

# Impact of DFE tap on FFE tap limits 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 draft 2.3, an adjustment of the minimum FFE main tap limit was adopted due to the addition of the DFE.
- In draft 3.1, the proper DFE normalization was adopted to correct possible inconsistencies in the interpretation of OMA quantities.
- The current presentation proposes to derive formally the FFE main tap and first postcursor tap values as a function of the DFE tap according to the new DFE normalization scheme. Once established, the limits on those taps are re-evaluated for the maximum DFE bmax value.

# Outline

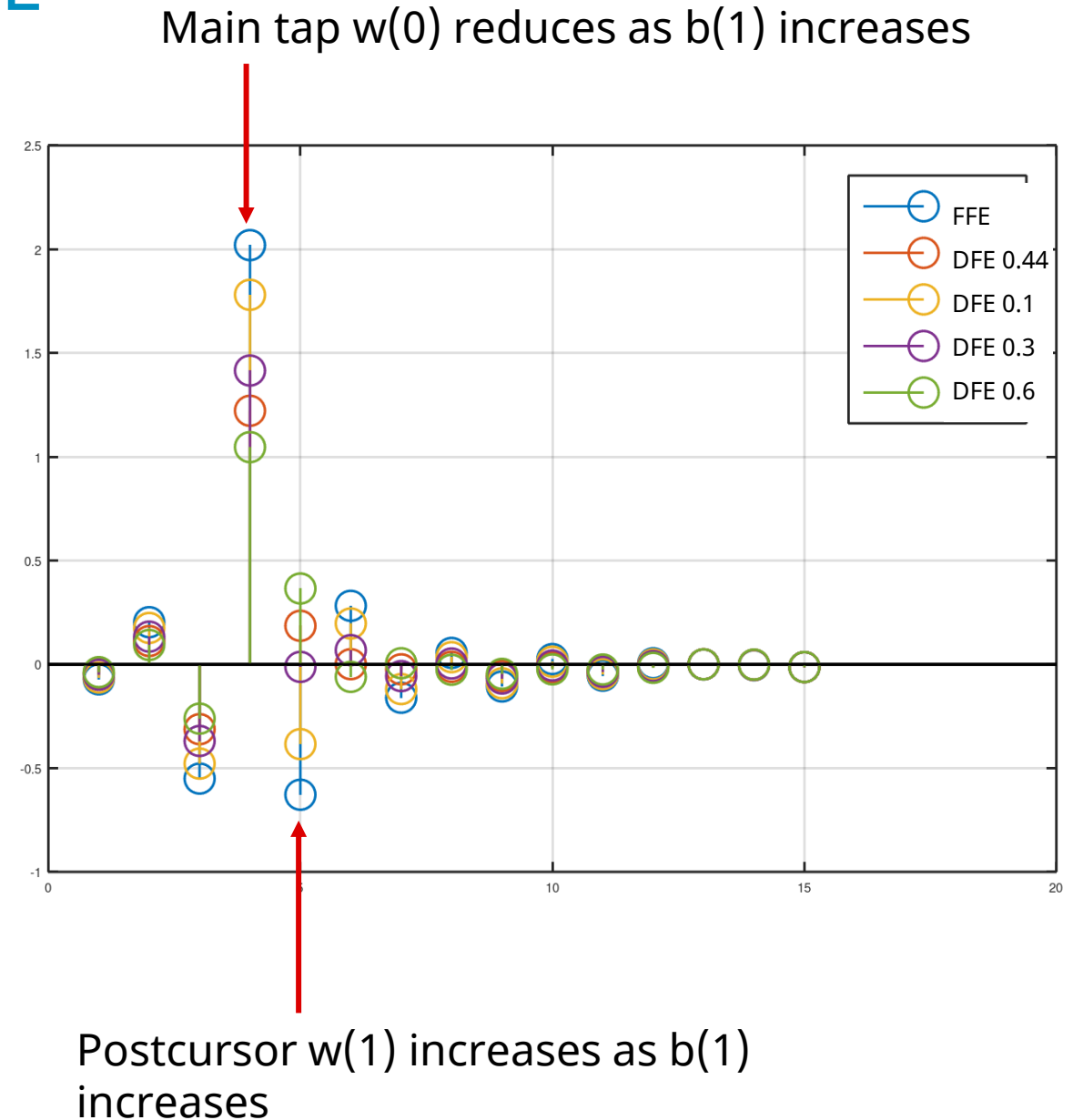
- Example of the evolution of the main FFE tap value as a function of the DFE tap
- Various OMA quantities at different reference points in the receiver/equalizer
- Example of an equivalent possible normalization in an actual receiver
- Example of actual signal levels in an actual receiver
- Relationship of input / output signal btw. ffe and dfe
- Proposed editorial changes to draft D3.1
- Conclusion and recommendation

