Adjusting TDECQ Limit with Addition of 1T DFE

(Comments 159, 160, 161,162, 163, 164, and 165)

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IEEE 802.3dj Interim Meeting

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Overview

- **Background**
- **TECQ correlation with receiver sensitivity**
- **200G TDECQ with addition of 1T DFE**
- **Overshoot penalty**
- **Summary**

  Note: Some of the TDECQ transmitters in this contribution are not representative of nominal transmitters. Specifically requested for transmitters with high TDECQ to help us guide on setting TDECQ limit with DFE receiver.

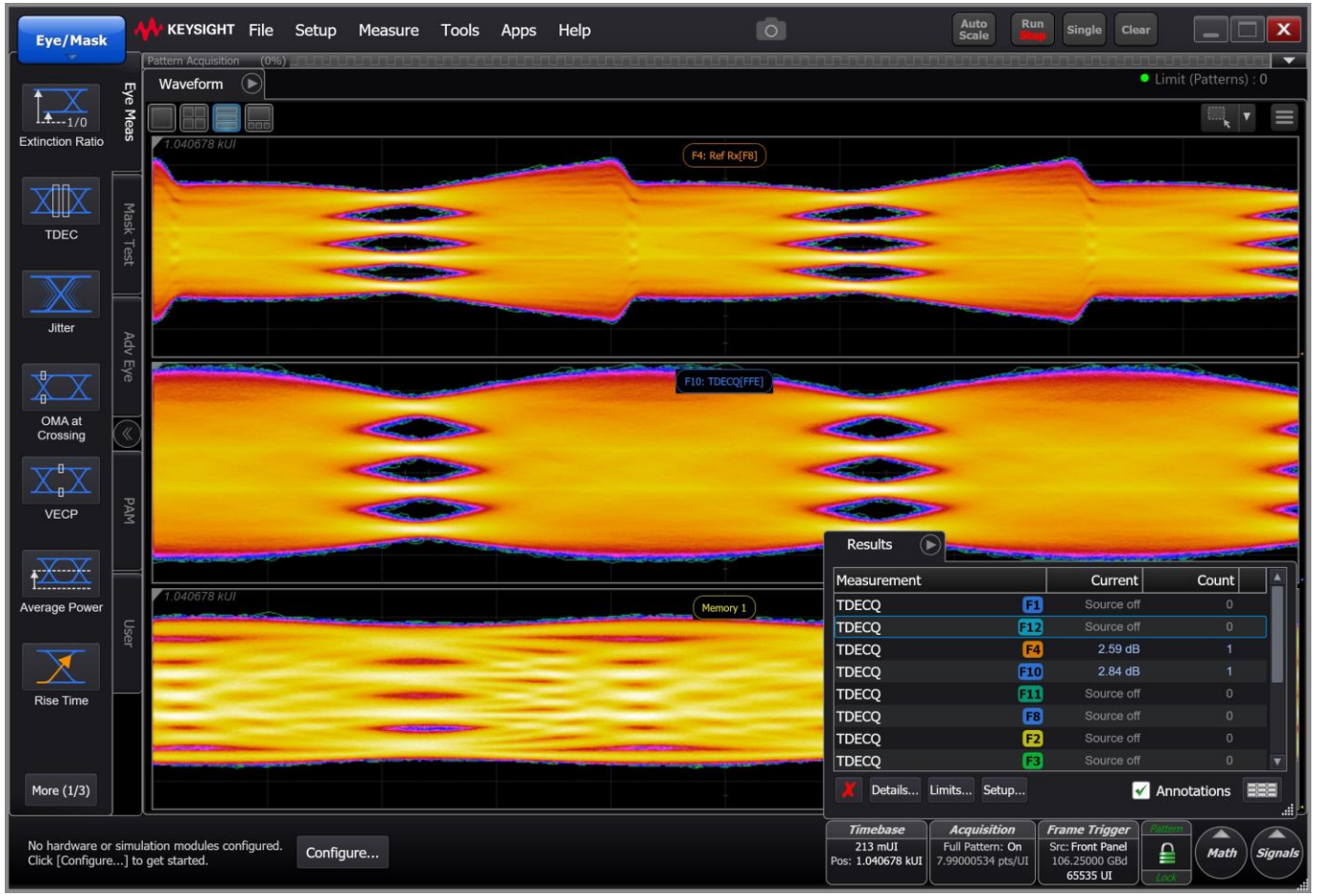
Special thanks and credit to Ahmad El-Chayeb of Keysight Technologies for TDECQ with DFE analysis support!

