Improving TDECQ Test Coverage

(Addressing comments 343, 345, 347, 349)

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Supporter

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Overview

- **Section I – Background why TDECQ is not capturing jitter**
- **Section II – Block TDECQ/Spherical TDECQ**
- **Section III – Additional tap limits to control block error**
- **Section IV – Functional receiver definition**
- **Summary**

Section I – Background Why TDECQ is not capturing jitter

Background on 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 Mazzini OIF 2024.449.02 due to bandlimited RJ later represented by ran_3dj_elec_01_240822 in 802.3dj
- **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.**

Getting to the Root Cause

- **ran_3dj_02a_2407 based on Mazzini work proposed to use $J3u_{03}$ and J_{RMS} for optical PMDs to mitigate block errors but giving these are average measurement will not mitigate block errors**
  - Bad transmitters with high high bandlimited jitter were identified by using a reference receiver
- **chayeb_3dj_01_2505 showed that some compliant TDECQ transmitters by purposely adding positive pre-cursors results in reference receiver having block errors**
  - This problem most likely due to receiver Muller-Muller timing recovery and TDECQ is not expected to catch it
  - The way to mitigate this issue is by limiting pre/post taps to not allow weirds settings
- **A BER test was suggested by Mr. Cole, see https://www.ieee802.org/3/df/email/optx/msg00153.html**
  - True BER/Block Error require Golden Hardware receiver which unlikely to exist
  - A compliant 802.3dj receiver adjusted for DUT transmitter and operated +1 dB above sensitivity can be used to observe transmitter contribution to block errors, this receiver is called "Functional Hardware Receiver"
- **Block TDECQ proposed by ghiasi_3dj_03a_2505 tries to captures 60 TDECQ blocks to determine if there is excursion in TDECQ due to burst and jitter**
  - Block TDECQ determines if transmitter has block penalty that may cause block errors in the receiver without needing a hardware receiver
- **Sometime transmitter with TX FIR settings resulting in TDECQ>3.4 dB produces better block BER**
  - With increasing overshoot waveform non-linearity increases and TDECQ not incorporating effects of compression and ENOB will not show actual penalty is increasing
  - OLT proposal ghiasi_3dj_01_2311 with presets and allow TDECQ for non-default presets to about + 1 dB excursion and receiver 1st tries default setting then it will cycle through other setting and pick the best
  - Also enabling 1 TDFE will mitigate the need for higher overshoot
  - Adding linearity test by using linear pulse fit is another option.

Pro and Cons of Various Methods to Supplement TDECQ

- **TDECQ is an average penalty using an ideal receiver and wasn't designed to captured block error penalty!**

Additional Test	Pro	Cons
J3U/JRMS	Can limit transmitter with high average jitter similar to TDECQ	Measurement redundant per Ghiasi and Anil Mehta (T11-2025-00114-v000) results presented in FC, and may result in additional yield loss
Phase noise measurement	Can limit transmitter with an integrated high phase noise over a band	Better than J3U/JRMS but this measurement is average and may not isolate transmitter with block errors
Overshoot/Peak to Average Penalty	TDECQ detector is ideal signal not penalized with increase overshoot and reducing overshoot is a good option (TDECQ with DFE doesn't rely on overshoot)	TDECQ can enhanced by incorporating Overshoot/PAR penalty if needed longer term
Limiting Weird Tap settings	Will address issue brought by chayeb_3dj_01_2505 which is related to timing recovery	Will address this issue but another DSP may have a different weakness
Adding DFE to TDECQ	Make reference receiver more like actual receiver and shifts margin from RX to TX	May add burst errors for Bmax>0.35 and can make LPO/RTLR implementations harder
Functional hardware receiver	Catch block errors and to reduce HW receiver block errors contribution must operate 1-2 dB above sensitivity	Can only catch growth block errors rather than quality of transmitter, may see different result with different DSP's
Block/Enhanced TDECQ	Address Mazzini high jitter case and will provide block TDECQ instead of average TDECQ	Will not address issue brought by chayeb_3dj_01_2505 as TDECQ doesn't include aspect of timing recovery

Pro and Cons of Various Method to Mitigate Block Errors

- **Some may have given up on TDECQ because some compliant transmitters may fail block BER and in some cases transmitters with higher TDECQ may have better block BER**
  - TDECQ is doing what it should do but can be enhanced and any other test will have its own limitation
    - Mazzini OIF 2024.449.02 raised issue is due to bandlimited transmit RJ that affect certain blocks unproportionally
    - chayeb_3dj_01_2505 raised issue with weird tap settings affecting certain DSP Timing Recover (TR) but TDECQ doesn't incorporate a TR
    - TDECQ doesn't include any compression or Peak-to-Average Ratio (PAR) Penalty, ghiasi_3dj_04a_2507, effects and given overshoot drives TDECQ lower without considering ADC penalties!

