In Response to TDECQ/SECQ Questions for Threshold Adjustments*

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Special thanks to Ali Ghiasi for fruitful discussion on making the point that TDECQ value without threshold adjust may require guard band, but adjustable threshold receiver would require adjustable threshold SRS stressor.

*: With data to support comment resolutions for adding Adaptive Threshold Adj. in computing TDECQ (floating slicing)

IEEE802.3cd ad hoc Conference Call, 14 February 2018

Outline

- Problem Statements
  - To follow up discussion/questions from Jan interim
- Why threshold adjustment is necessary
  - There exists a clear "hole" for module specification without threshold adjustments
- Investigate TDECQ vs. measured Sens. correlation
  - Current correlation with D3.0 is considered arguably "poor"
- Look into the consequence/impact on Rx side
  - With respect to real ASICs with low power DSP mode close to ref. 5T equalizers

Problem Statements

- Strong support to add Adaptive Slicing in Ref. equalizers to resolve TDECQ specs dilemma (mazzini_120617_3cd_adhoc-v2)
  - Supported by 27+ companies including the majority module and IC vendors as well as systems vendors/users.
  - Extensive data demonstrated some improvements (~0.3-0.4dB) across all transmitter types: DML, VCSEL, EML, and MZM.
  - Keysight and Tektronix schedule this week to release new beta FW with floating thresholds as defined in recent proposal. It includes setting an adjustable limit.
- Some questions asked "why threshold adj. is needed?" in real RX IC implementation – a tutorial.
- No analog equalizers available with 5T for link BER measurements.
- Follow up questions from the editorial team (cite JonathanK)
  - Show improves correlation between TDECQ vs measured receiver sensitivity.
  - Show not too high a stress for the receiver in SRS tests

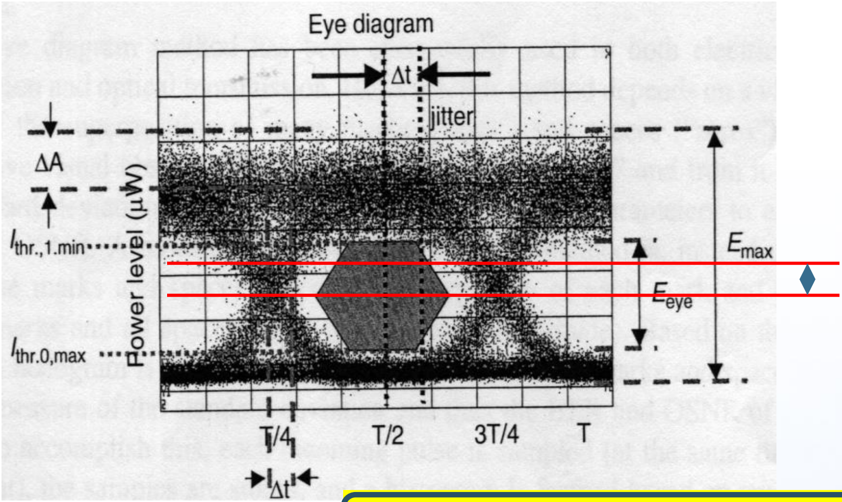
Why Threshold Adjustment is Necessary (1)

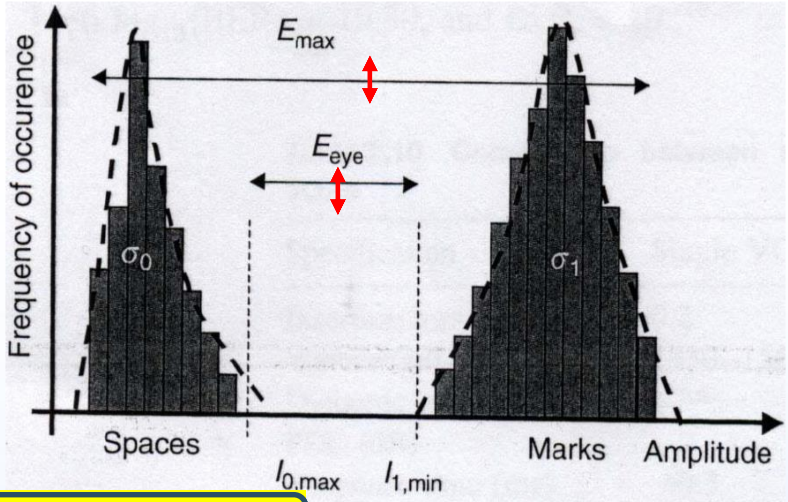
- Threshold adjustment has been well deployed for CDRs & SerDes IC for NRZ systems (2.5, 10G, 25G) with direct detection
  - Either manual or adaptive for optimized BER, refs. e.g.
    1) Matsumoto et al. "*An adaptive decision threshold control of the optical receiver for multi-gigabit terrestrial DWDM transmission systems*"; OFC 2001, Paper TuR2, March 2001. (2.5G NRZ)
    2) Park et al. "*Performance Analysis for Optimizing Threshold Level Control of a Receiver in Asynchronous 2.5 Gbps/1.2 Gbps Optical Subscriber Network with Inverse Return to Zero(RZ) Coded Downstream and NRZ Upstream Re-modulation*"; J. OSK V.13, No.3. pp361-366, Sept 2009. (2.5G/1.25G NRZ)
    3) Yan et al. "Performance enhancement in *10-Gb/s long-haul fiber links with adaptive eye mapping in an integrated Si-CMOS 16-bit transceiver IC*"; IEEE Photonics Tech. Letters, Vol.17, No.8, pp1752-4, Aug. 2005. (10G NRZ)
    4) Chang et al; "*Accurate in-situ monitoring of Q-factor and BER using adaptive sampling in a 10Gb/s CMOS optical receiver IC*"; IMS05, Paper WEPL-3, June 2005. (10G NRZ)

- Similar practice in QAM systems like QPSK & 16QAM for 100+G coherent DSP, refs. e.g.
    1) Chiba et al. "*Adaptive threshold adjustment for signal distortion-free digital-coherent optical demodulation system*"; Vol.16, No.26, Opt. Express, pp21647-55, Dec. 2008.

Why Threshold Adjustment is Necessary (2)

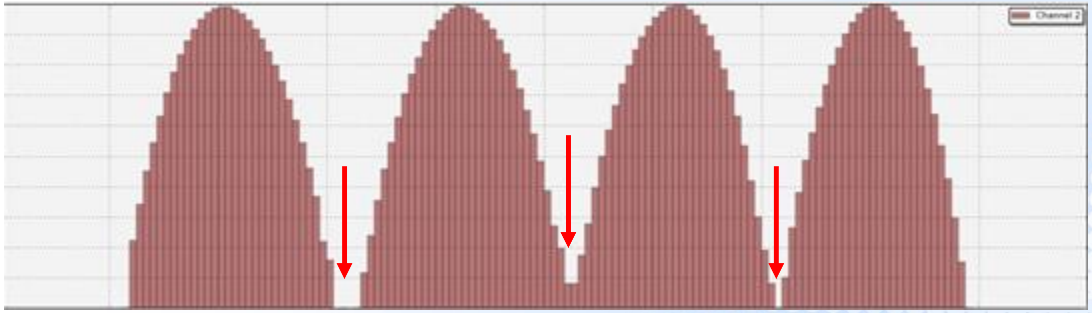
- Results from unevenly distributed noise on 0/1 levels





