Benefit of Adding DFE to TDECQ
(Comments 381, 382, 383, 384)

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

Overview

❑ **Background**

❑ **TECQ correlation with receiver sensitivity**

❑ **200G TDECQ with addition of 1T DFE**

❑ **Overshoot penalty**

❑ **Summary.**

Background

❑ **Most optical DSP implementations include a 1T DFE and optional MLSE**

  – To save power MLSE by default will be off to save power

❑ **The benefit of enabling 1T DFE in TDECQ**

  – Reduces reliance on transmitter overshoot to reduce TDECQ where it may degrade link BER as TDECQ doesn't incorporate any compression or ADC ENOB penalties

  – Enabling 1T DFE reduces TDECQ ~0.5 dB on complaint TDECQ transmitter

    • For transmitter with low overshoot and high TDECQ >5 dB there is ~1.5 dB reduction

  – Allow passing slower more linear waveforms with better link BER

  – Improved correlation of TDECQ penalty with receive sensitivity

  – Scope supplier already have implemented 1T DFE to EECQ which is based on TDECQ for electrical penalty

❑ **The drawback of enabling 1T DFE in TDECQ**

  – Burst error will be the main drawback but we do have ILT for optics and DFE Bmax can be limited to 0.35

  – Shift some margin from receiver to transmitter.

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

– Adding 1T DFE to the TDECQ equalizer will improve TECQ penalty with receive sensitivity penalty.
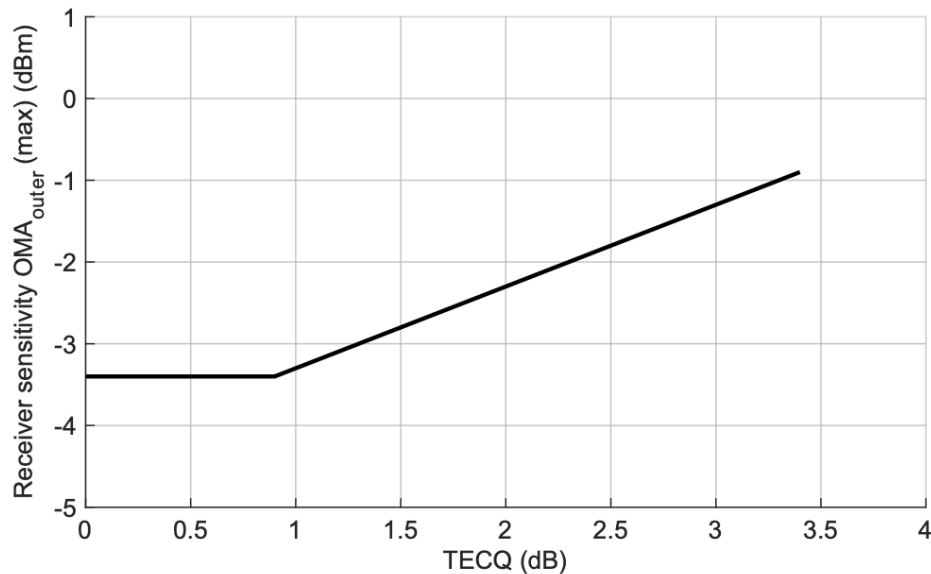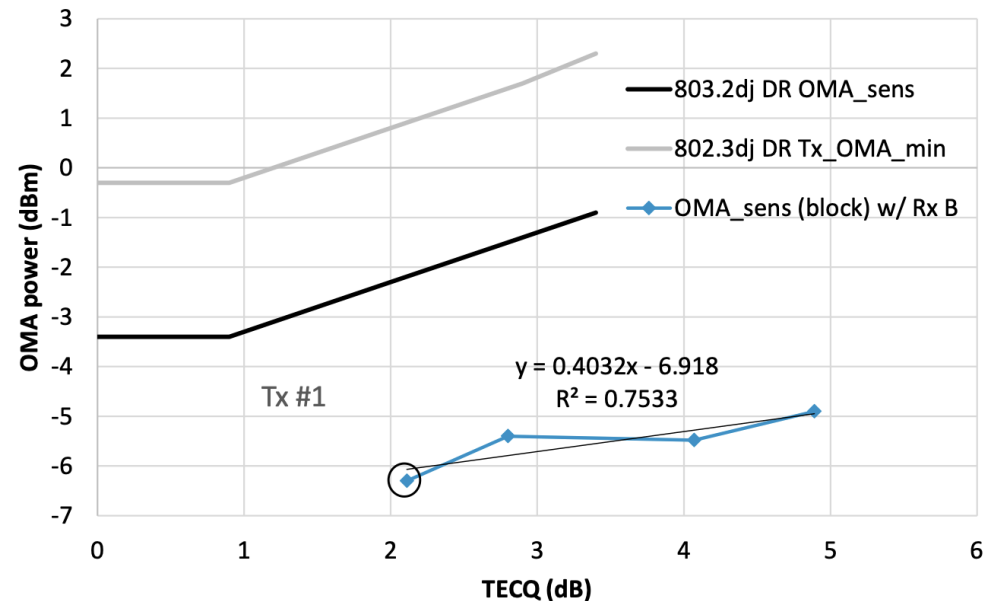