3 Key Issues Issues	J3U/JRMS	Phase noise measurement	Reduce Overshoot	Limiting Weird Taps	Adding DFE	Hardware Functional RX	Block TDECQ/Chayeb Improved TDECQ	Adding ILT Presets
Mazzini Raised Issue Passing TDECQ but failing Block BER	No	No	No	No	NO	Yes	Yes	NO
Chayeb Raised Issue Passing TDECQ fail block BER	No	NO	NO	Yes	No	Maybe	No	No
TDECQ>3.4 dB has Better block BER	No	NO	Yes	No	Yes	Maybe	No	Yes

Section II – Block TDECQ

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.

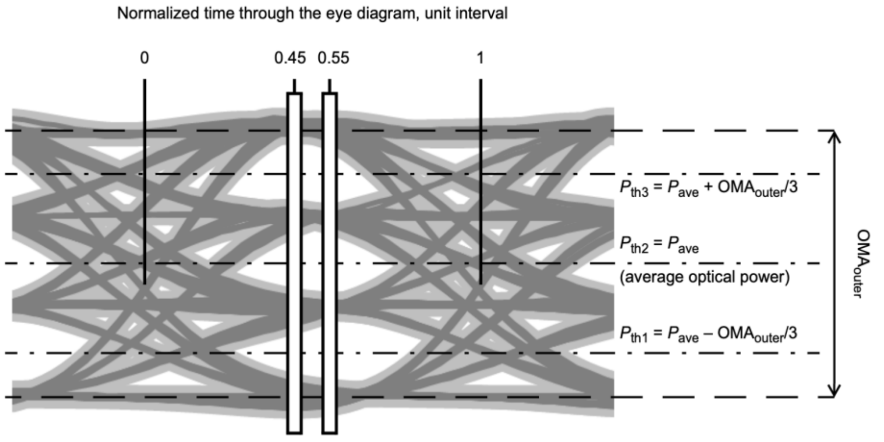
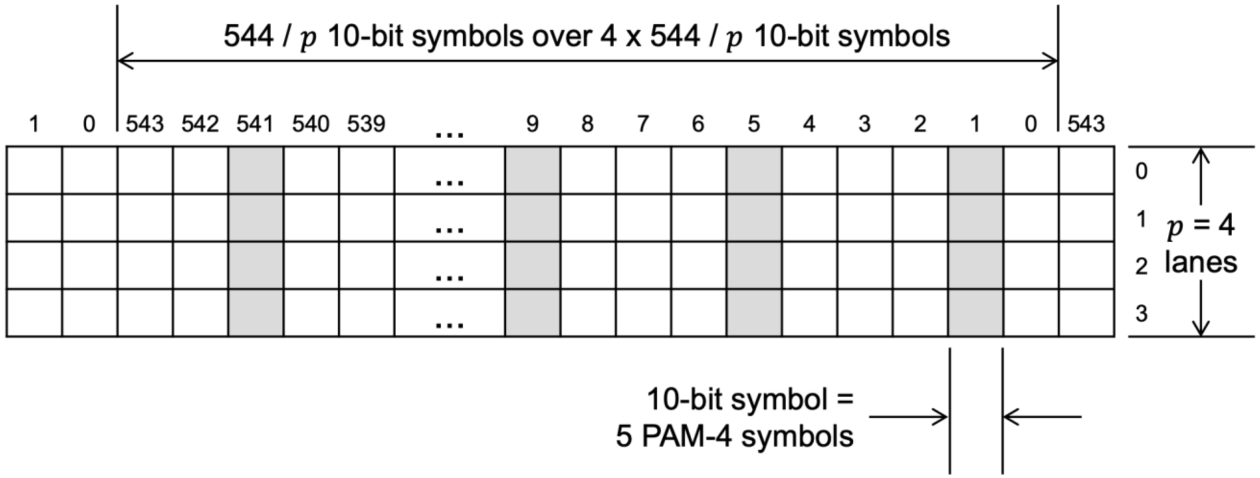
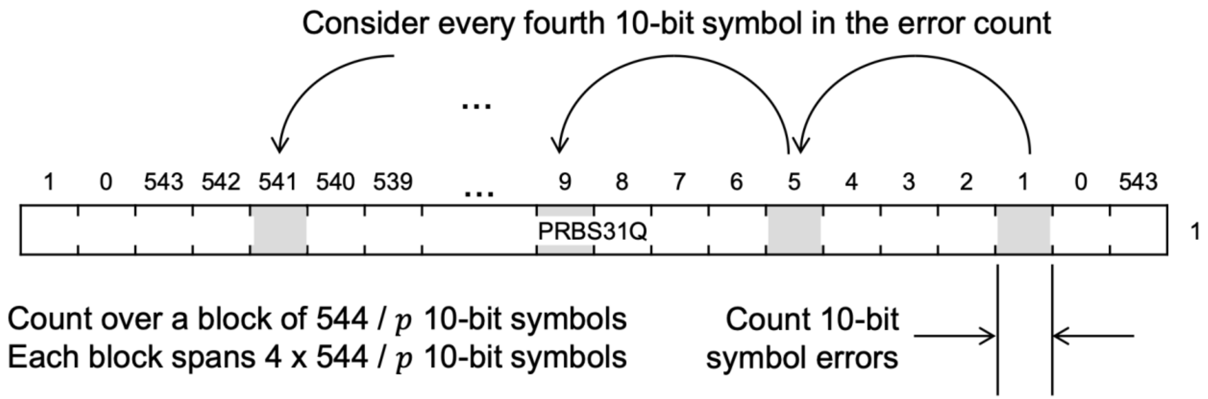


