

# $C_{eq}$ report in TDECQ penalty computation

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# Supporter List

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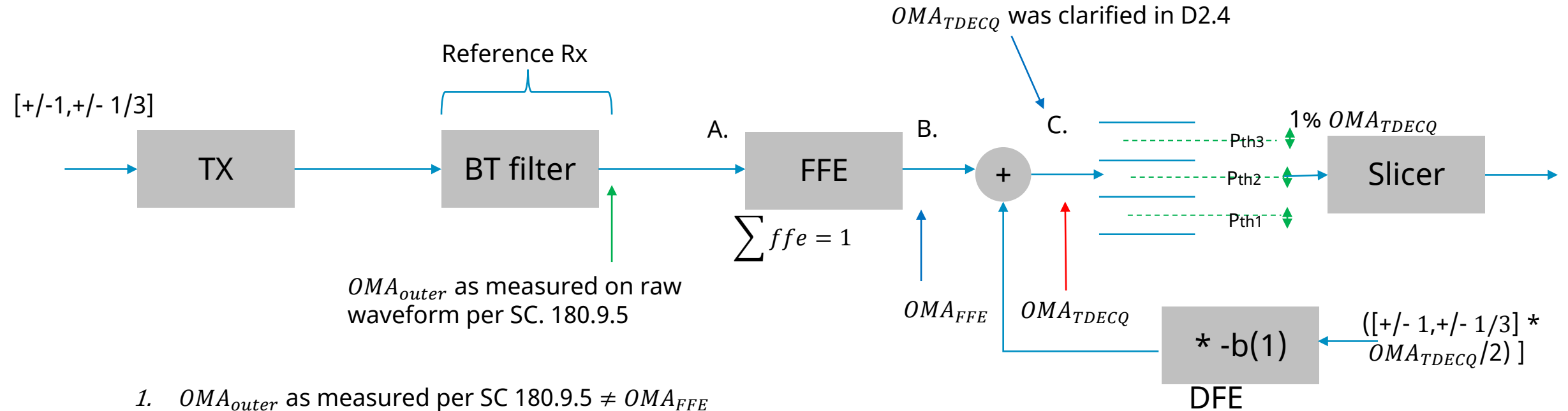
# Summary

- DFE was added in the IEEE 802.3 dj draft 2.0, as part of the TDECQ reference equalizer, thereby impacting the interpretation of  $C_{eq}$ , as a bandwidth limitation metric of the transmitter. Also considering the recent analysis of  $OMA_{outer}$  and TDECQ results discussed in the lead to the adoption of draft 2.4, it is preferable to align the report of  $C_{eq}$  to the same reference as the one used for the TDECQ report (i.e.  $OMA_{outer}$ ), such that the quantity  $TDECQ - C_{eq}$  retains a meaningful interpretation, such as that of un-equalizable impairment term.
- The current presentation proposes to align the report of the  $C_{eq}$  to the  $OMA_{outer}$  reference and to consider in its report the inclusion of the DFE in the reference receiver.
  - $C_{eq}$ , currently defined as the noise enhancement factor of the FFE, of which the sum of all taps is normalized to unity, is kept unchanged for the computation of the histograms in the TDECQ calculation
  - A new  $C_{eq\_DFE}$  term is added as a report of the penalty of equalizable ISI with a reference DFE receiver. This term can be subtracted from the TDECQ metric referenced to  $OMA_{outer}$  to yield the quantity  $TDECQ - C_{eq\_DFE}$
  - A new  $C_{eq\_FFE}$  term is also introduced as the noise enhancement penalty of the FFE portion of the reference equalizer
  - A new  $C_{eq\_TXBW}$  term is also introduced as the equivalent bandwidth limitation metric identical to that previously considered for an FFE receiver, and which can now be used for characterizing or constraining the transmitter bandwidth.

