OMAouter definition ambiguity

Addressing comments #171, 172, 173, 181 of IEEE 802.3 dj draft 2.1

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Summary

- Addressing comments #171, 172, 173, 181 against IEEE 802.3 dj draft 2.1
- The comments (same but for multiple PMDs) are that more explicit specification is needed for OMA measurement used for TDECQ; the proposed solution is to measure at input of FFE
- This presentation digs further into the gap of OMA measurement for TDECQ and identifies a discrepancy in OMA definitions existing in the link budget calculation and the one used in the TDECQ / TECQ penalty estimate
- This discrepancy is shown to be able to cause significant variation in OMA-TDECQ that disappears if a consistent definition is used. The proposed solution in the original comment is one of these consistent definitions that would make OMA-TDECQ more consistent.

Outline

- IEEE definitions of OMAouter
  for ER
  for TDECQ estimate
- **Which OMA for OMA – TDECQ metric in link budget?**
- Example of discrepancy between OMAouter
- Source of discrepancy:
    - Impact of FFE normalization
    - step response difference
    - OMAouter and signal variance difference
- Possible reconciliations
- Effect of DFE tap in TDECQ reference receiver
- Summary / proposal

ER, OMA measurements

OMAouter is measured **"before the reference equalizer"**

180.9.4 Outer Optical Modulation Amplitude (OMA_{outer})

The OMA_{outer} of each lane shall be within the limit given in Table 180–7. The OMA_{outer} is measured using a test pattern specified for OMA_{outer} in Table 180–14 as the difference between the average optical launch power level P_3, measured over the central 2 UI of a run of 7 threes, and the average optical launch power level P_0, measured over the central 2 UI of a run of 6 zeros, as shown in Figure 180–7. OMA_{outer} is measured using waveforms captured at the output of the reference receiver defined in 180.9.5, before the reference equalizer.

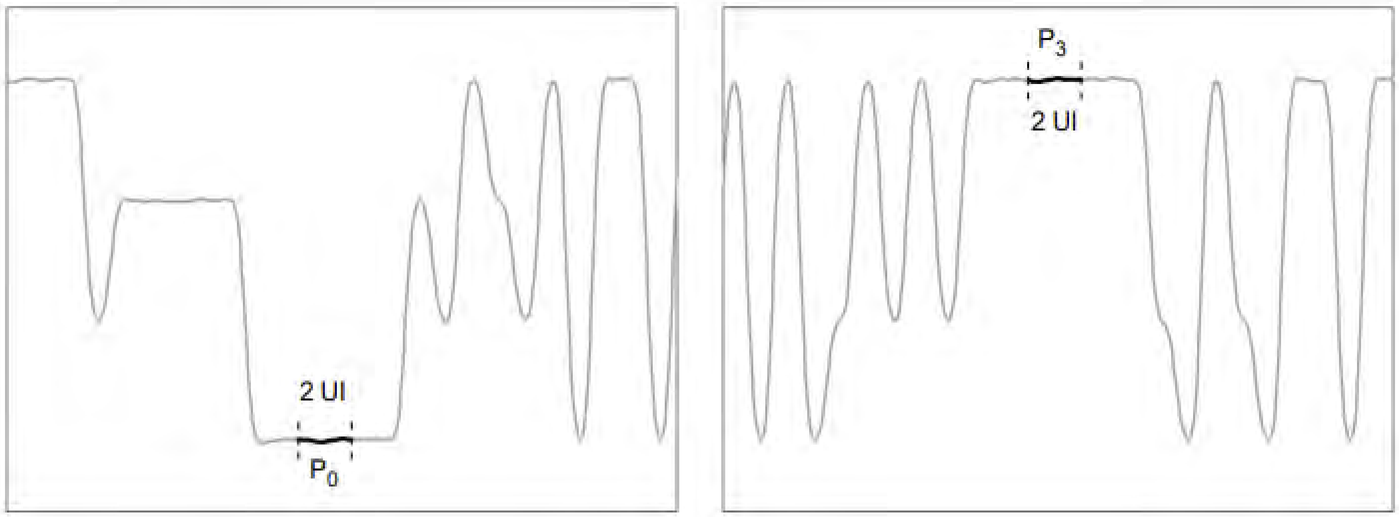


Figure 180–7—Example power levels P_0 and P_3 from PRBS13Q test pattern

TDECQ measurement

180.9.5 Transmitter and dispersion eye closure for PAM4 (TDECQ)

The TDECQ of each lane shall be within the limits given in Table 180–7 if measured using the methods specified in 121.8.5.1, 121.8.5.3, and 180.9.5.1, with the following exceptions:

For TDECQ, OMAouter is measured **“on the equalized signal”**

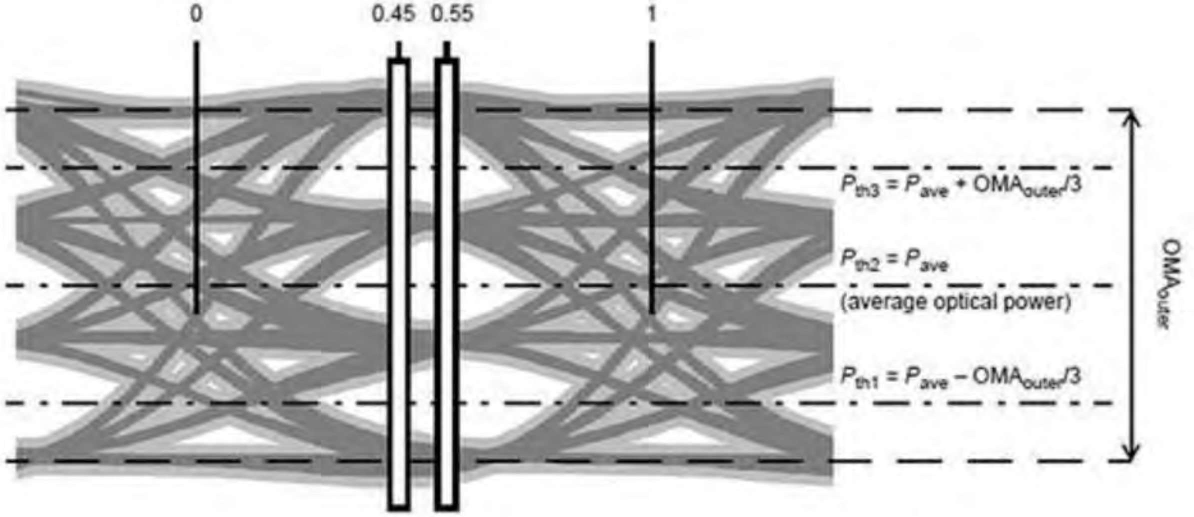


Image Source: IEEE

121.8.5.3 TDECQ measurement method

The standard deviation of the noise of the O/E and oscilloscope combination, σ_S, is determined with no optical input signal and the same settings as used to capture the histograms described below.

OMA_{outer} is measured according to 121.8.4 on the equalized signal.

$$TDECQ = 10\,log_{10}\left(\frac{OMA_{outer}}{6} \times \frac{1}{Q_t R}\right)$$

Q_t = 3.414 (Q-scale value for the target SER)

R = Noise added to the real signal generated by the DUT to achieve the target SER

Link budget: OMA-TDECQ

For Link budget calculation, it is ambiguous whether the OMAouter considered is measured “before the reference equalizer” or “on the equalized signal”

Since OMAouter-TDECQ is understood as the “usable” OMA of the TX as seen by the reference RX, both quantities need to be defined consistently.

The values of transmitter OMA_{outer} (max), transmitter OMA_{outer} (min) versus max (TECQ, TDECQ), and receiver sensitivity (OMA_{outer}) (max) versus TECQ are illustrated in Figure 180–5.

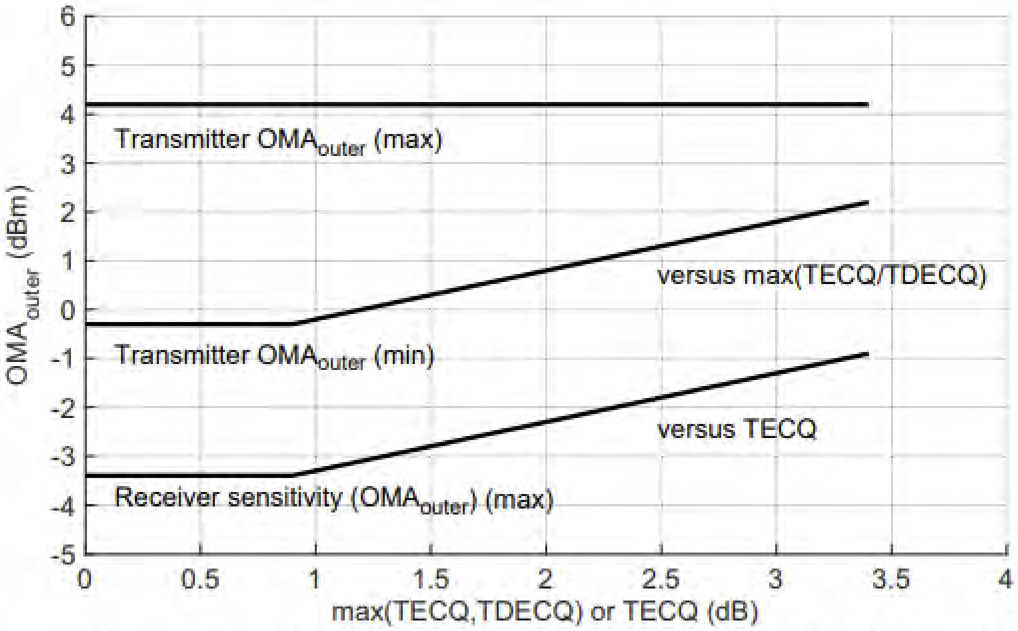


Figure 180–5—Transmitter OMA_{outer} each lane versus max(TECQ, TDECQ) and receiver sensitivity (OMA_{outer}) each lane versus TECQ

Example of discrepancy between OMAouter

3 modules characterized with different OMAouter/ER "before the reference equalizer" or "on the equalized signal"

⇒ 1 dBm of OMAouter-TDECQ difference, as currently defined

⇒ Consistent definitions lead to difference <0.2dBm

⇒ 1.2dB of difference of TDECQ

⇒ closer to 0.2dB after normalization to "un-equalized OMAouter"