Figure 121–5—Illustration of the TDECQ measurement

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).

Block/Improved TDECQ

- **What is in the draft today is average TDECQ**
  - Average TDECQ with current limits stay in the draft and will be called Average TDECQ
- **Block TDECQ captures worst case block penalty which will be higher than current average TDECQ**
  - Block TDECQ captures $TDECQ_{Max}$ will have excursion above the current average TDECQ (~+0.4 dB under study)
  - chayeb_3dj_01_2507 Hyper-Spherical TDECQ implements some aspects of Block TDECQ to better captures bandlimited RJ as was the cause of block errors in Mazzini OIF 2024.449.02
    - Chayeb improved "Hyper-Spherical TDECQ" works with both sampling and real-time scopes, but to capture uncorrelated events real-time scope would be required
    - TDECQ still is best metric for transmitter penalty
    - Inexpensive Functional receiver can supplement the improved TDECQ with sampling scope without needing real-time scope.

Section III – Additional tap limits to control block BER

Block Error Due to Weird Tap Settings

- **Issue was brought up by chayeb_3dj_01_2505 by setting SerDes to have positive pre-cursor Pre1 and negative post-cursor Post1**
  - Consequently, TDECQ FFE is trying to compensate for positive Pre1 by pushing its Pre1 negative and pushing its post positive
  - Limiting difference Post1-Pre1 TDECQ taps mitigates the observed block errors
    - When C(1) >0 then C(1)-C(-1)≤ |0.25|
    - This will prevent setting of FIR1-FIR6 which has high T-counts or failures!