Average threshold ≠ Optimum point

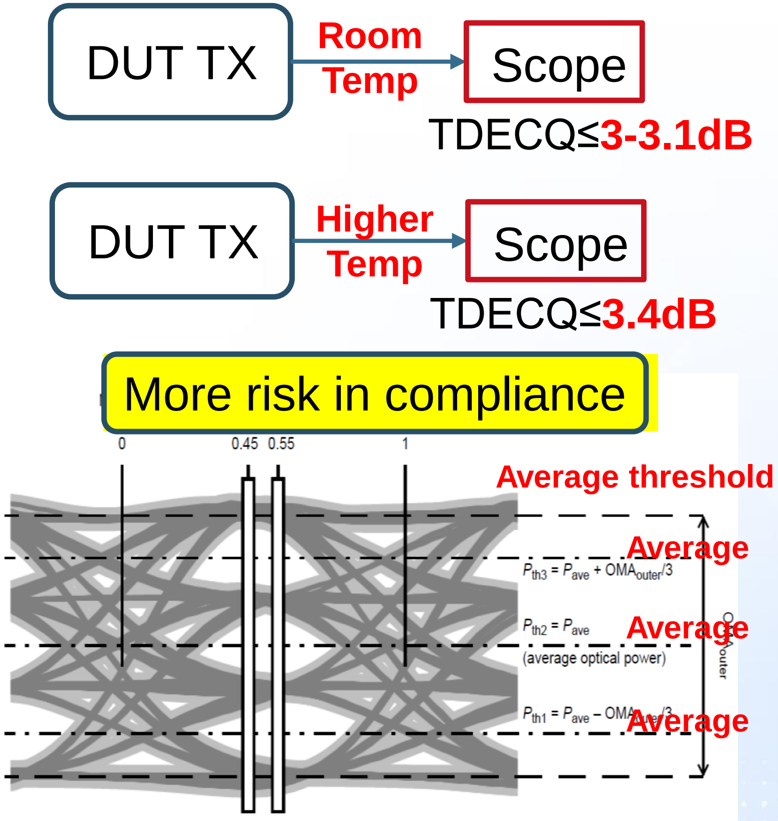
- Actually measured PAM4 histograms show similar

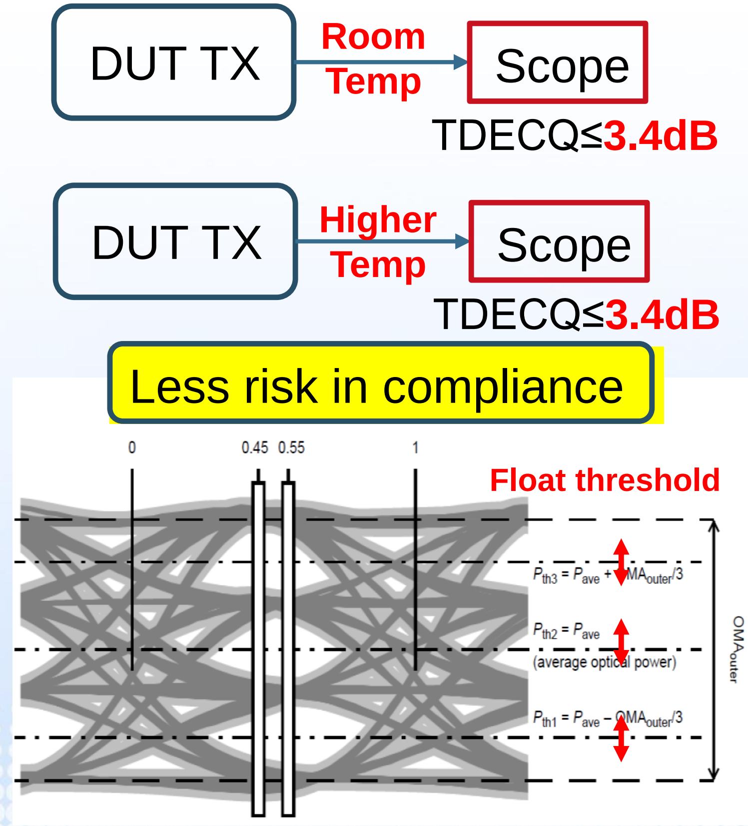


In real ASIC implementations, decision threshold level and phase of received data in the decision circuit are automatically adjusted to the optimum position

Why Threshold Adjustment is Necessary (3)

- Threshold adjustment help fill up D3.0 specs “hole” in TDECQ tests
  - NO **Guard Band** needed to compensate for threshold variations with Temp.
  - D3.0 case: 0.3-0.4dB guardband needed - With threshold Adjustments



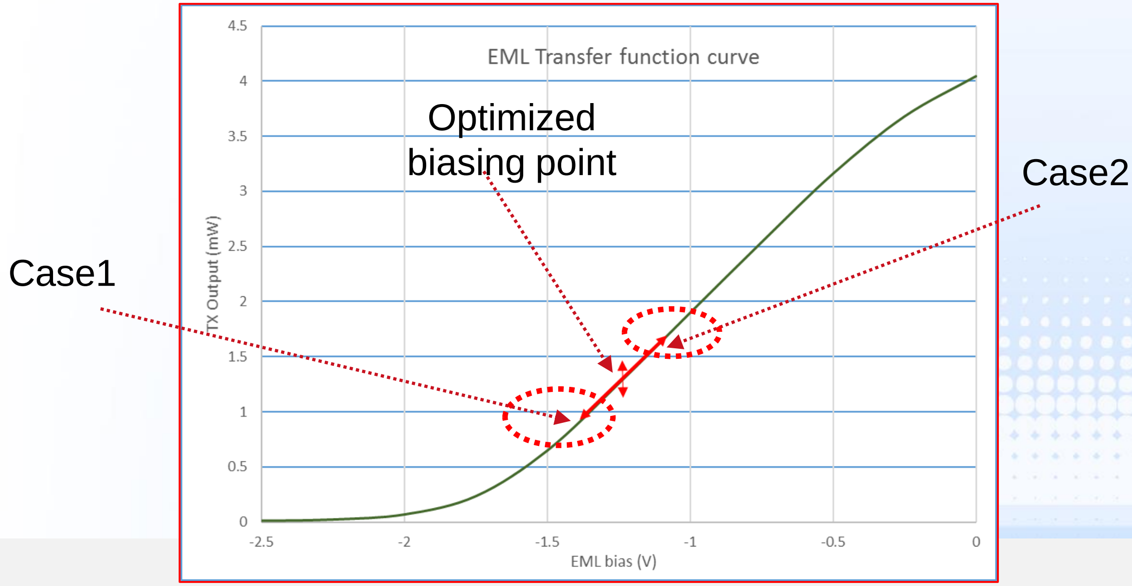


Correlate TDECQ with Rx Sensitivity

Under well controlled lab environments with golden EML TOSA, following 3 scenarios are considered for threshold adjustment within the limit of <2%

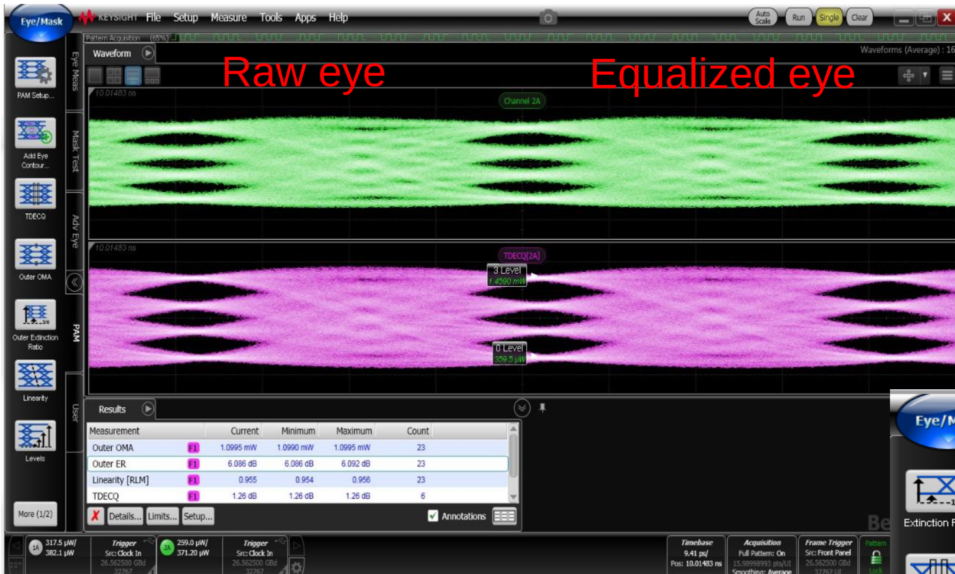
- (Setup refer to chang_011018_3cd_02_adhoc-v2 & chang_3cd_01a_0917)

- Full optimized EML condition, full link optimized with best BER condition.
  - Optimized EML Bias voltage, and Linear driver nonlinearity
- Off-optimized conditions,
  - Keep default EML bias voltage (VEML), vary Linear driver nonlinearity
- Unoptimized Case 1: Move two TX setting downwards;
  - Vary VEML bias down by ~ 150mV, and vary driver gain accordingly (all the rest no change)
- Unoptimized Case 2: move TX setting upwards;
  - Vary VEML bias up by ~ 150mV and vary driver gain accordingly (all the rest no change)