⇒ Similar sensitivity

Module	#1	#2	#3	
Txpower	4.17	4.10	4.05	dBm
OMAouter	3.18	3.27	3.32	dBm
ER	3.66	3.81	3.91	dB
TDECQ	1.83	2.33	2.97	dB
OMAouter-TDECQ	1.35	0.94	0.36	dBm
OMAEq	2.59	3.24	3.86	dBm
EReq	3.15	3.79	4.52	dB
OMAEq -TDECQ	0.76	0.91	0.89	dBm
TDECQmod	2.42	2.35	2.43	dB
OMAouter-TDECQmod	0.76	0.91	0.89	dBm
Rxpower @ sensitivity	-4.96	-4.96	-4.96	dBm
RX OMAouter @ sensitivity	-5.88	-5.80	-5.74	dBm
BER	1.69E-04	1.52E-04	1.43E-04	

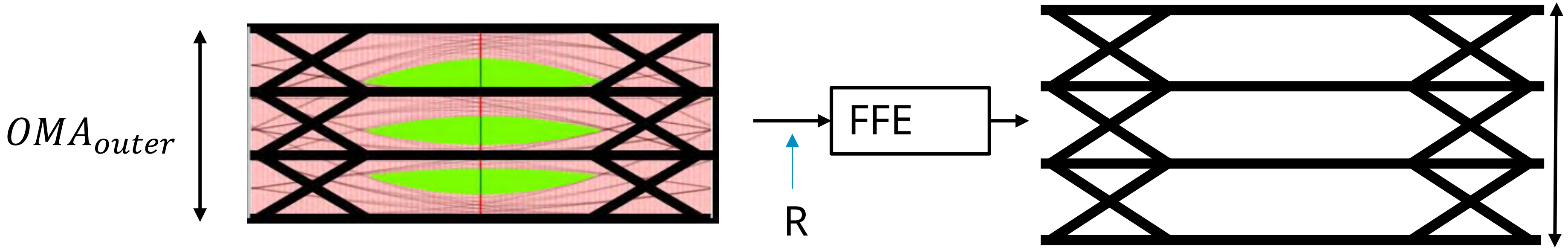
With $OMA_{eq} = OMA_{outer}$ defined at equalizer output, and $TDECQ_{mod} = TDECQ$ w/ $OMA_{eq} = OMA_{outer}$

If $OMA_{eq} = G * OMA_{outer}$, a scaled version of OMA_{outer},

in linear terms : $\frac{OMA_{eq}}{TDECQ} = \frac{OMA_{eq}}{(\frac{OMA_{eq}}{6} * \frac{1}{Q_t R})} = \frac{G*OMA_{outer}}{(\frac{G*OMA_{outer}}{6} * \frac{1}{Q_t R})} = \frac{OMA_{outer}}{(\frac{OMA_{outer}}{6} * \frac{1}{Q_t R})} = \frac{OMA_{outer}}{TDECQ_{mod}}$

Source of discrepancy: impact of FFE normalization

If $OMA_{eq} = G * OMA_{outer}$, a scaled version of OMA_{outer},

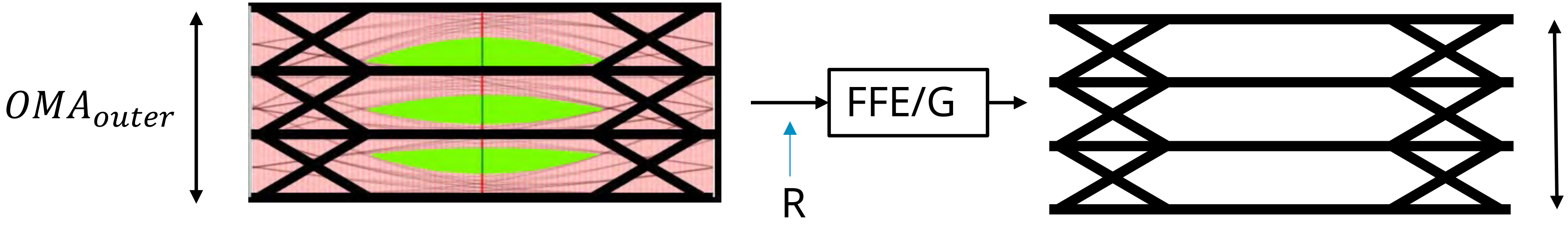


$OMA_{eq} \neq OMA_{outer}$

$OMA_{eq} = G * OMA_{outer}$,

$TDECQ$

R is noise σ to be added at input to FFE to achieve target BER wrt. OMA_{eq} yielding $TDECQ$ penalty



$OMA_{eq} = OMA_{outer}$,

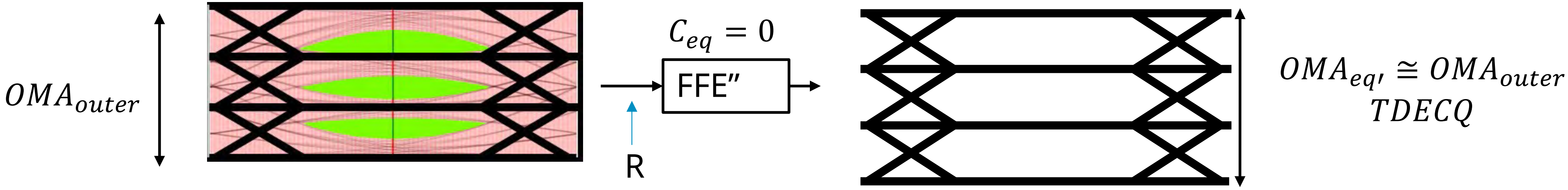
$$TDECQ_{mod} = \frac{OMA_{outer}}{6} * \frac{1}{Q_t R}$$