# Outline

- Definition of various OMA quantities at different reference points in the receiver/equalizer
- Example of impact of a reflection on the  $C_{eq}$  report (FFE only)
- Consequence for TDECQ-  $C_{eq}$  computation (FFE only)
- $C_{eq}$  evolution with DFE tap introduction
- Proposed editorial changes to draft D3.0
- Conclusion and recommendation

# Various OMA quantities @ reference receiver in D3.0

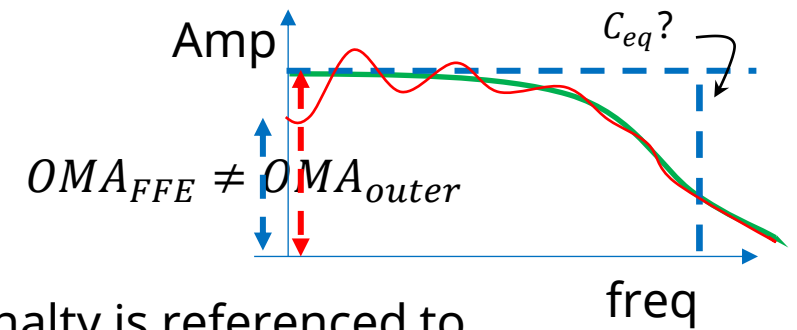


1.  $OMA_{outer}$  as measured per SC 180.9.5  $\neq OMA_{FFE}$
2.  $OMA_{FFE}$  tracks the low frequency level signal and goes up and down based on reflection type, while  $OMA_{outer}$  tracks more an averaged level
3.  $OMA_{FFE} = OMA_{TDECQ} * (1+b)$

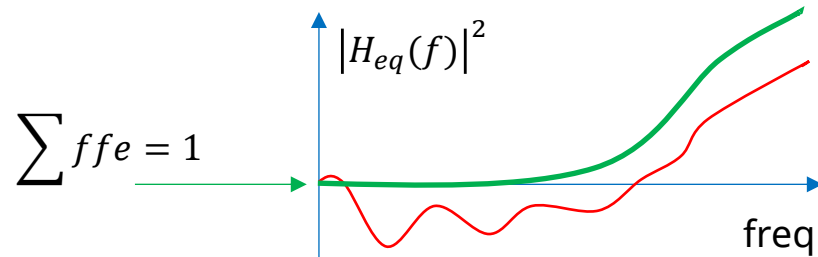
$\Rightarrow OMA_{FFE}$  goes up and down accordingly based on reflection type

# Example of impact of a reflection – FFE only

In case of a destructive reflection  $OMA_{FFE} < OMA_{outer}$ , as  $OMA_{outer}$  measured per SC 180.9.5 is equivalent to the OMA of a transmitter without the impact of the reflection.



However,  $C_{eq}$  is assessed with respect to  $OMA_{FFE}$ , while the TDECQ penalty is referenced to  $OMA_{outer}$  to remain independent of the impact of the reflection.



$$C_{eq} = \sqrt{\int_f N(f) \times |H_{eq}(f)|^2 df} \quad (180-9)$$

The  $C_{eq}$  value appears different for modules of same bandwidth but with different reflections

When considering TDECQ –  $C_{eq}$ , both quantities need to be referenced to the same  $OMA_{outer}$  level. Since  $OMA_{FFE}$  varies with the type of reflection (constructive vs destructive), while  $OMA_{outer}$  is independent of the reflection, TDECQ –  $C_{eq}$  may not be correct for modules that have a same bandwidth and a same  $OMA_{outer}$ .

# Consequence for TDECQ-CEQ computation – FFE only

In case of a destructive reflection  $OMA_{FFE} < OMA_{outer}$ ,  $C_{eq}$  will be lower. If constructive interference  $OMA_{FFE}$  will be higher and  $C_{eq}$  will be higher, thereby suggesting that the modulators have different bandwidth (i.e. different OMA @ Nyquist)

For 3 modules reported in [https://www.ieee802.org/3/dj/public/25\\_09/allain\\_3dj\\_01b\\_2509.pdf](https://www.ieee802.org/3/dj/public/25_09/allain_3dj_01b_2509.pdf)

refpoint	FFE only	Mod#1	Mod#2	Mod#3
C	OMAtdecq[dBm]	2.47	3.25	3.93
B	OMAffe [dBm]	2.47	3.25	3.93
A	OMAouter [dBm]	3.12	3.23	3.29
	Ceq [dB]	0.61	1.38	2.06
	Ceq_FFE [dB]	1.25	1.36	1.42
	TECQ [dB]	2.67	2.74	2.86
	TECQ [dB] -Ceq [dB]	2.06	1.37	0.80
	TECQ [dB] -Ceq_FFE [dB]	1.41	1.39	1.44