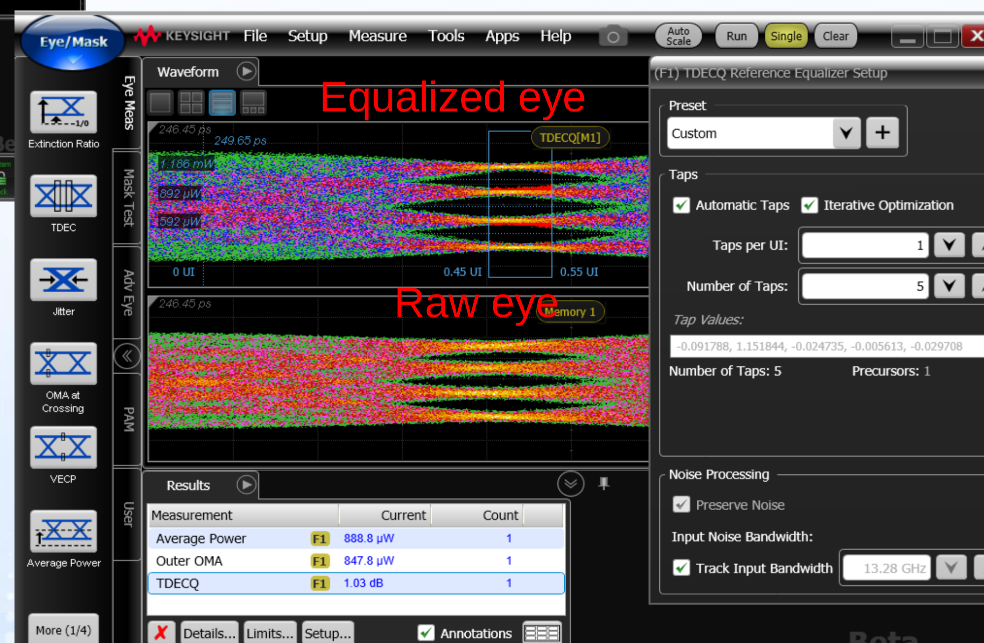


TX eye diagrams: optimized condition (D3.0)

Full optimized case (D3.0) ER=6.1dB
TDECQ/SECQ=1.26dB, RLM=0.955



Optimized case D3.0 with threshold Adj
TDECQ/SECQ=1.03dB



Note: DECQ tests for slides#8-11 are actually SECQ (without test fiber) and based on PRBS15 pattern.

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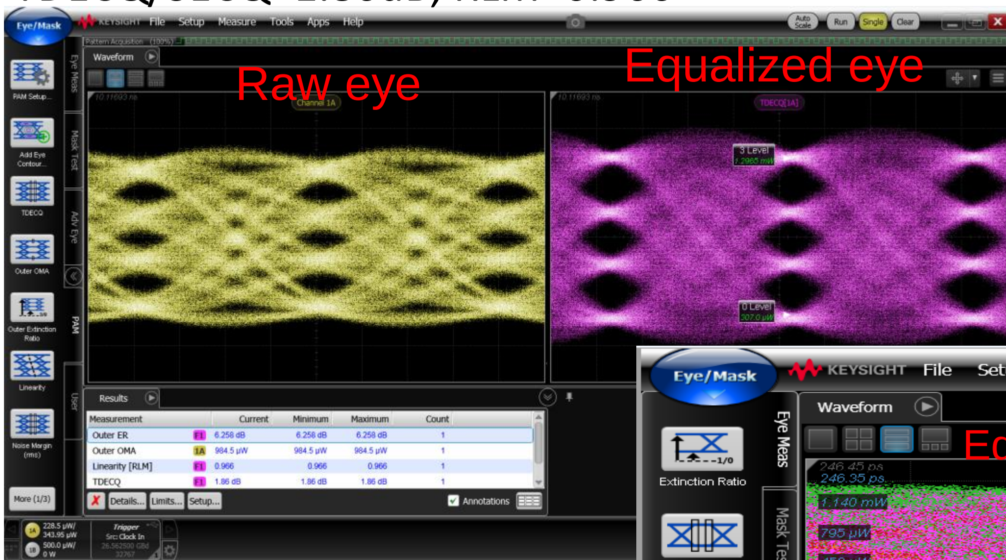
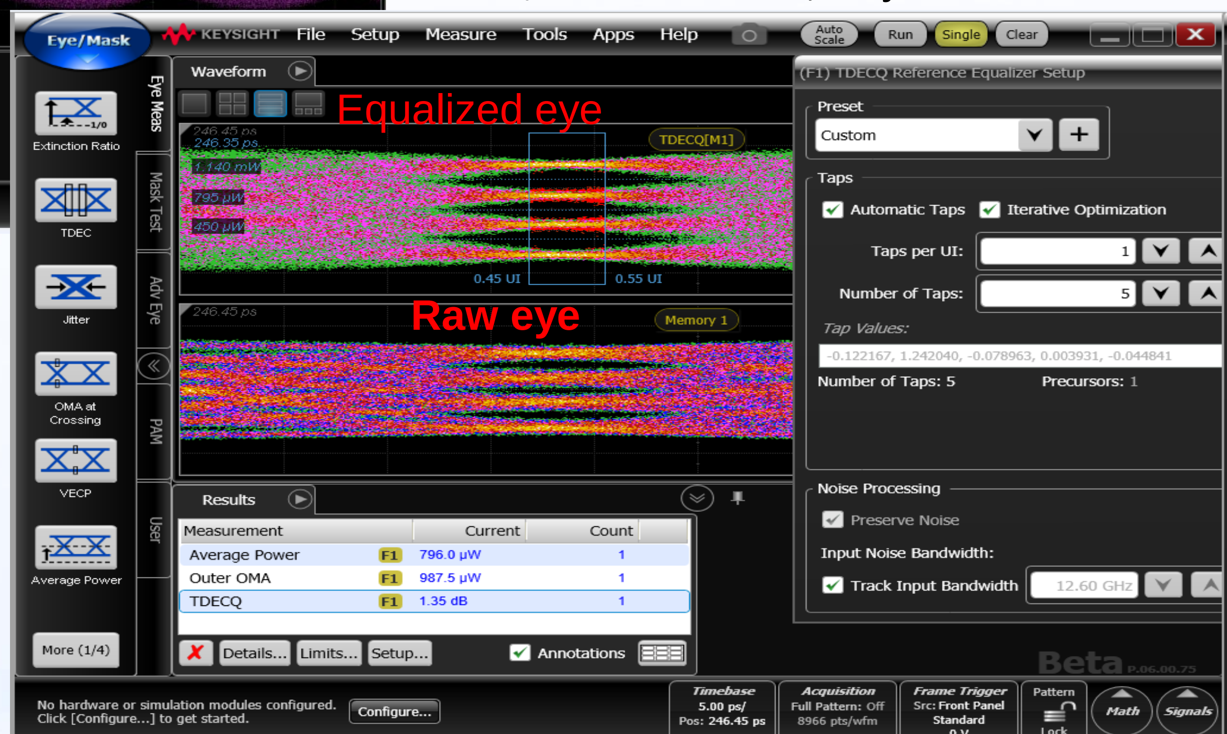
TX eye diagrams: off-optimized condition (D3.0)

Off-optimized case (D3.0) ER=6.2dB
TDECQ/SECQ=1.86dB, RLM=0.966



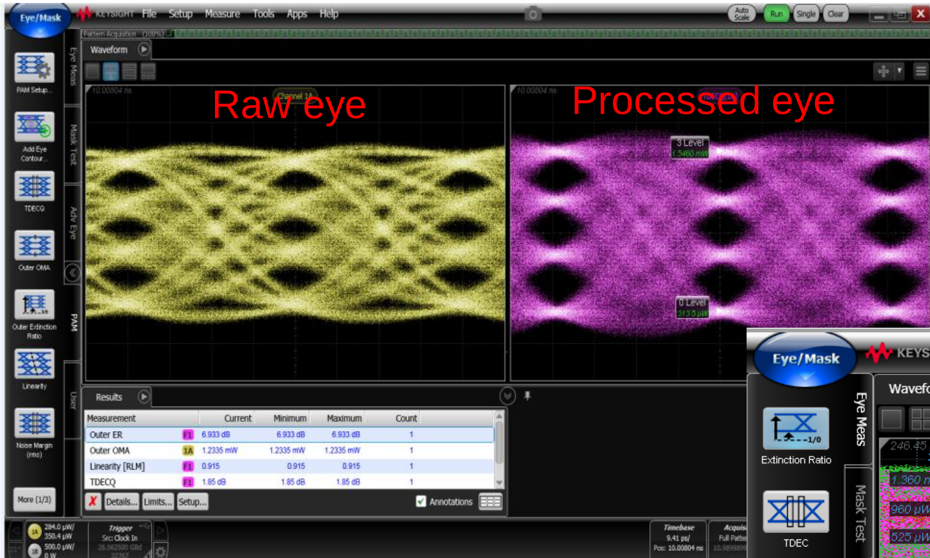
Off-optimized case D3.0 with threshold Adj
TDECQ/SECQ=1.35dB, Adj~1.% of



