802.3cd: proposed change in TDECQ method and reference receiver equalizer.

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Problem

- Several contributions raised the concern that many units that are able to close the link with good sensitivity/BER margins might fail TDECQ test.
- There is no convincing data showing 1dB-1dB TDECQ vs. link BER penalty correlation (raised at IEEE Sept meeting).

This is leading into two main proposals:

1. Keep current TDECQ limits and increase number of FFE taps into the reference receiver equalizer;
   - Would drive developers to target more complex equalizers.
2. Increase TDECQ maximum limits;
   - Would change the 'Allocation for penalties (for max TDECQ)' , used to define PMD budgets making these more challenging in terms of receiver sensitivity limits.

None of these provide a rationale about first two points.
So we would like to propose a change in the TDECQ method, that can be useful to overcome the problem and address future PMD definition too.

PAM4 signals: average versus optimum thresholds (1).

Into TDECQ method (802.3bs, 121.8.5.3), sub-eye threshold levels Pth1, Pth2, and Pth3, are determined from the OMA_{outer} and so are <u>average</u> thresholds for each of the three PAM4 eyes diagram (Pave) as defined in Equation (121–1), Equation (121–2), and Equation (121–3).

But in real implementations the optimum thresholds at lower BER are different from the average ones.

This is true even for a very clean eye, with lot of available bandwidth.

$$P_{th1} = P_{ave} - \frac{OMA_{outer}}{3} \quad (121\text{–}1)$$

$$P_{th2} = P_{ave} \quad (121\text{–}2)$$

$$P_{th3} = P_{ave} + \frac{OMA_{outer}}{3} \quad (121\text{–}3)$$

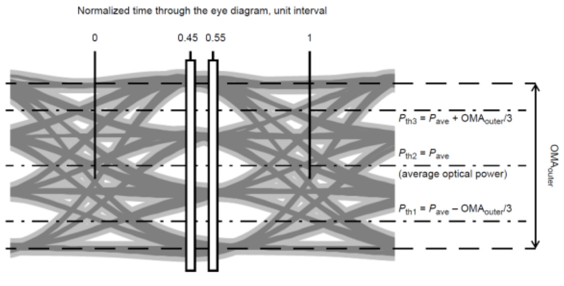
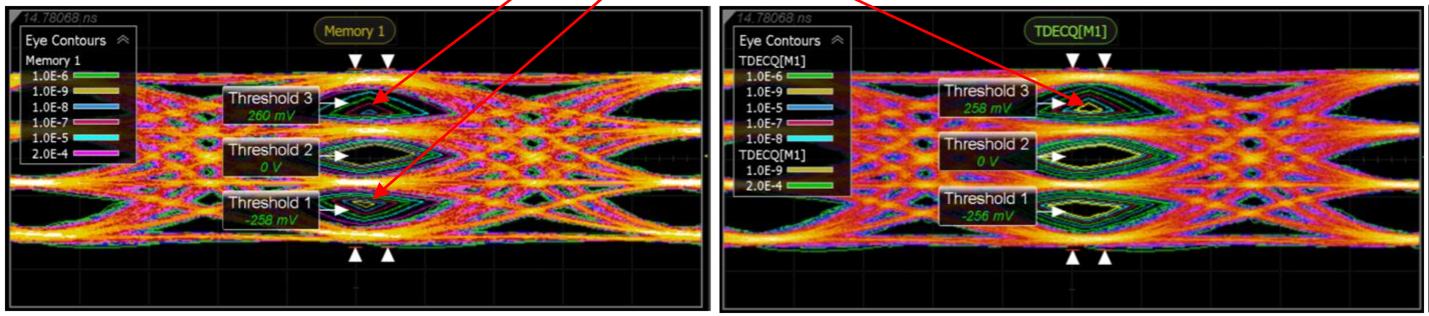


Figure 121–5—Illustration of the TDECQ measurement

0/1 & 2/3 optimum thresholds are closer to levels 1 and 2 respectively



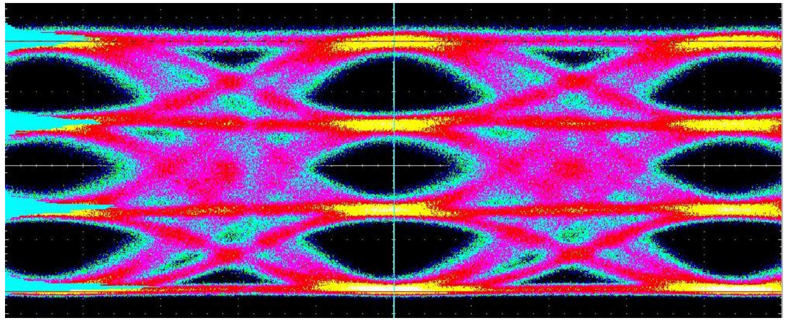
Measurement		Current
TDECQ	M1	1.00 dB
Eye 2/3 Level	F1	258.6 mV
Eye 1/2 Level	F1	-200 µV
Eye 0/1 Level	F1	-253.4 mV
Linearity [RLM]	F1	0.982
TDECQ	F1	0.27 dB
Outer OMA	F1	772.6 mV

Real receivers will implement threshold optimization to get the lowest BER.