Experimental Data: "Good" TDECQ, "Bad" Link Performance

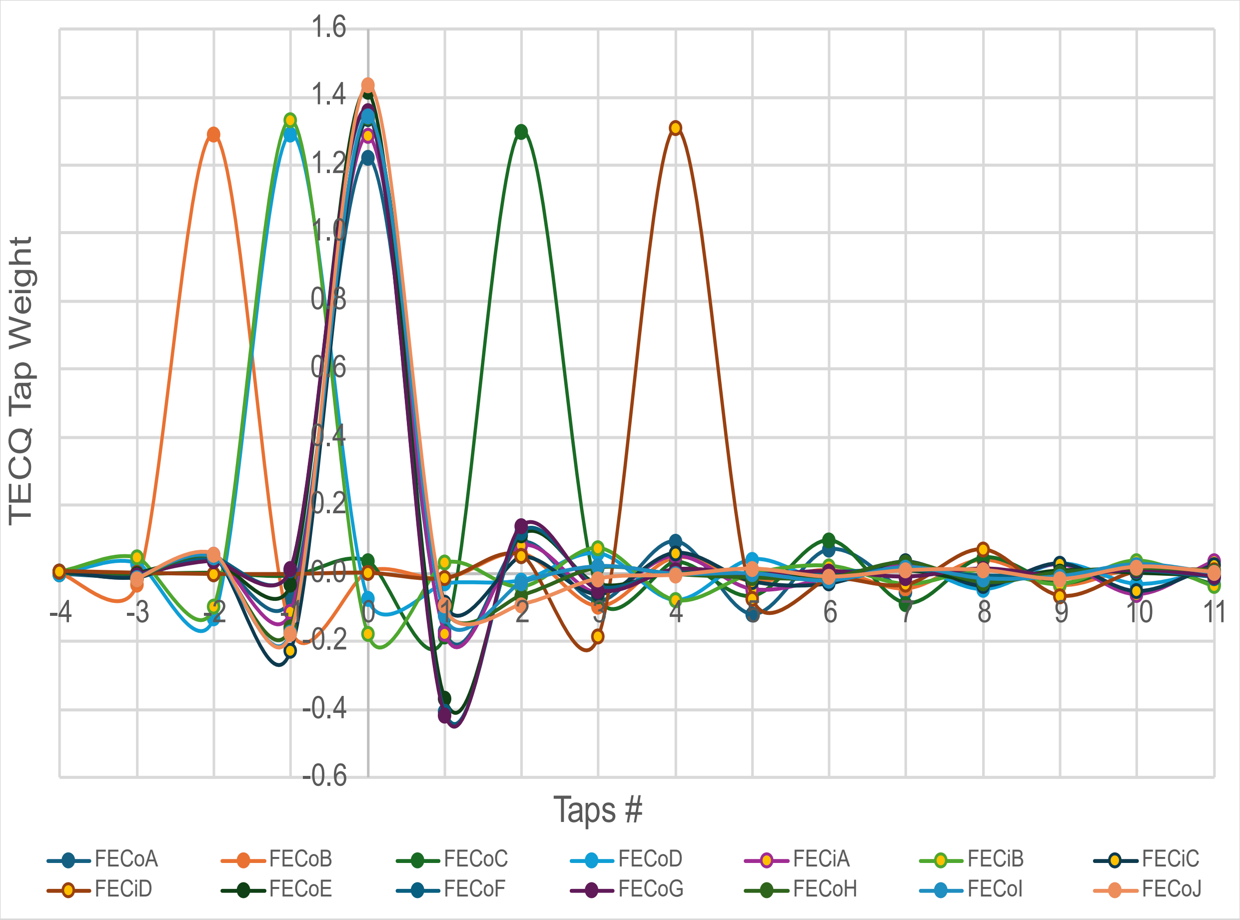
SerDes Main: FIR2; Pre1: FIR1; Post1: FIR3. TDECQ Main: FFE3; Pre1: FFE2; Post1: FFE4.

