as:

$$Q_t = \sqrt{2}\, erfc^{-1}\left(\frac{4}{3}SER_{target}\right)$$

Calculating TDECQ – *Continued*

R is the RMS noise that can be added by a receiver to the signal under test. It is calculated as:

$$R = \sqrt{C_{eq}^{-2}\sigma_g^2 + \sigma_s^2}$$

where,

σ_s is the intrinsic noise of the measurement channel.

σ_g is the maximum RMS value for the Gaussian noise $\eta(t)$ at the output of the equalizer.

C_{eq} is a coefficient that accounts for the noise gain of the reference equalizer.

An iterative process is used to find σ_g as the largest σ such that $SER(\sigma) < SER_{target}$.

Calculating TDECQ – *Continued*

The value of *Ceq* can be calculated from the product of the normalized noise power density spectrum *N(f)* at the input of the reference equalizer and the normalized frequency response $H_{eq}(f)$ of the feed-forward section of the reference equalizer, as shown in the equation below:

$$C_{eq} = \sqrt{\int_f N(f) \times |H_{eq}(f)|^2 df}$$

where,

> *N(f) is the normalized noise power density spectrum equivalent to white noise filtered by a fourth-order Bessel-Thomson response filter with a 3 dB bandwidth of 53.125 GHz.*

and

$$\int_f N(f)df = H_{eq}(f = 0) = 1$$

Calculating TDECQ – *Continued*

The nominal sub-eye threshold levels P_{th1}, P_{th2}, and P_{th3}, are determined from the OMA_{TDECQ} and the average optical power of the eye diagram (P_{ave}) as defined in the following equations and illustrated in the figure

$$P_{th1} = P_{ave} - \frac{OMA_{TDECQ}}{3}$$

$$P_{th2} = P_{ave}$$

$$P_{th3} = P_{ave} + \frac{OMA_{TDECQ}}{3}$$

where OMA_{TDECQ} is measured on the equalized captured waveform using the method defined in 180.9.5.

