Block TDECQ Test Method

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Overview

- **Concern about TDECQ not capturing jitter**
- **Current TDECQ method**
- **Block processing**
- **TDECQ based on block processing**
- **Summary.**

Improving TDECQ Test Method

- **Ghiasi_3dJ_01_2501 proposes several enhancements to TDECQ method**
  - Testing TDECQ in mission mode – part of D1.5
  - Adding counter propagating traffic during TDECQ test – Part of D1.5
- **Mi_3dJ_02a_2409 investigate possible method how to better define TECQ/TDECQ to capture effect of block errors – will improve TECQ/TDECQ correlation to post-FEC**
- **Current TDECQ test method provides average TDECQ over ~ 1 seconds assuming Oscope and all perturbation events gets averaged out**
  - The problem with average TDECQ method is that over this TDECQ measurement window over 39 Millions FEC frames are transmitted
    - A single FEC frame with 16 error symbols is sufficient to result in non-correctable FEC frame
  - This contribution leverages method of healey_3dj_02a_2409 to process SSPRQ waveforms as blocks with real time scope to determine the $TDECQ_{Max}$
  - $TDECQ_{Max}$ will also address concern raised by Mi_3dJ_02a_2409 on how to capture effect of block errors and concerns raised by ran_3dj_elec_01_240822 due to jitter
- **The advantage of measuring $TDECQ_{Max}$ by using Blocks is that there is no need for Golden hardware receiver which may introduce its own block errors and may not even be available commercially.**

Current TDECQ SER Calculation

- **Two normalized histogram created (Left and Right) are created and associated function F(yi) equal to the number of sample captured divided by number of sample in the histogram window**
  - The sum of all F(yi)=1
  - Three cumulative probability functions are created for left and right histogram F(yi)
    - The three histograms are for level 1, 2, 3
  - The left cumulative function given below:
    - $CF_{Li}(y_i) = \begin{cases} \sum_{y=P_{th1}}^{y_i} F(y) \; for \; y_i \geq P_{th1} \\ \sum_{y=y_i}^{P_{th1}} F(y) \; for \; y_i < P_{th1} \end{cases}$
    - Each element of CF_{L1}, CF_{L2}, and CF_{L3} are multiplied with associated threshold to partial SER for each level, then the 3 left cumulative distribution summed to get SER(left)
  - The larger of SER_L or SER_R is used for TDECQ calculation
- **The current TDECQ calculate SER_L or SER_R (PAM4 symbols)**
  - Currently one full SPPRQ waveform is captured on the Oscope for SER_L or SER_R and TDECQ calculation which takes ~ 3 seconds.

