DFE normalization in TDECQ penalty computation

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Summary

- DFE normalization was added in the IEEE 802.3 dj draft 2.2, after the addition of the DFE tap to the TDECQ reference equalizer was adopted along with its bmax limit, as part of draft 2.1. In light of the recent analysis of OMA_{outer} and TDECQ results discussed in the lead to the adoption of draft 2.4, some inconsistencies and possible mis-interpretation of what the current normalization means were highlighted.

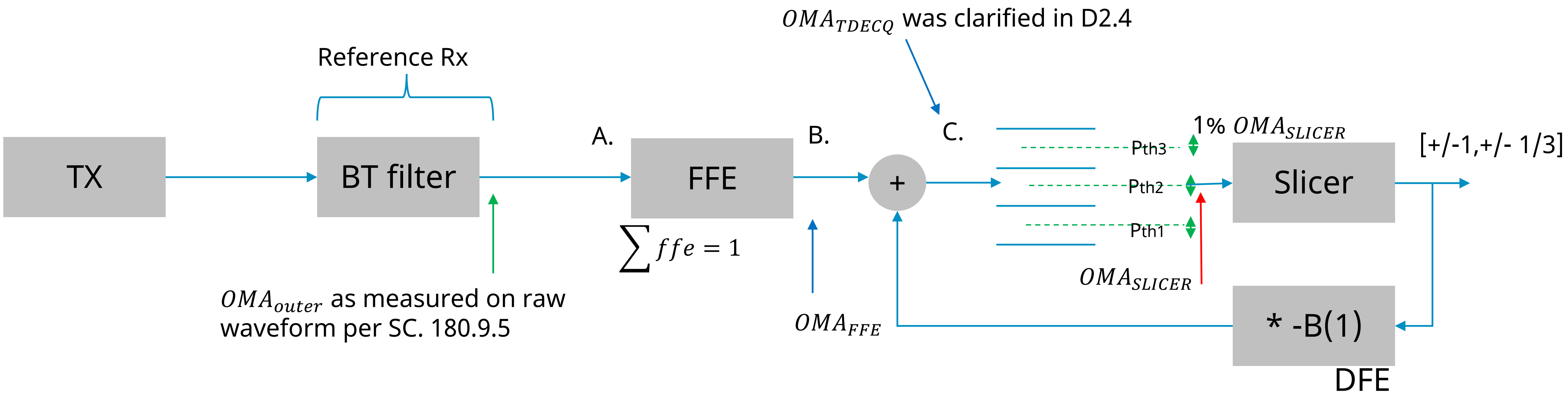
- The current presentation proposes to align the DFE normalization scheme to the DFE channel model used for DFE error propagation analysis :

  - It avoids possible ambiguity in the specification
  - It addresses the dependence of the normalized DFE tap magnitude to reflections impacting the ratio of OMA_{outer} and OMA after the FFE, which was also a source of concern for the TDECQ report addressed in D2.4.
  - It also corrects the pre-post coefficient difference limit equation.

Outline

- Various OMA quantities at different reference point in the receiver/equalizer
- Example of impact of a reflection on the normalized DFE tap value
- Consequence for TDECQ computation
- Alignment to DFE error propagation channel model
  https://www.ieee802.org/3/ck/public/18_09/zhang_3ck_01a_0918.pdf
- Pre-post equalizer coefficient limit equation and results
- Proposed editorial changes to draft D3.0
- Conclusion and recommendation

Various OMA quantities @ reference receiver in D3.0



1. Even with /because of $\sum ffe = 1$, the OMA referenced at the input to the FFE is identical to its output: OMA_{FFE} . However, 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 the rms level