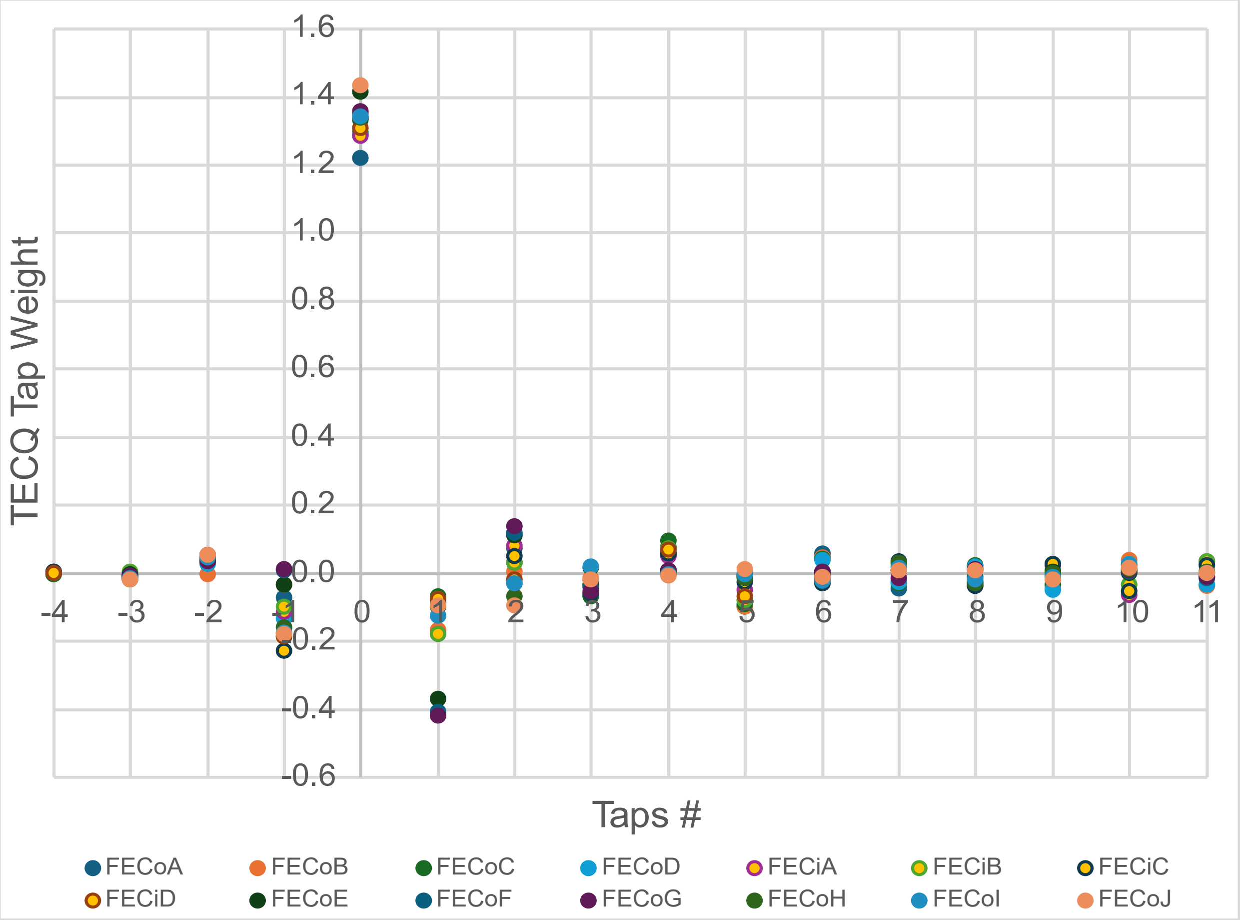
Ln0	FIR1	FIR2	FIR3	FIR4	FIR5	FIR6	FIR7	FIR8	Default	FIR9	FIR10	FIR11	FIR12	FIR13	FIR14	FIR15	FIR16
FIR1	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-39	-39	-39	-39	-39
FIR2	95	100	105	110	115	115	115	115	115	115	115	115	115	110	105	100	95
FIR3	-39	-39	-39	-39	-39	-34	-29	-24	-19	-14	-9	-4	0	5	10	15	20
FIR4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FIR5	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4
FIR6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
FIR7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7	-7
Lvl0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0	0 2 -2 0
TDECQ	2.52	2.11	1.81	1.61	1.52	1.38	1.26	1.12	1.03	0.9	0.85	0.84	0.85	0.98	1.15	1.34	1.66
ER	2.988	2.988	2.989	2.992	2.992	2.977	2.966	2.96	2.956	2.954	2.954	2.958	2.958	2.95	2.948	2.94	2.936
Ceq	0.44	0.33	0.19	0.05	-0.09	-0.08	-0.08	-0.06	-0.06	-0.05	-0.05	-0.05	-0.06	0.07	0.21	0.35	0.5
RLM	0.97	0.972	0.976	0.979	0.984	0.987	0.988	0.988	0.99	0.992	0.991	0.992	0.992	0.988	0.986	0.982	0.98
De-emp	-0.297619	-0.297619	-0.297619	-0.297619	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976	-0.2976
Overshoot (1e-2)	11.23	11.54	11.62%	12.35%	12.80%	10.89%	9.86%	8.78%	9.05%	9.87%	11.59%	13.45%	14.91%	14.82%	14.68%	14.31%	14.09%
Trans	17.40	16.40	15.40	10.60	11.00	10.60	10.60	10.00	10.00	10.00	10.00	10.00	10.00	10.00	14.40	15.20	16.20
FFE1	0.0914	0.0660	0.0545	0.0428	0.0337	0.0287	0.0293	0.0321	0.0375	0.0492	0.0603	0.0730	0.0827	0.0928	0.0989	0.1067	0.1113
FFE2	-0.3664	-0.3059	-0.2701	-0.2223	-0.1799	-0.1446	-0.1066	-0.0665	-0.0277	-0.0026	0.0293	0.0590	0.0845	0.0730	0.0797	0.0847	0.1087
FFE3	1.0312	1.0142	0.9860	0.9617	0.9432	0.9556	0.9610	0.9684	0.9749	0.9766	0.9733	0.9653	0.9581	0.9825	1.0090	1.0321	1.0420
FFE4	0.1652	0.1516	0.1632	0.1564	0.1473	0.1207	0.0904	0.0516	0.0104	-0.0220	-0.0599	-0.0968	-0.1294	-0.1560	-0.2053	-0.2569	-0.3238
FFE5	0.0786	0.0741	0.0663	0.0614	0.0557	0.0396	0.0259	0.0144	0.0049	-0.0013	-0.0031	-0.0004	0.0042	0.0076	0.0178	0.0335	0.0618
