

TDECQ and SECQ vs Rx sensitivity:
review of previous presentations
and proposed changes
(comments i-58, i-82, i-83, i-84, i-79, i-80 i-81)

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Introduction

- TDECQ is a statistical transmitter and path penalty for a worst case channel and receiver
 - The current TDECQ definition has a reference receiver with BT4 bandwidth of half the symbol rate and a reference equalizer which is a 5 tap T-spaced FFE
 - It's designed to estimate worst case transmitter and path penalties for a reference receiver that includes a reference equalizer
 - One of TDECQ's jobs is to screen out transmitters that won't close link for a worst case channel and receiver
- This presentation looks at published measurements of TDECQ, SECQ and receiver sensitivity (multiple sources below) to see how TDECQ and SECQ metrics perform, in the context of comments made against P802.3cd draft 3.0
- *Thank you* to the multiple teams who have collected and presented data on PAM4 metrics and link performance
- Sources
 - *way_3bs_01a_0517, way_3bs_01a_0717, chang_3cd_01_1117, baveja_3cd_01_1117*

Relationship to comments against 802.3cd

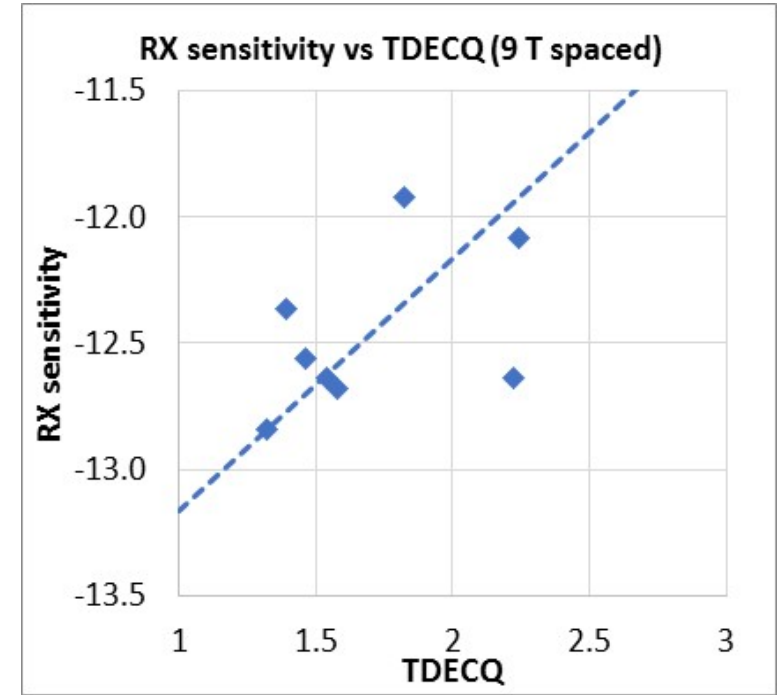
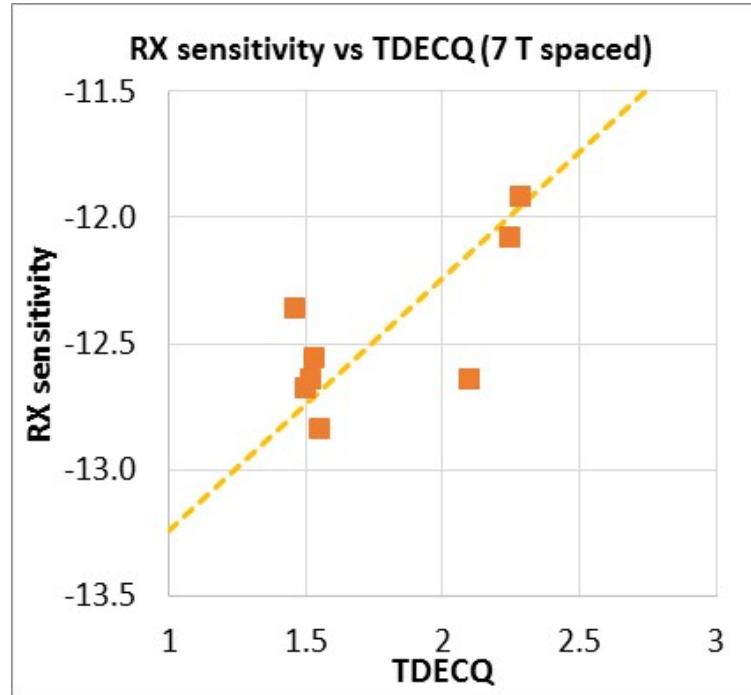
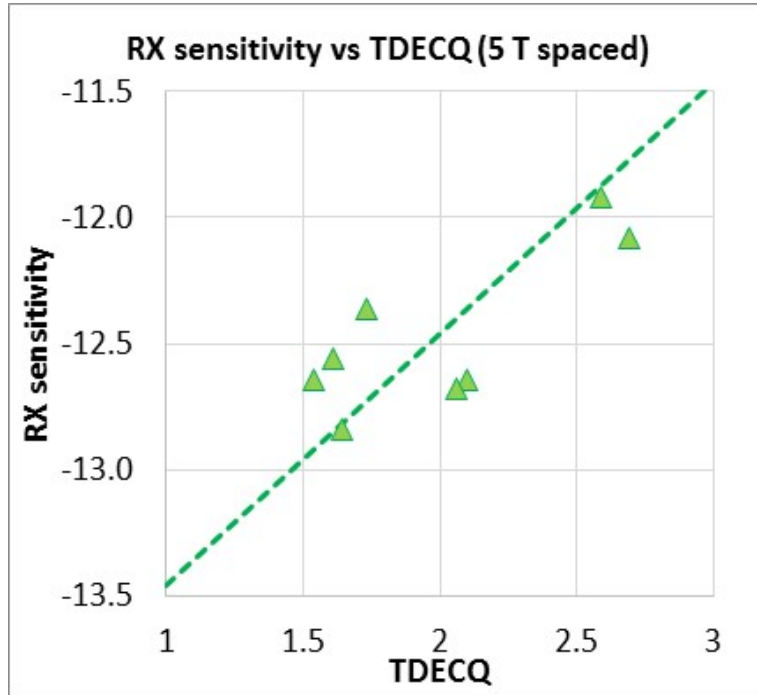
- Previous presentations reporting TDECQ, SECQ and Rx sensitivity measurements have been cited to support proposals to
 - Increase the number of TDECQ taps (no comments against D3.0)
 - Write a prescription for the amounts of SJ, SI, and GN for the stressed source used in SRS testing (i-58, i-82, i-83, i-84)
- Let's see what the data says
- There's also been a proposal to add threshold adjustment to TDECQ (i-79, i-80 i-81)
 - A summary of a comparison of the current TDECQ fixed threshold definition and the impact of adding threshold adjustment to TDECQ is included here
 - Ref: *king_3cd_01_0118_adhoc*