If FFE is normalized by G, such that now $OMA_{eq} = OMA_{outer}$, R is still noise σ to be added at input to FFE to achieve target BER wrt. $OMA_{eq} = OMA_{outer}$, yielding $TDECQ_{mod}$ penalty

With $(OMA_{eq} - TDECQ) = (OMA_{outer} - TDECQ_{mod})$ => normalization of FFE affects the pair $(OMA_{eq}, TDECQ)$, but not their difference!

FFE tap power normalized to unity?

We let equalizer reconstruct the OMA_{eq}, and expect it to be a close version of OMA_{outer},



R is still noise σ to be added at input to FFE to achieve target BER wrt. OMA_{eq} yielding $TDECQ$ penalty, but now OMA_{eq} is the reconstructed OMA at the output of the equalizer truly representing the Transmitter and expected closer to OMA_{outer} !

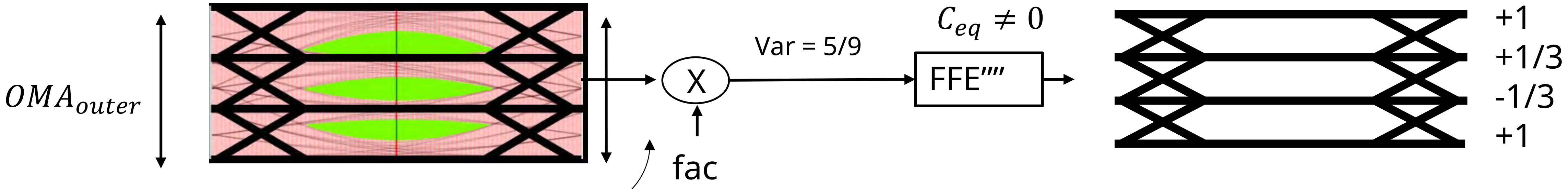
- OMAeq is the OMA of an equivalent ideal PAM4 TX, no BW limitation (i.e. CEQ=0) that has same variance as the TX for this application

- OMAeq-TDECQ is the correct TX performance metric

Module	#1	#2	#3		
Txpower	4.17	4.10	4.05	dBm	
OMAouter	3.18	3.27	3.32	dBm	IEEE 802.3dj Rev2.1
ER	3.66	3.81	3.91	dB	
TDECQ	1.83	2.33	2.97	dB	
OMAouter-TDECQ	1.35	0.94	0.36	dBm	
TDECQmod	2.42	2.35	2.43	dB	Option B
OMAouter-TDECQmod	0.76	0.91	0.89	dBm	
OMAEq	2.67	2.68	2.67	dBm	Option D
EReq	3.27	3.28	3.27	dB	
TDECQ	1.68	1.63	1.72	dB	
OMAEq -TDECQ	0.98	1.05	0.95	dBm	

Power normalization at input to FFE ?

Let us normalize the power of the input to the equalizer to that of an ideal PAM4 signal of amplitude +/-1 and variance 5/9 and let us consider the output target level of the equalizer to be +/- 1, +/-1/3



$OMA_{eq} \cong OMA_{outer} \; TDECQ$

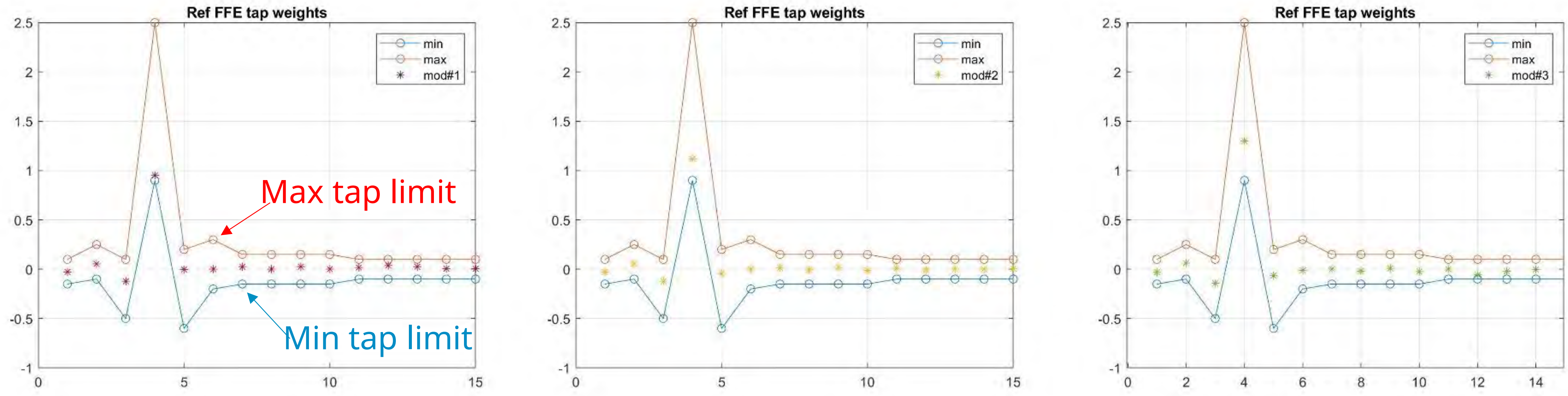
OMA_{eq} is the equivalent OMA of an ideal PAM4 of variance 5/9 referred back to the actual TX signal power, but w/o C_{eq} adjustment