Figure 180–4—Receiver sensitivity (OMA$_{outer}$), each lane (max)

$$y = 0.4032x - 6.918$$
$$R^2 = 0.7533$$

- 803.2dj DR OMA_sens
- 802.3dj DR Tx_OMA_min
- OMA_sens (block) w/ Rx B

Tx #1

Adding 1T DFE to the TDECQ Equalizer

☐ **Add 1T DFE to the TDECQ equalizer**

    – Table 180-15, 181-15, 182-15, and 183-15.

Table 180–15—Reference equalizer tap coefficients

| Parameter	Symbol	Value	
		Minimum	Maximum
Feed-forward equalizer (FFE) length	N_b	15	
Number of equalizer pre-cursor taps	—	0	3
Main tap coefficient limit	$c(0)$	0.9	2.5
Normalized equalizer coefficient limits:[a]	$c(i)$		
$i = -3$		−0.15	0.1
$i = -2$		−0.1	0.25
$i = -1$		−0.5	0.1
$i = 1$		−0.6	0.2
$i = 2$		−0.2	0.3
$i = 3$		−0.15	0.15
$i = 4$		−0.15	0.15
$i = 5$		−0.15	0.15
$i = 6$		−0.15	0.15
$i \geq 7$		−0.1	0.1
Equalizer gain[b]	—	1	

[a] The main tap is marked by $i = 0$. The minimum and maximum values are relative to this tap's coefficient.
[b] The sum of the equalizer coefficients.