Background

- **In Madrid 1T DFE was added to the TDECQ equalizer but due to limited time TDECQ limit and overshoot/undershoot limits were not addressed**
  - With 1T DFE providing ~ 1dB of equalizer gain the TDECQ limits need to be reduced
    - By enabling 1T DFE in TDECQ significant margin has shifted from receive DSP to optical transmitter, unless TDECQ limit is lowered the receive DSP will be left with no margin
  - Another key reason 1T DFE was proposed and adopted was to reduce reliance on overshoot/undershoot where TDECQ doesn't capture compression and clipping effects, where higher overshoot can result in pre/post FEC BER degradation
    - It has been reported that transmitter with with higher overshoot but with lower TDECQ have worse BER than transmitter with lower overshoot and higher TDECQ
- **This contribution proposes to leave the TECQ/TDECQ limit unchanged at 3.4 dB for DR-500, FR-500 but reduce the TDECQ for DR and FR4 from 3.4 dB to 3.0 dB and LR4 from 3.9dB to 3.5dB.**

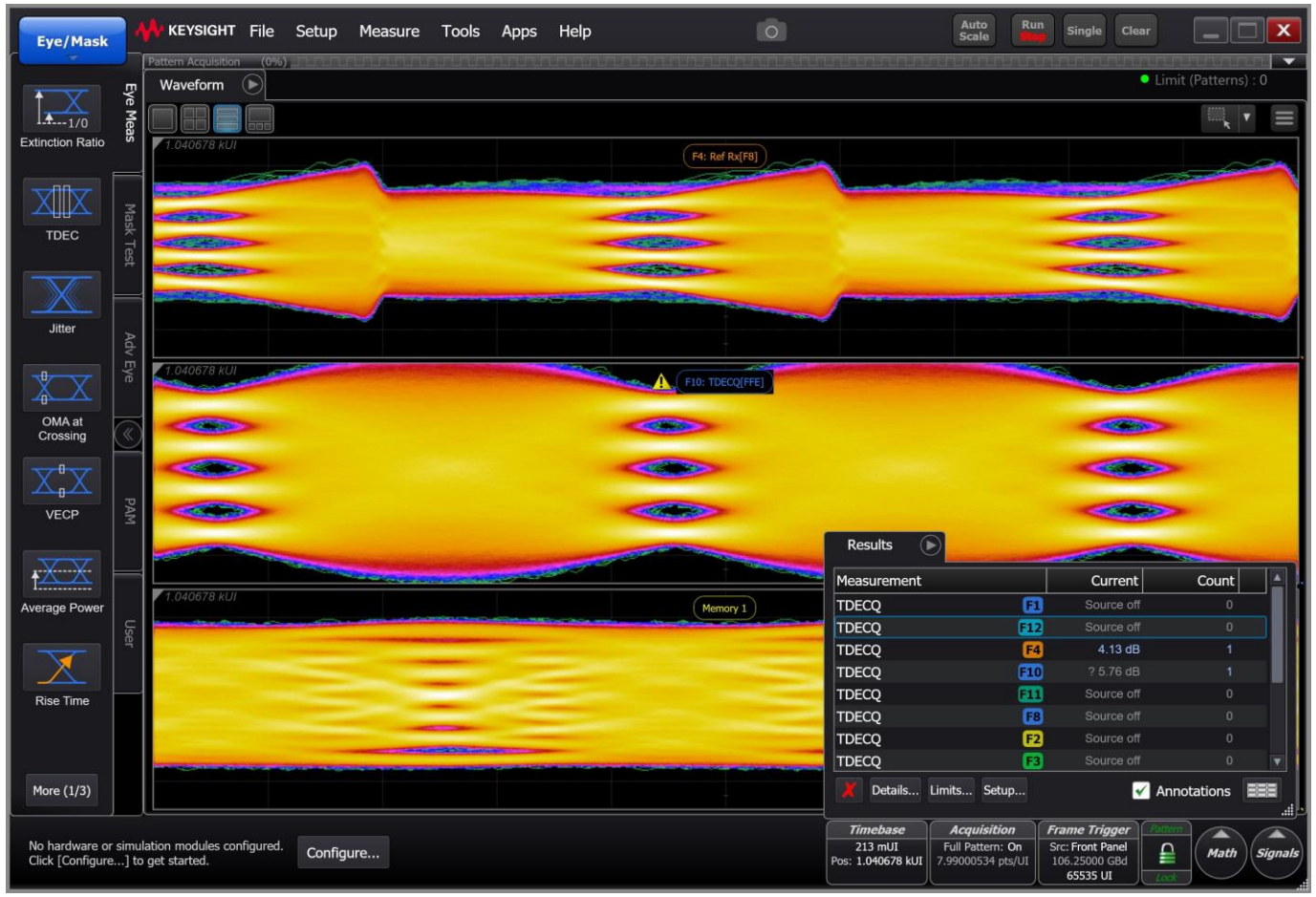
Supplier 1 - 200G SiPho MZM TDECQ with Addition of DFE

- **TDECQ reduction with 1T DFE for TX with low TECQ, see [ghiasi_3dj_04c_2507]**
  - TDECQ with 15T FFE is 2.84 dB
    - FFE Taps -0.017081, 0.078124, -0.275357, **1.490161**, -0.321593, 0.124306, -0.092210, 0.044500, -0.074899, 0.056275, -0.028502, 0.021386, -0.014024, 0.012652, -0.003738
  - TDECQ with 15T FFE + 1T DFE is 2.59 dB
    - FFE Tap -0.008442, 0.045556, -0.166764, **0.995970**, 0.181786, -0.000968, -0.031856, 0.005959, -0.042369, 0.019865, -0.005469, 0.007087, -0.004892, 0.005041, -0.000504
    - DFE Tap 0.283636.



