KEYSIGHT

Refining the Definition of $TDECQ_{CER}$

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Addressing comments #112, #113, #114, #115, #117 and #118 against IEEE P802.3dj D2.2

AGENDA

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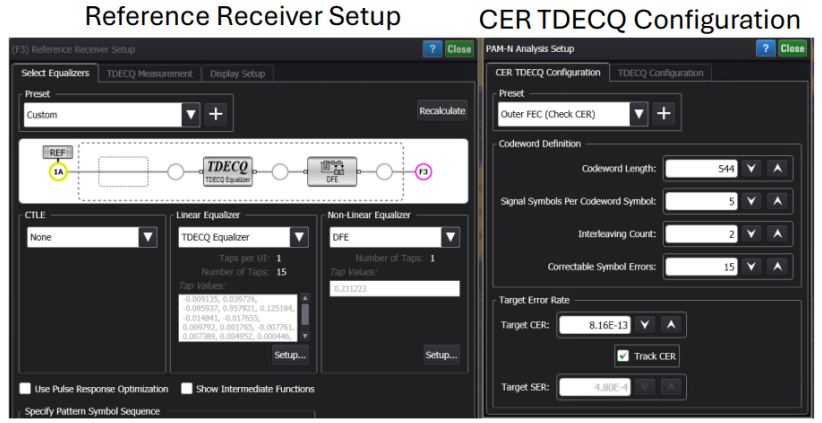
Introduction

- IEEE 802.3dj adopted $TDECQ_{CER}$ (clause 180.9.7) as an additional transmitter power-penalty metric for optical transmitters in clauses 180, 181, 182 and 183 as proposed in chayeb_3dj_01b_2509.
- This presentation proposes several changes that aim to refine the definition of $TDECQ_{CER}$ and address a few TBD parameters left in the current draft (IEEE 802.3dj D2.2).
- This presentation also provides additional test data that supplements the experimental data presented in chayeb_3dj_01c_2507 and addresses measurement repeatability concerns brought up during the last IEEE 802.3 WG meeting.
- The presentation also proposes a wording change to clarify the equations used to calculate the probability of error for each symbol, *Ln*.
- This presentation addresses comments #112, #113, #114, #115, #117 and #118 against IEEE 802.3dj D2.2.

Addressing $TDECQ_{CER}$ Measurement Repeatability Concerns

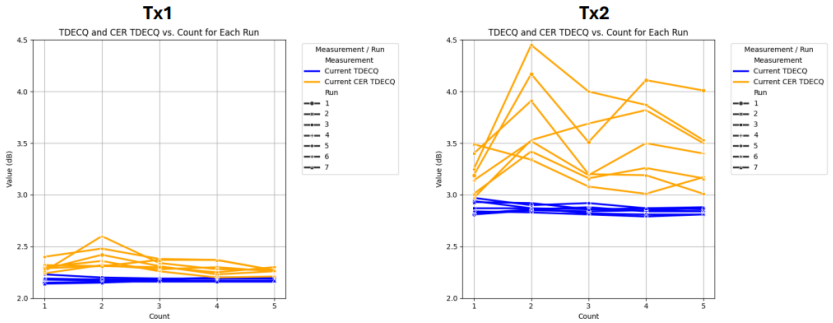
Initial evaluation of $TDECQ_{CER}$ raised concerns around measurement repeatability

- IEEE 802.3dj draft 2.2 adopted $TDECQ_{CER}$ as an additional transmitter power-penalty metric for optical transmitters in clauses 180, 181, 182 and 183 as proposed in chayeb_3dj_01b_2509.
- A FlexDCA beta with an early implementation of $TDECQ_{CER}$ was circulated among IEEE 802.3dj WG members to gather data and validate the new metric.
- Rodes_3dj_02a_2509 gave an initial evaluation of $TDECQ_{CER}$ and concluded that the measurement serves a valuable purpose but needed further refinement ti improve measurement repeatability.
- The FlexDCA beta used to collect the data used a default value of 8 samples/UI to acquire the waveforms which was not sufficient to guarantee at least one sample/symbol/histogram.