| Parameter	Symbol	Minimum	Maximum
Number of feedback taps	B(1)	0	0.35

Configuring TDECQ with DFE

☐ **Keysight Scope FlexDCA A.07.81.6 already supports TDECQ with 1T DFE**

– Instead of using TDECQ equalizer generic Reference Rx is selected

– Then under Linear Equalizer TDECQ Equalizer is selected

• Then set SER and other TDECQ parameters.
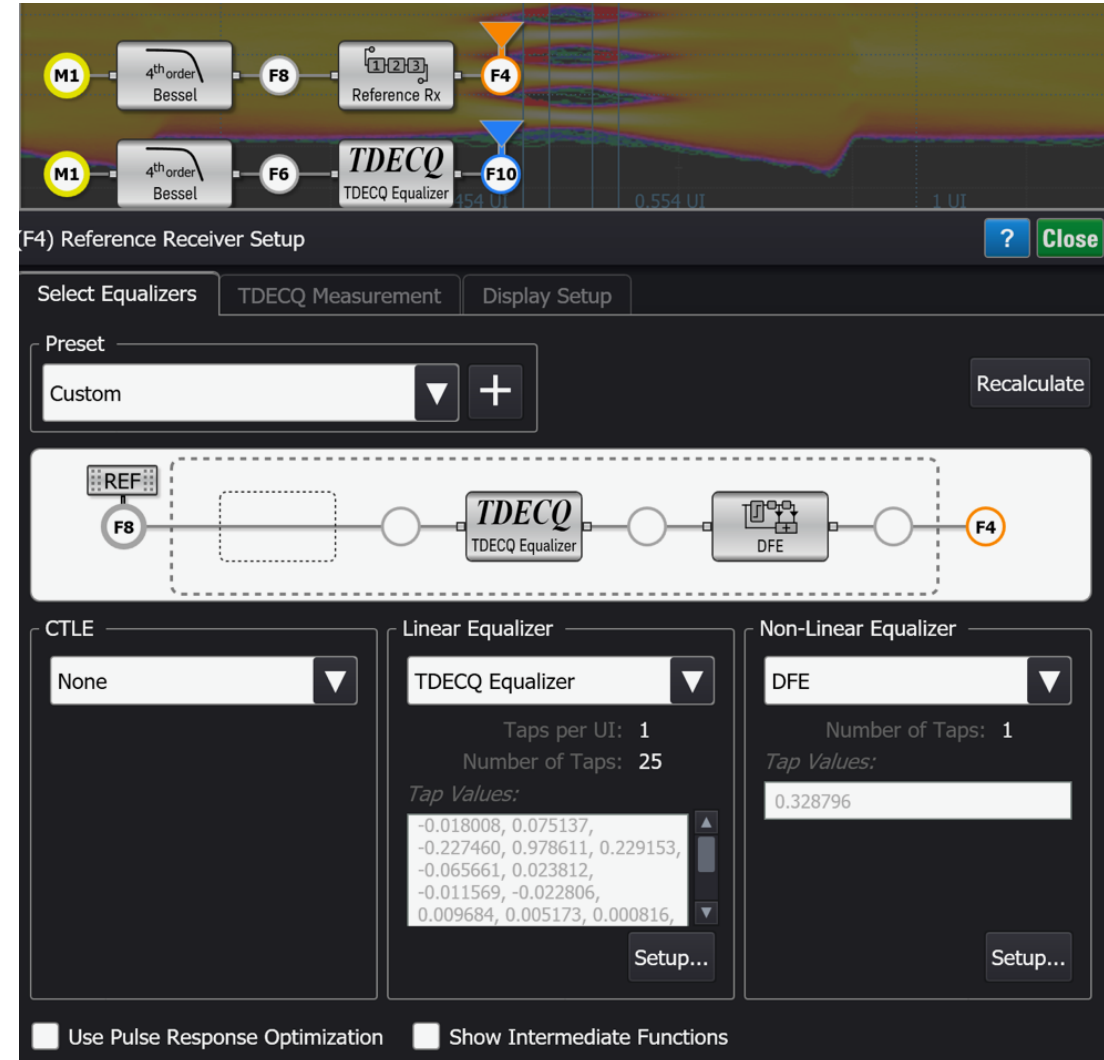
200G MZM TDECQ with Addition of DFE

☐ **TDECQ reduction with 1T DFE for TX with low TECQ**

- 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.
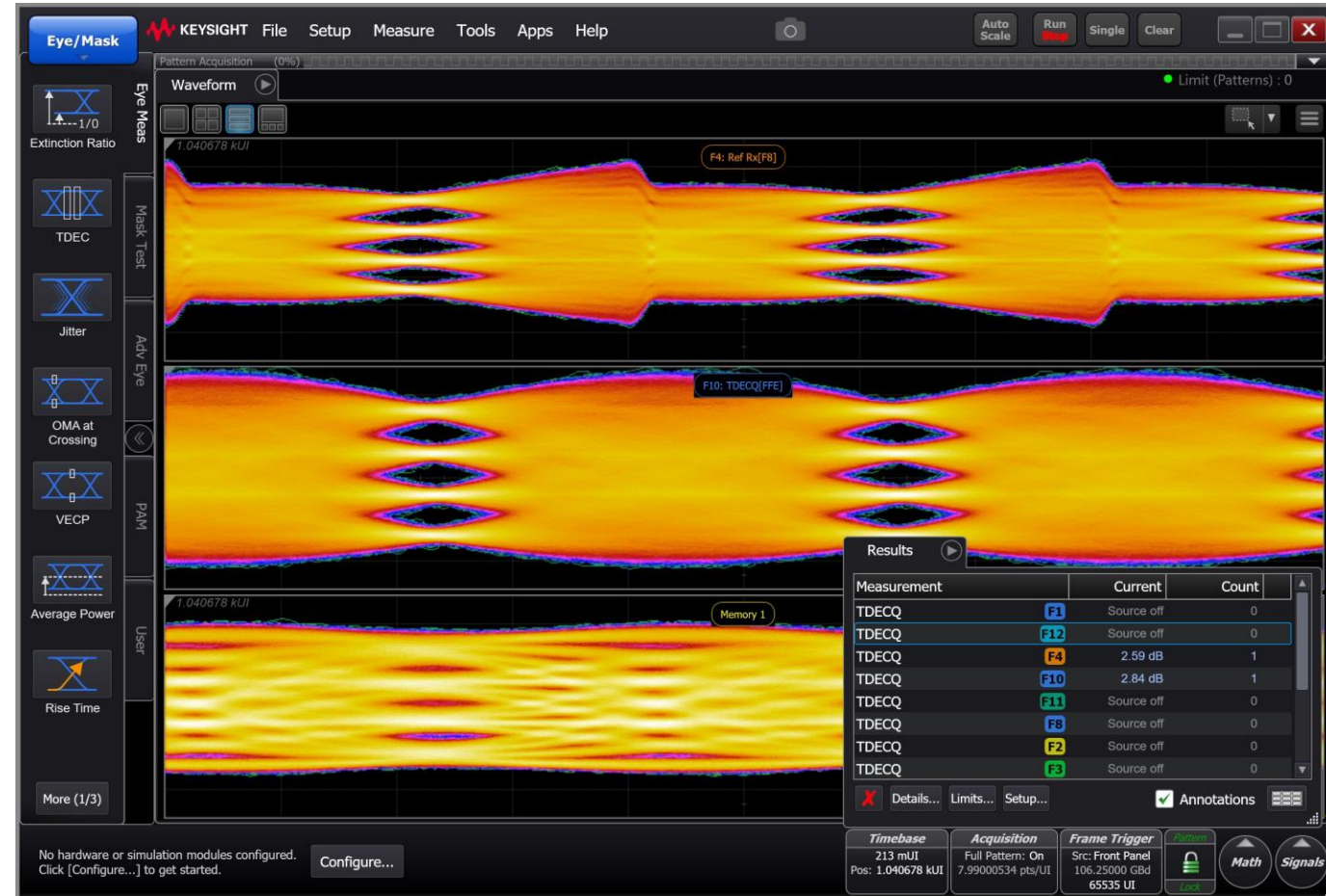
200G MZM TDECQ with Addition of DFE