# Evolution of FFE taps with DFE

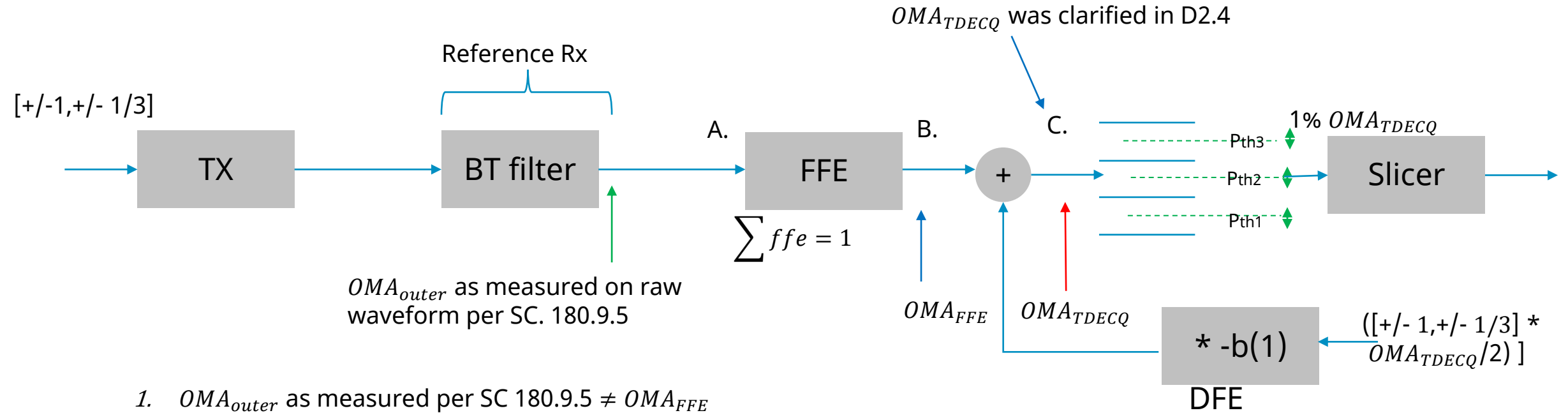
Observations:

- 1) First postcursor  $w(1)$  increases as DFE tap  $b(1)$  increases
- 2) Main tap  $w(0)$  reduces proportionally to DFE tap  $b(1)$  increases

Qi: what is the relationship?