Calculating TDECQ – *Continued*

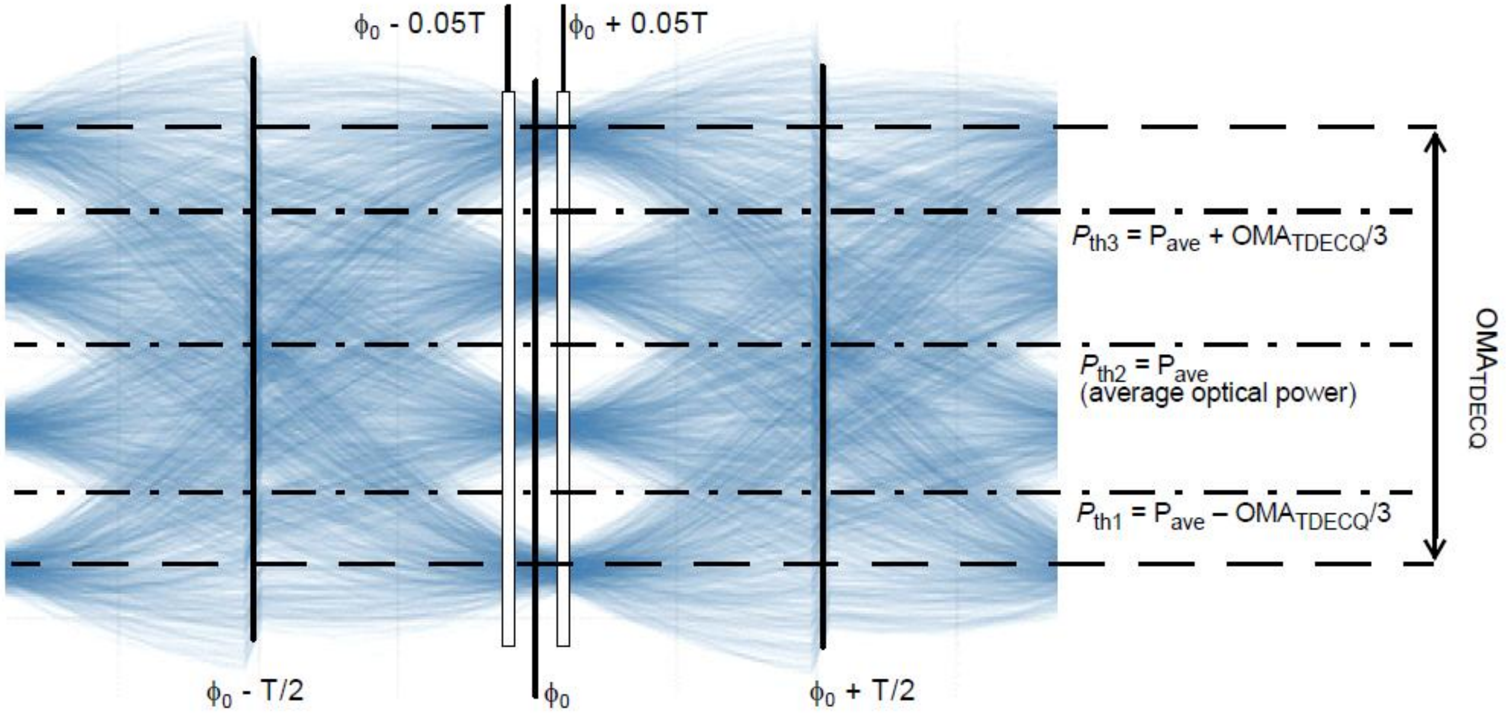

Figure 180–11—Illustration of the TDECQ measurement

Editors note: The histogram windows are shown in a non-ideal locations and should be centered.

Calculating SER(σ)

Let $y_n(t)$ be the output sample for the *nth* symbol with an offset of t, $0 \le t \le T$.

For a given phase offset, ϕ, two regions of a UI are considered, each centered 0.05UI before and after the sampling phase ϕ and have a width of 0.04UI. For the left side, all samples such that $\phi - \frac{0.07}{T} \le t \le \phi - \frac{0.03}{T}$ will be included. For the right side, all samples such that $\phi + \frac{0.03}{T} \le t \le \phi + \frac{0.07}{T}$ will be included.

The probability that a sample value, $y_n(t)$, will become an error given the additional noise, $\eta(t)$ with RMS σ can be calculated as:

$$P(\mathrm{y}_{\mathrm{n}(\mathrm{t})}, \sigma) = \frac{1}{2} \begin{cases} erfc\left(\frac{P_{th_1} - \mathrm{y_n(t)}}{\sqrt{2}\sigma}\right) & x_n = 0 \\ erfc\left(\frac{\mathrm{y_n(t)} - P_{th_1}}{\sqrt{2}\sigma}\right) - erfc\left(\frac{P_{th_2} - \mathrm{y_n(t)}}{\sqrt{2}\sigma}\right) & x_n = 1 \\ erfc\left(\frac{\mathrm{y_n(t)} - P_{th_2}}{\sqrt{2}\sigma}\right) - erfc\left(\frac{P_{th_3} - \mathrm{y_n(t)}}{\sqrt{2}\sigma}\right) & x_n = 2 \\ erfc\left(\frac{\mathrm{y_n(t)} - P_{th_3}}{\sqrt{2}\sigma}\right) & x_n = 3 \end{cases}$$

Calculating SER(σ) – *Continued*

The Symbol Error Rate for the left and right histograms can be calculated as:

$$SER_L(\phi,\sigma) = \frac{1}{N} \sum_{\forall yn(t) \in RL(\phi)}^{k} P(\mathrm{y_n}(\mathrm{t}), \sigma)$$

$$SER_R(\phi,\sigma) = \frac{1}{N} \sum_{\forall y_n(t) \in RR(\phi)}^{k} P(\mathrm{y_n}(\mathrm{t}), \sigma)$$

Where,

$$R_L = \left\{ \mathrm{y_n}(\mathrm{t}) \middle| \phi - \frac{0.07}{T} \le t \le \phi - \frac{0.03}{T} \right\}$$

$$R_R = \left\{ \mathrm{y_n}(\mathrm{t}) \middle| \phi + \frac{0.03}{T} \le t \le \phi + \frac{0.07}{T} \right\}$$

N is the total number of samples used.

Calculating SER(σ) – *Continued*

Alternatively, the *y* values can be collected into histograms, one histogram for each combination of signal level and side. The two sides are combined as:

$$SER(\phi,\sigma) = max\{SER_L(\phi,\sigma), SER_R(\phi,\sigma)\}$$

When the $SER(\phi,\sigma)$ is calculated, the thresholds, P_{th1}, P_{th2}, and P_{th3} are adjusted by up to $\pm 1\%$ of OMA_{TDECQ} to find a minimum.

Finally, $SER(\sigma)$ is the minimum $SER(\phi,\sigma)$ over $0 \leq \phi \leq T$.

Summary

- This contribution addresses multiple concerns raised by the IEEE 802.3dj CRG and proposes the complete text to replace the current TDECQ calculation method.
- The proposed text describes the TDECQ calculation method in a simplified way that makes it easier for the reader to follow which helps improve TDECQ measurement accuracy and repeatability.
- The proposed text removes the confusion created by describing how an eye diagram can be obtained with the presence of a decision feed back tap in the reference equalizer (TDECQ does not require an eye diagram to be computed).
- The proposed method uses the Q-function to compute the symbol error rate SER instead of the current method that combines the cumulative distribution function for individual thresholds.
- The proposed text does **NOT** change the MMSE optimization method for the TDECQ reference equalizer that was adopted in draft 3.1.
- The contribution provides the full text to be adopted in the IEEE 802.3dj spec to avoid ending up in an interim state with a broken spec.

Thank you