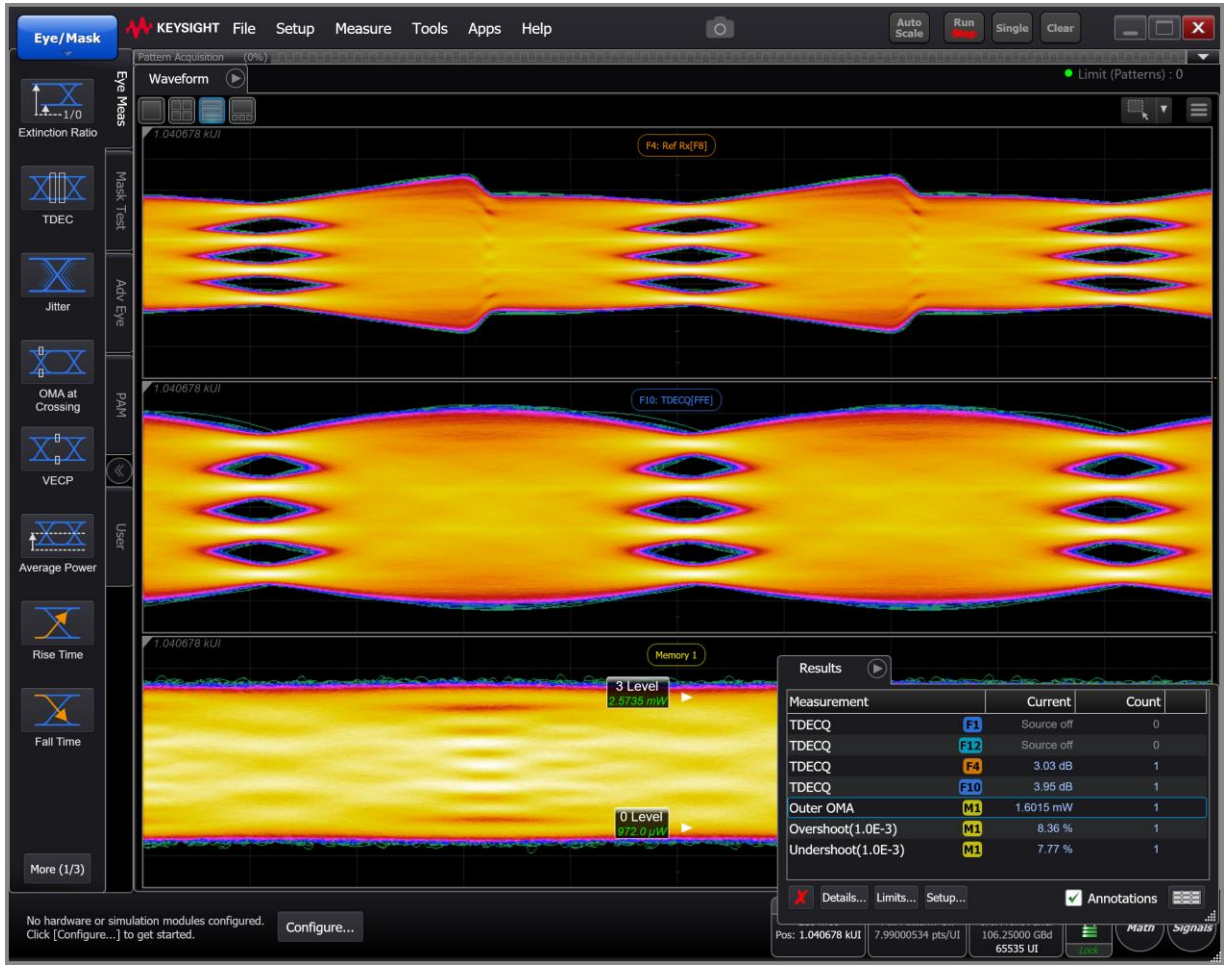
Supplier 1-200G Sipho MZM TDECQ with Addition of DFE

- **TDECQ reduction with 1T DFE for TX with high TECQ, see [ghiasi_3dj_04c_2507]**
  - TDECQ with 15T FFE is **5.76 dB**
    - FFE Taps -0.060232, 0.182759, -0.506969, **1.818684**, -0.532089, 0.157879, -0.044774, 0.005974, -0.044100, 0.035797, -0.010159, 0.003285, 0.018303, 0.004811, -0.029168
  - TDECQ with 15T FFE + 1T DFE is **4.13 dB**
    - FFE taps -0.017394, 0.073976, -0.226514, **0.979468**, 0.253183, -0.073706, 0.026715, -0.012512, -0.023035, 0.008908, 0.006088, -0.000323, 0.013989, 0.010717, -0.019560
    - DFE Tap 0.343287