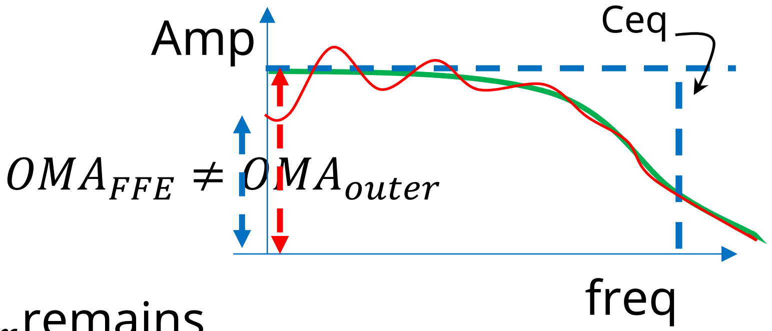
3. OMA_{FFE}= OMA_{SLICER} / (1-b) (see later slide)

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

$\Rightarrow$ normalized b = (B/ (OMA_{outer} /2)) will vary even though modules have same BW !

Example of impact of a reflection

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, the magnitude of B is proportional to OMA_{FFE}, while OMA_{outer} remains independent of the impact of the reflection.

By normalizing b to OMA_{outer} in draft 2.2, as in b = B/(OMA_{outer}/2)) we now report a normalized DFE tap b, which varies with the impact of the reflection.

The normalized DFE tap b appears different for modules of same bandwidth but with different reflections

For 3 modules reported in https://www.ieee802.org/3/dj/public/25_09/alloin_3dj_01b_2509.pdf

refpoint		Mod#1	Mod#2	Mod#3
C	dfenormOMAslicer	0.44	0.46	0.46
B	dfenormOMAffe	0.31	0.31	0.31
A	dfenormOMAouter (b)	0.27	0.31	0.35
C	OMAslicer [dBm]	0.82	1.53	2.19
B	OMAffe [dBm]	2.46	3.24	3.88
A	OMAouter [dBm]	3.08	3.24	3.34

When normalized to OMA_{outer}

Consequence for TDECQ computation

In case of a destructive reflection $OMA_{FFE} < OMA_{outer}$, OMA_{FFE} will be lower and normalized b will be lower. If constructive interference OMA_{FFE} will be higher and normalized b will be higher, which may exceed the acceptable bmax limit.

refpoint		Mod#1	Mod#2	Mod#3
C	dfenormOMAslicer	0.44	0.46	0.46
B	dfenormOMAffe	0.31	0.31	0.31
A	dfenormOMAouter (b)	0.27	0.31	0.35
C	OMAslicer [dBm]	0.82	1.53	2.19
B	OMAffe [dBm]	2.46	3.24	3.88
A	OMAouter [dBm]	3.08	3.24	3.34
	TECQ [dB]	3.62	3.74	3.87
	TECQ [dB] -bmax	-	3.75	3.89

Exceeds bmax limit = 0.3

Still acceptable in this example !

Consequences:

Mod #3 will be flagged as failing b <0.3
Mod #1 will be considered best in class
But all 3 modules offer same bandwidth !

Mod#3 will be reoptimized for max b limit = 0.3 and will likely be given a new higher TDECQ penalty, even though it passed originally the bmax criteria if proper normalization to OMA_{SLICER} /2 had been considered !

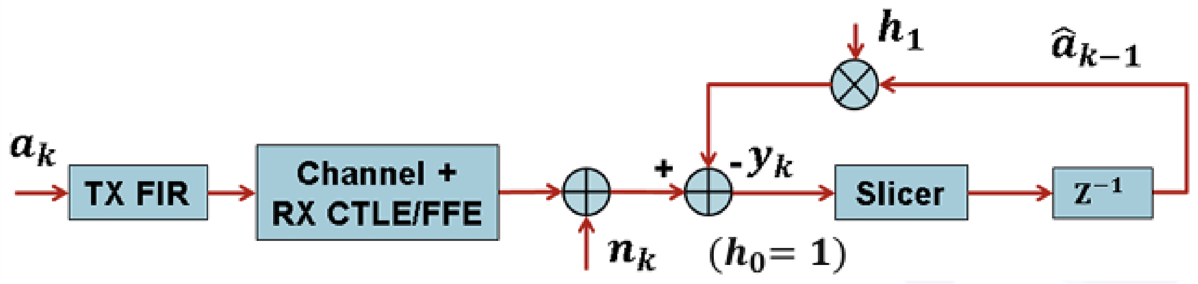
Align normalization to 1-tap DFE channel model

Be aware ! Current DFE normalization wrt. OMA_{outer} is not aligned to normalized DFE tap b and its associated acceptable bmax limit considered for error propagation.