Above example: clean electrical eye, 773mV VMAouter, @53GBaud, lab-grade equipment, observed BW = 60GHz.

PAM4 signals: average versus optimum thresholds (2).

In the optical domain, we also have to consider laser RIN, so expect to have more noise over levels 2 and 3.



Levels	Mean	StdDev	PkPk
Level3	3.4 mW	44 uW	437 uW
Level2	2.5 mW	36 uW	307 uW
Level1	1.5 mW	26 uW	229 uW
Level0	568 uW	18 uW	181 uW

Global Measurements	
OMA Outer	2.8 mW
Level Mismatch (R_{LM})	0.97

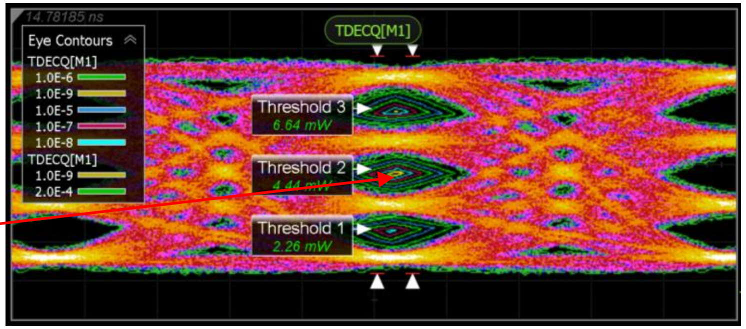
SiP eye, no equalization.

Real receivers will implement threshold optimization.

And also consider some residual distortion after equalization.

Below example over one of the ad-hoc published waveforms: L2 RMS > L3 RMS.

For this case, 1/2 $ave_{th} \neq$ 1/2 opt_{th}



Results

Measurement		Current	Minimum	Maximum	Count
Level 3 RMS	F1	156 µW	156 µW	156 µW	1
Level 2 RMS	F1	200 µW	200 µW	200 µW	1
Level 1 RMS	F1	160 µW	160 µW	160 µW	1
Level 0 RMS	F1	120 µW	120 µW	120 µW	1
Linearity [RLM]	F1	0.882	0.882	0.882	1
TDECQ	F1	2.24 dB	2.24 dB	2.24 dB	1
Outer OMA	F1	6.570 mW	6.570 mW	6.570 mW	1

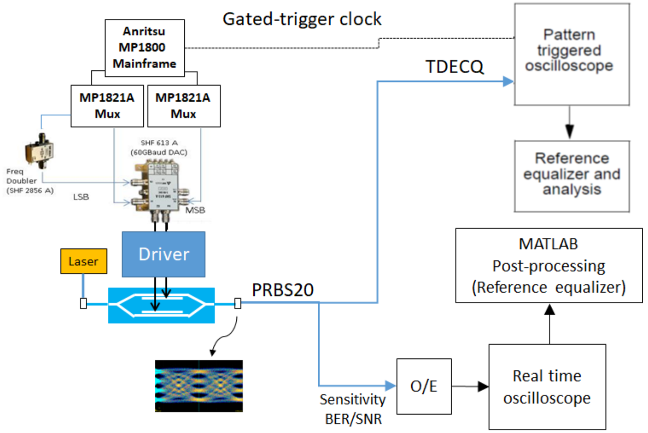
So we've been back to results presented in mazzini_3bs_01_0917 to verify if the optimum threshold can provide a better TDECQ/Sensitivity slope fit.

53GBaud PAM4 TX/RX : sensitivity/TDECQ correlation.

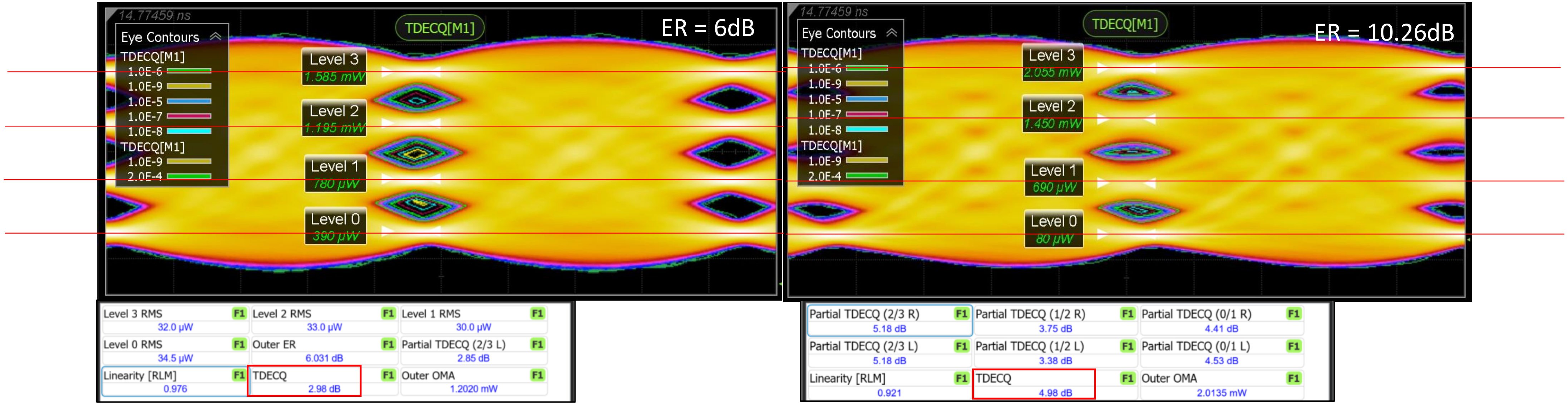
Same set-up and waveforms presented in mazzini_3bs_01_0917