# Various OMA quantities @ reference receiver in D3.1

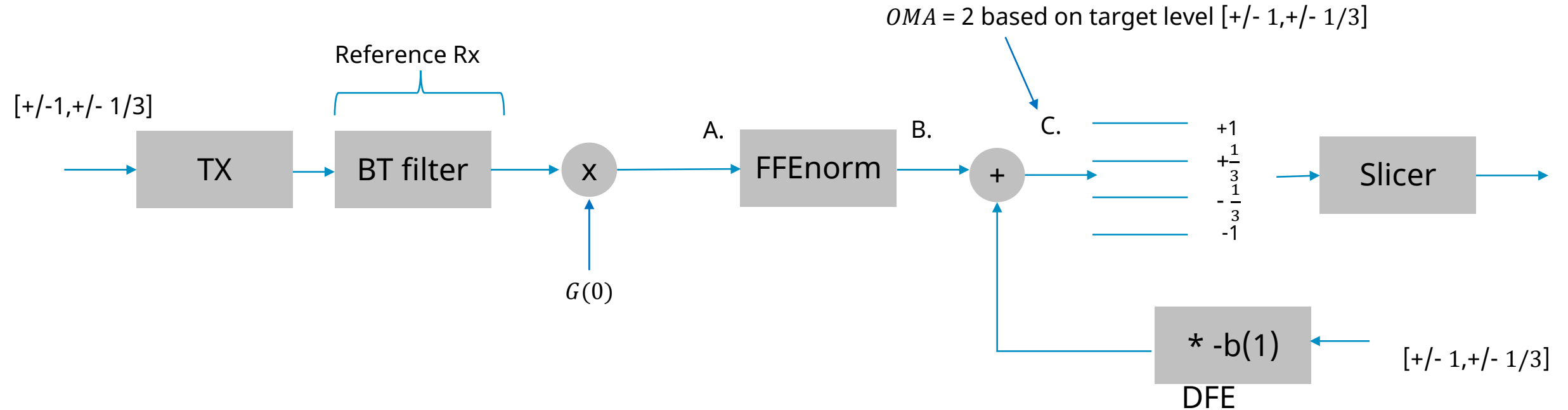


1.  $OMA_{outer}$  as measured per SC 180.9.5  $\neq OMA_{FFE}$
2. Because of  $\sum ffe = 1$ ,  $OMA_{FFE}$  tracks the low frequency level signal
3.  $OMA_{FFE} = OMA_{TDECQ} * (1+b)$

$b(1)$  is now normalized to  $OMA_{TDECQ}/2$  was clarified in D3.1

$b_{max} = 0.33$

# Example of a possible normalization in actual receiver



A possible normalization scheme in an actual receiver brings, thru. an AGC, the signal level at the FFE input in the vicinity of the chosen target slicer level. In this case, the main FFE tap is unity

1. The FFE taps are normalized to  $w(0)$ , such that

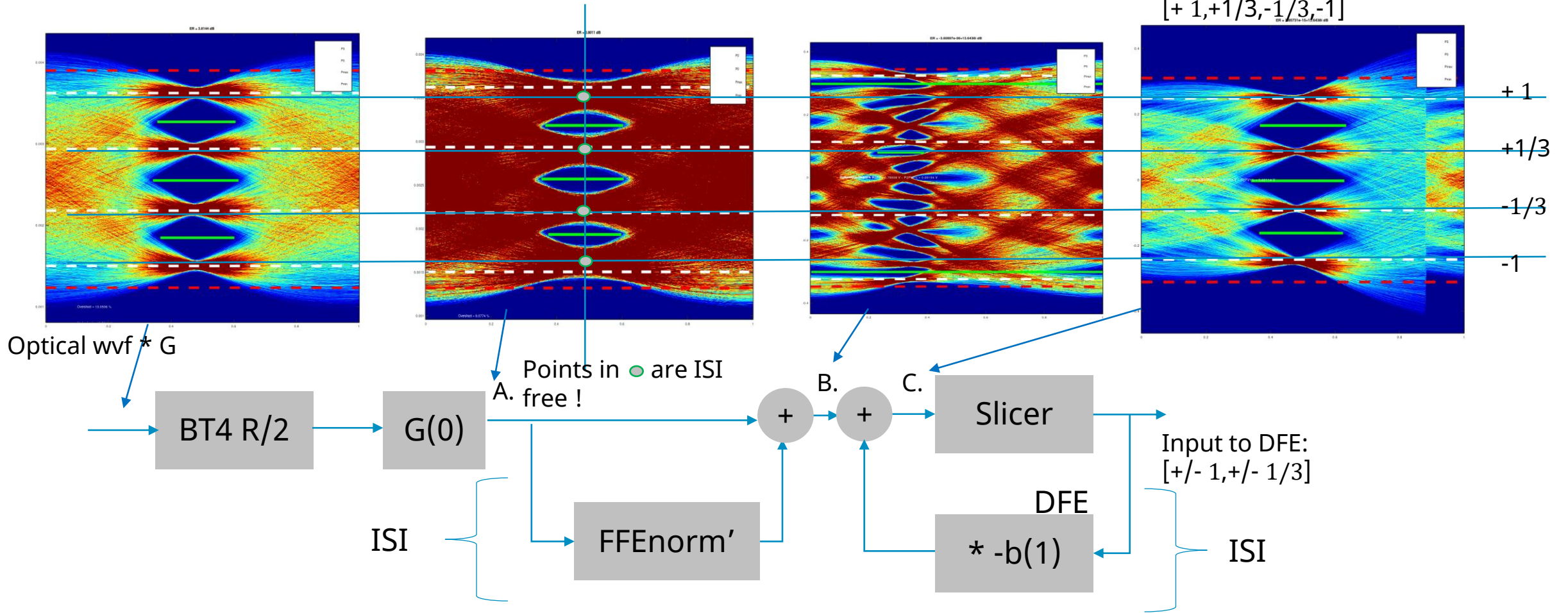
$$\text{FFEnorm} = [w(-3)/w(0) \dots w(-1)/w(0) \quad 1 \quad w(1)/w(0) \dots w(11)/w(0)]$$