See STG SE/Apps & Architecture Management Weekly
https://www.ieee802.org/3/ck/public/18_09/zhang_3ck_01a_0918.pdf

Error propagation model for 1-tap DFE

Slide 8



$$y_k = a_k + h_1 \cdot (a_{k-1} - \hat{a}_{k-1}) + n_k + ISI_{res}$$

In here, it is clearly shown that the assumed channel model is h0 + h1 D with h0 = 1
where h0 is the amplitude of the main tap of the convolved TX + channel + RX FFE impulse response

This model is identical to normalizing b to $OMA_{SLICER}/2$

Align normalization to 1-tap DFE channel model

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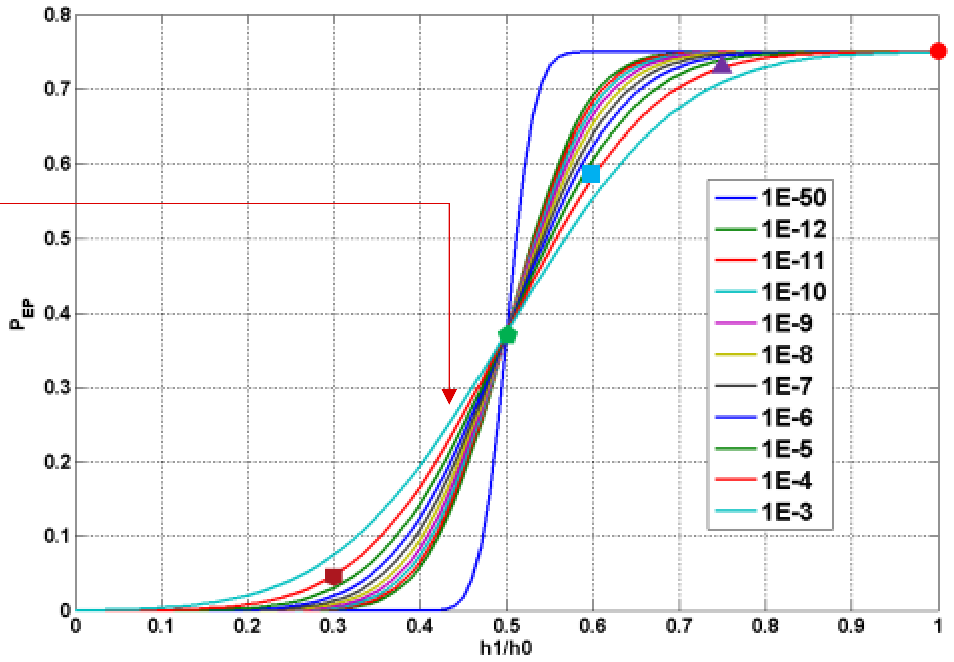
Slide 21

While we may think bmax = 0.3, leads to a probably of error propagation $P_{EP} \ll 0.1$,
normalizing b to $OMA_{Outer}/2$ effectively leads to an equivalent bmax = 0.4286 ~ 0.43 with $P_{EP} \gg 0.2$
in the 1-tap DFE error propagation model

bmax = 0.43 = 0.3/(1-0.3)