☐ **TDECQ reduction with 1T DFE for TX with high TECQ**

- 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
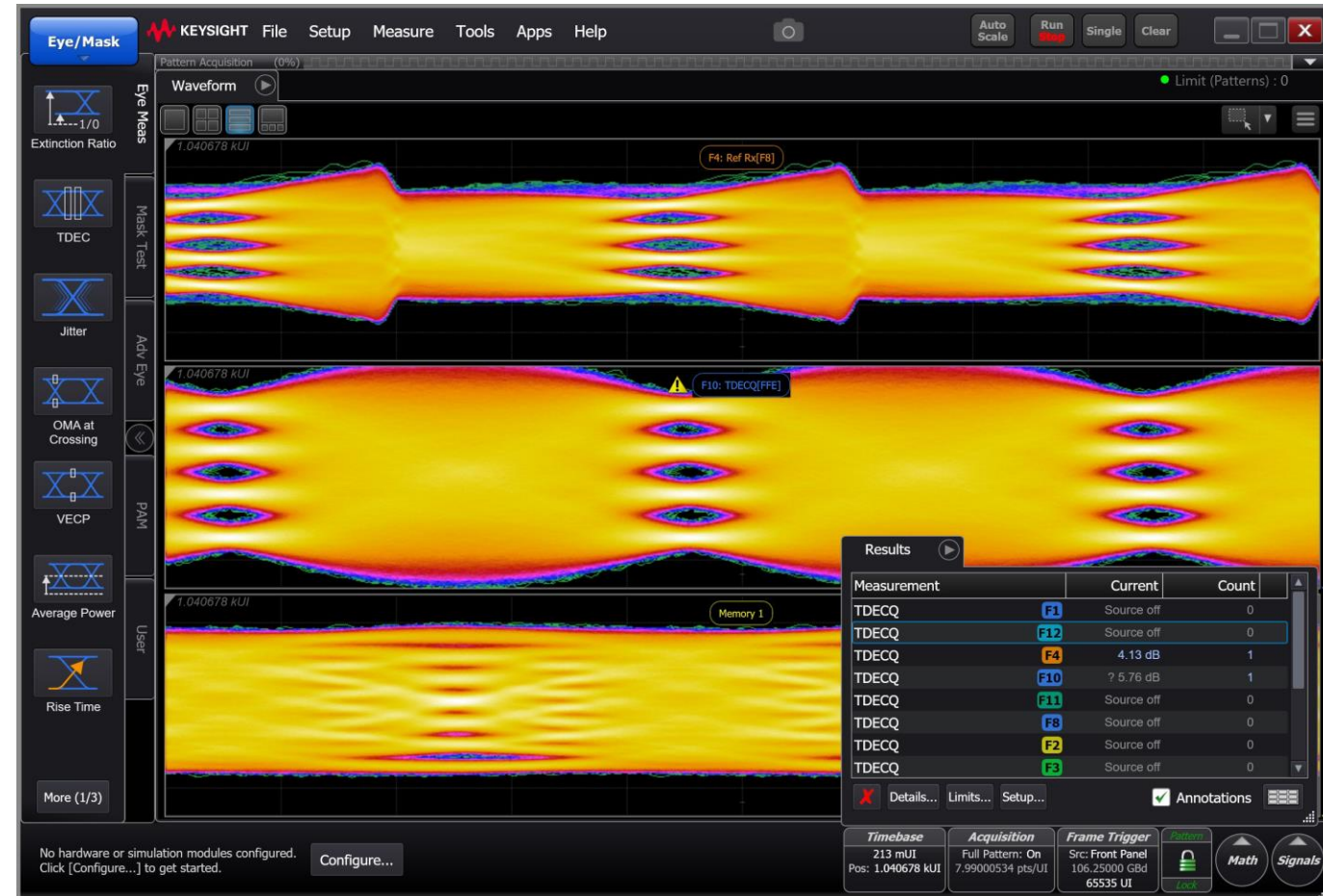
Benefit of Adding DFE to TDECQ