1. Different Driver settings allow to change over different TX characteristics.
2. The TX PRBS20 pattern is given to both sampling scope and real time scope (after O/E conversion).
3. The **same reference 5T receiver equalizer** is used when run the TDECQ algorithm and the sensitivity test.
4. We then calculated delta TDECQ and delta sensitivity results over two different TX waveforms.

- SSPRQ pattern available in our labs, but not yet for this experiment.
- TDECQ algorithm applied with no fiber (SECQ).
- Overall O/E BW of ≈30GHz.



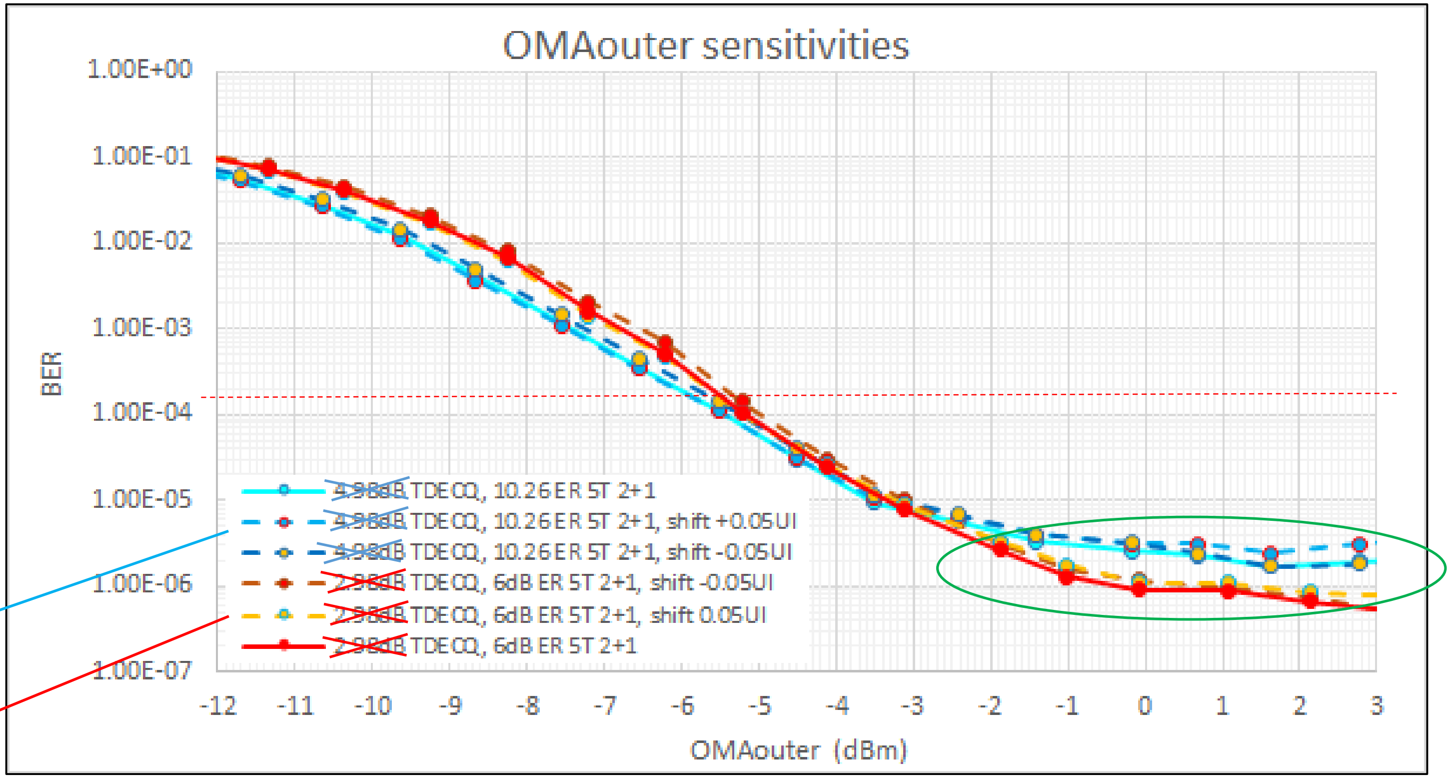
Two PRBS20 waveforms were aquired with Keysight DCA-M N1092A scope, then TDECQ algorithm
New results (P.05.70.687 SW) are still in line with ones already presented.
The reference equalizer return similar taps weights, the 6dB transmitter show better TDECQ (2.98dB) than the 10.26dB transmitter (TDECQ = 4.98dB). The right eye in principle would not achieve the BER limit.