Test Repeatability

- Record TDECQ and CER TDECQ for every pattern accumulation up to 5 (Count)
- repeating the test 7 times (runs)
- On a higher TECQ Tx and a lower TECQ Tx



CER TECQ can varies and does not seem to converge when collecting more data (up to 5 counts)
The variation is higher for high TECQ Tx

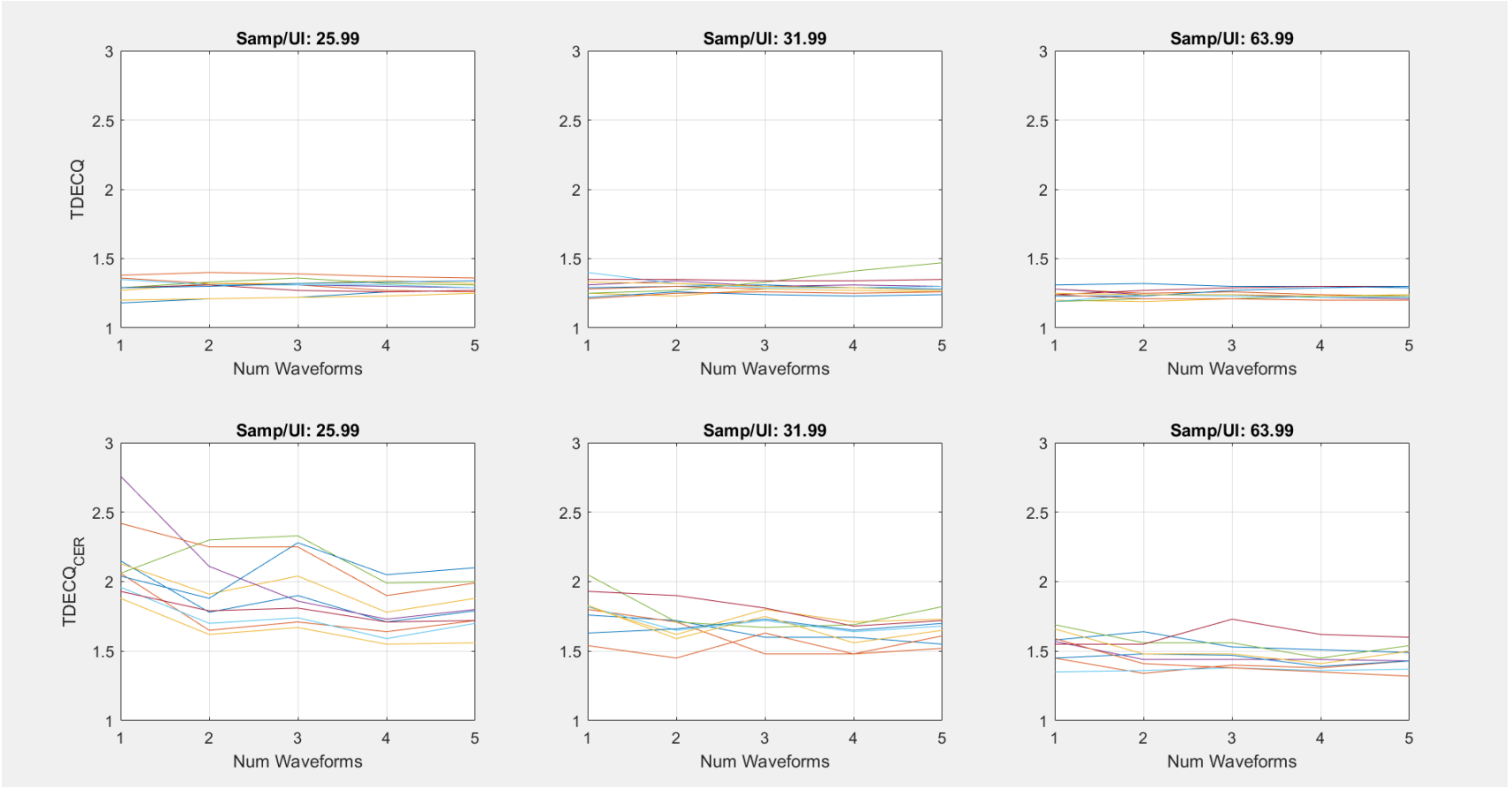
Rodes_3dj_02a_2509

Experimental Data on $TDECQ_{CER}$ Measurement Repeatability

New FlexDCA P08.30.73 beta implementation of $TDECQ_{CER}$ shows improvement in measurement repeatability