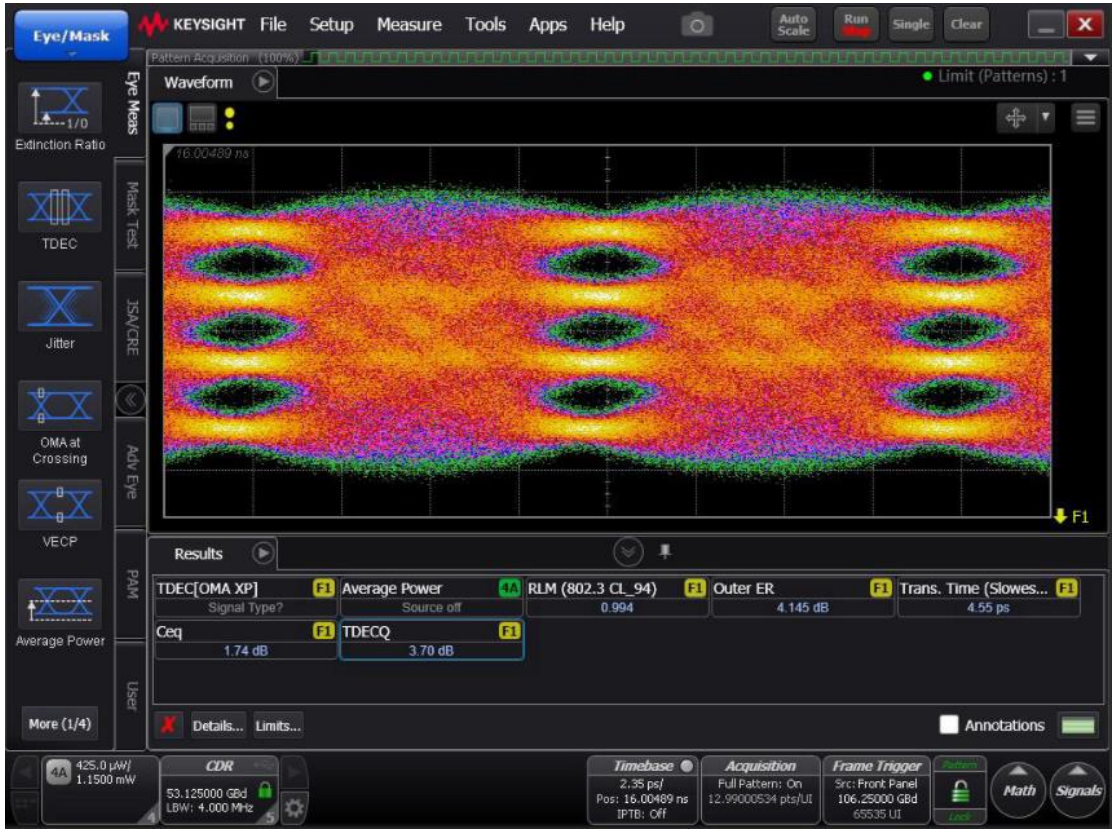
Supplier 2-200G Sipho MZM TDECQ with Addition of DFE

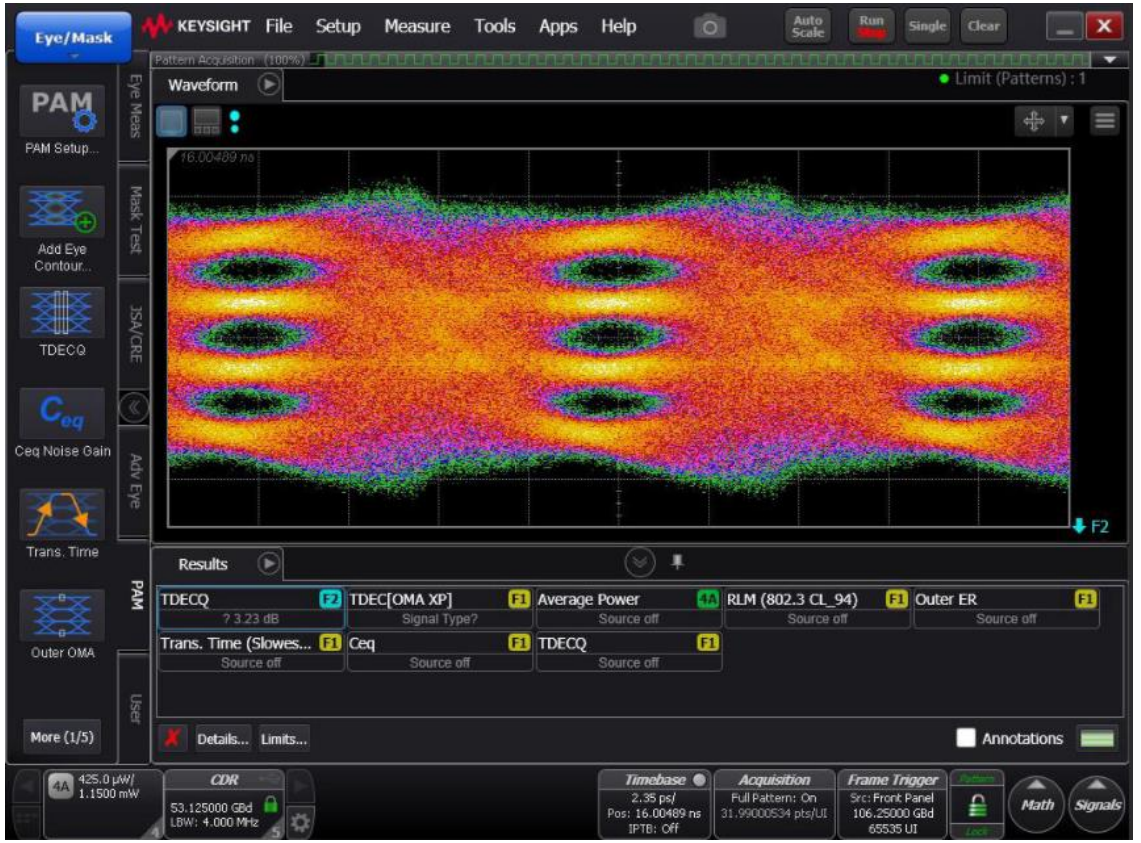
- **TDECQ reduction with 1T DFE for TX with high TECQ**
  - TDECQ with 15T FFE is **3.95 dB**
    - FFE Taps -0.026009, 0.080618, -0.264278, **1.465403**, -0.317154, 0.067630, -0.007742, -0.067456, 0.120564, -0.041145, -0.009050, 0.025035, -0.017886, -0.004995, -0.003535
  - TDECQ with 15T FFE + 1T DFE is **3.03 dB**
    - FFE taps -0.008907, 0.049752, -0.147116, **0.931613**, 0.141911, -0.024886, 0.015423, -0.041761, 0.069482, 0.007109, -0.011049, 0.019237, -0.000762, -0.003416, 0.003370
    - DFE Tap 0.243342