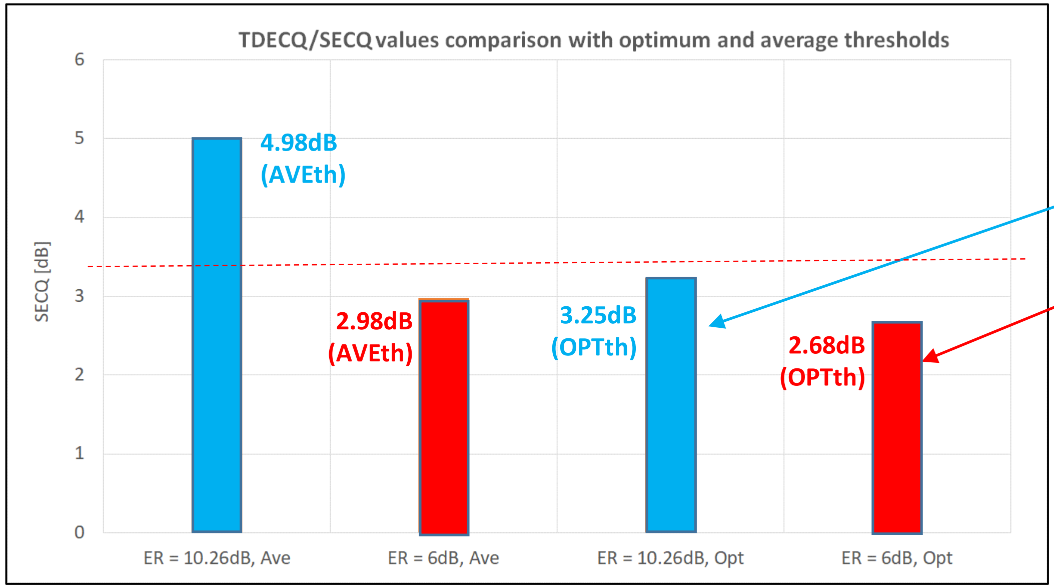


53GBaud PAM 4 TX/RX : sensitivity/TDECQ correlation.

These same PRBS20 waveforms were processed by Keysight by considering:

- Threshold optimization into TDECQ algorithm.
- Equalization is done at 0.5UI sample location, with 0.1UI window applied.





Both TX conditions now pass the 53GBaud SECQ limit of 3.4dB.
This is more in line with the sensitivity results presented into mazzini_3bs_01_0917, 1dB to 1dB match seems to be at BER floor.

Comments

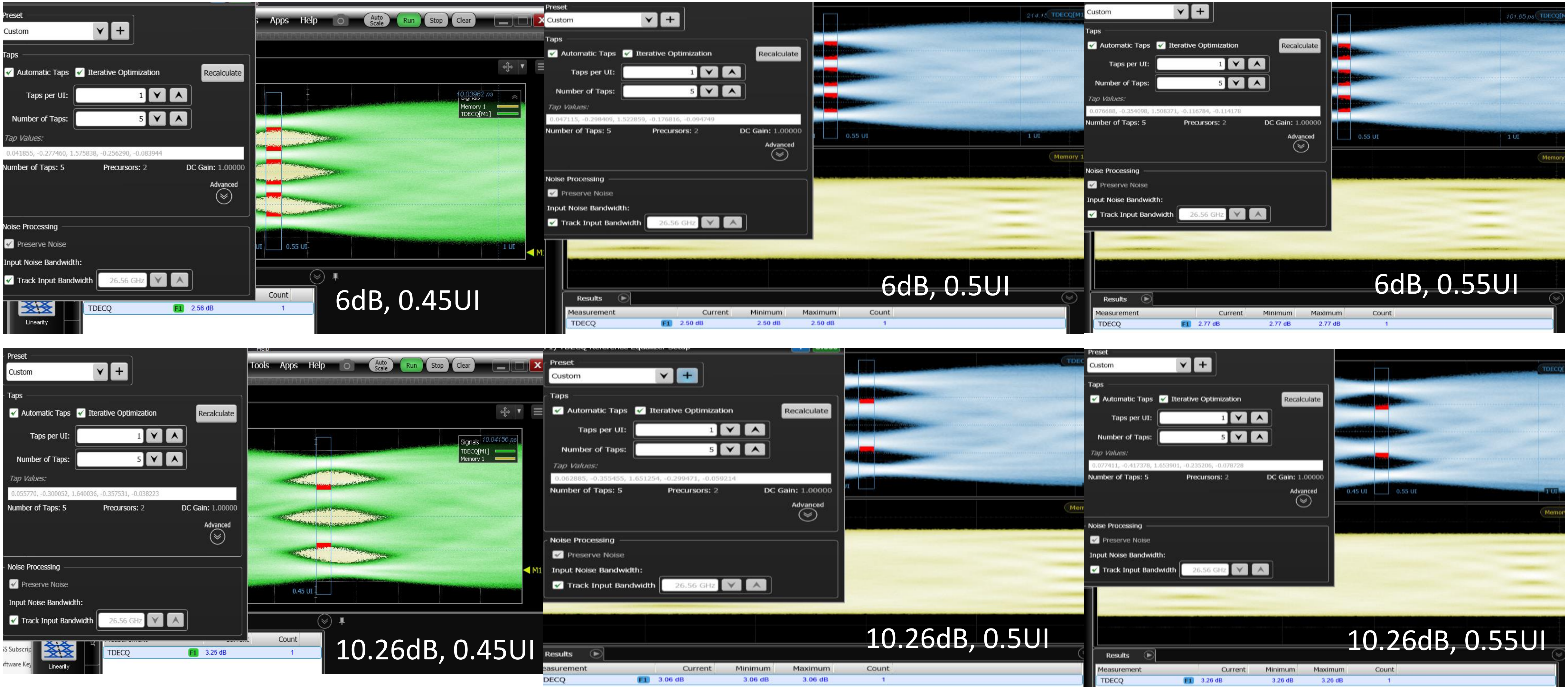
- Several contributions raised the concern that current TDECQ definition might fail many good units that are able to pass the link test.
- We think one explanation could be in the fact that all actual PAM4 receivers (have to) implement receiver threshold optimization.
  - Shown good match between SECQ/TDECQ values and sensitivity BER floor considering same reference 5T receiver.
- The change will not impact good transmitters, where $\text{Average}_{th} \cong \text{Optimum}_{th}$ one.
- It will give some more margin to worsen transmitters, still passing current TDECQ limits with this new (but more realistic) definition of the reference receiver.
  - Keep freedom to use less complex equalizers.
  - No changes in current TDECQ/SECQ values.
- We expect better match between TDECQ/SECQ and sensitivity, so we think this change in the TDECQ method can be useful to address future PMD power budget too.