Test Setup:

- Waveforms were acquired with 25.99, 31.99 and 63.99 samples/UI
- TDECQ and $TDECQ_{CER}$ were measured for 1, 2, 3, 4 and 5 accumulated waveforms.
- Measurement was repeated 10 times for each waveform acquisition
- Results show less than 0.5dB variability with 63.99 samples/UI
- Further improvement is expected as the measurement matures



Additional Experimental Data

- Re-measured the waveforms collected from 8 different modules and presented in chayeb_3dj_01b_2509.
- All modules were running at 212.5 Gbps with KP4 FEC encoding.
- Results are consistent with previous measurements and considered within the measurement accuracy margin.
- Power Penalty calculated using two reference equalizers:
  1. 15-tap FFE
  2. 15-tap FFE + 1T DFE
- Modules 1, 2, 5 and 6 have similar very TDECQ results despite the different FEC bin count.
- CER TDECQ seems to be penalizing modules 5 and 6.

Module	Data Rate (Gbps)	Pattern	OMA (dBm)	ER (dB)	RLM	Ceq (dB)	TDECQ (FFE) (dB)	CER TDECQ (FFE) (dB)	TDECQ (+DFE) (dB)	CER TDEC (+DFE) (dB)	FEC Bin Count
1	212.5	SSPRQ	1.804	4.368	0.987	0.74	2.19	2.24	1.78	1.85	2
2	212.5	SSPRQ	1.816	4.371	0.985	0.72	2.24	2.21	1.8	1.8	2
3	212.5	SSPRQ	1.781	5.034	0.995	0.73	3.68	4.8	3.64	4.86	7
4	212.5	SSPRQ	1.769	5.004	0.996	0.75	3.79	5.14	3.69	5.28	7
5	212.5	SSPRQ	1.237	3.528	0.956	0.23	2.22	2.28	1.9	3.12	7
6	212.5	SSPRQ	1.24	3.546	0.957	0.24	2.22	2.21	1.92	3.14	7
7	212.5	SSPRQ	0.389	2.831	0.988	0.71	3.14	3.31	2.61	2.7	7
8	212.5	SSPRQ	0.389	2.835	0.989	0.72	3.13	3.2	2.56	2.6	7

Defining $TDECQ_{CER}$ Parameters for KP4 FEC PMDs (Clauses 180, 181)

Addressing the TBDs in the draft

- The current IEEE 802.3dj draft 2.2 has TBDs for SER_{target} and CER_{target} in table 180-17, clause 180.9.7
- All the experimental data shared previously were collected using an CER_{target} consistent with the target SER for TDECQ defined in clause 180.9.6 ($SER_{target} = 4.56e^{-4}$)
- **<u>Suggested Remedy:</u>** Change the values for SER_{target} and CER_{target} to be consistent with the target SER in clause 180.9.6
  - $SER_{target} = 4.56e^{-4}$
  - $CER_{target} = 3.82e^{-13}$

Table 180–17—$TDECQ_{CER}$ parameters

Parameter name	Value
Number of symbols per FEC codeword, d	544
Codeword interleaving depth, r	4
Number of correctable FEC symbols per FEC codeword, k	15
Number of PAM4 symbols per FEC symbol, m	5
Target SER, SER_{target}	TBD
Target CER, CER_{target}	TBD

IEEE P802.3dj Draft 2.2 – Clause 180.9.7

Defining $TDECQ_{CER}$ Parameters for iFEC PMDs (Clauses 182, 183)

Addressing editor's note in clauses 182 and 183

- The current IEEE 802.3dj draft 2.2 has an editor's note indicating the need for additional details to implement $TDECQ_{CER}$ in clauses 182 and 183.
- **Suggested Remedy:** Add a new $TDECQ_{CER}$ parameters table, 182-xx, in clause 182.9.7

Parameter name	Value
Number of symbols per FEC codeword, *d*	64
Codeword interleaving depth, *r*	8
Number of correctable FEC symbols per FEC codeword, *k*	3
Number of PAM4 symbols per FEC symbol, *m*	1
Target SER, SER_{target}	$9.60e^{-3}$
Target CER, CER_{target}	$3.41e_{-3}$

- Add an exception for $TDECQ_{CER}$ in clause 182.9.7:
  "- $TDECQ_{CER}$ is calculated using the parameter values in table 182-xx."
- Implement remedy in clause 183.9.7 with editorial license.