Supplier 3 EML TDECQ with Addition of DFE

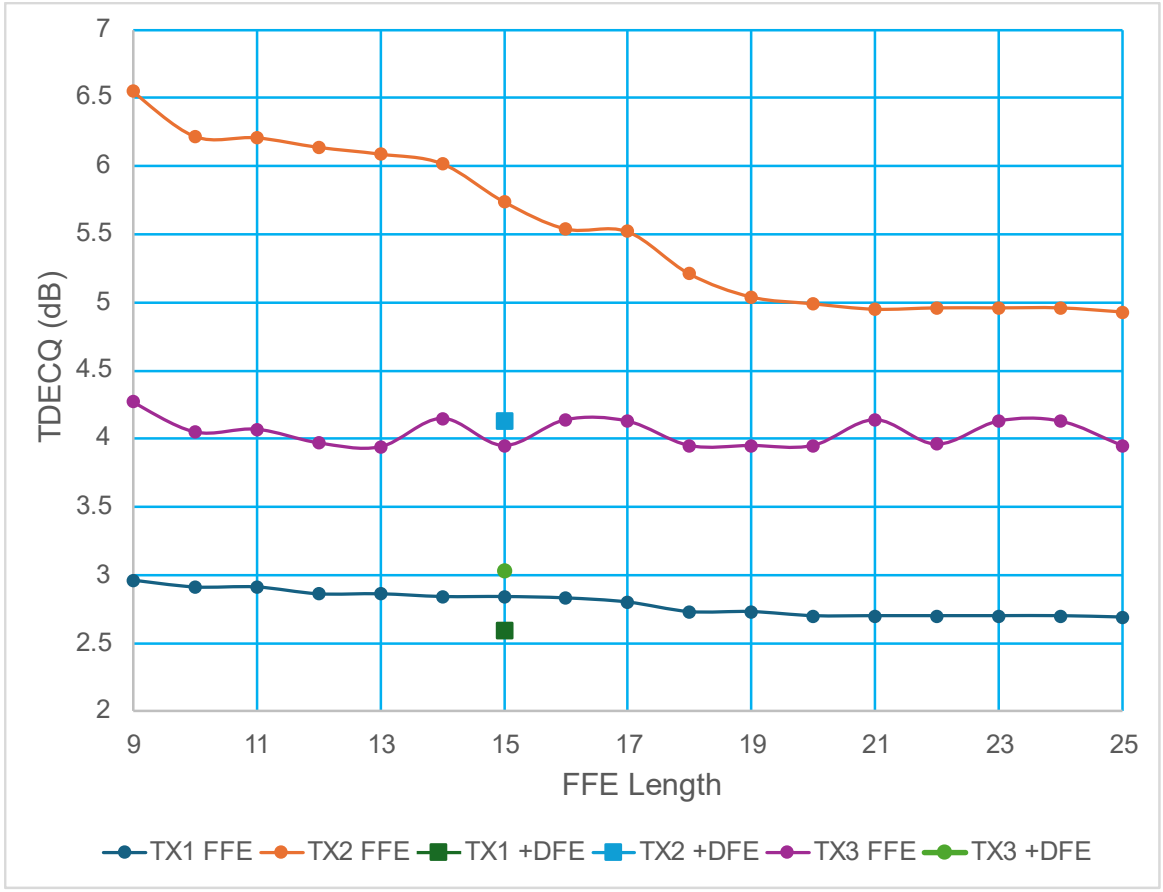
- **Unfortunately, the data saved was after equalizer so can't report on exact equalizer settings or tap weights, but TDECQ did decrease by ~0.5 dB for this EML with DFE.**