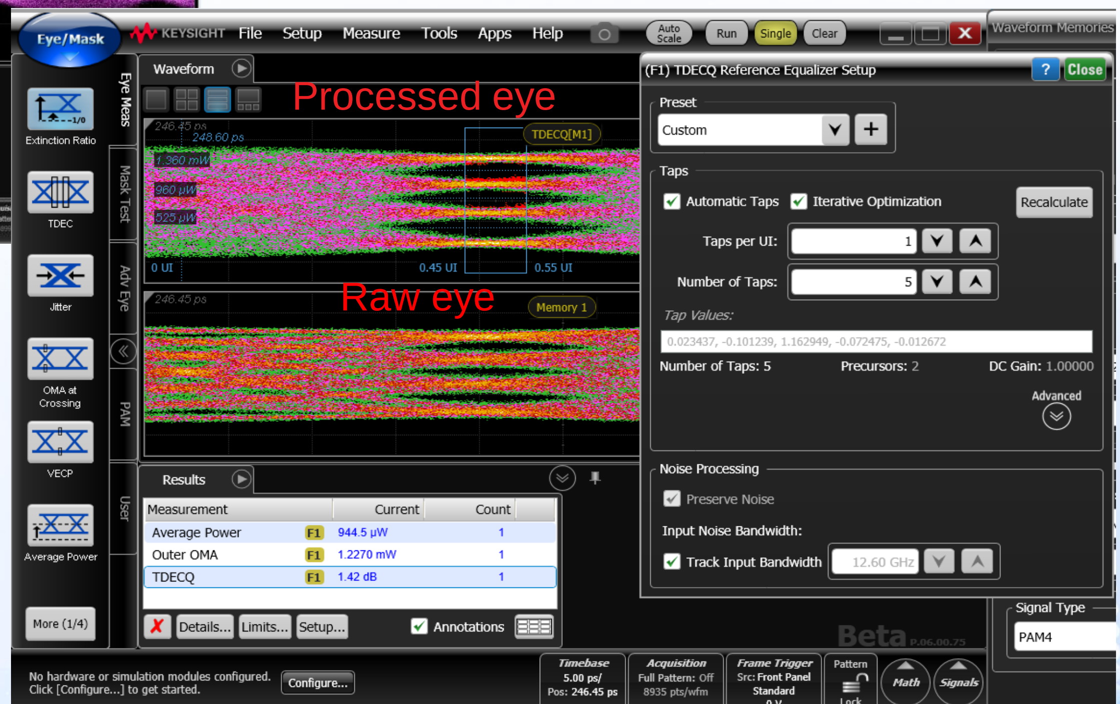
		Adj	%
Pth3	1130.167	-9.83333	-0.99%
Pavg	796	-1	-0.13%
Pth1	466.8333	-6.83333	-0.69%

TX eye diagrams: Case1 (D3.0)

Unoptimized Case1: ER=6.9dB
TDECQ/SECQ=1.85dB, RLM =0.915



Case1(D3.0 with threshold Adj)
TDECQ/SECQ=1.42dB Adj within +1.95%



		Adj	%
Pth3	1353.5	6.5	0.53%
Pavg	944.5	15.5	1.95%
Pth1	535.5	-10.5	-0.86%

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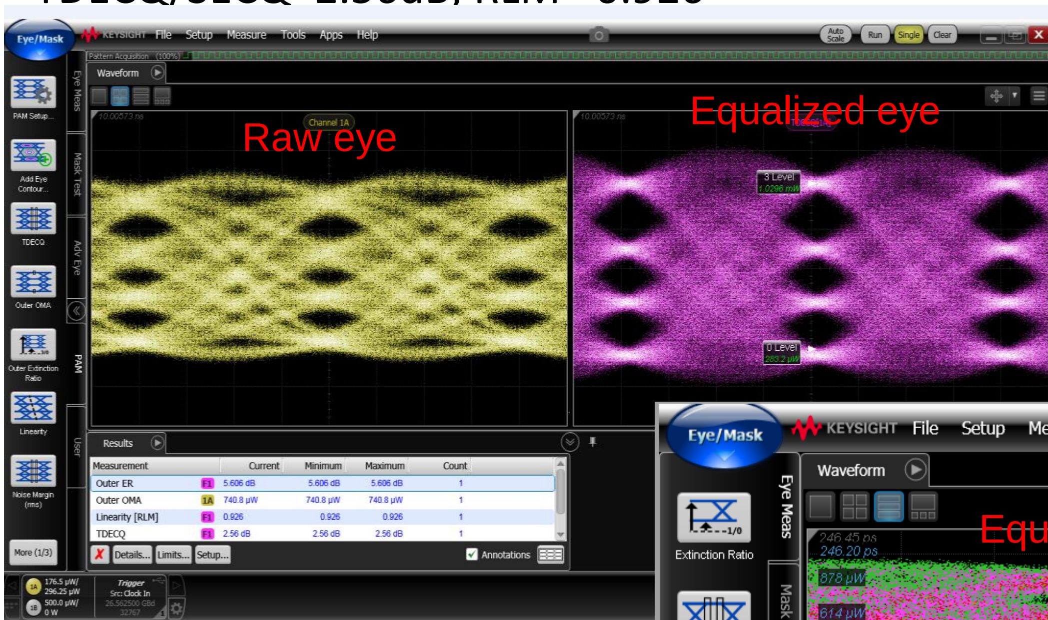
TX eye diagrams: Case2 (D3.0)

Unoptimized case2 ER=5.6dB,
TDECQ/SECQ=2.56dB, RLM =0.926

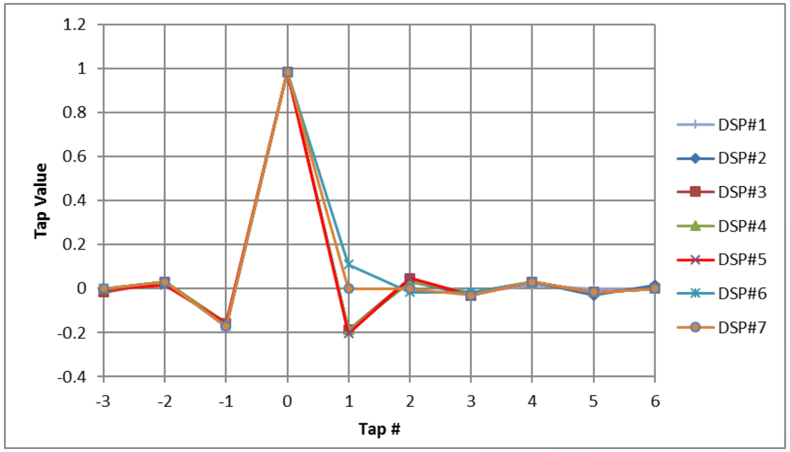


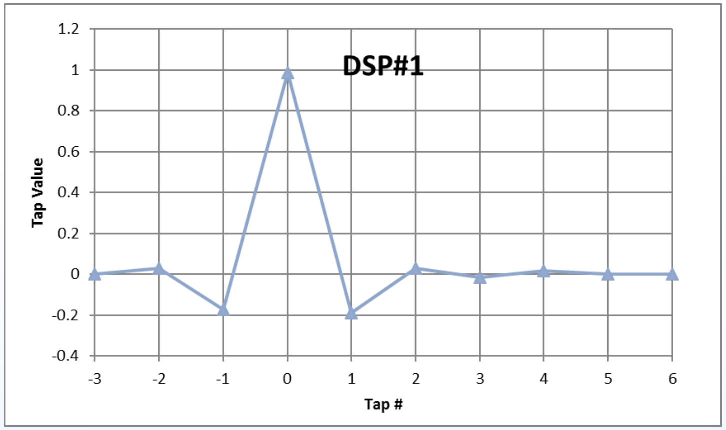
Case2 (D3.0 with threshold Adj)
TDECQ/SECQ=1.68dB, Adj within -1.93%