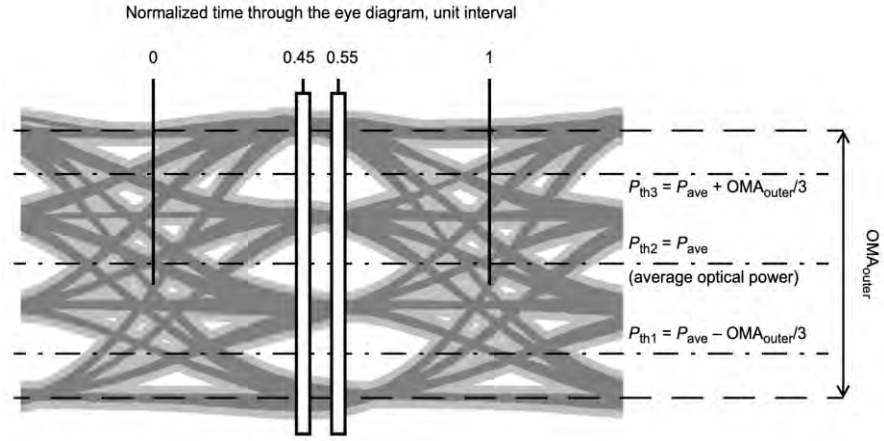
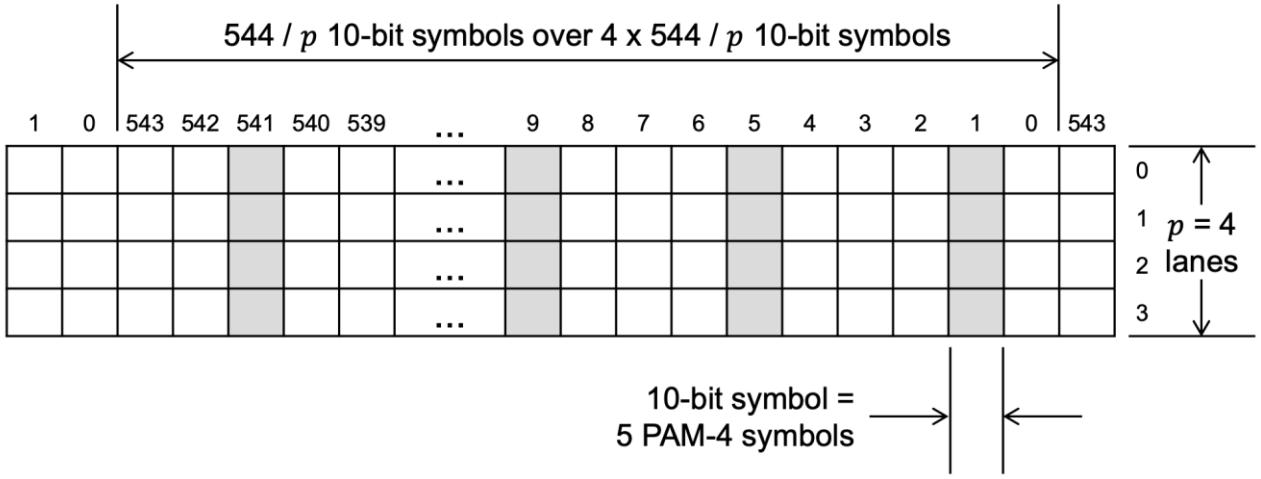
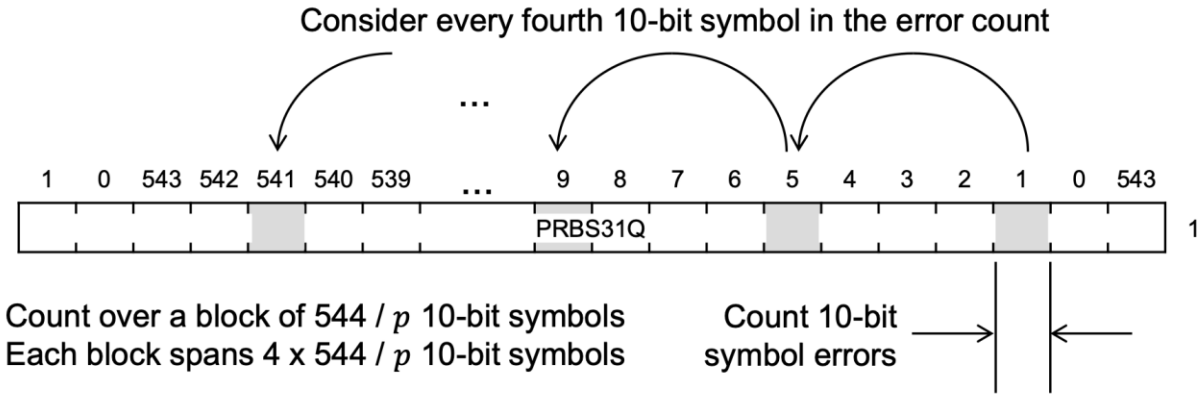


Figure 121–5—Illustration of the TDECQ measurement

Block Processing to Determine $TDECQ_{Max}$

- **Proposal from healey_3dj_02a_2409 show mechanisam to process PRBS data similar to FEC symbols block processing**
  - Exact same mechanisam can be used for optical signal at TP2 with real time scope and SSPRQ pattern
  - Block processing of SSPRQ waveform at TP2 will capture perturbations and jitter
  - TDECQ processed block waveform results in $TDECQ_{Max}$.
  - To capture blocks as shown below require real time scope but Equivalent Time Oscope (ETO) also captures periodic jitter/effects but the reported penalty/TDECQ maybe < $TDECQ_{Max}$
    - ETO's blocks are assembled from bits are from later samples but at the same exact location in the waveform and may not capture $TDECQ_{Max}$.