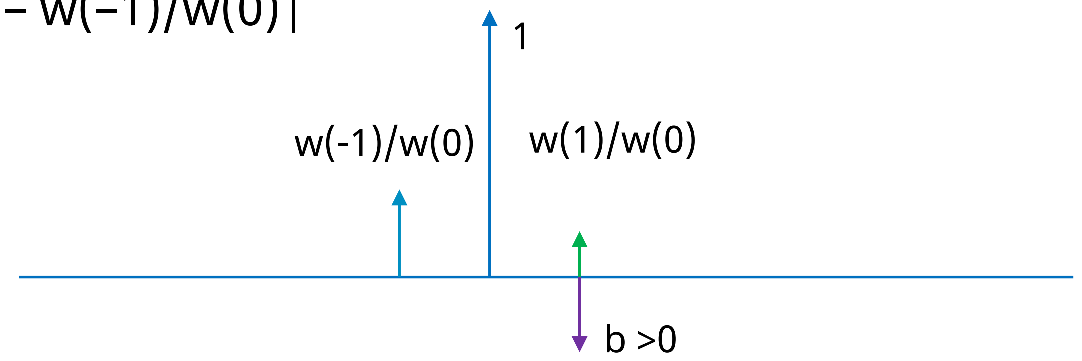
Follows the relationship : $(OMA_{FFE}\ /OMA_{SLICER})$ = b/ (1-b)
when b is normalized to $OMA_{FFE}\ /2$



=> bmax value of 0.3 may still be acceptable, but is effectively 0.43 in the error propagation model !

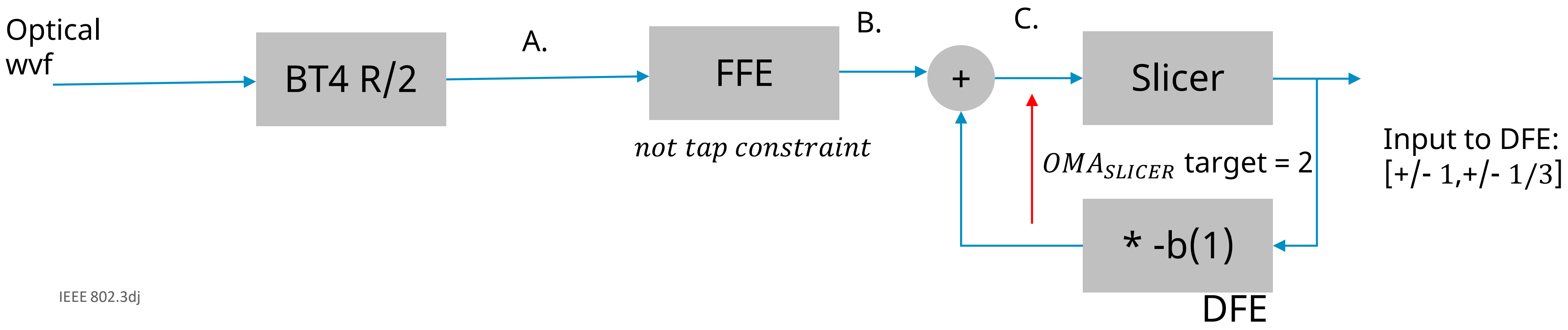
Pre-post equalizer coefficient difference limit

The pre-post equalizer coefficient difference limit equation was amended to reflect the addition of the DFE in draft 2.2 to |w(1)/w(0) – b(1) – w(–1)/w(0)|



where w(i) are the FFE coefficients and b(1) is the normalized DFE tap wrt. $OMA_{outer}/2$

However, for this equation to be correct, the DFE tap should be normalized wrt.$OMA_{SLICER}/2$, as in the following model:



Pre-post equalizer coefficient difference limit

If Pre-post equalizer coefficient limit equation: |w(1)/w(0) – b(1) – w(–1)/w(0)|, holds for b = B/(OMA_{SLICER} /2)

Then the equation expressed in terms for b' = B/(OMA_{outer} /2) = b * (OMA_{outer} / OMA_{SLICER})

b'= b * (OMA_{outer} / OMA_{FFE}) * (OMA_{FFE} / OMA_{SLICER}) = b/(1+b) * (OMA_{outer} / OMA_{FFE})

Error due to possible difference between OMA_{outer} and OMA_{FFE}

(1+b)

There is a factor (1+b) related to the fact that b' was derived wrt. to point A/B (before the DFE) instead of C (after the DFE), along with an additional factor when the OMA_{outer} != OMA_{FFE} (difference of reference points A and B).