Suggested remedy

- Into 802.3cd, paragraph 138.8.5 and 140.7.5, add sentence
  - The precise threshold amplitude position is optimized to further minimize TDECQ.
- Into paragraph 139.7.5.3, change sentence ‘TDECQ for 50GBASE-FR and 50GBASE-LR is measured as described in 121.8.5.3 with the exception that the reference equalizer is as specified in 139.7.5.4 and the precise threshold amplitude position is optimized to further minimize TDECQ’.

THANK YOU

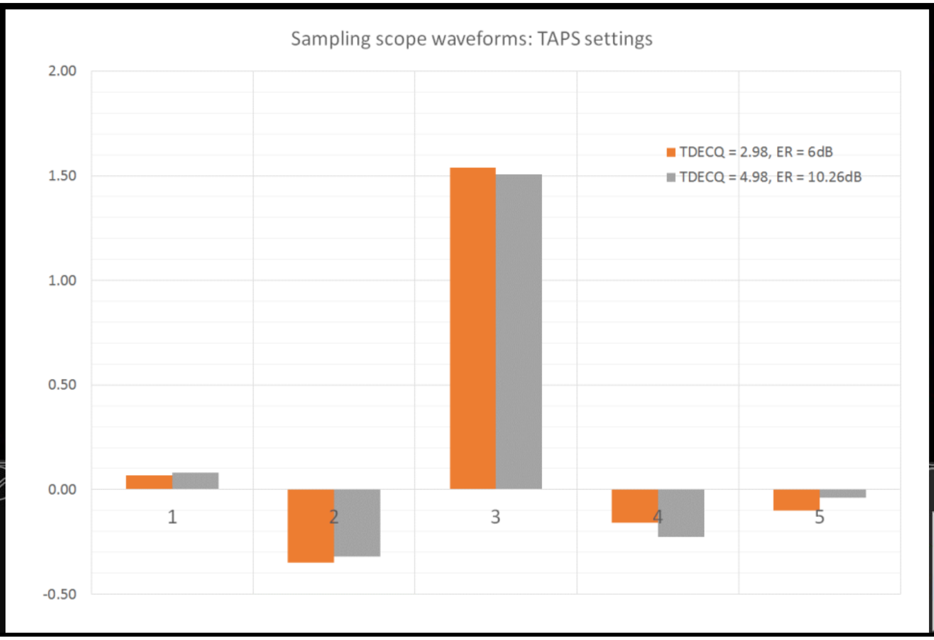
BACK-UP

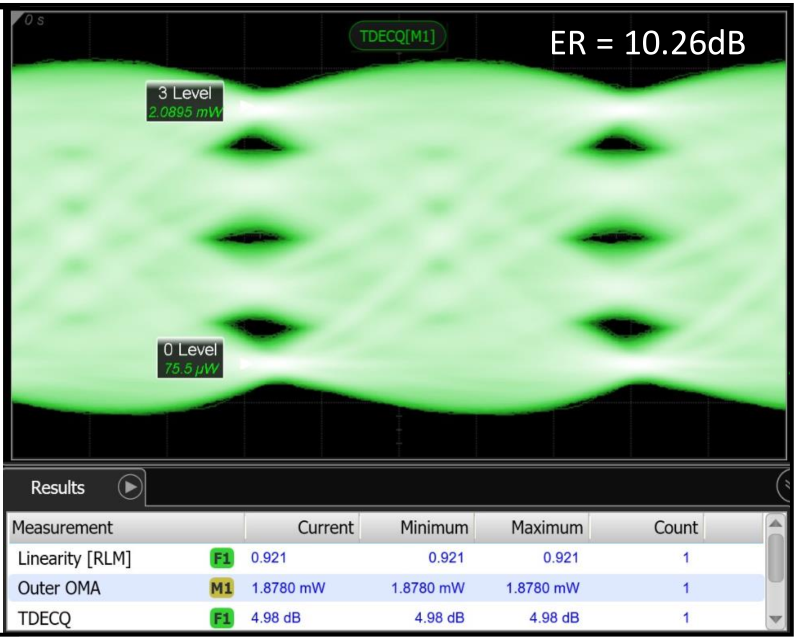


Summary of TDECQ values achieved by optimizing the equalizer at 0.45, 0.5 and 0.55UI respectively, without the 0.1UI phase window application.
Similar results as slide 9.
Considering mazzini_3bs_01_0917, 1dB sensitivity to 1dB TDECQ match seems to be at BER floor.