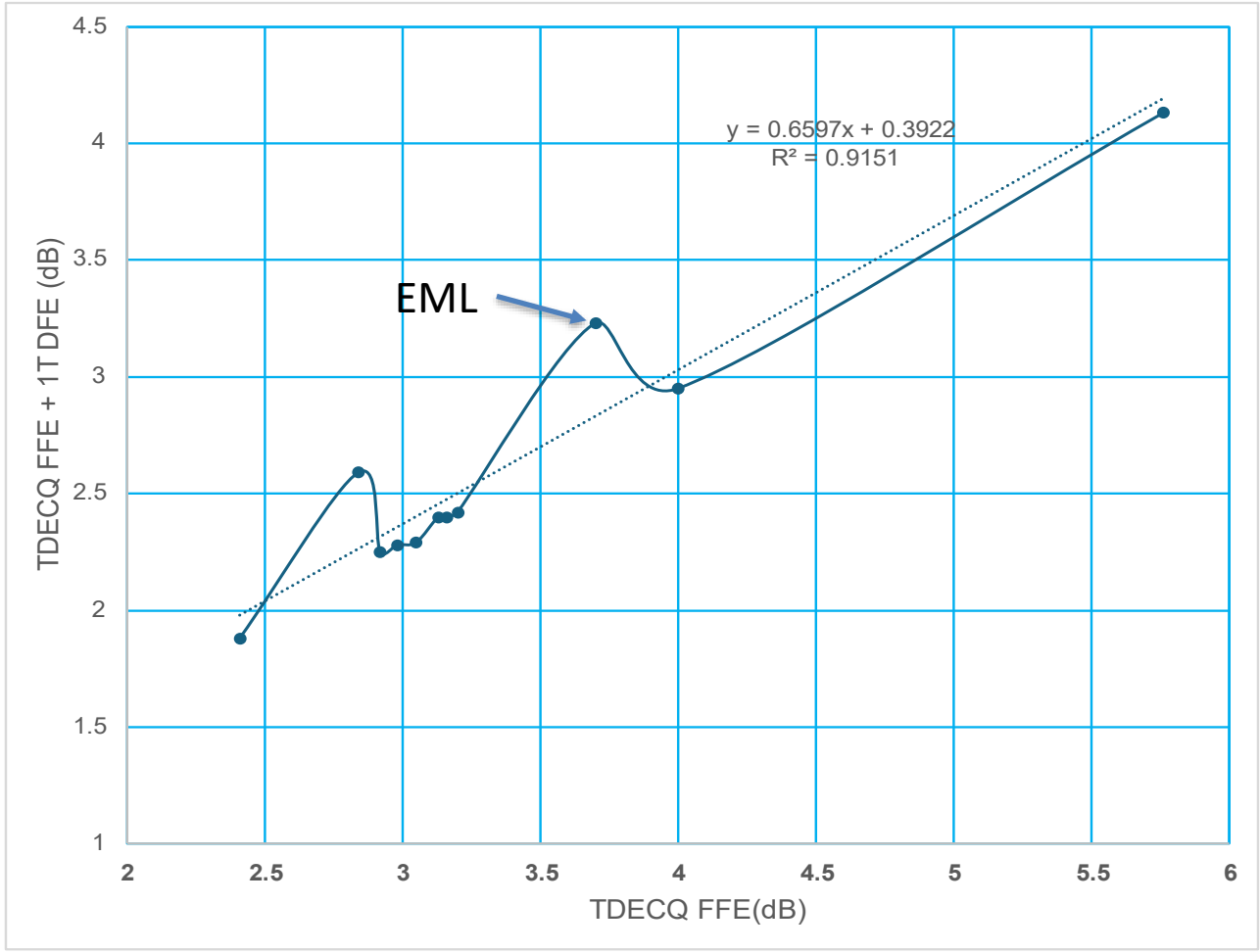
Benefit of Adding DFE to TDECQ

- **Adding 1T DFE to current 15T FFE TDECQ offer more gain than even a 25T FFE**
- **Adding 1T DFE also improves TDECQ to Receiver sensitivity penalty**
- **TECQ reduction with the addition of 1T DFE**
  - Only ~ 0.25 dB low TECQ TX1 transmitter
  - ~ 1.5 dB for high TECQ ISI impaired TX2 transmitter
  - ~ 1 dB low noise dominated TX3 transmitter
  - EML raw data was not available to include
- **DFE is providing gain across a range of transmitters!**



Supplier 1 and 2 TDECQ Results with/without DFE

- **The 3.4 dB FFE TDECQ limit is equivalent to 2.6 dB TDECQ limit with DFE**
- **A 3.4 dB DFE TDECQ limit is equivalent to an FFE TDECQ of 4.7 dB which is your typical Functional Receiver**
- **Propose to reduce TDECQ for inner FEC PMDs given relaxation from DFE and higher SER!**



Clause 182 TDECQ/TECQ Reduction (Comments 159, 164)

- **Also update Figure 182-3, 182-4, and 182-5 and SECQ in Table 182-7**

Table 182–7—200GBASE-DR1-2, 400GBASE-DR2-2, 800GBASE-DR4-2, and 1.6TBASE-DR8-2 transmit characteristics *(continued)*

Description	200GBASE-DR1-2	400GBASE-DR2-2 800GBASE-DR4-2 1.6TBASE-DR8-2	Unit
Average launch power, each lane[a] (min)	–3.1[b]		dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.2		dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min) for max(TECQ, TDECQ) < 0.9 dB for 0.9 dB ≤ max(TECQ, TDECQ) ≤ ~~3.4~~ 3.0 dB	–0.1 –1 + max(TECQ, TDECQ)		dBm dBm
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	~~3.4~~ 3.0 dB		dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	~~3.4~~ 3.0 dB		dB
|TDECQ – TECQ|, each lane (max)	~~2.5~~ 2.2 dB		dB
Transmitter functional symbol error histogram, each lane (max)	See Table 180–17		—