	Adj	%
Pth3	877.3333	0.666667	0.09%
Pavg	629.4	-15.4	-1.93%
Pth1	381.4667	0.533333	0.07%

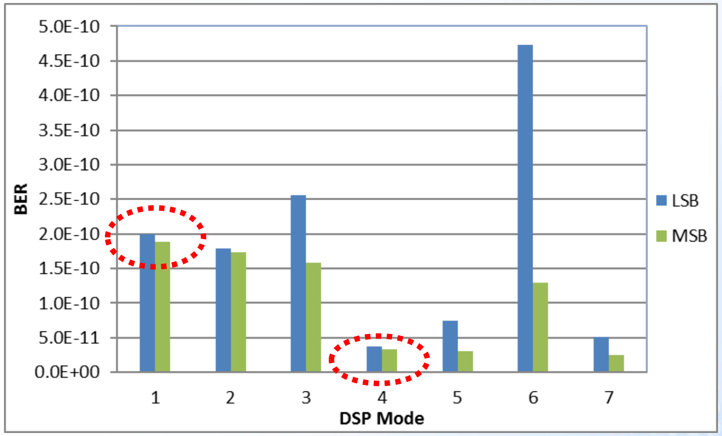
Correlate TDECQ with Rx Sens: how to tackle the analog equalizer non-availability issue

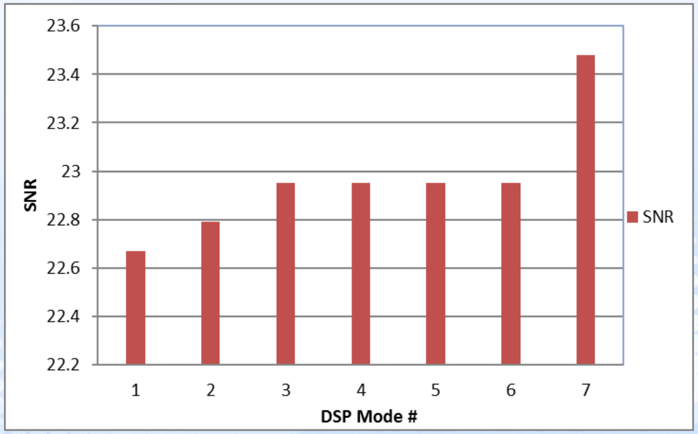
- Emulated low power DSP Mode with closer to Ref 5T equalizers for link BER measurements.





- Comparing performance of various DSP modes (for BER flooring)





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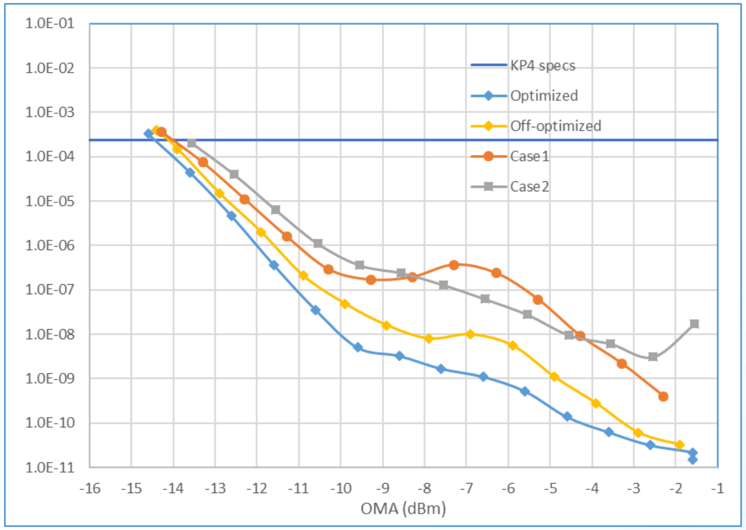
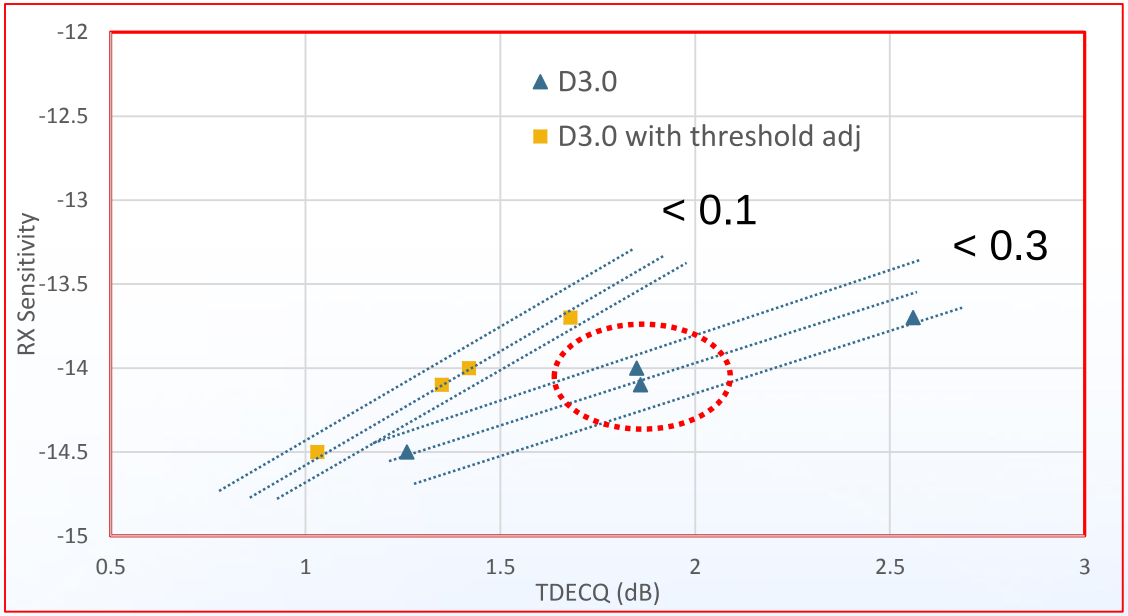
Correlate TDECQ with Rx Sensitivity

- Link BER performance



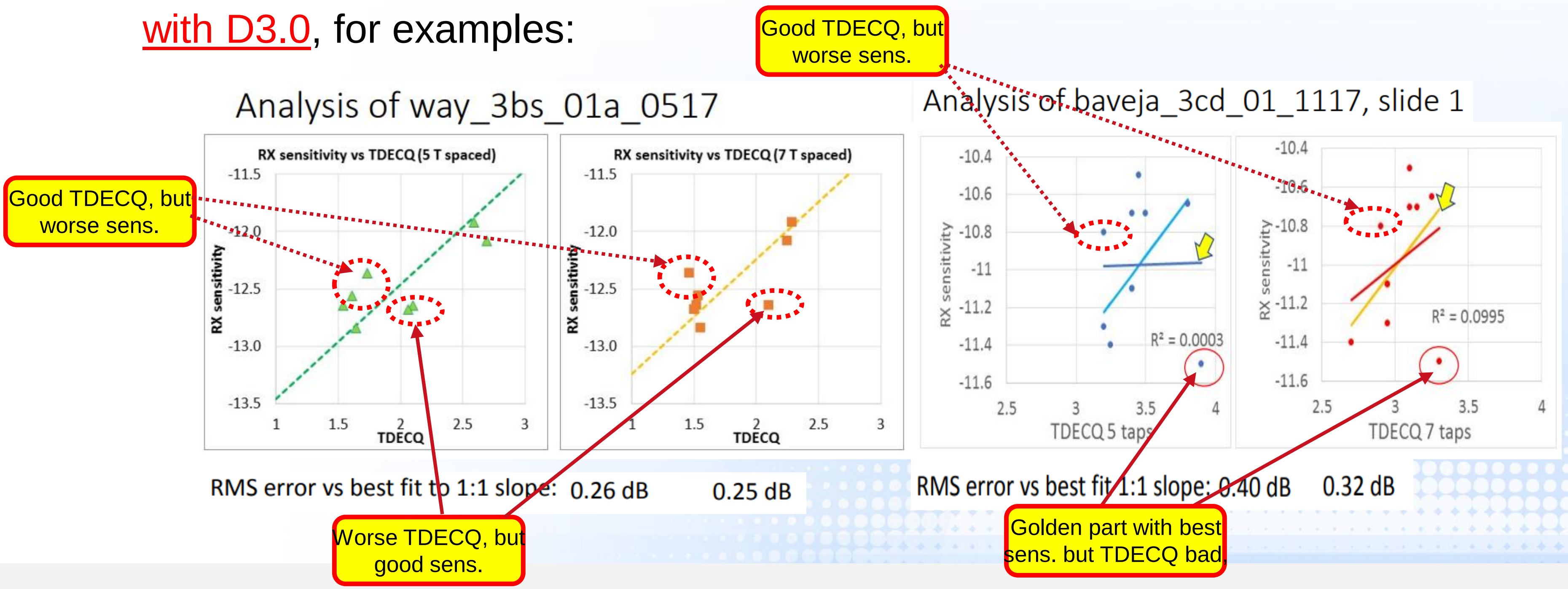


	Full optimized	off-optimized	Case1 <-2%	Case2 <+2%
EML bias	-1.28	-1.26	-1.41	-1.12
ER	6.1	6.2	6.9	5.6
TDECQ (D3.0)	1.26	1.86	1.85	2.56
TDECQ (TH adj	1.03	1.35	1.42	1.68
OMA Sens.	-14.5	-14.1	-14	-13.7