2. Accordingly, a gain  $Gf(0) = tw * w(0)$ , precedes the normalized FFE filter

# Example of actual signal levels in actual receiver

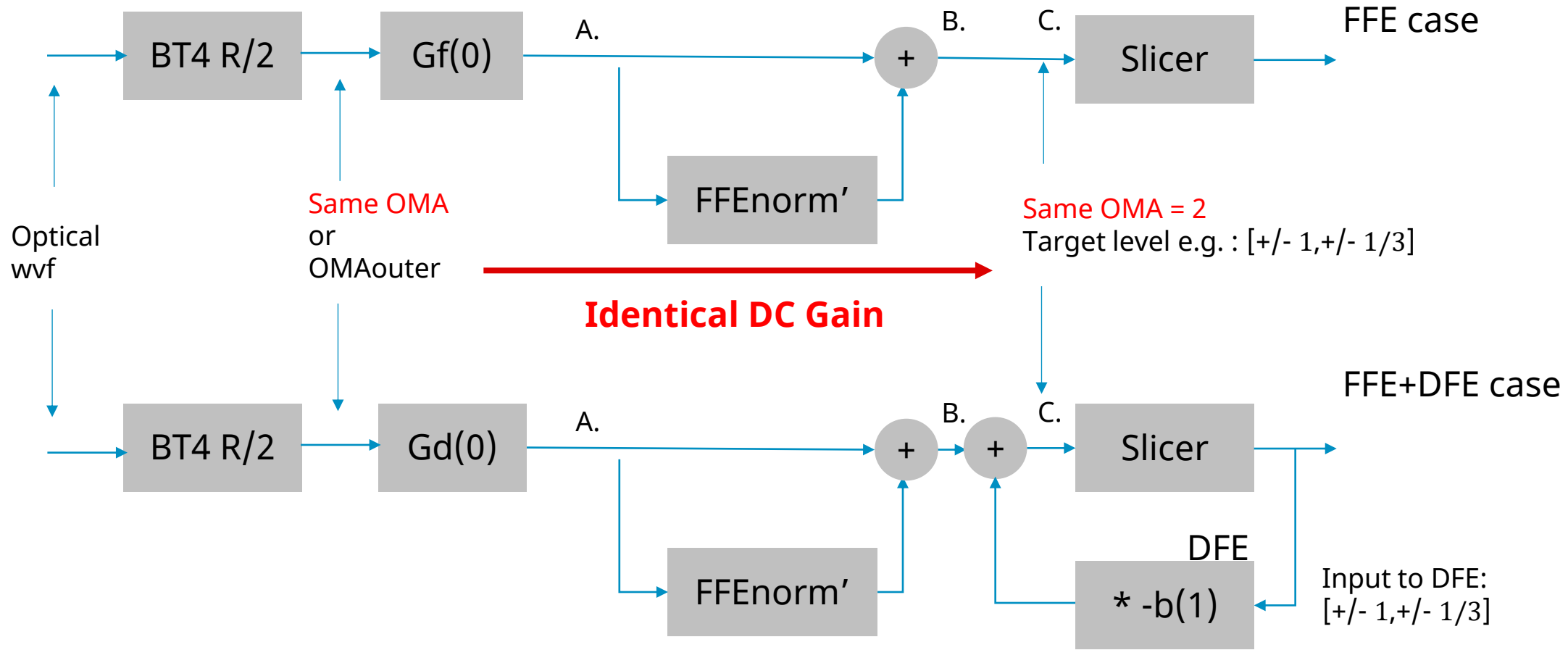
$$\text{FFEnorm} = w(i)/w(0) \text{ for } i = -3 \text{ to } 11$$

Target at FFE+DFE  
output :  
[+ 1,+1/3,-1/3,-1]



An equal amount of ISI will be added by the FFEnorm' and DFE, which leaves the level of the signal unchanged ! On average, the input to the FFEnorm' filter has same amplitude as the input to the DFE => the coefficients  $w'(i)$  and  $b(1)$  can be compared  
 $\text{FFEnorm}' = [w(-3)/w(0) \dots w(-1)/w(0) \ 0 \ w(1)/w(0) \dots w(11)/w(0)]$