← Inconsistent BW metric

← Consistent BW metric

← Inconsistent un-equalizable terms

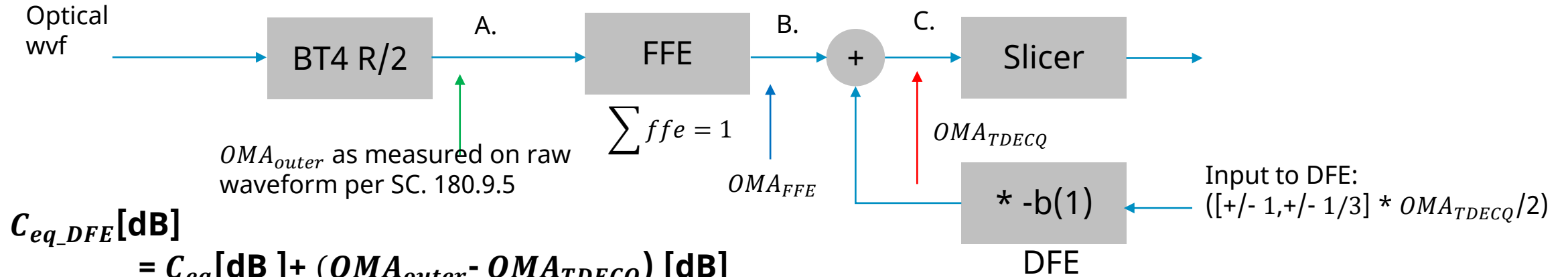
Consequences:

Mod #3 will be flagged as undershooting  
 Mod #1 will be flagged for overshooting  
 But all 3 modules offer very similar bandwidth !

Whereas  $C_{eq\_FFE}[\text{dB}] = C_{eq}[\text{dB}] + (OMA_{outer} - OMA_{TDECQ})[\text{dB}]$  shows that all 3 modules are similar. Hence, TDECQ -  $C_{eq\_FFE}$  estimates are now consistent, while TDECQ -  $C_{eq}$  estimates are not

# CEQ evolution with DFE tap

In the following model, where the DFE tap  $b$  is normalized wrt.  $OMA_{TDECQ}/2$ , as proposed in [https://www.ieee802.org/3/dj/public/26\\_03/aloin\\_3dj\\_02a\\_2603.pdf](https://www.ieee802.org/3/dj/public/26_03/aloin_3dj_02a_2603.pdf)



$$\begin{aligned}
 C_{eq\_DFE} [\text{dB}] &= C_{eq} [\text{dB}] + (OMA_{outer} - OMA_{TDECQ}) [\text{dB}] \\
 &= C_{eq} [\text{dB}] + (OMA_{outer} - OMA_{FFE} + OMA_{FFE} - OMA_{TDECQ}) [\text{dB}] \\
 &= C_{eq\_FFE} [\text{dB}] + (OMA_{FFE} - OMA_{TDECQ}) [\text{dB}]
 \end{aligned}$$

From the relationship :  $(OMA_{FFElin} / OMA_{TDECQlin}) = (1+b)$  when  $b$  is normalized to  $OMA_{TDECQ}/2$   
 $\Rightarrow C_{eq\_DFE} [\text{dB}] = C_{eq\_FFE} [\text{dB}] + 10 * \log_{10}(1+b) [\text{dB}]$

While  $C_{eq\_DFE}$  can now be used in TDECQ -  $C_{eq\_DFE}$  to derive an un-equalizable impairment quantity,  
 $C_{eq\_FFE} [\text{dB}] = C_{eq\_DFE} [\text{dB}] - 10 * \log_{10}(1+b) [\text{dB}]$  still can be used as a the FFE noise enhancement penalty.

# Comparison of CEQ\_FFE for FFE and FFE+DFE

In case of a destructive reflection  $OMA_{FFE} < OMA_{outer}$ ,  $C_{eq}$  will be lower. If constructive interference  $OMA_{FFE}$  will be higher and  $C_{eq}$  will be higher, thereby suggesting that the modulators have different bandwidth (i.e. different OMA @ Nyquist)

refpoint	FFE +DFE	Mod#1	Mod#2	Mod#3
C	dfe [b]	0.20	0.21	0.22
C	OMAtdecq[dBm]	1.64	2.38	3.05
B	OMAffe [dBm]	2.47	3.24	3.93
A	OMAouter [dBm]	3.12	3.23	3.29
	Ceq [dB]	-0.39	0.33	0.98
	Ceq_DFE [dB]	1.09	1.18	1.22
	Ceq_FFE [dB]	0.28	0.34	0.38
	TXBW [dB]	1.27	1.37	1.43
	TECQ [dB]	2.40	2.48	2.51
	TECQ [dB] -Ceq [dB]	2.78	2.16	1.53
	TECQ [dB] -Ceq_DFE [dB]	1.31	1.31	1.29
	TECQ [dB] -Ceq_FFE [dB]	2.11	2.14	2.13

← Consistent BW metric

← Consistent un-equalizable terms

Consequences:

Mod #3 will be flagged as OK

Mod #1 will be flagged for overshooting

But all 3 modules offer same bandwidth !