Recap of previous presentations

Recap of way_3bs_01a_0517

- TDECQ and Rx sensitivity for 8 EML 50 Gb/s PAM4 transmitters
- TDECQ calculated for 5, 7, & 9 taps, T or T/2 spaced
 - TDECQ version per P802.3bs draft 3.1 – reference receiver bandwidth equal to 0.75x symbol rate, PRBS15 test pattern used, no timing optimization.
- BER plots for PRBS31 test pattern, unspecified receiver characteristics
 - No information on unstressed receiver sensitivity, or equalization capabilities

Analysis of way_3bs_01a_0517



RMS error vs best fit to 1:1 slope:

0.26 dB

0.25 dB

0.33 dB

0 dB intercept:

-14.46 dB

-14.24 dB

-14.16 dB

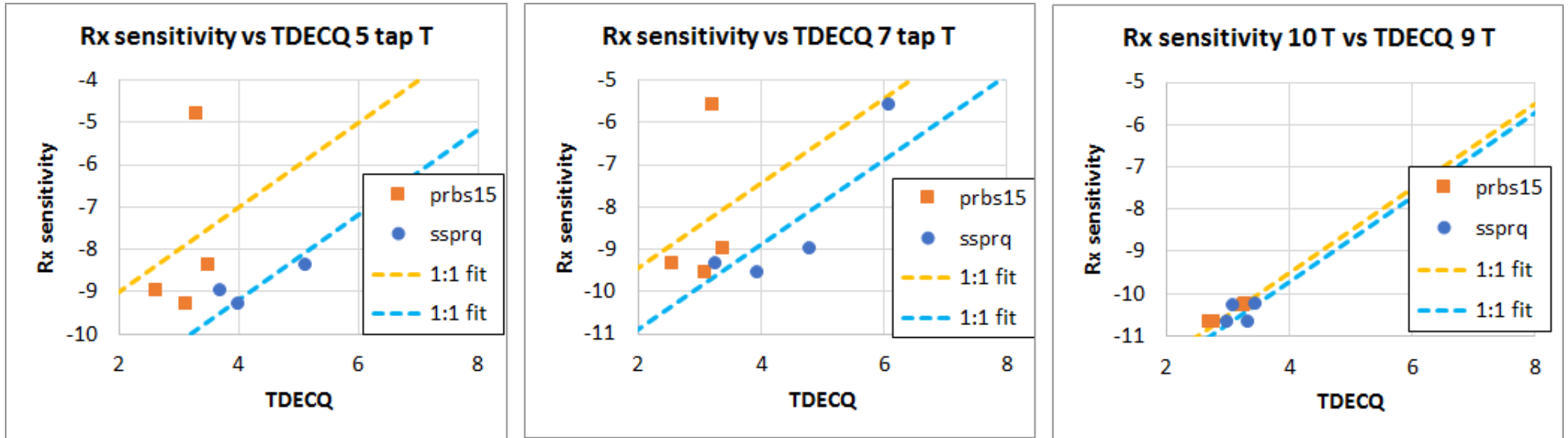
- The data shows a reasonable match to a 1 dB per dB relationship for TDECQ and RX sensitivity – the RMS error is consistent with correlation of two practical measurements
 - Difference in TDECQ values for 5 T-spaced taps correlates with difference in receiver sensitivity – similarly for 7 or 9 taps

Recap of way_3bs_01a_0717

- TDECQ and Rx sensitivity measurements for 4 transmitters
- TDECQ calculated for 5, 7, & 9 taps, T spaced
 - TDECQ version per P802.3bs draft 3.2 – reference receiver bandwidth was higher than 0.5x symbol rate, PRBS15 and SSPRQ test patterns used, no timing optimization.
- BER plots for PRBS31 test pattern, unspecified receiver characteristics
 - RX sensitivity results for 5, 7, and 10 T-spaced taps obtained via a linear O/E and offline DSP
- Comments:
 - One of the transmitters show large differences in TDECQ and receiver sensitivity for SSPRQ vs PRBS15 test patterns, potentially due to low frequency (baseline wander) issues.
 - Longer EQs don't address baseline wander
 - In general, the transmitters shows restricted bandwidth characteristics i.e. strong dependence of receiver sensitivity and TDECQ with number of EQ taps.

Analysis of way_3bs_01a_0717

Receiver sensitivity (measured with SSPRQ) vs average TDECQ values for 5, 7, and 9 T-spaced taps



- TDECQ measured with PRBS15 underestimates the RX sensitivity penalty
 - The data shows the SSPRQ test pattern is a better indicator of receiver sensitivity than PRBS15
- The data shows TDECQ measured with SSPRQ is a reasonable match to a 1 dB per dB relationship with RX sensitivity for TDECQ $\sim \leq 5$ dB
 - For example, difference in TDECQ values (SSPRQ, 5 tap T spaced EQ) values correlate with difference in receiver sensitivity measured, with an RMS error of 0.35 dB

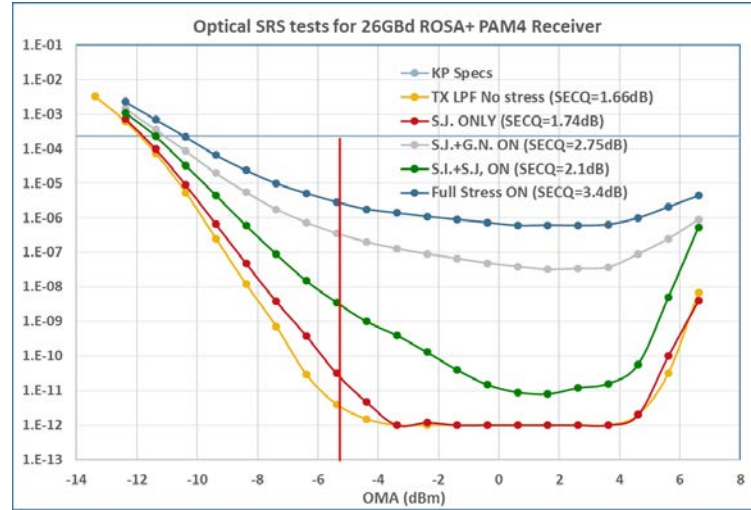
Recap of chang_cd_01_1117

- SRS tests with PRBS31Q
- Measured receiver sensitivity vs SECQ for Gaussian noise (GN) and sinusoidal interferer (SI) dominated stressed sources