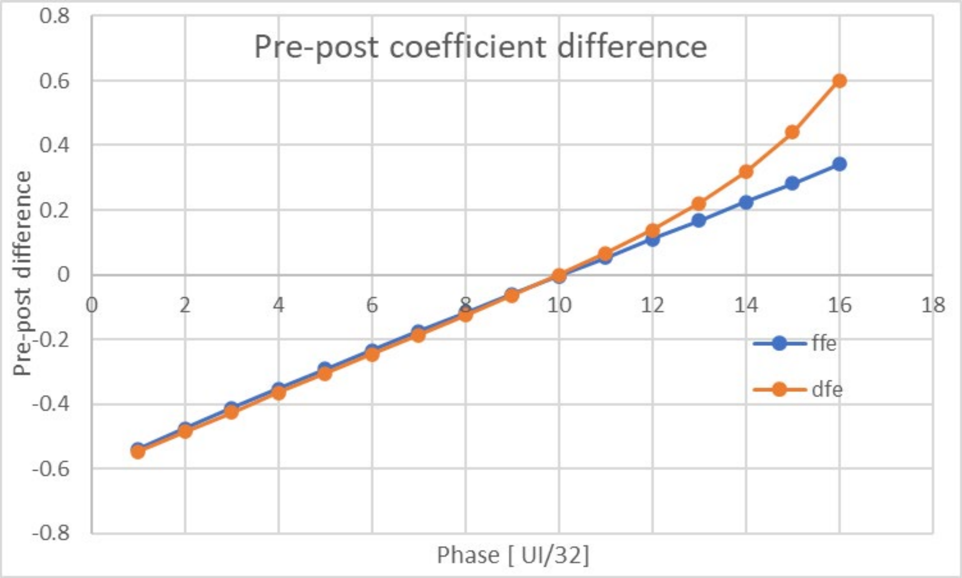
Since b' = b/(1+b) or b = b'/(1-b'), if b is referenced to OMA_{FFE}/2,

the limit eq should become : |w(1)/w(0) – (b(1)/(1-b(1)) – w(–1)/w(0)|

Also updated equation only holds with current normalization provided OMA_{outer} = OMA_{FFE} !

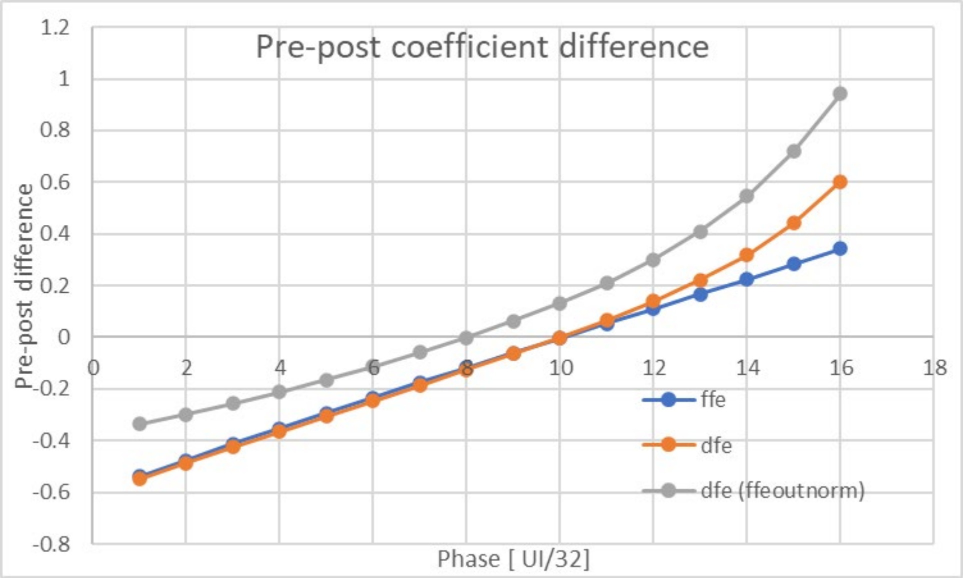
Results of pre-post coeff limit implementation