NormFFE1	5	4	4	3	2	2	2	3	4	5	5	6	7	7	7	7	7
NormFFE2	-21	-19	-18	-15	-13	-11	-9	-6	-3	0	3	5	7	6	6	6	7
NormFFE3	60	63	64	67	69	74	79	85	92	93	86	81	76	75	72	68	63
NormFFE4	10	9	11	11	11	9	7	5	1	-2	-5	-8	-10	-12	-15	-17	-20
NormFFE5	5	5	4	4	4	3	2	1	0	0	0	0	0	1	1	2	4
Pre-FEC (max AOP)	2.20E-04	1.14E-04	3.51E-05	7.10E-06	1.80E-06	2.18E-07	9.21E-09	3.37E-10	2.19E-11	3.18E-12	5.22E-13	EF	EF	EF	5.22E-14	5.22E-14	3.13E-12
Post-FEC (3min)	6.35E-06	1.02E-06	2.73E-08	1.50E-10	T=15 (soft)	T=9 (bursty)	T=3	T=2	T=1	T=1	T=1	T=0	T=0	T=0	T=1	T=1	T=1
Note: reset (Attenuator on/off toggle) applied for every Tx FIR change for Rx measurements																	
AOP (60s m	FIR1	FIR2	FIR3	FIR4	FIR5	FIR6	FIR7	FIR8	Default	FIR9	FIR10	FIR11	FIR12	FIR13	FIR14	FIR15	FIR16
-0.12	2.20E-04	1.14E-04	3.51E-05	7.10E-06	1.80E-06	2.18E-07	9.21E-09	2.97E-10	2.19E-11	3.18E-12	5.22E-13	EF	EF	EF	5.22E-14	5.22E-14	3.12E-12
-1.3	2.16E-04	3.41E-05	6.00E-06	1.37E-06	2.87E-07	4.44E-08	1.71E-09	6.66E-11	1.55E-11	2.66E-12	4.69E-13	1.56E-13	3.12E-13	EF	EF	1.57E-13	8.93E-12
-2.42		1.42E-04	1.09E-05	1.18E-06	2.35E-07	2.43E-08	1.97E-09	1.12E-10	1.71E-11	4.38E-12	1.88E-12	3.13E-13	1.57E-13	1.25E-12	6.25E-13	3.13E-12	1.77E-11
-3.52		7.52E-05	1.14E-05	1.71E-06	4.56E-07	4.88E-08	4.43E-09	4.91E-10	8.43E-11	2.78E-11	7.02E-12	1.72E-12	5.64E-12	1.06E-11	1.82E-11	6.65E-11	6.00E-10
-4.59		7.85E-05	1.04E-05	1.93E-06	5.55E-07	1.16E-07	2.07E-08	4.62E-09	1.59E-09	4.98E-10	1.82E-10	1.29E-10	1.47E-10	2.74E-10	8.20E-10	3.31E-09	2.40E-08
-5.65			1.91E-05	4.39E-06	1.69E-06	5.23E-07	1.79E-07	5.64E-08	3.24E-08	1.38E-08	7.63E-09	5.73E-09	6.94E-09	1.33E-08	3.40E-08	1.32E-07	1.60E-06
-6.71			8.10E-05	2.28E-05	1.09E-05	4.69E-06	2.46E-06	1.27E-06	7.77E-07	5.09E-07	3.80E-07	2.97E-07	2.91E-07	5.60E-07	1.49E-06	4.55E-06	9.75E-05
-7.75				1.84E-04	8.65E-05	5.25E-05	3.38E-05	2.07E-05	1.65E-05	1.26E-05	1.01E-05	9.44E-06	9.17E-06	1.54E-05	3.36E-05	1.29E-04	
-8.78						4.31E-04	3.23E-04	2.57E-04	2.08E-04	1.83E-04	1.57E-04	1.48E-04	1.54E-04	2.34E-04	2.47E-04		