Updated transmitter results over two reference settings: PRBS20.

Presented in mazzini_3bs_01_0917



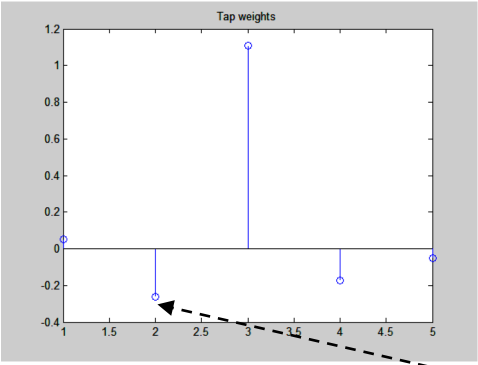


Two PRBS20 waveforms were aquired with Keysight DCA-M N1092A scope, then TDECQ algorithm (latest beta P.05.70.614 SW) was run on both of them.
The reference equalizer return similar taps weights, the 6dB transmitter show better TDECQ (2.98dB) than the 10.26dB transmitter (TDECQ = 4.98dB).

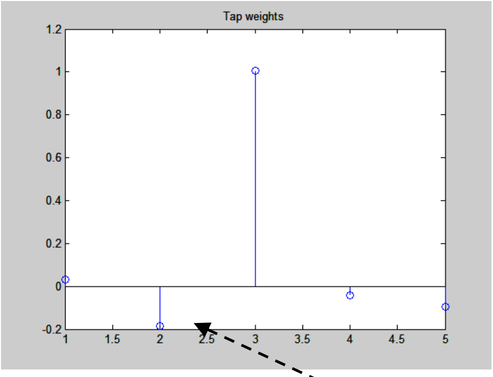
Processed signal BW.

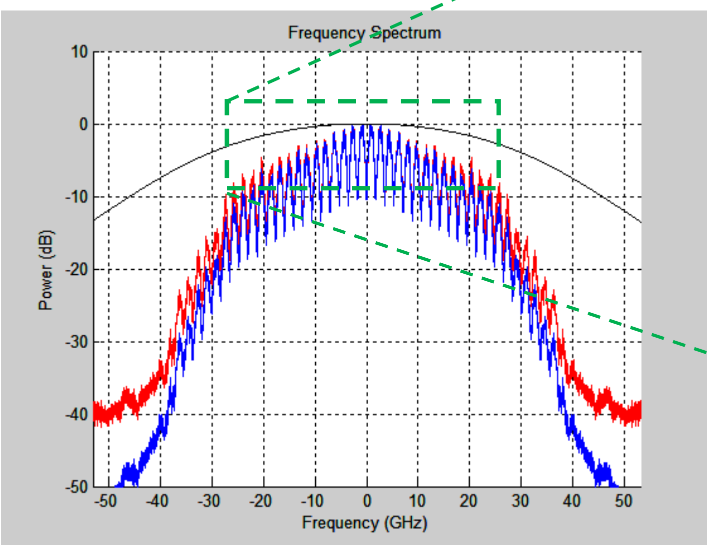
We also post-processed the same saved waveforms including a 4th order BT filter, to understand if any strong difference between TDECQ and sensitivity occours because the actual receiver BW.