When implemented with the proper DFE normalization, the pre-post equalizer coefficient limit equation tracks the delay of the signal sampled with a varying phase offset



Pre-post equalizer coefficient limit equation :
|w(1)/w(0) – b(1) – w(–1)/w(0)| for b = B/(OMA_{SLICER} /2)

FFE and DFE difference equations align

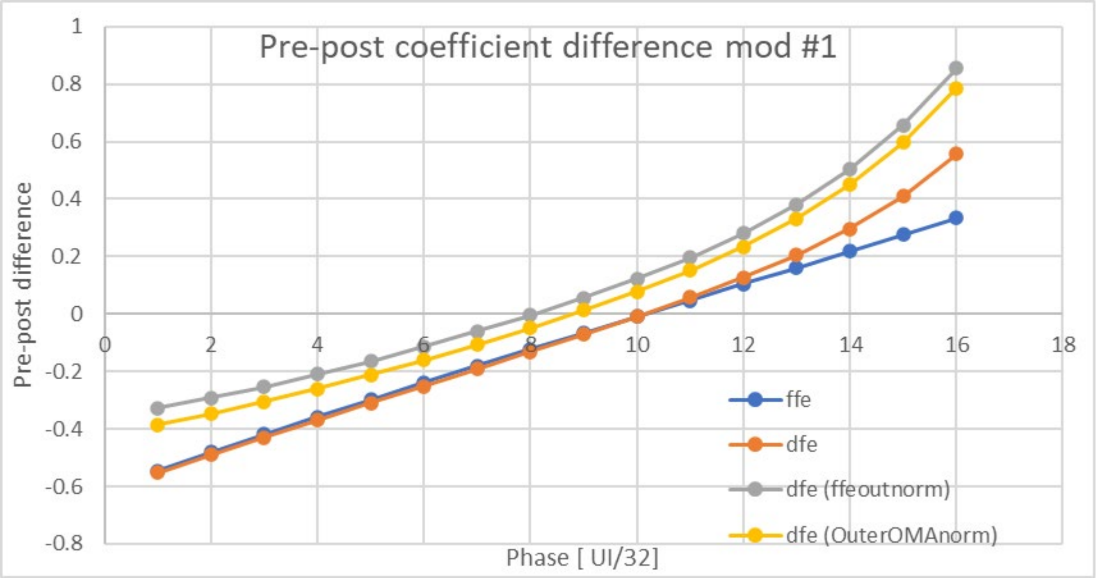


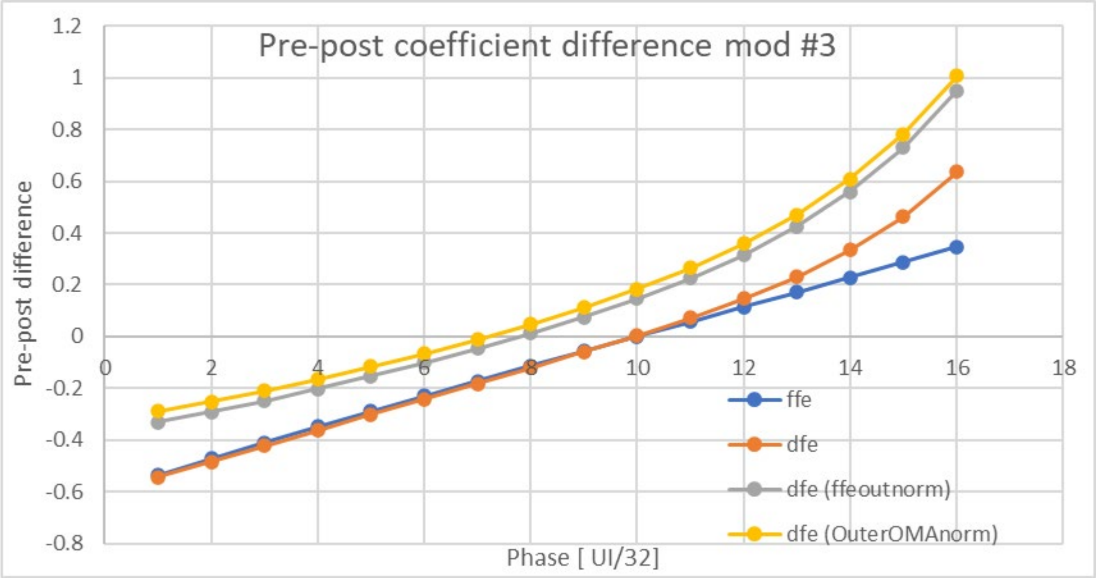
Pre-post equalizer coefficient limit equation :
|w(1)/w(0) – b’(1) – w(–1)/w(0)| for b’ = B/(OMA_{FFE}/2)