- OMAeq is the OMA of an equivalent PAM4 TX with BW limitation ($C_{eq} \neq 0$) equivalent in variance and BW to the TX for this application
- OMAeq-TDECQ is still the correct TX performance metric

Module	#1	#2	#3		
Txpower	4.17	4.10	4.05	dBm	
OMAouter	3.18	3.27	3.32	dBm	IEEE 802.3dj Rev2.1
ER	3.66	3.81	3.91	dB	
TDECQ	1.83	2.33	2.97	dB	
OMAouter-TDECQ	1.35	0.94	0.36	dBm	
TDECQmod	2.42	2.35	2.43	dB	Option B
OMAouter-TDECQmod	0.76	0.91	0.89	dBm	
OMAEq	2.98	2.99	3.00	dBm	Option E
EReq	3.55	3.55	3.56	dB	
TDECQ	2.00	1.94	2.05	dB	
OMAEq -TDECQ	0.98	1.05	0.95	dBm	

Equalizer taps and tap limits

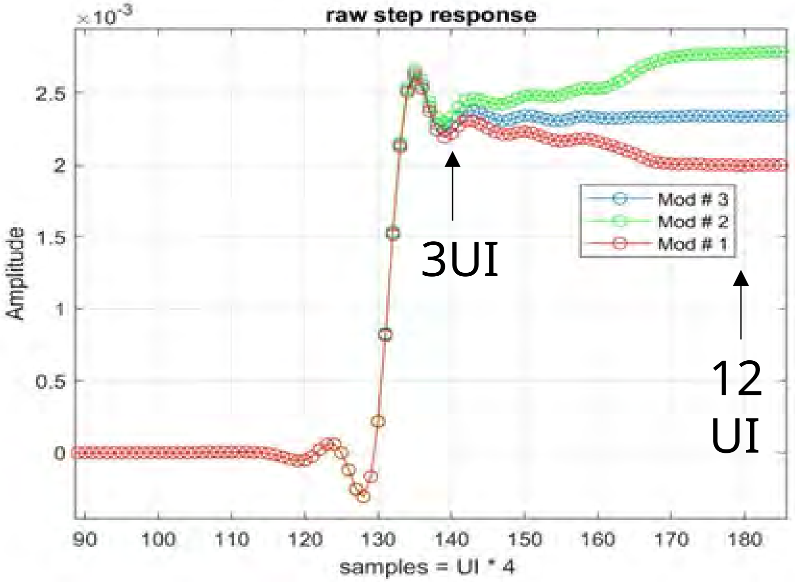
Note: All reference receiver 15 tap equalizer responses respect tap weight limit for all 3 modules, when the sum of taps is normalized to unity (current scheme)

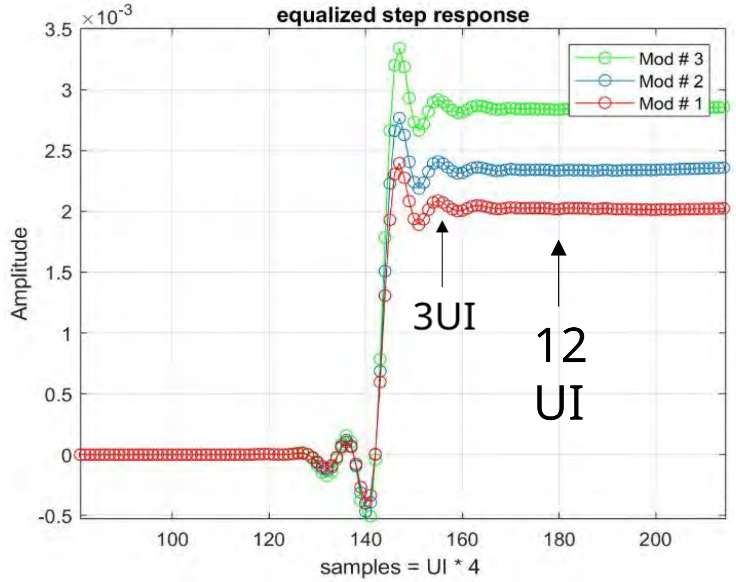


Source of discrepancy: step response

3 modules differ in their underlying overall channel step response:

Un-equalized channel responses show similarity within 3 UI of step.
Equalized response shows already significant amplitude difference within the 3rd UI following the step





Notes:

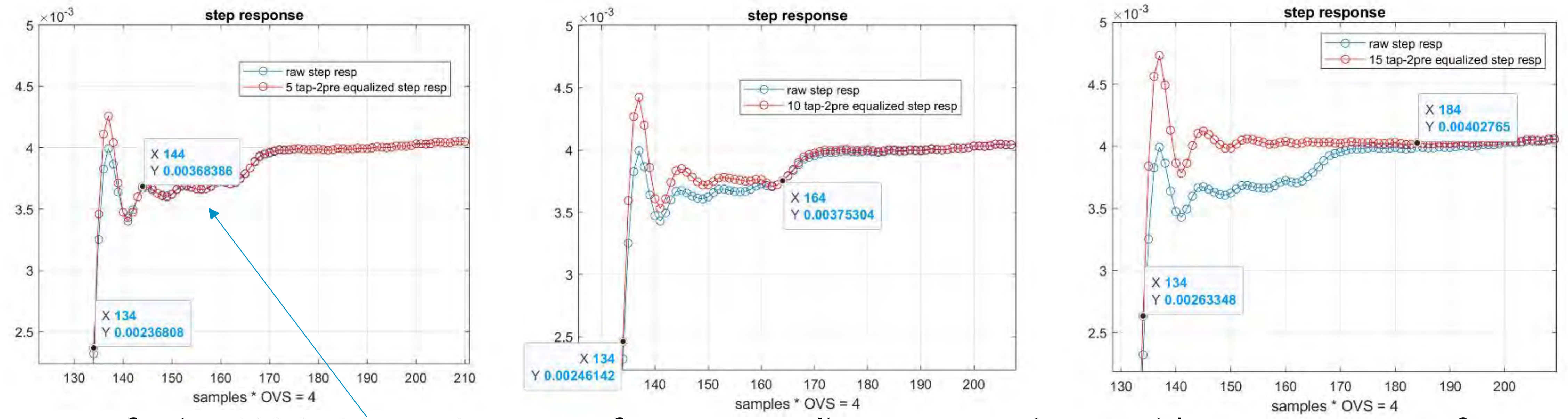
- 2 and 3 UI after step is what is used for OMAouter measurement, with runs of 7 threes and 6 zeros
- 12 UI after step is what would be where to measure the settled OMAouter
- The equalized step responses are shown with sum of FFE taps normalized to unity

Source of discrepancy: equalizer tap lengths

A discrepancy of equalized and un-equalized channel responses comes from the inconsistency between the OMA pattern length and the number of taps of reference equalizer.

It gets worse with the increase of taps of reference equalizer

Here, step responses differ following an increase of number of post-cursors:

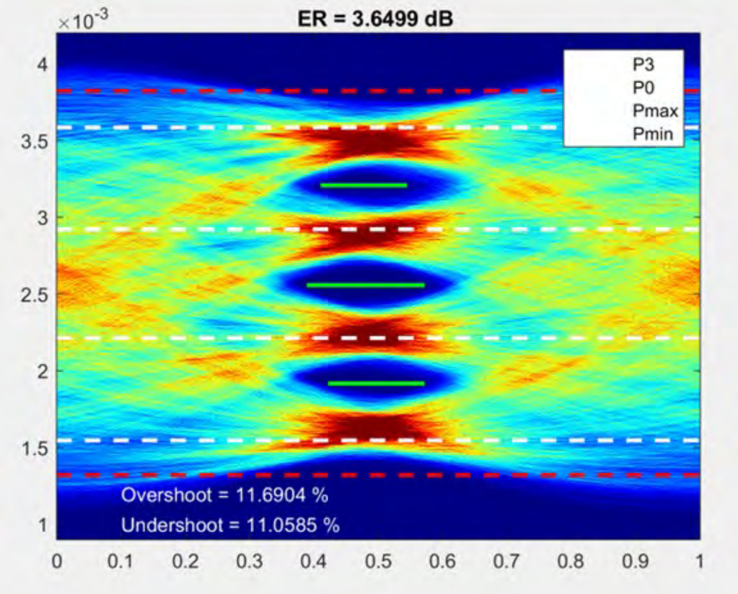


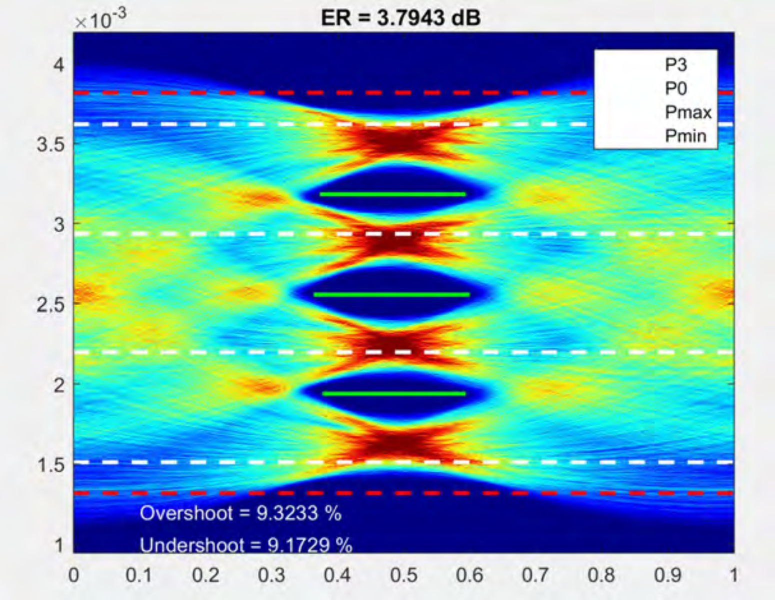
Use of prior 400GBASE-DR4 5 taps reference equalizer was consistent with measurement of raw waveform as currently defined in IEEE.