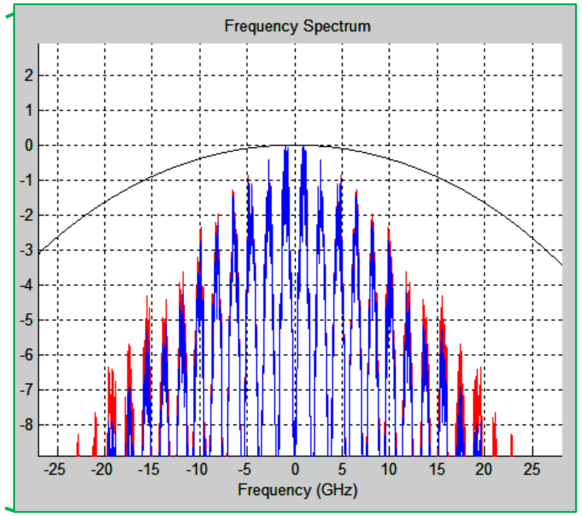
5T, m3, 0UI
Calc SNR (dB) = 20.204



5T, m3, 0UI
Calc SNR (dB) = 20.199







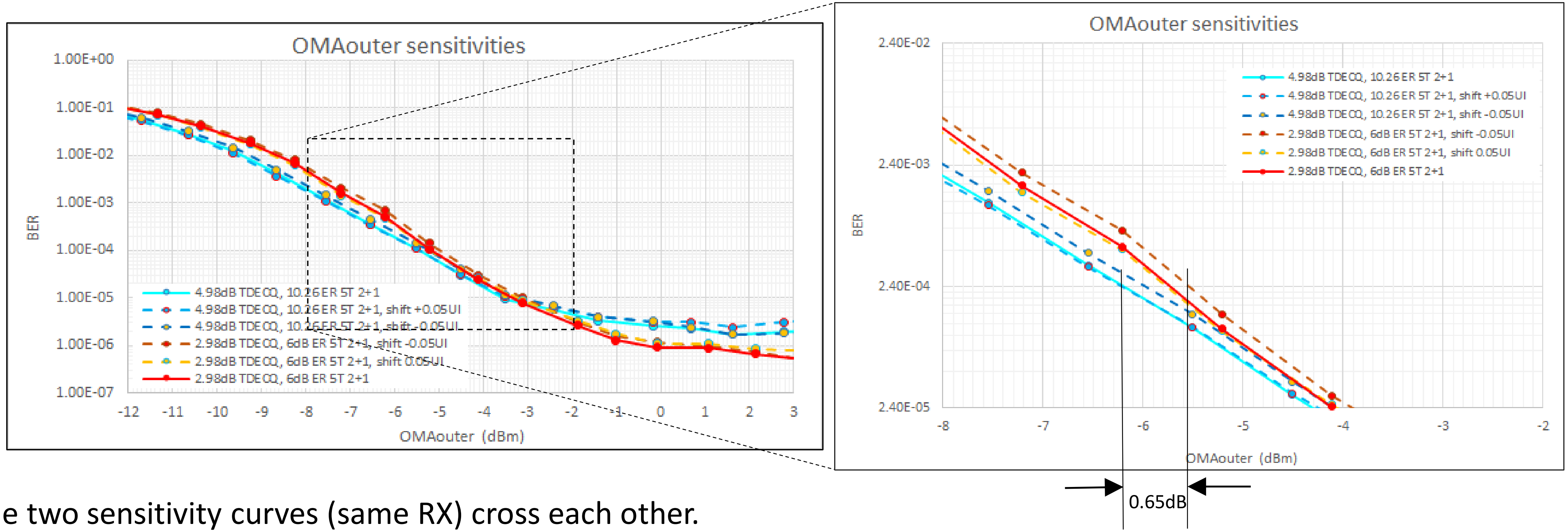
The 26.56GHz 4th order BT filtering has a small effect over the signal shape, tap weight at 1UI and calculated SNR.
Sensitivity results with and without filter are almost the same.

Presented in mazzini_3bs_01_0917

Different TDECQ: Delta Sensitivity at 2.4E-4 BER.

Presented in mazzini_3bs_01_0917

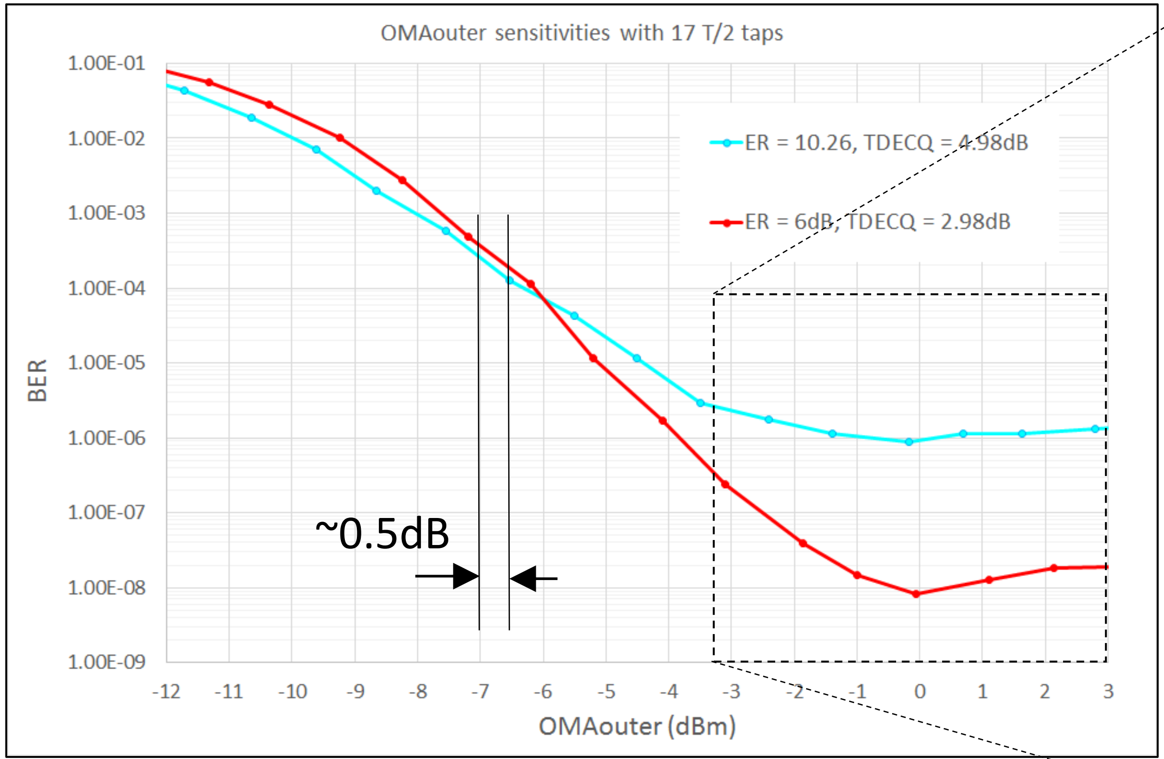
PRBS20 sensitivity tests were done over the same two driver settings.
The acquired waveforms were post-processed with 5T equalizer, 2 pre-cursor taps.
The sampling phase was offset by +/-0.05UI, so to have in principle similar TDECQ impact.