❑ **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**

  – Receive OMA sensitivity 2.4E-4 PreFEC are:
    • TX1 OMA Sensitivity -6.1 dB
    • TX2 OMA Sensitivity -4.6 dB
  – Delta sensitivity = **1.5 dB**
  – Delta TDECQ with 15T FFE = 2.92 dB
  – Delta TDECQ with 15T FFE + 1T DFE = **1.54 dB.**
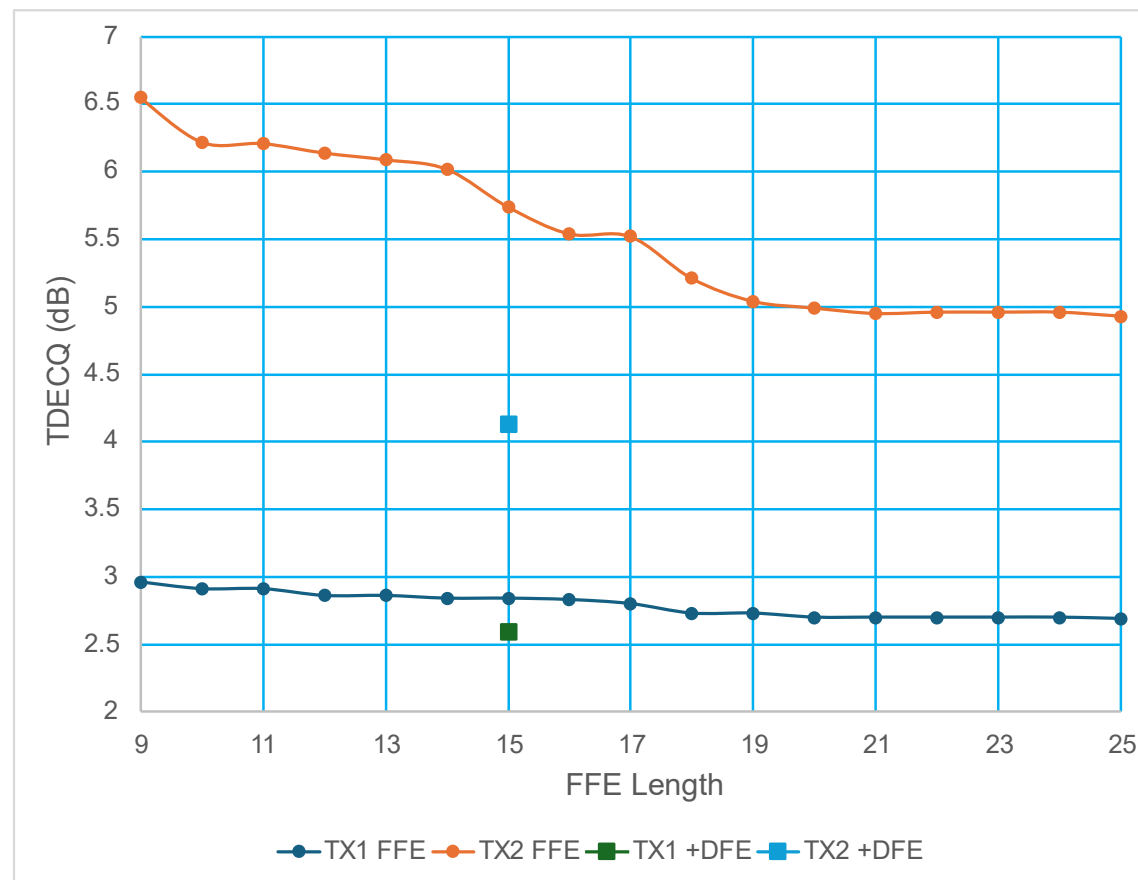
Benefit of Adding DFE to TDECQ