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

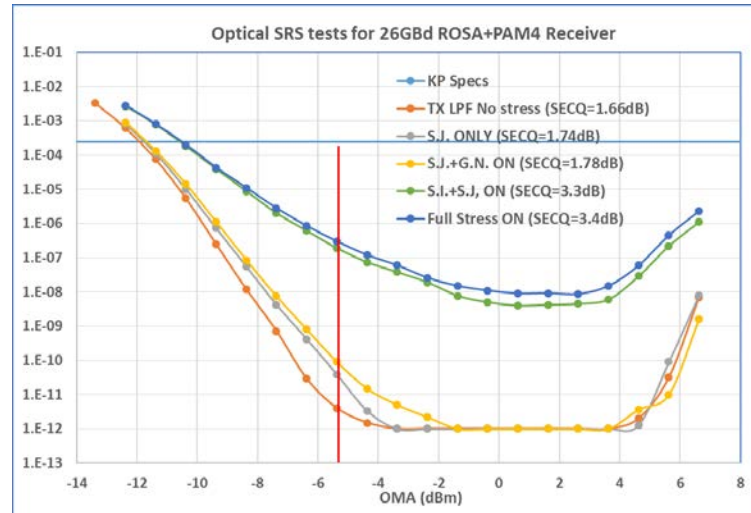
Gaussian noise
dominant

RMS error < 0.3 dB

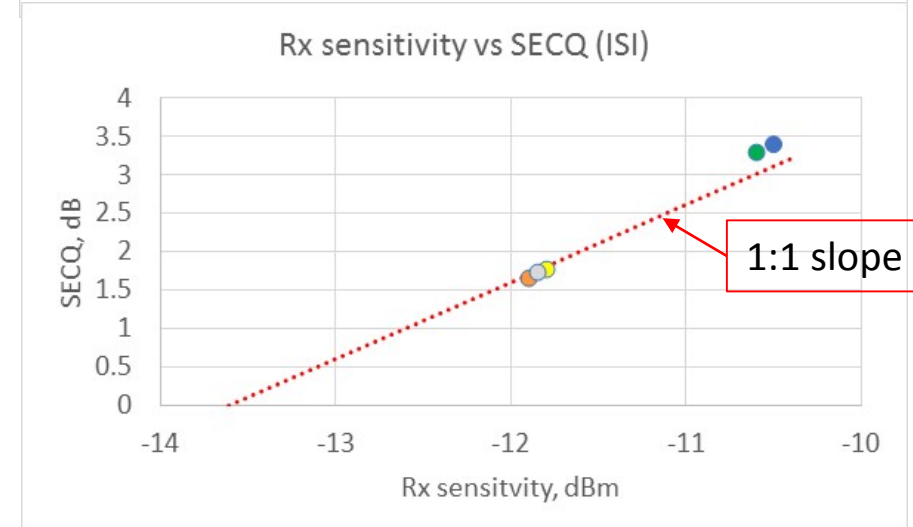
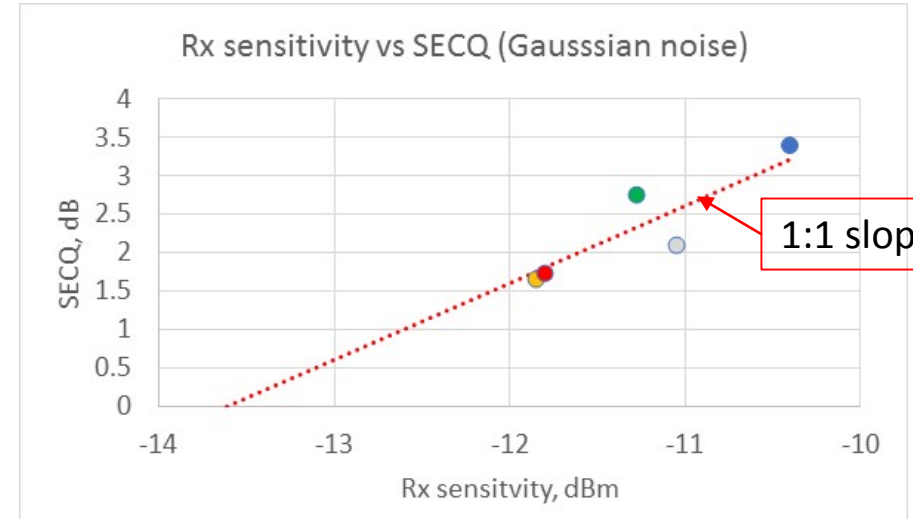


SI dominant

RMS error < 0.2 dB




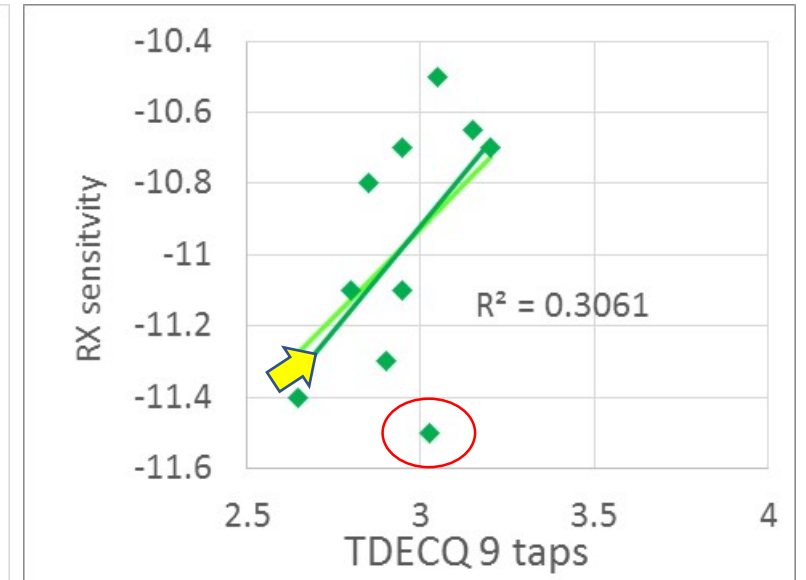
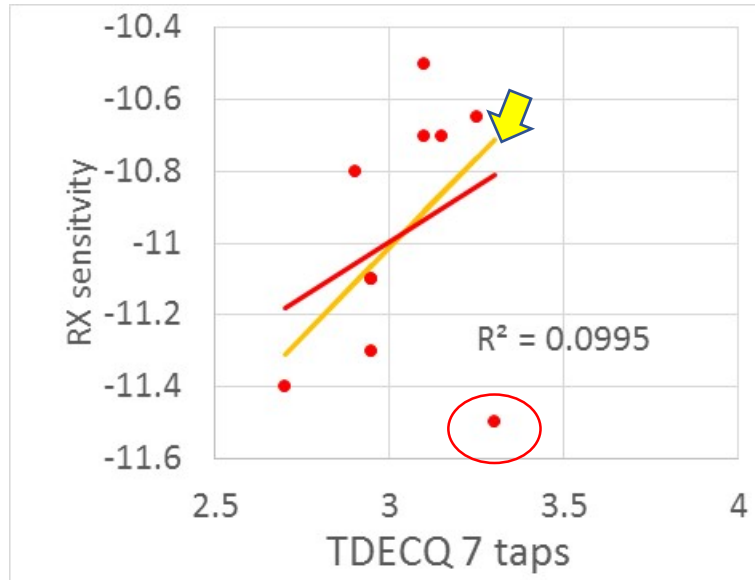
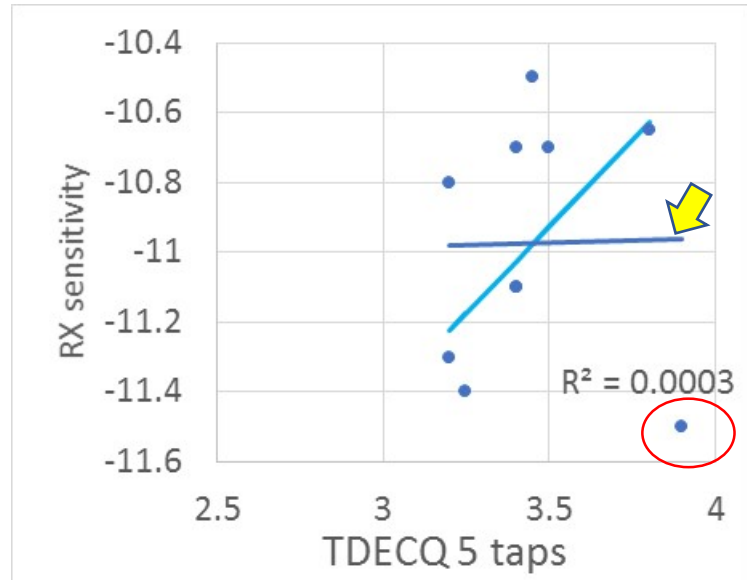
Very good dB/dB fit for
both cases