Show better correlation with TDECQ and predict well how RX sens. will vary when threshold adjustment is implemented with limits

Correlating TDECQ with Rx Sensitivity (D3.0)

- Some thoughts: All of us who took the data feel this correlation is “poor”. Where is the “disconnection” with data analysis by king_3cd_01_0118?
  - The data analysis were good but based on statistics in macro scale with large fitting error of 0.3-0.4dB. If looking into individual TOSAs, there are many exceptions for the situation that good TDECQ values delivers worse RX Sens and vise verse, so simply tough to predict RX sensitivity from TDECQ values with D3.0, for examples:

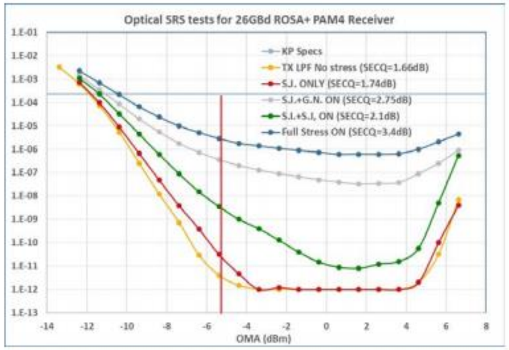


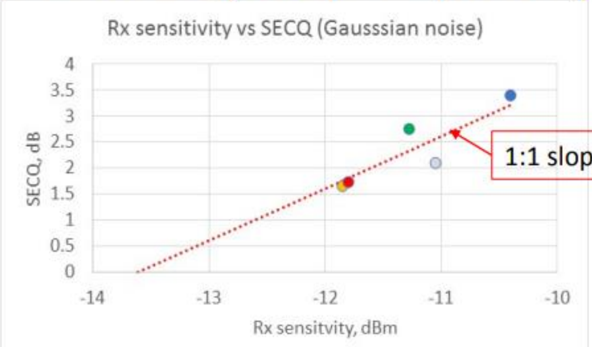
The Impact to RX SECQ (D3.0)

- Recap current analysis with D3.0 by (king_3cd_01_0118)
  - LN MZM TX for instrument testers are well behaved linear devices, and expect to show better correlation.

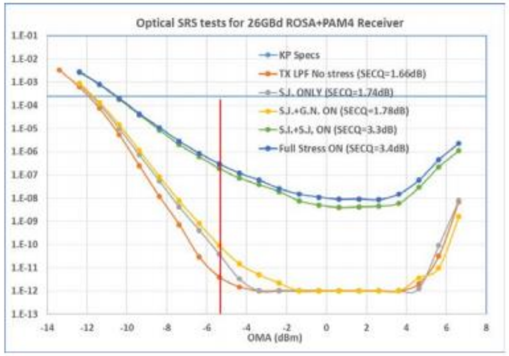
Analysis of chang_cd_01_1117: BER plots vs SECQ (5 tap T-spaced)

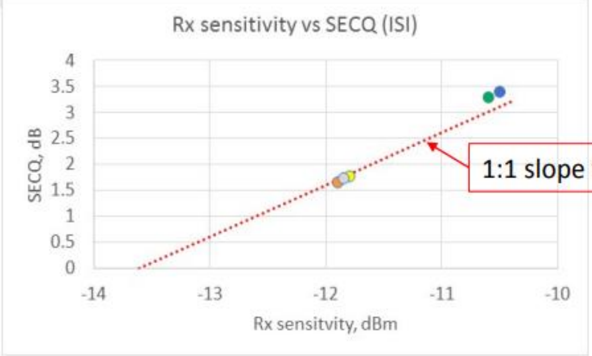
Gaussian noise dominant
RMS error < 0.3 dB





SI dominant
RMS error < 0.2 dB





Very good dB/dB fit for both cases

- *chang_3cd_01_1117* concluded that "*There exists strong interplay between G.N and S.I (with S.J.). G.N. impact most the BER degradation in SRS.*". **But the data shows very good correlation between SECQ and Rx sensitivity for both GN and SI dominant stress (RMS error of <0.3 dB)**

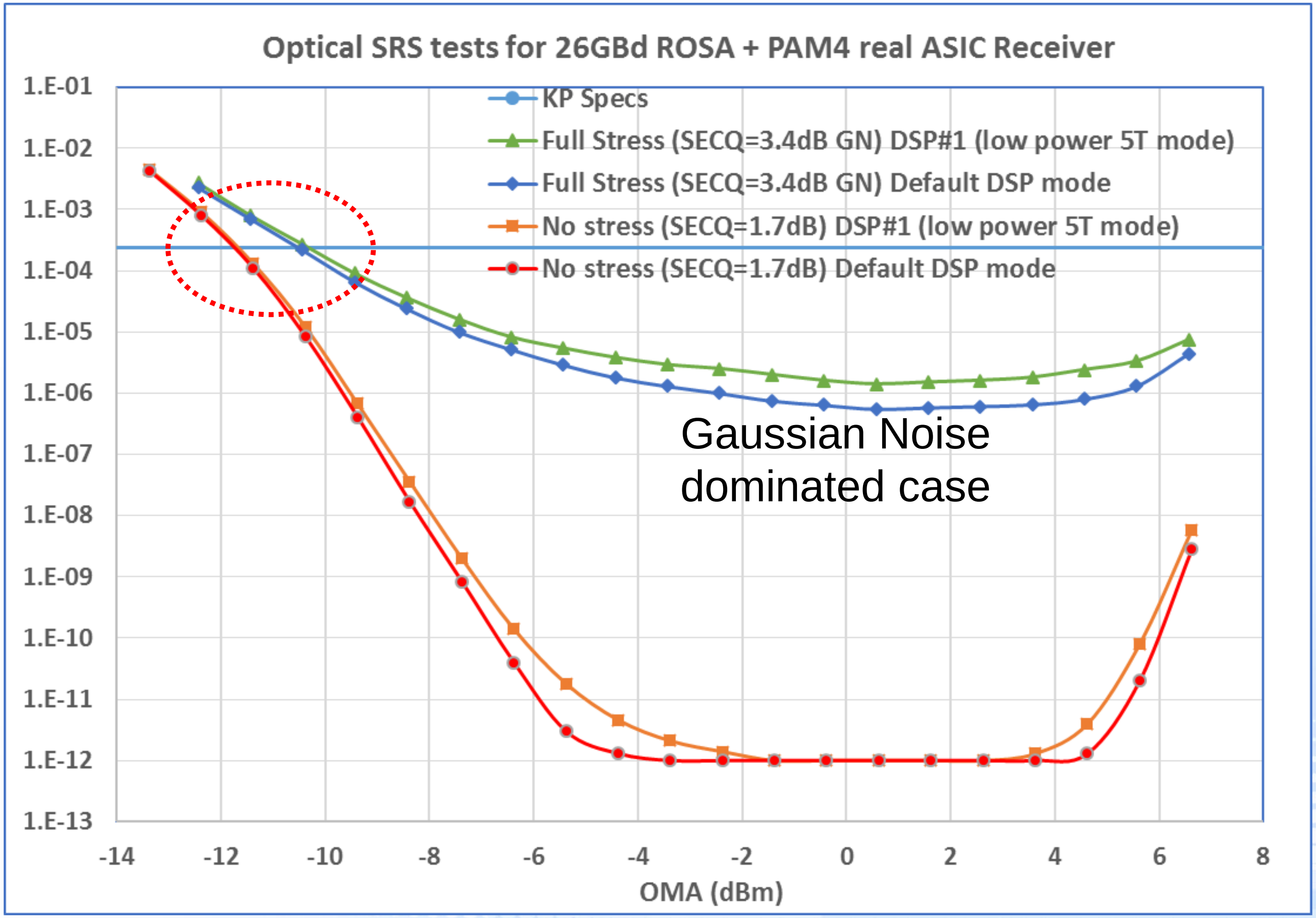
10

Impact to RX SRS (D3.0) by different DSP modes

- Negligible impact on RX SRS Sensitivity by different DSP modes. (only little degrade on BER flooring) chang_3cd_01_1117