FFE and DFE difference equations deviate !

Results of pre-post coeff limit implementation

When implemented with the proper DFE normalization, the pre-post equalizer coefficient limit equation tracks the delay of the signal sampled with a varying phase offset





Pre-post equalizer coefficient limit equation : |w(1)/w(0) – b'(1) – w(–1)/w(0)| for b' = B/(OMA_{outer}/2)

FFE and DFE difference equations deviate !

Plus, it is now impacted by different reflections across modules !

Proposed edits to D3.0

4. In Table 180-16, line 24, p482 : the DFE coefficient b(1) should be referenced to OMA_{TDECQ} /2 measured at the output of the equalizer (FFE+DFE), not OMA_{outer} /2.

b(1) Maximum may need to be updated from 0.3 to 0.43

We do recommend change to the current DFE normalization, as the current normalization is not accurate for its use in the tap limit equations !

=> Changes !

Table 180–16—Reference equalizer tap coefficients

Parameter	Symbol	Value: Minimum	Value: Maximum
Normalized equalizer coefficient limits:	$w(i)/w(0)$		
$i = -3$		–0.15	0.1
$i = -2$		–0.1	0.25
$i = -1$		–0.5	0.1
$i = 1$		–0.6	0.2
$i = 2$		–0.2	0.3
$i = 3$		–0.15	0.15
$i = 4$		–0.15	0.15
$i = 5$		–0.15	0.15
$i = 6$		–0.15	0.15
$i \geq 7$		–0.1	0.1
Pre-post equalizer coefficient difference limit: $\|w(1)/w(0) - b(1) - w(-1)/w(0)\|$	—	—	0.25
Equalizer DC gain[a]	—	1	
Decision feedback equalizer (DFE) length	N_b	1	
DFE coefficient limit[b]	$b(1)$	0	0.3

=> Changes !

[a] The sum of all 15 equalizer coefficients, $w(i)$.
[b] The DFE coefficient $b(1)$ is referenced to $OMA_{outer}/2$ measured at the input of the FFE equalizer.

Conclusion / Recommendation

We recommend changing the DFE normalization for the TDECQ computation.

It corrects ambiguities in the current specification, which may lead to different interpretations of the bmax value in terms of error propagation

It addresses the issue for modules where $OMA_{outer} \neq OMA_{FFE}$ and it corrects the pre-post coefficient difference limit equation, which otherwise is an approximation.

While the current DFE normalization and approximate Pre-post equalizer coefficient limit equation only impacts the TDECQ of modules “at the edges”, correcting the DFE normalization is desirable. The specification should be mathematically correct and unambiguous.

Referencing the DFE at the output of the equalizer does not appear to present any specific problem in the TDECQ computation.

If T&M manufacturers want to implement an alternate normalization scheme that enables a faster TDECQ computation, they can, provided that the approach yields similar results as the specification

Thank you