Table 182–8—200GBASE-DR1-2, 400GBASE-DR2-2, 800GBASE-DR4-2, and 1.6TBASE-DR8-2 receive characteristics

Description	Value	Unit
Signaling rate, each lane (range)	113.4375 ± 50 ppm	GBd
Modulation format	PAM4	—
Lane wavelengths (range)	1304.5 to 1317.5	nm
Damage threshold[a], each lane	5	dBm
Average receive power, each lane (max)	4	dBm
Average receive power, each lane[b] (min)	–7.1	dBm
Receive power (OMA_{outer}), each lane (max)	4.2	dBm
Receiver reflectance (max)	–26	dB
Receiver sensitivity (OMA_{outer}), each lane (max) for TECQ < 0.9 dB for 0.9 dB ≤ TECQ ≤ SECQ	 –4.4 –5.3 + TECQ	dBm
Stressed receiver sensitivity (OMA_{outer}), each lane (max)	–1.9	dBm
Conditions of stressed receiver sensitivity test[c]:		
Stressed eye closure for PAM4 (SECQ), lane under test	~~3.4~~ 3.0 dB	dB
OMA_{outer} of each aggressor lane[d]	4.2	dBm

Clause 183 TDECQ/TECQ Reduction FR4 (Comments 160, 165)

- **Update Figure 183-3, 183-4, 183-5, and 183-6 and SECQ in Table 183-8**

Table 183–6—800GBASE-FR4 and 800GBASE-LR4 transmit characteristics

Description	800GBASE-FR4	800GBASE-LR4	Unit
Signaling rate, each lane (range)	113.4375 ± 50 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19	nm
Side-mode suppression ratio (SMSR), each lane (min)	30		dB
Total average launch power (max)	10.9	11.5	dBm
Average launch power, each lane (max)	4.9	5.5	dBm
Average launch power, each lane[a] (min)	–2.2[b]	–1.1[c]	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (max)	4.8	5.7	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane (min) for max(TECQ, TDECQ) <0.9 dB for 0.9 dB ≤ max(TECQ, TDECQ) ≤ ~~3.4~~ dB TBD dB for max(TECQ, TDECQ) <1.4 dB for 1.4 dB ≤ max(TECQ, TDECQ) ≤ ~~3.9~~ dB 3.5 dB	 0.8 Equation (183–1) — —	 — — 1.9 Equation (183–2)	 dBm dBm dBm dBm
Difference in launch power between any two lanes (OMA_{outer}) (max)	4	3	dB
Transmitter and dispersion eye closure for PAM4 (TDECQ), each lane (max)	~~3.4~~ TBD dB	~~3.9~~ 3.5 dB	dB
Transmitter eye closure for PAM4 (TECQ), each lane (max)	~~3.4~~ TBD dB	~~3.2~~ 3.0 dB	dB
| TDECQ – TECQ |, each lane (max)	~~2.5~~ TBD dB	~~2.5~~ 2.2 dB	dB
Transmitter functional symbol error histogram, each lane (max)	See Table 180–17		—

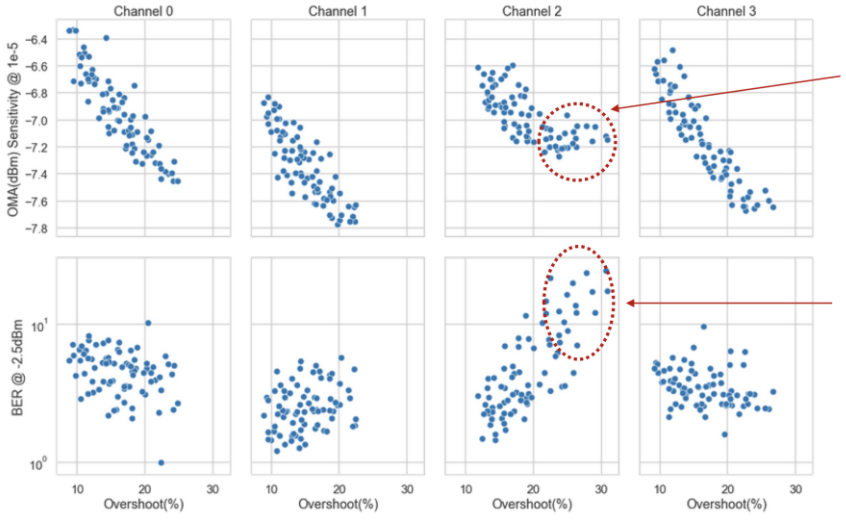
Table 183–7—800GBASE-FR4 and 800GBASE-LR4 receive characteristics