LM MZM TX SSPRQ pattern

Compare Rx SRS under different DSP modes for no (B2B) and fully stressed



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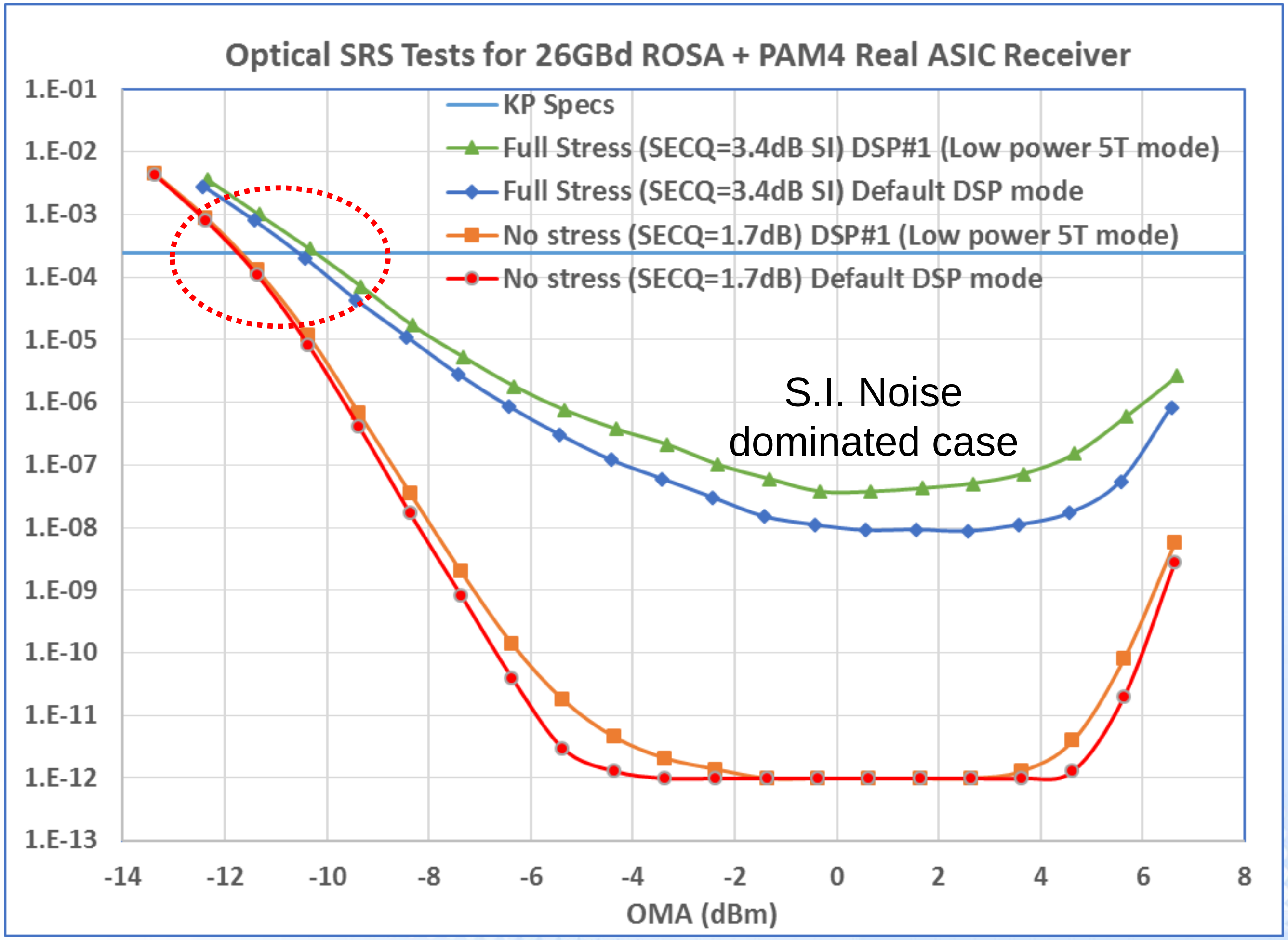
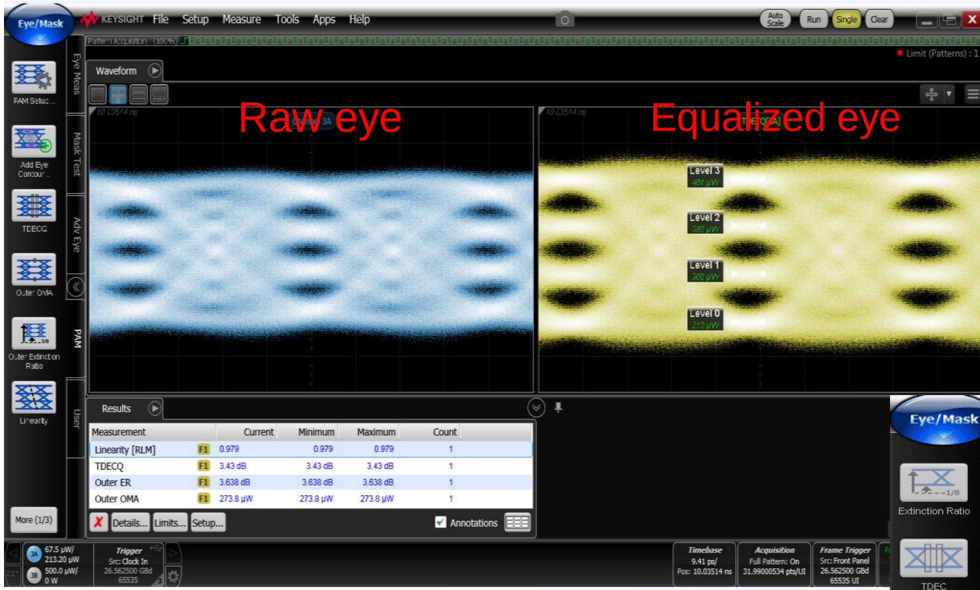
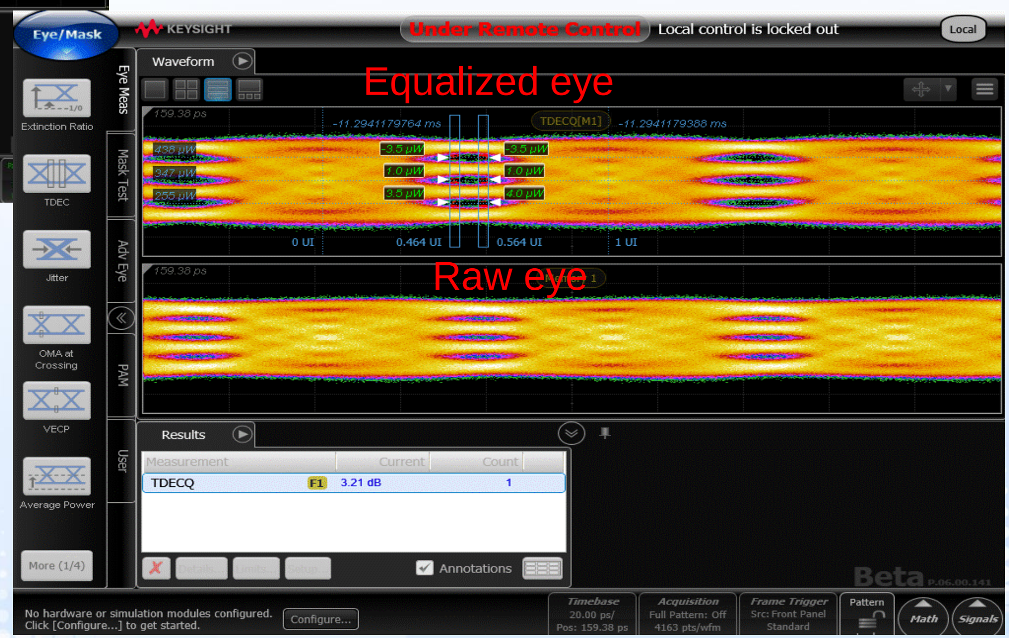