182.9.7 Codeword error ratio TDECQ ($TDECQ_{CER}$)

The $TDECQ_{CER}$ of each lane shall be within the limit given in Table 182–7.

$TDECQ_{CER}$ is measured using the methods specified in 180.9.7, with the following exception:

— $TDECQ_{CER}$ is calculated using the equalized waveform and all optimized parameters from the TDECQ measurement specified in 182.9.6.

Editor's note: This subclause is a result of the approach adopted by D2.1 Comment #179 implementing slides 12 to 19 of https://www.ieee802.org/3/dj/public/25_09/chayeb_3dj_01b_2509.pdf. The presentation provide guidance for clauses with only outer FEC. A new contribution is required to provide the necessary details to implement for clauses with inner FEC. For instance, FEC codeword length, symbol length, interleaving and target codeword error ratio will need to be defined.

IEEE P802.3dj Draft 2.2 – Clause 182.9.7

183.9.7 Codeword error ratio TDECQ ($TDECQ_{CER}$)

The $TDECQ_{CER}$ of each lane shall be within the limit given in Table 183–6.

$TDECQ_{CER}$ is measured using the methods specified in 180.9.7 with the following exception:

— $TDECQ_{CER}$ is calculated using the equalized waveform and all optimized parameters from the TDECQ measurement specified in 183.9.6.

Editor's note: This subclause is a result of the approach adopted by D2.1 Comment #179 implementing slides 12 to 19 of https://www.ieee802.org/3/dj/public/25_09/chayeb_3dj_01b_2509.pdf. The presentation provide guidance for clauses with only outer FEC. A new contribution is required to provide the necessary details to implement for clauses with inner FEC. For instance, FEC codeword length, symbol length, interleaving and target codeword error ratio will need to be defined.

IEEE P802.3dj Draft 2.2 – Clause 183.9.7

Defining Minimum Required Samples/UI to Calculate $TDECQ_{CER}$

Guaranteeing at least one sample falls within both left and right histograms for each symbol

- The current definition for $TDECQ_{CER}$ calculation method does not specify a minimum number of samples/UI for waveform acquisition on a sampling scope.
- $TDECQ_{CER}$ calculation requires at least one sample to fall within both left and right histogram per symbol.
- On a sampling oscilloscope, the waveform should be acquired with greater than 25 samples/UI, for the histogram width of 0.04UI, to guarantee at least one sample/histogram/symbol.
- **<u>Suggested Remedy:</u>** Add the text below at the end of the first sentence in sub-clause 180.9.7.1

  "The waveform should be acquired with greater than 25 samples/UI. For the histogram width of 0.04 UI, to guarantee at least one sample falls within both the left and the right histogram, for each symbol."

180.9.7.1 $TDECQ_{CER}$ measurement method

$TDECQ_{CER}$ is calculated using the equalized waveform and all optimized parameters from the TDECQ measurement specified in 180.9.6.4.

$CER_L(\sigma)$ and $CER_R(\sigma)$ are the codeword error ratios with a given RMS noise σ, associated with the left and right histograms illustrated in Figure 180–11. $CER_L(\sigma)$ is defined in Equation (180–13), $CER_R(\sigma)$ is defined in Equation (180–14).

$$CER_L(\sigma) = 1 - G_L(\sigma) \quad (180–13)$$

$$CER_R(\sigma) = 1 - G_R(\sigma) \quad (180–14)$$

IEEE P802.3dj Draft 2.2 – Clause 181.9.7.1

Calculating the Probability of Error for Each Symbol in $TDECQ_{CER}$

Guaranteeing at least one sample falls within both left and right histograms for each symbol

- The definition for the probability of error for each symbol, *Ln*, in clause 180.9.7.1 is not clear.
- **<u>Suggested Remedy:</u>** Change the text in figure to:

"The probability of error for each symbol L_n is calculated by first taking all the samples points within the limits of the target histogram of the *n*th symbol. The amplitude of the *M* samples are $y_{n,i}$.