- [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)**

Analysis of baveja_3cd_01_1117, slide 1

Rx sensitivity vs TDECQ from baveja_3cd_01_1117; linear fits  to data were shown



JPK analysis: RMS error vs best fit 1:1 slope:

0.40 dB

0.32 dB

0.28 dB

RMS error calculated from a best fit of a 1:1 slope to the RX sensitivity vs TDECQ data points.

A linear fit to a limited data range is not a good way to evaluate the dB/dB correlation of RX sensitivity and TDECQ

Note: One measurement out of the 10 shows 2x larger shift in TDECQ as number of taps increase – a warning flag

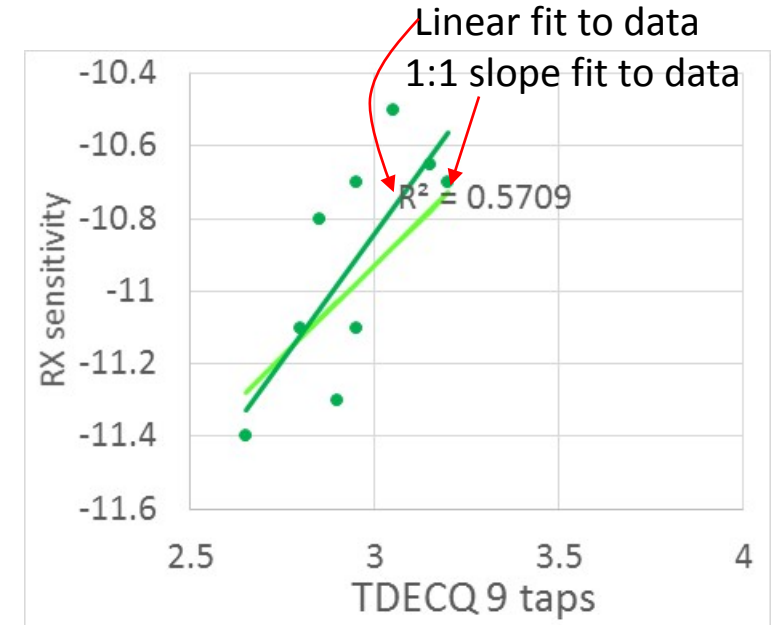
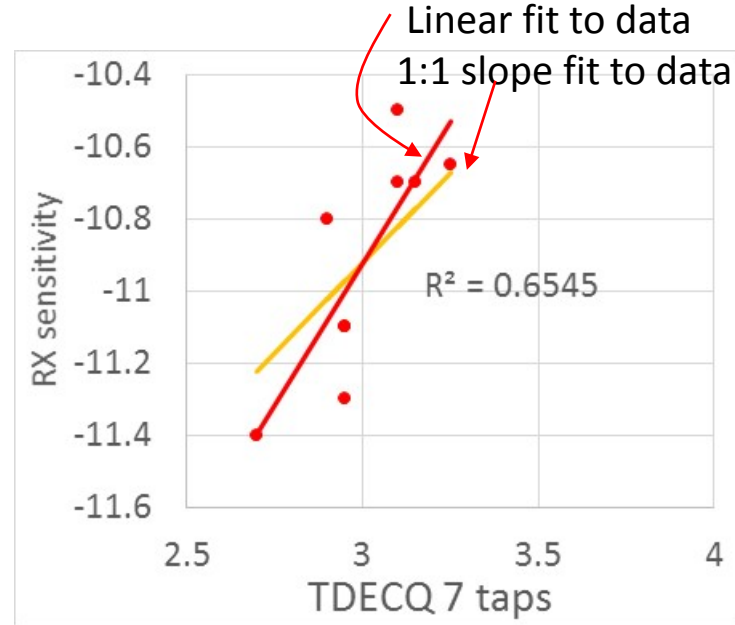
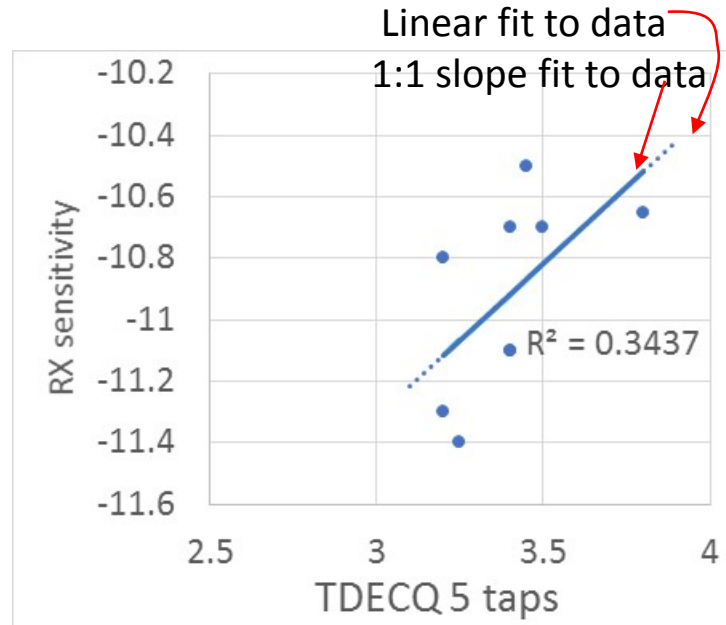
Probably because the RX used for this data has >>9 taps, and the outlier TX has significant ISI extending to 9 UI

This one data point dramatically affects the rest of the data

“Don’t let 1 data point skew up your conclusions” - Mr Geddes, Mark Hall Comprehensive

Analysis of baveja_3cd_01_1117, slide 2

Outlier TX point removed



RMS error vs

best fit 1:1 slope: 0.25 dB

0.20 dB

0.22 dB

Without the outlier point, the data shows a 5 tap TDECQ has a good fit to a 1:1 slope for Rx sensitivity vs TDECQ with 5, 7, and 9 taps.