Red when there is post-FEC error

FECo and FECi TECQ Data (Pre/Post Taps Normalized to Main)

- **Data from ghiasi_3dj_02a_2409 with block error issue raised by chayeb_3dj_01_2505**
  - Limiting C(1)-C(-1)≤0.25 when C(1)>0 with all TDECQ having larger negative C(-1) not impact to any yield but just prevents weird tap settings!





Section IV – Functional receiver definition

Functional Receiver

- **Background on functional receiver**
  - A compliant 802.3dj receiver operating at +1 dB above receive sensitivity to minimize receiver contributed block errors
  - The purpose of functional receiver is to test the DUT transmitter block errors with PRBS31 or scrambled Idle
- **Functional receiver proposed test method**
  - Functional receiver is operating +1 dB above the receive sensitivity (result in pre-FEC BER of ~$1.0\text{x}10^{-5}$)
    - If actual receive sensitivity is as shown in Figure 180-4 -3.4 dBm no further adjustment needed
      - Otherwise adjust receive sensitivity in Figure 180-4 based on Functional Receiver sensitivity
    - The functional receiver is operated power level
      - -2.4 dBm for TECQ <0.9
      - -3.3+TECQ dBm for 0.9≤TECQ≤3.4 dB
  - With a compliant input signal, a PMD receiver is expected to meet the block error ratio of 1.45×10^{-11} (see 174A.5), measured at the PMA adjacent to the PMD using the method described in 174A.8, with BER_{added} equal to 6.4×10^{-5}

Receiver Sensitivity

- **Assumed receiver sensitivity as shown in Figure 180-4 show 1:1 relationship between TDECQ and receive sensitivity but actual data from he_3dj_01_2505 1:0.4 relationship**
  - The reason for shallow slope is that the HW receiver is that hardware receiver is more capable compared to TDECQ equalizer
    - ghiasi_3dj_04a_2507 proposes to add 1T DFE to the TDECQ improves the correlation from 1:0.4 to 1:0.98 a perfect match
    - Functional receiver relies on accurate TECQ penalty to receive sensitivity for OMA adjustment
    - If receive sensitivity correlation to TECQ is not improved then functional receiver 1st has to determine the receive sensitivity to TECQ slope.