The probability that the *n*th symbol is in error, can be calculated as:

$$P_{err,n}(\sigma) = \frac{1}{M}\sum_{i=0}^{M-1} P_{n,i}(\sigma)$$

where $P_{n,i}(\sigma)$ is the probability of the *i*th sample of the *n*th symbol being in error, defined as:

$$P_{n,i}(\sigma) = \frac{1}{2}\begin{cases} erfc\left(\frac{P_{th_1} - y_{n,i}}{\sqrt{2}\sigma}\right) & L_n = 0 \\ erfc\left(\frac{y_{n,i} - P_{th_1}}{\sqrt{2}\sigma}\right) + erfc\left(\frac{P_{th_2} - y_{n,i}}{\sqrt{2}\sigma}\right) & L_n = 1 \\ erfc\left(\frac{y_{n,i} - P_{th_2}}{\sqrt{2}\sigma}\right) + erfc\left(\frac{P_{th_3} - y_{n,i}}{\sqrt{2}\sigma}\right) & L_n = 2 \\ erfc\left(\frac{y_{n,i} - P_{th_3}}{\sqrt{2}\sigma}\right) & L_n = 3 \end{cases}$$

where *erfc*() is the complementary error function."

The probability of error for each symbol L_n is calculated by first taking the sample point closest to the center of the target histogram while being within the limits of the histogram. The amplitude of that sample is y_n.

The probability that L_n is in error, is calculated according to Equation (180–15)

$$P_{err,n}(\sigma) = \begin{cases} \frac{1}{2}erfc\left(\frac{P_{th1} - y_n}{\sqrt{2}\sigma}\right), \text{ for } L_n = 0 \\ \frac{1}{2}erfc\left(\frac{y_n - P_{th1}}{\sqrt{2}\sigma}\right) + \frac{1}{2}erfc\left(\frac{P_{th2} - y_n}{\sqrt{2}\sigma}\right), \text{ for } L_n = 1 \\ \frac{1}{2}erfc\left(\frac{y_n - P_{th2}}{\sqrt{2}\sigma}\right) + \frac{1}{2}erfc\left(\frac{P_{th3} - y_n}{\sqrt{2}\sigma}\right), \text{ for } L_n = 2 \\ \frac{1}{2}erfc\left(\frac{y_n - P_{th3}}{\sqrt{2}\sigma}\right), \text{ for } L_n = 0 \end{cases} \quad (180\text{–}15)$$

where *erfc*() is the complementary error function

IEEE P802.3dj Draft 2.2 – Clause 181.9.7.1

Summary

- Initial evaluation of $TDECQ_{CER}$ shows that the new metric can capture errors synchronous to the pattern which are not captured by the TDECQ as demonstrated in chayeb_3dj_01b_2509 and rodes_3dj_02a_2509.

- TDECQ and $TDECQ_{CER}$ will have a similar power penalty for a well-behaved transmitter, whereas $TDECQ_{CER}$ will penalize transmitters with pattern dependent distortion which cannot be corrected by the FFE as shown in ghiasi_3dj_01_2511.

- Experimental data shows that $TDECQ_{CER}$ is a power penalty metric that correlates to post FEC CER without adding additional burden since it leverages the existing test infrastructure as shown in chayeb_3dj_02_2511.

- This presentation proposes several refinements to the definition of $TDECQ_{CER}$ that addresses TBDs in draft 2.2, clarifies the calculation method and improves the measurement repeatability.

- $TDECQ_{CER}$ is still a new metric that can improve further with contributions from the broader community in IEEE 802.3 working group.

- This presentation provides suggested remedies to address comments #112, #113, #114, #115, #117 and #118 against IEEE 802.3dj draft 2.2.

KEYSIGHT

Thank you