Summary of analysis of data in baveja_3cd_01_117

- The data shows that TDECQ with 5 T-spaced taps is a good predictor of RX sensitivity
 - reasonable fit to a dB for dB relationship, with RMS error consistent with correlation of two practical measurements.
- The data shows that TDECQ with more taps may allow outlier transmitters, e.g. with very high ISI, to pass TDECQ, with the potential risk of interoperability issues.

Summary of previous work review

The data shows

- TDECQ with 5 T-spaced taps is a good predictor of RX sensitivity
 - reasonable fit to a dB for dB relationship, with RMS error consistent with correlation of two practical measurements (RMS error of 0.3 to 0.4 dB for measurements from several sources)
- TDECQ with more taps may allow outlier transmitters, e.g. with very high ISI, to pass TDECQ, with a potential risk to interoperability
- Good correlation between SECQ and Rx sensitivity (at 2.4×10^{-4} BER) for SRS test sources with either Gaussian noise or SI dominant stress (RMS error of <0.3 dB)

Threshold adjust

Threshold adjustment for TDECQ

(Comments i-79, i-80, i-81)

- The D3.0 definition of TDECQ penalizes transmitters with unequal eye heights - while allowing trade-off against OMA, through the Tx_OMA-TDEC spec. This was first proposed in king_01a_0416_smf.pdf and then agreed by the Task Force in adopting the changes described in king_3bs_01a_0516.pdf .
- The suggested remedies to these comments allow sub-eye inequality to be compensated by adjusting threshold levels as part of TDECQ, but propose to limit Tx non-linearity by adding an R_{LM} spec, or limiting the threshold adjustment range. It's not clear the suggested remedies would improve the draft.

http://www.ieee802.org/3/bs/public/adhoc/smf/16_04_19/king_01a_0416_smf.pdf

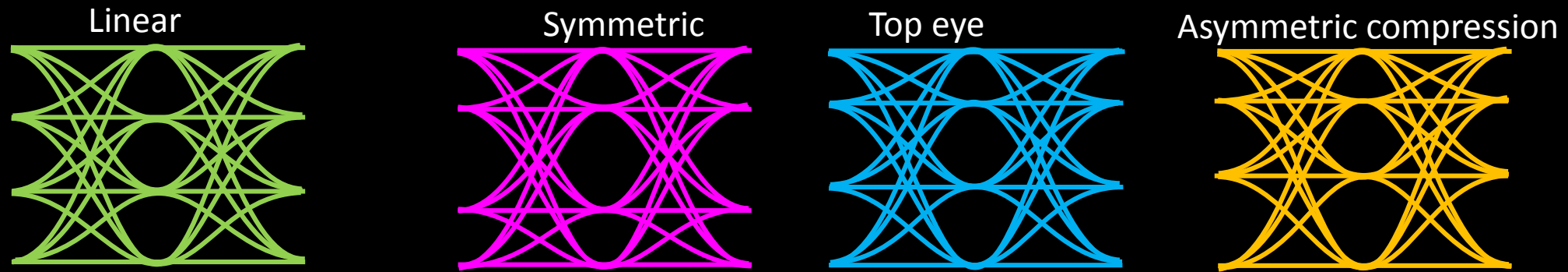
http://www.ieee802.org/3/bs/public/16_05/king_3bs_01a_0516.pdf

Recap of king_3cd_0118_adhoc

A simple model

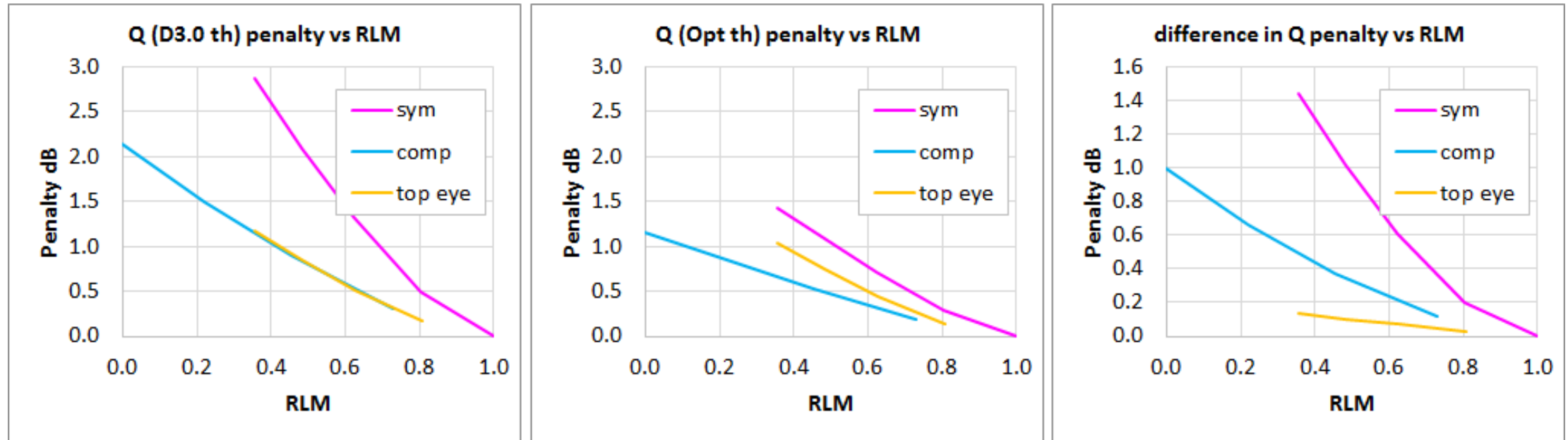
- Considers modulation levels at time-centre of eye opening
- Assumes receiver noise limited (RIN is negligible)
 - so that optimized thresholds are in the middle of each sub-eye
- 3 cases, each with same $\text{OMA}_{\text{outer}}$:

- **Symmetric compression around P_{ave}**
- **Top eye only compression**
- **Asymmetric power compression (higher optical levels see more compression)**