$TDECQ_{Max}$ Based on Block Processing

- **Block processing of SSPRQ waveform (SSPRQ pattern length 65,535 PAM4 symbols)**
  - $TDECQ_{Max}$ ignores effect of averaging across lanes for simplicity
  - A FEC block would consist of 5 PAM4 symbols
  - Capture 10 SSPRQ waveform, each SSPRQ waveform forms 655,350 PAM4 symbols
  - KP4 FEC with 4-way interleaving creates 4*544 or 2176 FEC symbol blocks (10880 PAM4 symbols)
  - 10 repetition of SSPRQ forms ~60 4-way KP4 frames
  - Pick the worst 6 4-way KP4 frames to form the PDF
    - Calculate TDECQ on each of 60 blocks to determine the worst 6 blocks
  - From the PDF calculate SER_L or SER_R
  - Use existing TDECQ definition by using the larger of SER_L or SER_R to calculate $TDECQ_{Max}$
- **TDECQ based on 10 SSPRQ waveforms extend asynchronous jitter capture from ~810 kHz (single SSPRQ waveform capture) to ~81 kHz**
- **Number of errors per 4*544 FEC frame or 10880 PAM4 symbol**
  - FECo at target SER of 4.8e-4 has ~5 errored PAM4 symbols (or ~15 for 3 4-way KP4 frame)
  - FECi at target SER of 9.6e-3 has ~104 errored PAM4 symbols (or ~312 for 3 4-way KP4 frame).

Average TDECQ vs $TDECQ_{Max}$

- **What is in the draft today is average TDECQ**
  - Average TDECQ with current limits stay in the draft and will be called Average TDECQ
- **Proposed limit for $TDECQ_{Max}$ is under study (+0.4 dB?) excursion above the current average TDECQ limit based on worst TDECQ block**
  - One may establish the relationship between average block TDECQ for the design to avoid measuring $TDECQ_{Max}$ on every module.

Methods to Mitigate and Quantity Optical Block Errors

- **ran_3dj_02a_2407 proposed to use $J3u_{03}$ and J_{RMS} for optical PMDs to mitigate block errors**
  - $J3u_{03}$ and J_{RMS} may help mitigate some error events but given that jitter spectrum is not measured and jitter measurement is not across FEC frame unlikely to be an effective method to discriminate against FEC block errors on passing TDECQ
  - ran_3dj_elec_01_240822 is an improvement by measuring phase noise but given phase noise measurement is averaged errored FEC blocked may not indicate
- **A functional hardware receiver was suggested by Mr. Cole, see https://www.ieee802.org/3/df/email/optx/msg00153.html**
  - A functional hardware receiver is not a Golden reference receiver and should not be operated at sensitivity as it may introduce its own block errors
- **Block TDECQ measurement – this proposal**
  - Block TDECQ determines if transmitter has block penalty that may cause block errors in the receiver without needing a hardware receiver
    - Worth investigating whether Equivalent Time OScope (ETO could be used to gain some indication of variability in TDECQ measurements indicating potential FEC tail issues
    - As the speed increases cost of real time and ETOs are converging and at higher rate building CDR for ETO is an issue!

Summary

- **There have been reports of compliant TDECQ transmitters resulting in high FEC codeword errors and we need to address these shortcoming in DJ taskforce**
  - TDECQ measurement is now tested in mission mode, see Ghiasi_3dj_01_2501
  - TDECQ measurement is now include counter-propagating crosstalk source, see Ghiasi_3dj_01_2501
- **Measuring $TDECQ_{Max}$ is the best way to determine transmitter/host/PLL/power supply are not causing any issue that may result in FEC tail**
- **Both real time and Equivalent Time OScope (ETO) may be used to measure $TDECQ_{Max}$**
  - Real time scope offers block processing more like KP4 FEC block processing and 3 out of 30 worst blocks are used for $TDECQ_{Max}$ calculation – more exact solution
  - ETO constructs the block from non-consecutive samples in the waveform and expect to produce similar result for repetitive jitter/noise events – need confirmation
    - Since 6 out of 60 worst blocks are used for TDECQ calculation on ETO measured TDECQ value will be higher than average TDECQ and closer to $TDECQ_{Max}$.
- **Other methods proposed that can improve burst error if only average TDECQ is defined**
  - Functional hardware receiver may not catch non-pathological cases given operation well above sensitivity
  - Jitter measurement offer some benefit but doesn't provide clear indication that measured TP2 jitter will or will not cause blook errors.