☐ **TDECQ with 15T FFE + 1T DFE improves transmitter penalty to matches receive sensitivity penalty 1:1**

- He_3dj data are from he_3dj_01_2505 and reported data were Block BER

- New data with 15T FFE and 15T FFE+1T DFE are pre-FEC BER

- With 1T DFE pre-FEC sensitivity matches TECQ penalty!
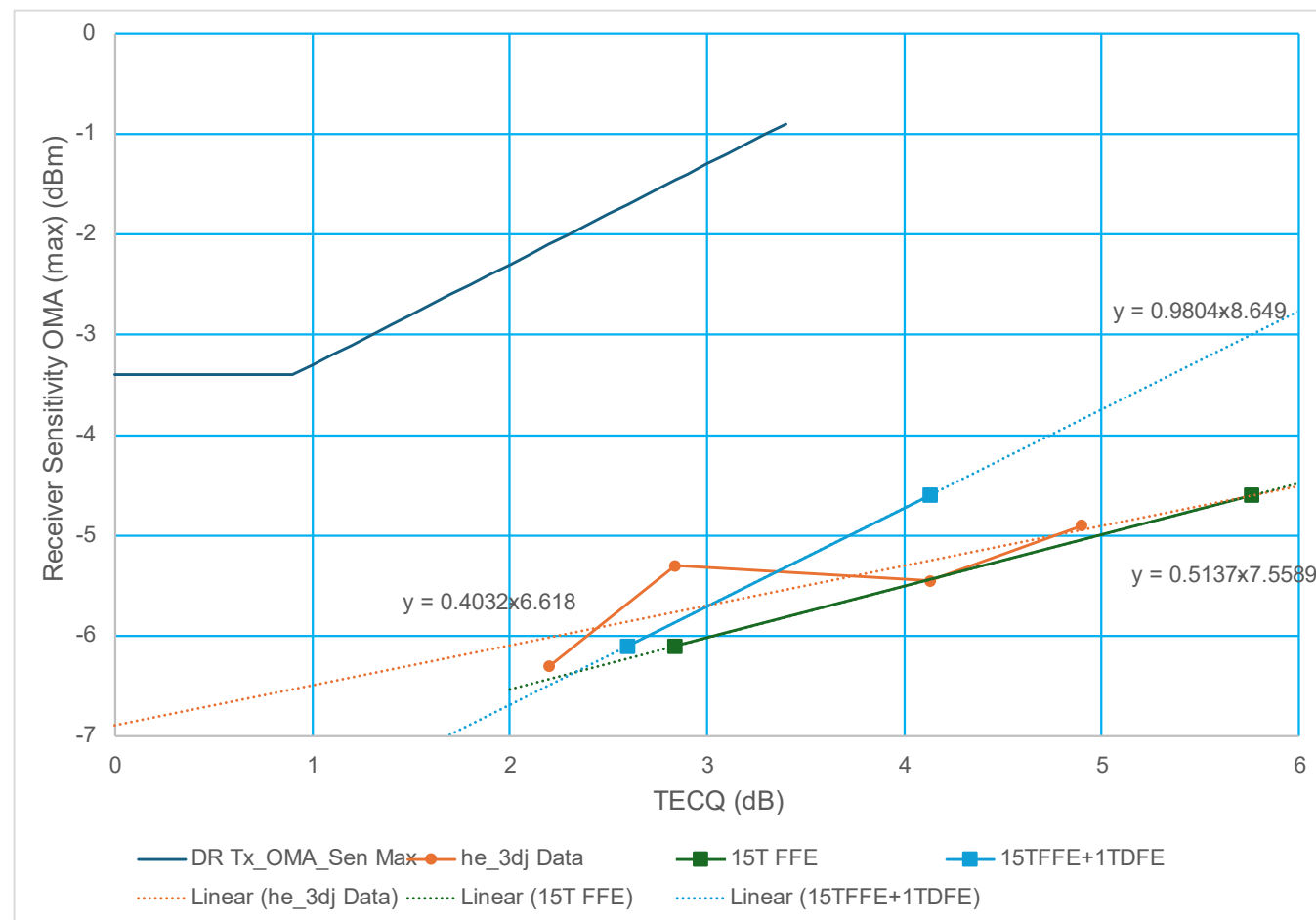
How to Further Improve TDECQ