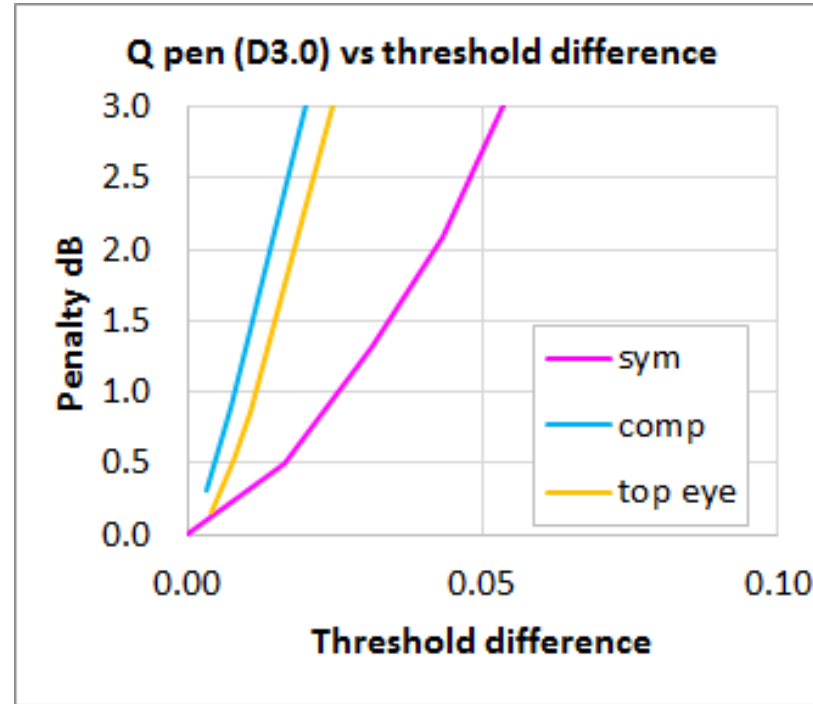
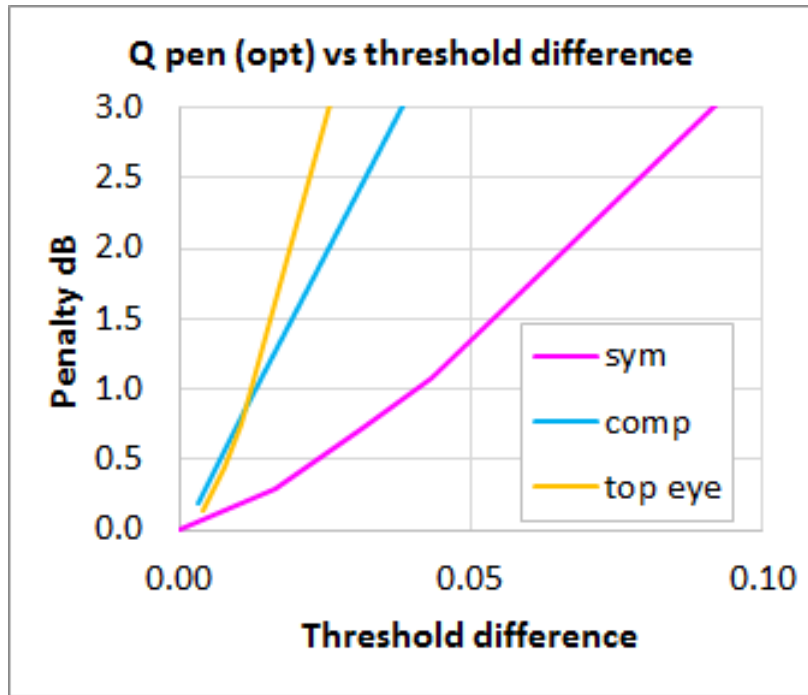
- Calculate modulation levels, D3.0 thresholds, optimum thresholds, R_{LM} , Q penalty
 - Q penalty is calculated from the average of the partial error probabilities for each modulation level and nearest threshold pair (analogous to the calculations performed in TDECQ; Q penalty is a proxy for TDECQ)

Q penalty vs R_{LM}



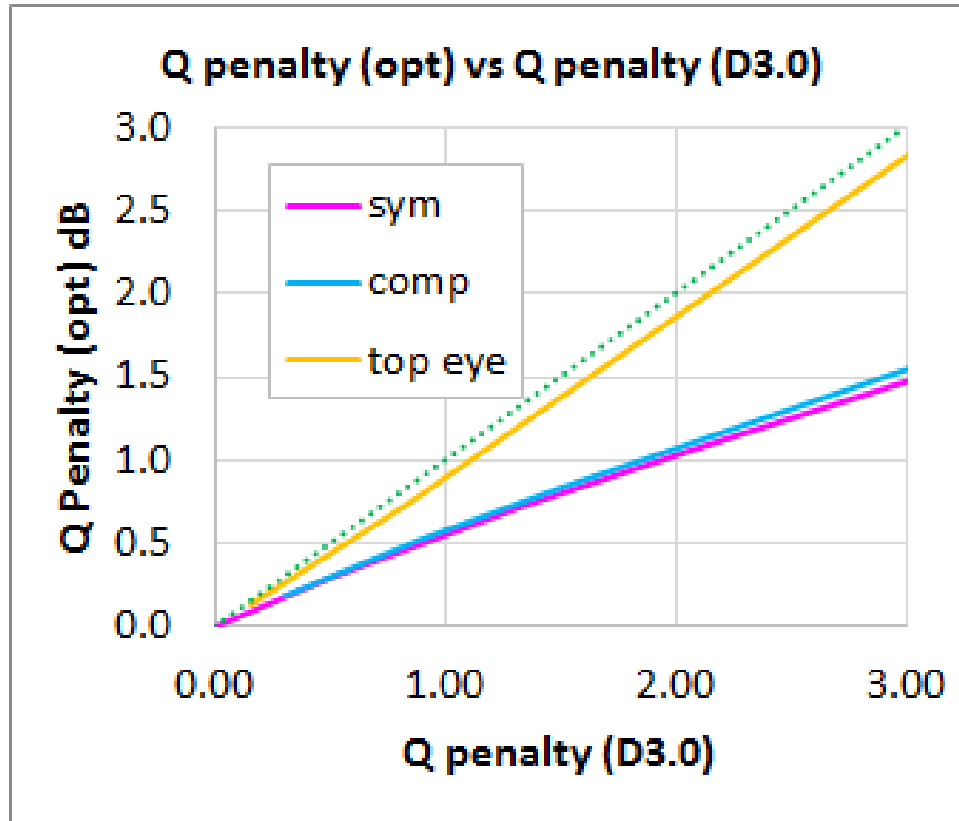
- Symmetric eye inequality produces higher penalty than other forms of eye distortion
- R_{LM} is a poor predictor of Q penalty

Q penalty vs threshold difference (D3.0 vs optimum)



- Threshold difference is a bad predictor of Q penalty
 - Avoid using it as a spec limit

Q penalty (optimum) vs Q penalty (D3.0)



TDECQ is measured on a static waveform, dynamic threshold optimization effects are ignored in the measurement

A real receiver could be expected to have some error between the optimum threshold position and its actual threshold at any point in time
The Q penalty for optimized thresholds should be viewed as a minimum penalty.