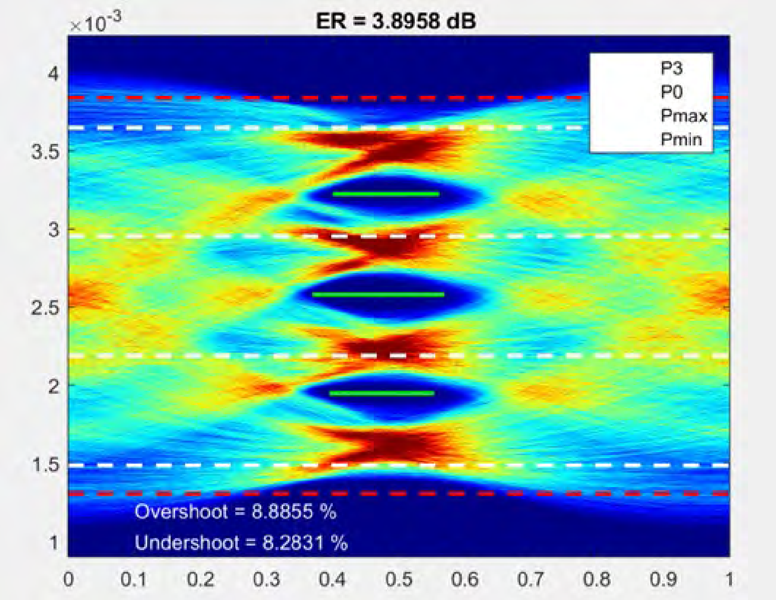
OMAouter and signal variance

OMAouter is not “always” a good metric of the signal power associated with the link budget
Below, OMAouter is measured at position 2/3 in runs 6/7 of prbs13Q after BT filter

OMAouter







OMAouter

Mod #1: OMAouter: 3.10 dBm Mod #2: 3.25 dBm Mod # 3:3.35 dBm

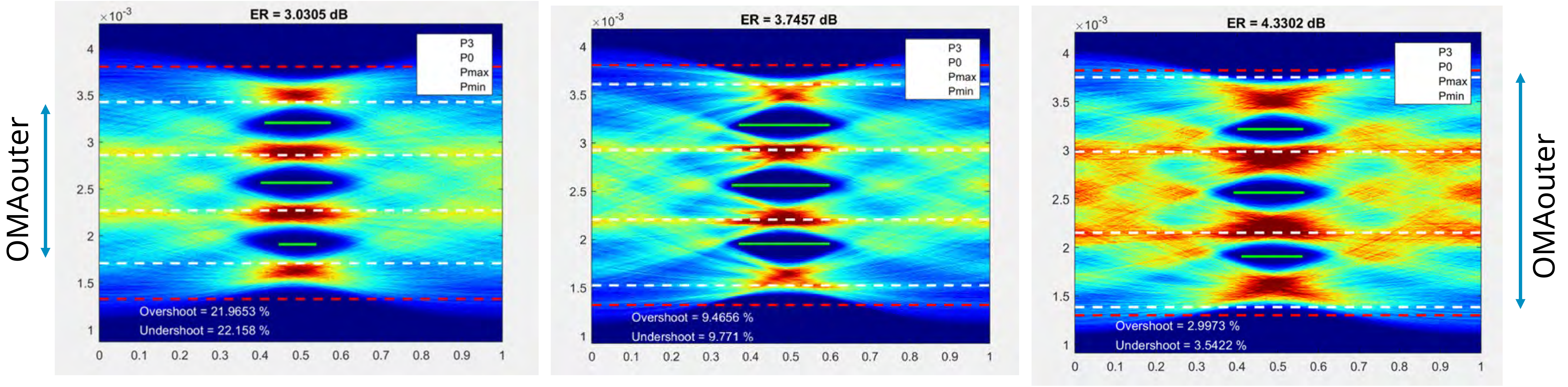
Signal power and OMAouter levels are consistent across modules

Notes:
OMAavg = L3avg –L0avg at middle of eye
varS = variance of signal with R =1A/W
varSd = variance of signal at middle of eye

Module	**#1**	**#2**	**#3**	
Txpower	4.10	4.10	4.10	dBm
OMAouter(2/3)	3.10	3.25	3.35	dBm
OMAavg	2.74	2.78	2.81	dBm
varSd	-95.9	-95.83	-95.68	dBm
varS	-96.5	-96.4	-96.24	dBm

OMAouter and signal variance

OMAouter is not “always” a good metric of the signal power associated with the link budget
Below, OMAouter is measured at position 12 on SSPRQ sequence after BT filter



Mod #1: OMAouter: 2.36 dBm   Mod #2: 3.20 dBm   Mod # 3:3.74 dBm

While Signal power levels are consistent across modules, estimated OMAouter levels are not !