Whereas  $C_{eq\_DFE} [dB] = C_{eq} [dB] + (OMA_{outer} - OMA_{TDECQ}) [dB]$  shows that all 3 modules are similar. Hence,  $TDECQ - C_{eq\_DFE}$  estimates are now consistent

# Restoring TX bandwidth metric

The  $C_{eq\_FFE}$  quantity derived from a FFE only receiver is a proxy for a TX bandwidth metric,  $C_{eq\_TXBW}$

It can be recalculated based on the  $C_{eq\_FFE}$  value derived from the FFE+DFE reference receiver:

$$C_{eq\_TXBW} = C_{eq\_FFE} \text{ [dB]} + 10 \cdot \log_{10}(1/(1-b)) = C_{eq\_FFE} \text{ [dB]} - 10 \cdot \log_{10}(1-b)$$

$$C_{eq\_TXBW} = 10 \log_{10}(C_{eq}) + 10 \log_{10}(OMA_{outer}) - 10 \log_{10}(OMA_{TDECQ}) - 10 \cdot \log_{10}(1+b) + 10 \cdot \log_{10}(1/(1-b))$$

This term accounts for possible mismatch between  $OMA_{outer}$  and  $+ OMA_{FFE}$  because FFE normalization  $\sum ffe = 1$

The term  $-10 \cdot \log_{10}(1+b)$  account for the reduction of OMA due to the DFE tap b

The term  $+10 \cdot \log_{10}(1/(1-b))$  in  $C_{eq\_TXBW}$  is the bandwidth loss of the partial equalization  $1 + \alpha$  D channel at high frequency with respect to the full equalization channel.

# Proposed edits to D3.0

Appending to TDECQ definition in line 39 thru. 48, p483, the following new metric definitions

$$C_{eq\_DFE} [\text{dB}] = 10 \log_{10}(C_{eq}) + 10 \log_{10}(OMA_{outer}) - 10 \log_{10}(OMA_{TDECQ})$$

*represents the equalizable ISI penalty associated with the reference DFE receiver, which can be subtracted from TDECQ*

$C_{eq\_FFE} [\text{dB}] = C_{eq\_DFE} - 10 \log_{10}(1+b)$  where b is the normalized DFE coefficient defined in Table 180-16  
*represents the Noise enhancement penalty associated due to the FFE portion of the reference receiver*

$C_{eq\_TXBW} [\text{dB}] = C_{eq\_FFE} [\text{dB}] - 10 \log_{10}(1-b)$   
*represents the intrinsic bandwidth limiting metric of the transmitter”*

# Conclusion / Recommendation

We recommend adding three quantities  $C_{eq\_FFE}$ ,  $C_{eq\_DFE}$  and  $C_{eq\_TXBW}$  to complement the  $C_{eq}$  value currently used in the TDECQ computation.

$C_{eq\_DFE}$  addresses an erroneous interpretation of the  $C_{eq}$  value for modules where  $OMA_{outer} \neq OMA_{FFE}$  and it allows the quantity to become consistent with the TDECQ report, such that the quantity (TDECQ -  $C_{eq\_DFE}$ ) can be derived that represents an un-equalizable impairment term.

$C_{eq\_FFE}$  which is directly related to  $C_{eq\_DFE}$  through the DFE tap value  $b$  (normalized to  $OMA_{TDECQ} / 2$ ), is the equivalent noise enhancement of the FFE portion of the reference equalizer.

$C_{eq\_TXBW}$  is a TX bandwidth metric, independent of the receiver type and identical to the one derived using an FFE only reference receiver, which can be now considered for characterizing and constraining transmitter overshoot and undershoot.

Formalizing those three quantities would help avoid ambiguities in interpreting the metric (TDECQ -  $C_{eq}$ ) for modules where  $OMA_{outer} \neq OMA_{FFE}$ , as well as reinstating the original  $C_{eq}$  report as a transmitter bandwidth metric prior to the introduction of the DFE tap in the reference equalizer.

Thank you