- Q penalty (D3.0) is a reasonable predictor of worst case penalty for a receiver with optimized thresholds
 - Q penalty (D3.0) is a proxy for the D3.0 definition of TDECQ

Conclusions from king_3cd_0118_adhoc

- The D3.0 definition of TDECQ limits sub-eye inequality by using thresholds which are referenced only to $\text{OMA}_{\text{outer}}$ and average power
- A simple model of sub-eye inequality indicates that the D3.0 definition of TDECQ is a good predictor of the *worst case* penalty for optimized thresholds.
- R_{LM} is a poor predictor of Q penalty due to unequal sub-eyes
- The difference between D3.0 thresholds and optimum thresholds is a poor predictor of Q penalty due to unequal sub-eyes

Overall summary

- TDECQ with 5 T-spaced taps is a reasonable predictor of RX sensitivity
 - reasonable fit to a dB/dB relationship; RMS error consistent with correlation of two practical measurements (RMS error of 0.3 to 0.4 dB)
 - Longer reference EQs don't improve correlation, and seem to allow outlier transmitters, e.g. with very high ISI, to pass TDECQ, with a potential risk to interoperability
- Good correlation shown between SECQ and Rx sensitivity (at 2.4×10^{-4} BER) for SRS test sources with either Gaussian noise or SI dominant stress (RMS error of <0.3 dB)
- The draft 3.0 definition of TDECQ limits sub-eye inequality by using thresholds which are referenced only to OMA_{outer} and average power. A simple model shows it is a good predictor of worst case penalty due to sub-eye inequality.
 - R_{LM} and threshold adjustment range are poor indicators of penalty due to sub-eye inequality

Back-up

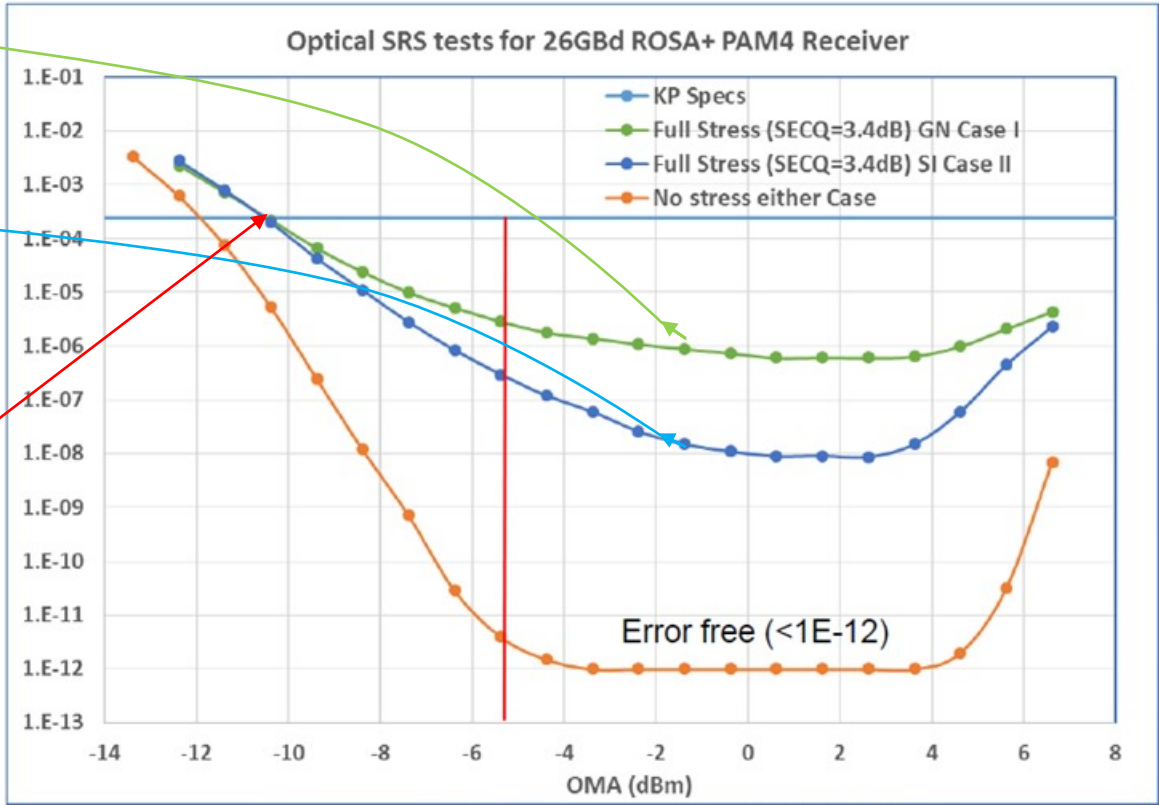
Base data from chang_cd_01_1117 -

■ Same SECQ=3.4dB but with different BER behavior

Gaussian noise dominant

SI dominant

Exact match at target BER (as expected)



Case1	
S.I. dominance	
SECQ	
Ideal Tx	0.87
TX+LPF	1.66
S.J. only	1.74
S.J.+G.N.	1.78
S.J.+ S.I.	3.3
S.J.+ G.N.+S.I.	3.4

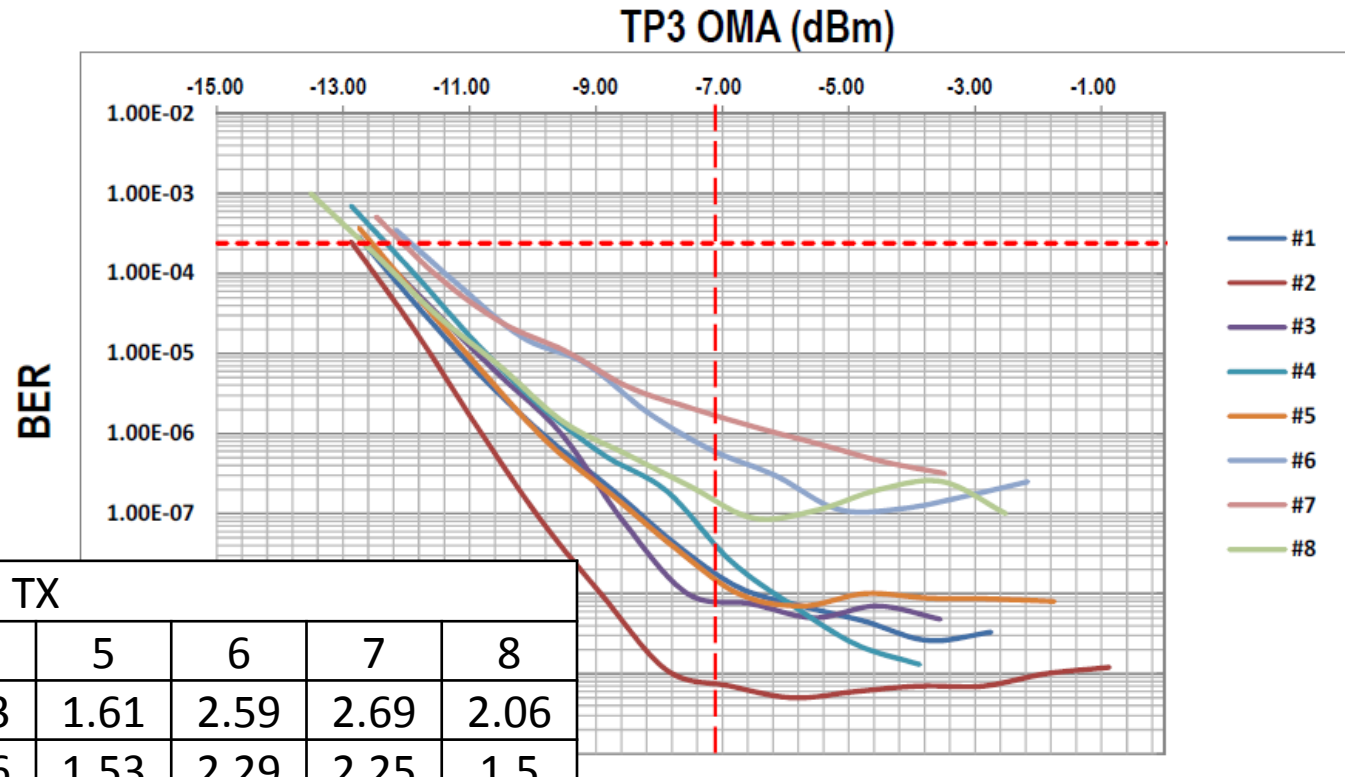
Case2	
G.N. dominance	
SECQ	
Ideal Tx	0.87
TX+LPF	1.66
S.J. only	1.74
S.J+S.I.	2.1
S.J.+ G.N.	2.75
S.J.+ G.N.+S.I.	3.4