❑ **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
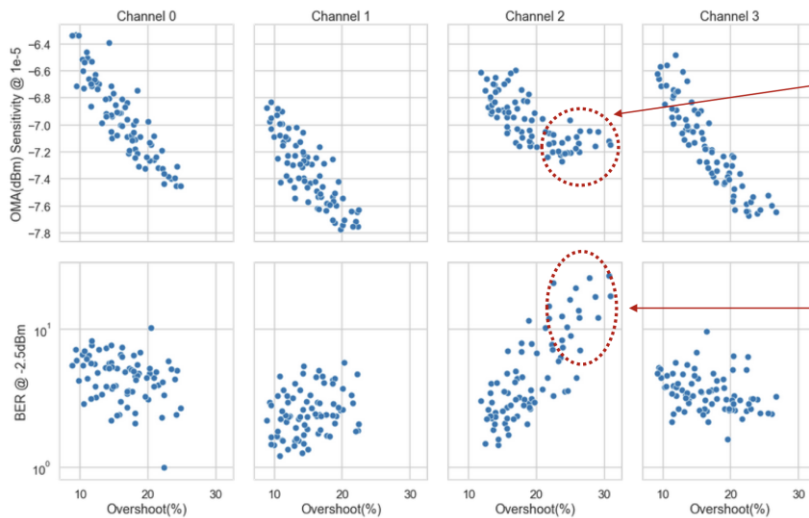
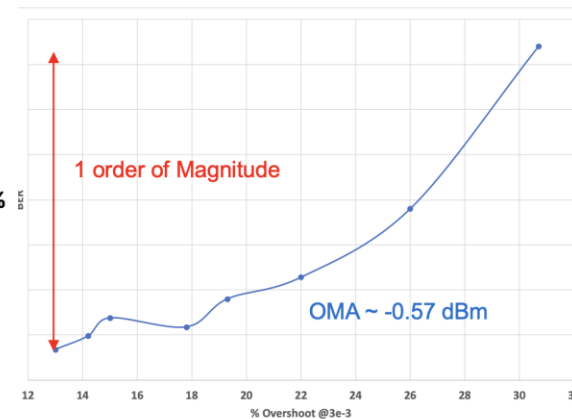❑ Overshoot tends to improve sensitivity. It saturates for values larger than 22%

❑ Overshoot values larger than 22% increase error floor significantly
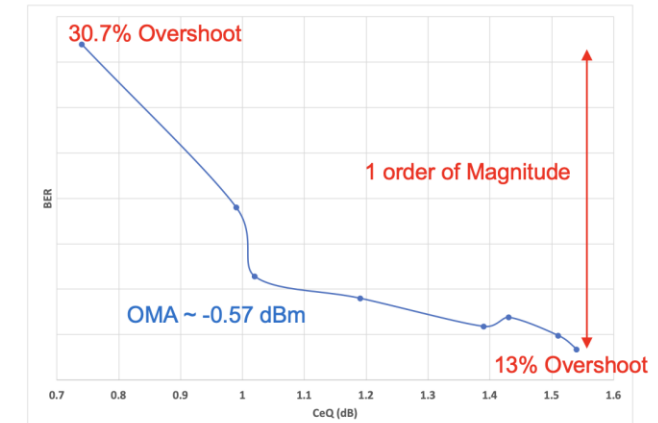
rodes_3cu_adhoc_030520_v2

Overshoot vs Ceq Protecting Receiver for Excess Overshoot

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

ghiasi_802.3db_01_092321

ADC SNR Definition

❑ **ADC SNR is defined as following in textbooks** wirelesspi.com

- $SNR = 6.02N + 1.76 - 20log_{10}\frac{Vmax}{A}$, where N is number of ADC bits, Vmax upper range of ADC, and A is the amplitude.
  - A 6 bits ADC with zero overshoot has an SNR of 37.88 dB
  - A 6 bits ADC with 22% overshoot has an SNR of 36.15 dB or 1.7 dB of PAR penalty
- Reducing overshoot to 12% reduces PAR penalty to 1 dB which is a good trade-off for a TDECQ with 1T DFE
  - Data on previous page show negligible penalty with 12% overshoot.