Description	800GBASE-FR4	800GBASE-LR4	Unit
Signaling rate, each lane (range)	113.4375 ± 50 ppm		GBd
Modulation format	PAM4		—
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	1294.53 to 1296.59 1299.02 to 1301.09 1303.54 to 1305.63 1308.09 to 1310.19	nm
Damage threshold[a], each lane	5.9	6.5	dBm
Average receive power, each lane (max)	4.9	5.5	dBm
Average receive power, each lane[b] (min)	–6.2	–7.4	dBm
Receive power (OMA_{outer}), each lane (max)	4.8	5.7	dBm
Difference in receive power between any two lanes (OMA_{outer}) (max)	4.1	3.3	dB
Receiver reflectance (max)	–26		dB
Receiver sensitivity (OMA_{outer}), each lane[c] (max) for TECQ < 0.9 dB for 0.9 dB ≤ TECQ ≤ SECQ for TECQ < 1.4 dB for 1.4 dB ≤ TECQ ≤ SECQ	 –3.7 –4.6 + TECQ — —	 — — –5.5 –6.9 + TECQ	 dBm dBm dBm dBm
Stressed receiver sensitivity (OMA_{outer}), each lane[c] (max)	–1.2	–3	dBm
Conditions of stressed receiver sensitivity test:[d]			
Stressed eye closure for PAM4 (SECQ), lane under test	~~3.4~~ 3.0 dB	~~3.9~~ 3.5 dB	dB
OMA_{outer} of each aggressor lane	0.8	0.3	dBm

Excessive Overshoot/Undershoot can Result in FEC Tail

- **Currently TDECQ doesn't incorporate PAR (Peak to Average) penalty**
  - Without PAR penalty overshoot can drive the TDECQ lower while link BER degrades
  - TDECQ not having PAR penalty the overshoot should be reduced <12% as receiver with DFE don't require such large overshoot!

Overshoot vs Rx performance



- Overshoot tends to improve sensitivity. It saturates for values larger than 22%
- **Overshoot values larger than 22% increase error floor significantly**

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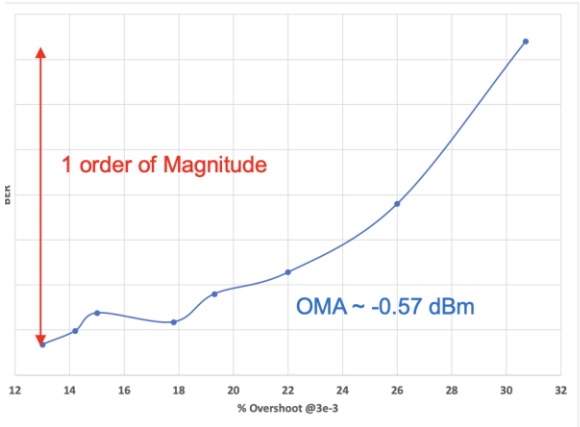
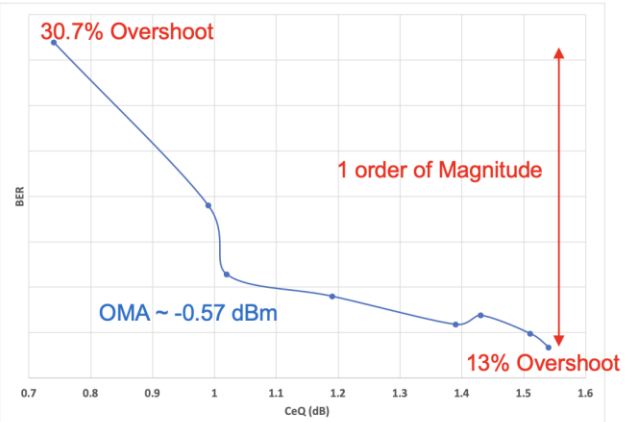
Overshoot vs Ceq Protecting Receiver for Excess Overshoot

- Transmitter overshoot is a direct quantitative parameter protecting the receiver for excess pre-emphasis/overshoot





IEEE 802.3db Taskforce

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Overshoot/Undershoot Comments

- **Comment 162**
  - Reduce Clause 180.7.1 overshoot/undershoot from 22% to 12%
- **Comment 163**
  - Reduce Clause 181.7.1 overshoot/undershoot from 22% to 12%
- **Comment 164**
  - Reduce Clause 182.7.1 overshoot/undershoot from 22% to 12%
- **Comment 166**
  - Reduce Clause 183.7.1 overshoot/undershoot from 22% to 12%.

Summary

- **The TDECQ/EECQ with 1T DFE reduces high TDECQ (FFE only) by ~ 1 dB and given that we have more powerful equalizer the TDECQ limit may need to be reduced**
  - A TDECQ of 3.4 dB with DFE is equivalent to ~4.7 dB FFE
  - Feedback received from optics suppliers is that we should not reduce 3.4 dB TDECQ given that at higher TDECQ the TX OMA is increased
  - The feedback from DSP suppliers is that 3.4 dB/~4.7 dB TDECQ (DFE/FFE only) is tolerable, but we should reduce LR4 limit of 3.9 dB which will be equivalent to 5.5 dB
    - Given that inner-FEC PMDs clasue 182 and 183 benefit from both DFE and higher SER level another reason why all these PMDs upper TDECQ limit should be reduced
  - The feedback from T&M is that may need to hold off any adjustment to TDECQ limit given that DFE limit and DFE reference point not yet implemented
- **Given the feedback received and the fact DSP can operate at ~4.7 dB TDECQ (FFE only) may want to keep the current 3.4 dB limit for lower optics cost and only reduce LR4 TDECQ from 3.9 dB to 3.5 dB**
- **With DFE receiver 22% overshoot/undershoot are no longer needed and given real risk of error floor and clipping the limit should be reduced**
  - Limit for Overshoot/undershoot for DR-500, FR4-500, DR, and FR4, and LR4 all should be reduced to 12%.

Thank You!