Base data from way_3bs_01a_0517

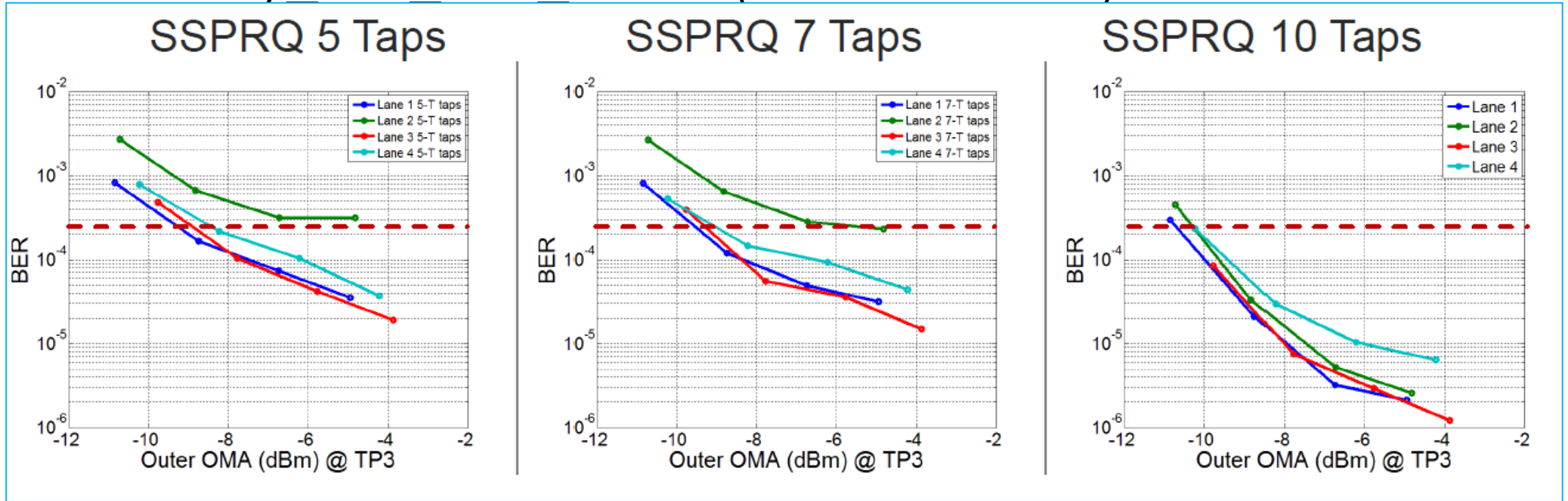
BER versus OMA

- Test results of 8 individual lanes – All pass with sufficient BER and OMA margin

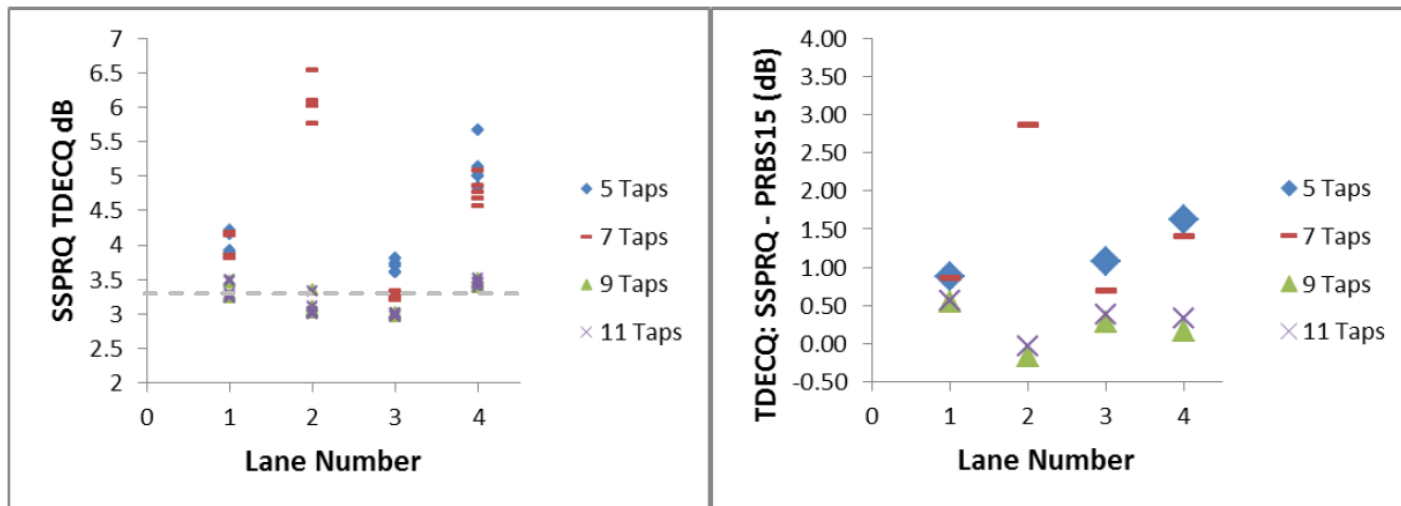


		TX							
		1	2	3	4	5	6	7	8
5 tap T	TDECQ	1.54	1.64	2.1	1.73	1.61	2.59	2.69	2.06
7 tap T	TDECQ	1.52	1.55	2.1	1.46	1.53	2.29	2.25	1.5
9 tap T	TDECQ	1.54	1.32	2.22	1.39	1.46	1.82	2.24	1.58
RX sensitivity		-12.64	-12.84	-12.64	-12.36	-12.56	-11.92	-12.08	-12.68

Base data from way 3bs 01a 0717 (slides 6 and 7)



SSPRQ TDECQ, TDECQ (SSPRQ – PRBS15)



- *Note: Multiple measurements of TDECQ for 4 different transmitters with SSPRQ and PRBS15 test patterns were shared. Average value of TDECQ used for subsequent analysis.*

Base data and analysis shown in baveja_3cd_01_1117