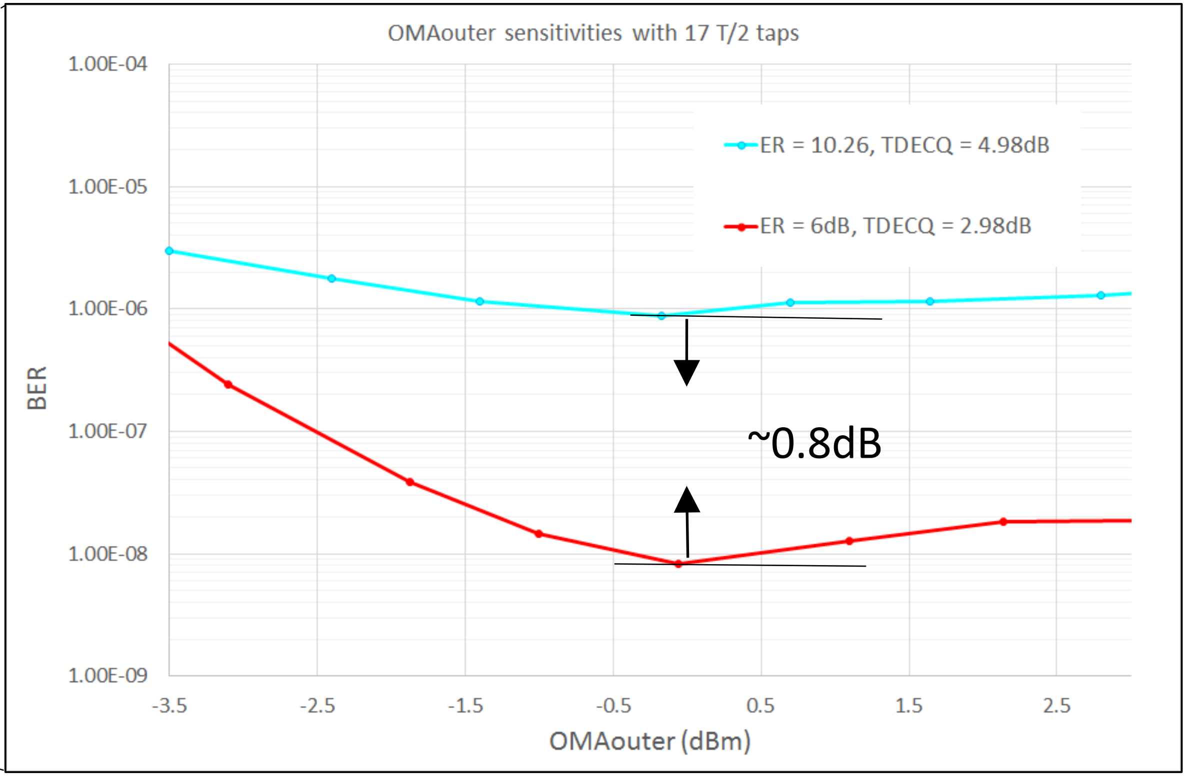


The two sensitivity curves (same RX) cross each other.
Over these two particular case, we observed an inversion of the trend between sensitivity and TDECQ (best TDECQ case of 2.98dB shows 0.65dB worse sensitivity than 4.98dB TDECQ case).
Next slide showing analysis done around BER 'flat' region.

Different TDECQ: Delta Sensitivity considering BER @2.4E-4 and floor with longer equalizer (17 T/2 taps).

Presented in mazzini_3bs_01_0917





Sensitivity delta @2.4E-4 leads into same comments as per slide 6.
On BER floor, calculating deltaOMA from deltaBER (deltaSNR) as deltaOMA = deltaSNR/2, we have now around 0.8dB equivalent deltaOMA.
Also in this case is shown no 1:1 correlation between delta sensitivity and dTEDCQ (2dB delta against 0.8dB delta).