The Impact to RX SECQ

D3.0 Full stressed, RX LPF~13.28GHz
- TDECQ=3.43dB, ER=3.6dB



Re-process using new beta FW release with threshold Adj TDECQ=3.21dB, Adj within 1.46%



	uW	Adj (uW)	
Pth3	438	-3.5	-1.28%
Pavg	347	1	0.37%
Pth1	255	4	1.46%
OMAouter	273.8		

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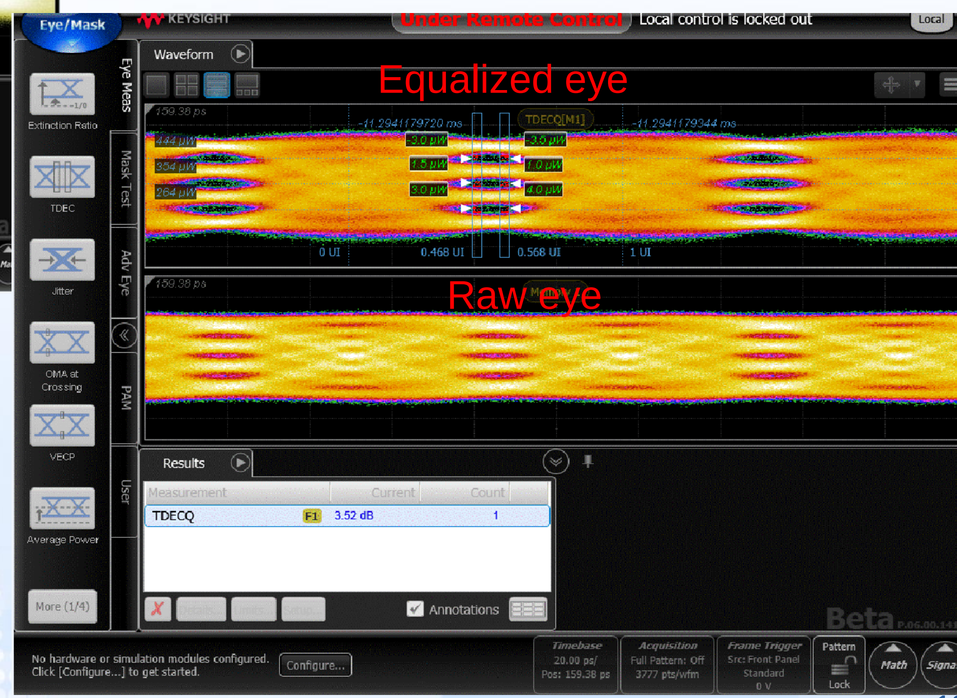
The Impact to RX SECQ

D3.0 over-stressed, RX LPF~13.28GHz
TDECQ=3.64dB, ER=3.5dB

Re-process using new beta FW release with threshold Adj
TDECQ=3.52dB, Adj within -0.73%



	uW	Adj (uW)	
Pth3	446	-2	-0.73%
Pavg	354	1	0.37%
Pth1	263	1.5	0.55%
OMAouter	274.7		

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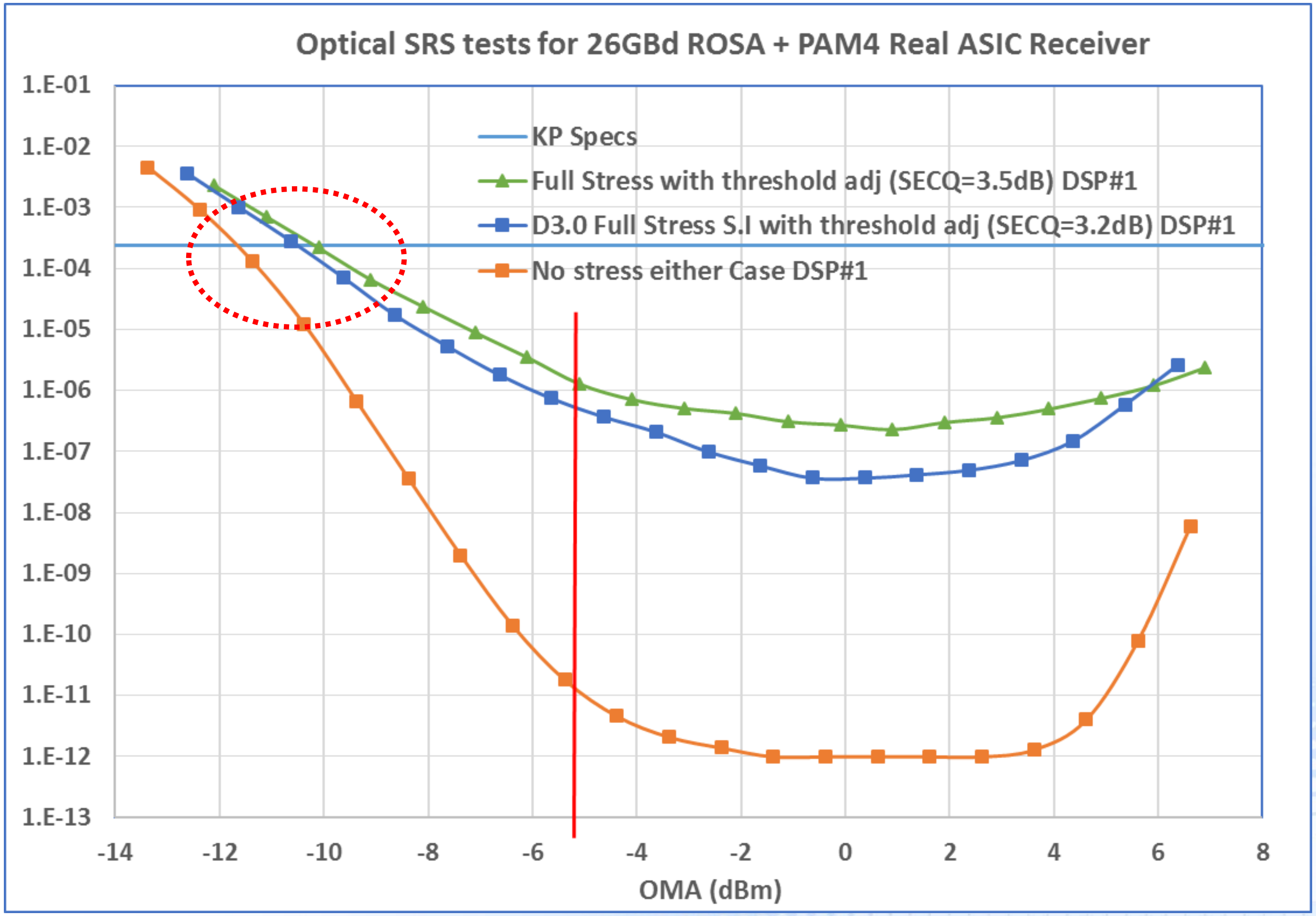
The Impact to RX SRS Sensitivity

- The impact on the Rx SRS is <0.2dB.
  - The real ASIC has threshold adjustment implemented.



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Concluding Remarks

- Adding threshold adjustment will fill the specs “hole” to leave the guard band reserved for environmental variations like temperature and aging.
- Measured link BER with an emulate 5T equalizers by operating at low power DSP mode.
  - Eliminate the dilemma due to the non-availability of analog equalizers usable for such kinds of tests.
- Show threshold adjustments significantly improves correlation between TDECQ vs measured receiver sensitivity.
- The stress on RX SRS tests falls well within 0.1-0.2dB (or less). It seems much less than what we originally thought with setting the limits to the adjustable range.

Recommendations for Threshold Adjustment:

- Minimum risks to add threshold adjustment into TDECQ algorithm.
  - Unless real receiver have threshold adjustment, the transmitter environmental variations and aging will result in TDECQ degradation requiring TDECQ guard band, otherwise there will be a “hole” in specification.
  - Given that real receiver will implement adjustable threshold to optimize environmental variations then might as well use this capability in TDECQ by allowing threshold adjustment.
- This will make significant improvement over D3.0 and put an end to the TDECQ battle.
- Next step to provide comment proposal for how to change the text. (Per Mark’s input to the team)

Thank You