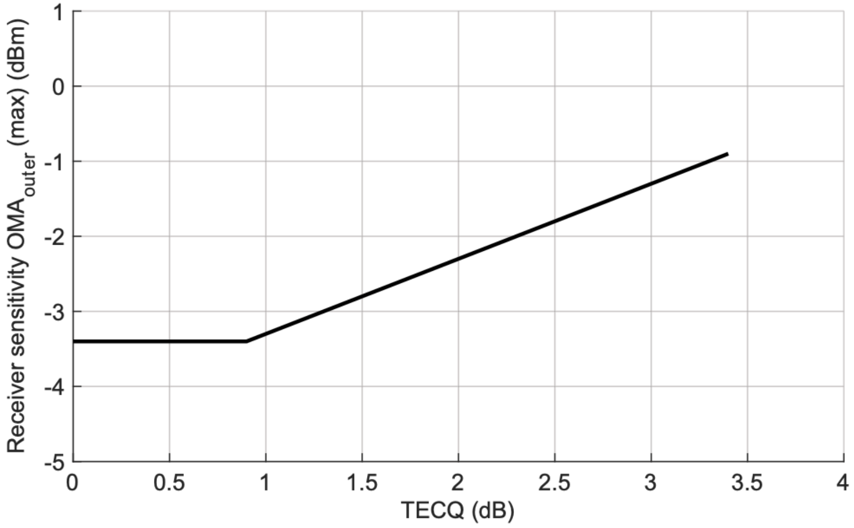
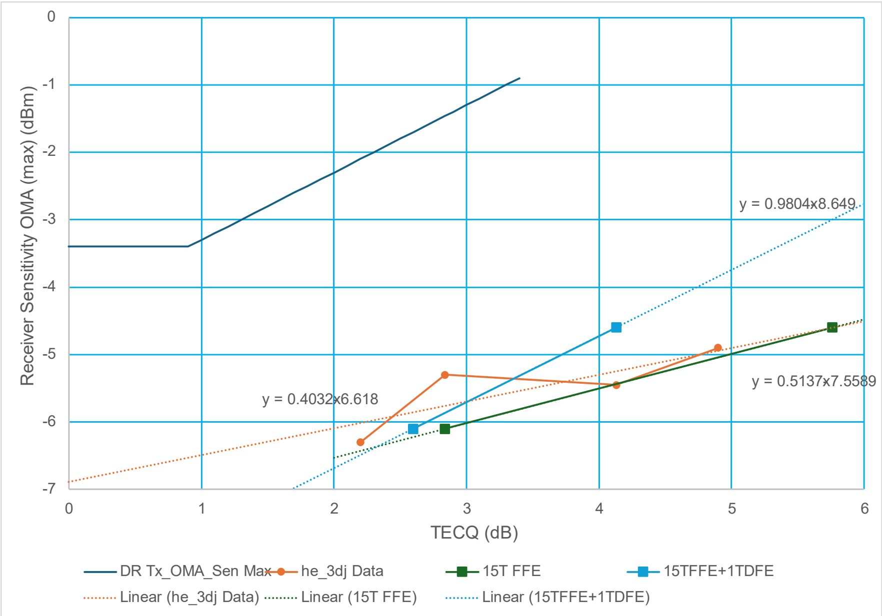


Figure 180–4—Receiver sensitivity (OMA_{outer}), each lane (max)



Comments 343, 345, 347, 349 Remedies

- **Remedies for block errors**
  - Consider adopting the improved chayeb_3dj_01_2507 Hyper-Spherical TDECQ which improves TDECQ sensitivity to jitter
  - With block TDECQ requiring real time scope Functional receiver can supplement Hyper-Spherical TDECQ, see cole_3dj_01b_2507
- **Limit difference Post1-Pre1 TDECQ taps mitigates the observed block errors When C(1) >0 then C(1)-C(-1)≤ |0.25|.**

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 – Done ✓**
- **Mazzini OIF 2024.449.02 raised issue is due to bandlimited transmit RJ that affect certain blocks unproportionally – Need to be addressed ✗**
  - Block TDECQ with real-time scope will fully capture bandlimited transmit RJ and chayeb_3dj_01c_012507 Hyper-Spherical TDECQ partially captures these effects
  - Functional receiver as proposed in this contribution can supplement the improved Hyper-Spherical TDECQ on sampling scopes
- **chayeb_3dj_01_2505 raised issue with weird tap settings affecting certain DSP Timing Recovery (TR) but TDECQ doesn't incorporate a TR – Need to be addressed ✗**
  - As proposed in this contribution limiting TDECQ pre/post taps is the best way to mitigate this issue
- **Figure 180-4 show 1:1 relationship between TDECQ and receive sensitivity but actual data from he_3dj_01_2505 1:0.4 relationship – Need to be addressed ✗**
  - As proposed by Ghiasi_3dj_04_2507 adding DFE taps to TDECQ equalizer and enabling ILT Presets as proposed by Ghiasi_3dj_01_2507.

Thank you