6 Bits ADC
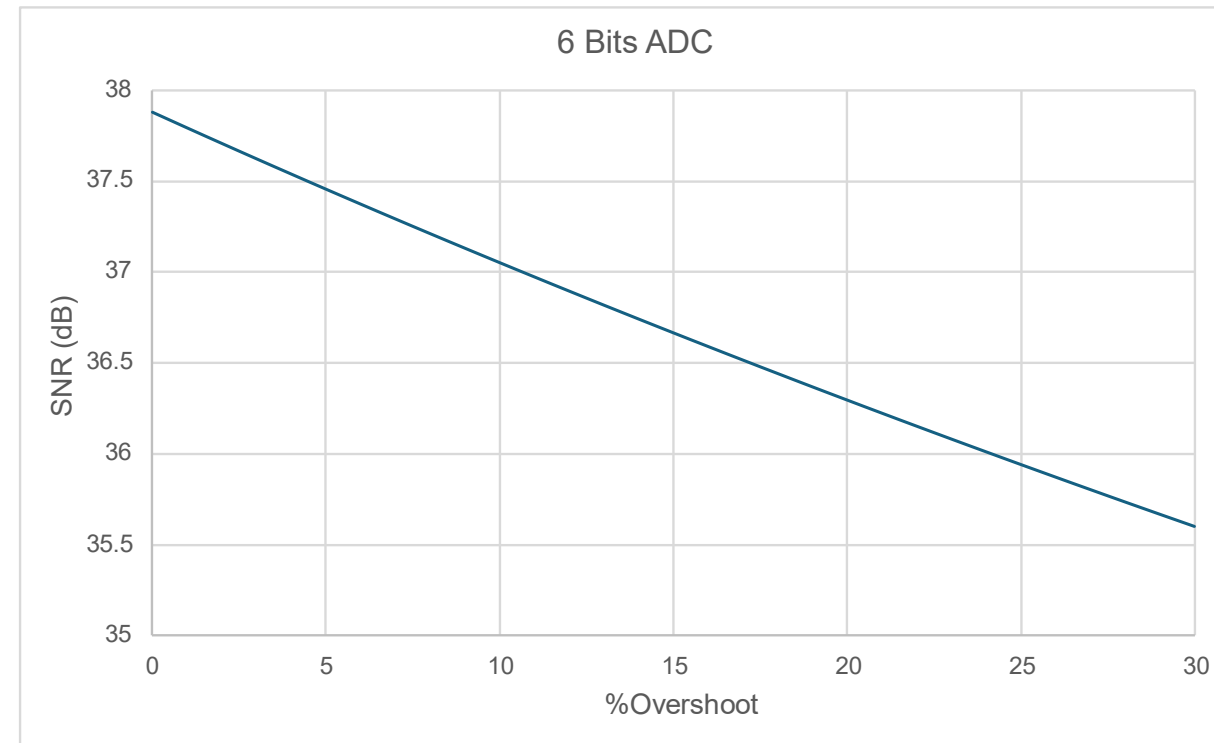
Summary

- **With FFE receiver transmitter are set with high overshoot in order to improve TDECQ which often results in inferior block BER**
  - Another issue with FFE only TDECQ given that receiver has a DFE the TECQ penalty doesn't correlate with receiver sensitivity
- **The current 15T FFE is a good compromise between complexity, power, and benefit**
  - Adding 1T DFE to the 15T FFE offer much better performance than even a 25T FFE
- **Adding 1T DFE to TDECQ/EECQ with Bmax≤0.35 penalty due to burst error is negligible and provide following benefits**
  - Reduces TDECQ by ~0.5 dB for compliant (≤3.4) transmitters
  - Reduces TDECQ by ~1.5 dB for slow high TDECQ (≥5.0) transmitters
  - Given the amount of improved proposed DFE TDECQ limit ≤3.1 dB
- **Another key benefit of adding 1T DFE to the TDECQ equalize is the significant improvement of TDECQ penalty correlation with receive sensitivity penalty**
  - To mitigate PAR penalty overshoot should be limited to ≤12%
- ***Comments 381, 382, 383, and 384 remedy: enable 1T DFE for TDECQ with Bmax≤0.35, reduce TDECQ limit to 3.1 dB, and limit Overshoot to 12%.***

Thank You!