Notes:
OMAavg = L3avg –L0avg at middle of eye
varS = variance of signal with R =1A/W
varSd = variance of signal at middle of eye

Module	**#1**	**#2**	**#3**	
Txpower	4.10	4.10	4.10	dBm
OMAouter(12)	2.36	3.20	3.74	dBm
OMAavg	2.76	2.81	2.85	dBm
varSd	-96.49	-96.29	-96.05	dBm
varS	-97.02	-96.82	-96.57	dBm

Possible reconciliations

A. Perform OMAouter measurement 12 UI after step on un-equalized signal in sequence of length 15. Problem: PRBS13Q has length of 0s/1s of duration 6/7 only – SSPRQ has length of 0s/1s of duration 14 only

B. Use OMAouter measured on the unequalized signal in TDECQ metric computation (formula 121-12).

C. Use OMAeq –TDECQ, but be mindful that OMAeq by itself is not a good proxy for signal power in the link budget anymore!

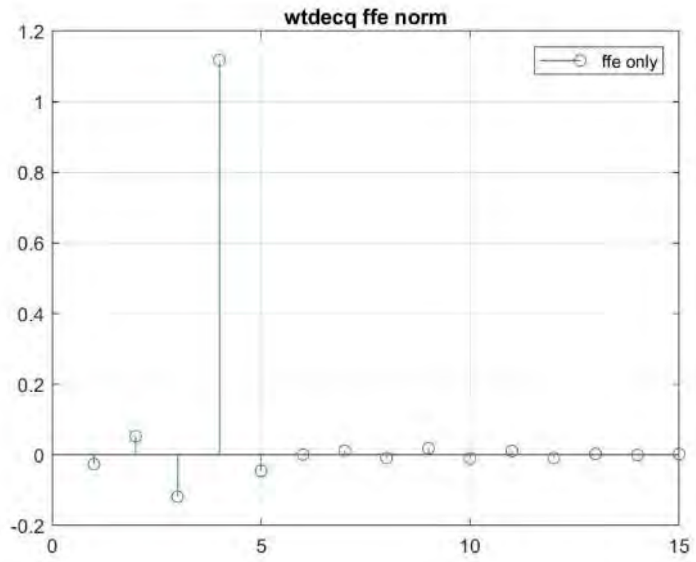
D. Report (OMAeq, TDECQ) **normalizing equalizer taps power to unity**, and use OMAeq as substitute to OMAouter in link budget

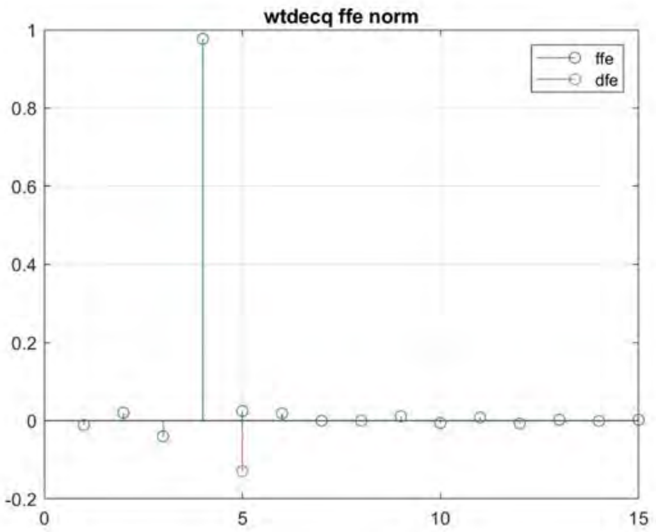
E. Report (OMAeq, TDECQ) **normalizing signal power at input of FFE**, and use projected OMAeq w/o Ceq adjustment as substitute to OMAouter in link budget

Options A, B, C assumes normalizing sum of FFE taps to unity, as in "current scheme".
Options D, E would normalize differently the FFE taps and is a more meaningful resolution.
Option B approaches a similar result as Option E, provided OMAouter ≈ OMAeq in option E.

Effect of DFE tap

With inclusion of DFE in reference Rx equalizer, OMAouter used in TDECQ is altered after normalization of FFE to unity => TDECQ penalty therefore also needs adjustment to be in line with OMAouter for link budget computation, when using a DFE





Module		
Txpower	4.17	dBm
OMAouter	3.23	dBm
OMAEq (FFE)	3.21	dBm
OMAEq (FFE+DFE)	2.64	dBm

Summary / proposal

- Currently, the TDECQ metric is associated with OMAouter being measured on the equalized signal, while OAMouter used in the link budget via the OMA-TDECQ performance metric is measured on the unequalized signal.

- With the extension to 15 tap reference equalizer (min 12 post-cursors), those two OMAouter quantities may differ significantly. Hence, the OMA-TDECQ is not longer consistent across different modules.

- Furthermore, inclusion of a DFE in the reference receiver also alters the OMAouter on the equalized signal used for the TDECQ penalty, thereby introducing a similar inconsistency in the link budget computation when using a DFE.

- The preferred solution is to report OMAouter and associated TDECQ metric at the output of the equalizer, **normalizing equalizer taps power to unity**, or **normalizing the signal power at input of FFE,** and use those two quantities in the link budget.

- The proposed solution in the original comment is one of these consistent definitions that would make OMA-TDECQ more consistent.

Thank you