# Relationship of input / output signal btw. ffe and dfe



Same input OMA, same output OMA => Identical DC gain !

$$(1) \quad Gf(0) * \sum_{i=-3}^{11} \frac{wf(i)}{wf(0)} = Gd(0) * \sum_{i=-3}^{11} \frac{wd(i)}{wd(0)} * \frac{1}{(1+b)}$$

# Identity of Gain $G_f(0)$ of ffe and $G_d(0)$ of dfe receiver

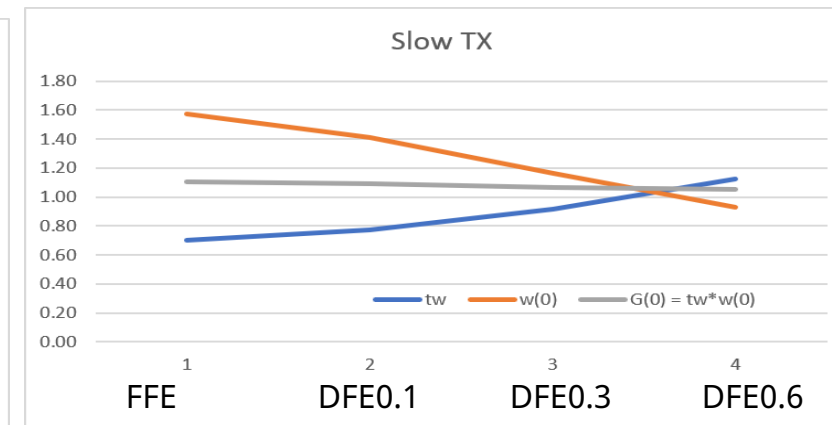
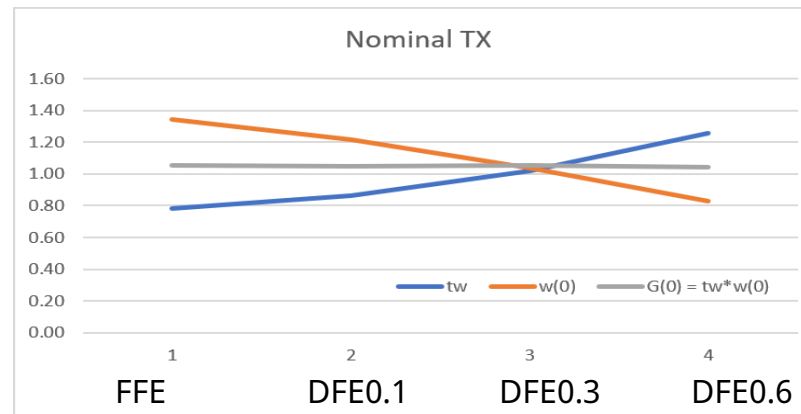
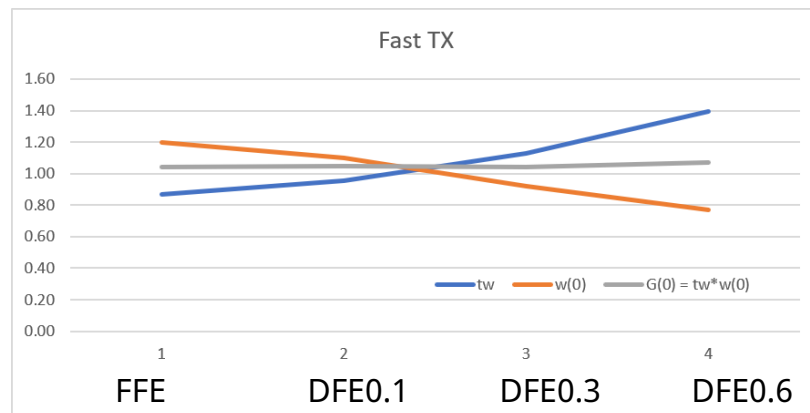
Given that the signal at point A. is independent of the ref. equalizer structure,

$$(2) \quad G_f(0) = G_d(0)$$

With  $G_f(0) = twf * wf(0)$  and  $G_d(0) = twd * wd(0)$  where :

- $wf(0)$  and  $wd(0)$  is the main of the FFE when normalized to  $\sum ffe = 1$  for the FFE or FFE+DFE reference equalizer
- $twf$  and  $twd$  is the  $\sum ffe$  prior to normalization

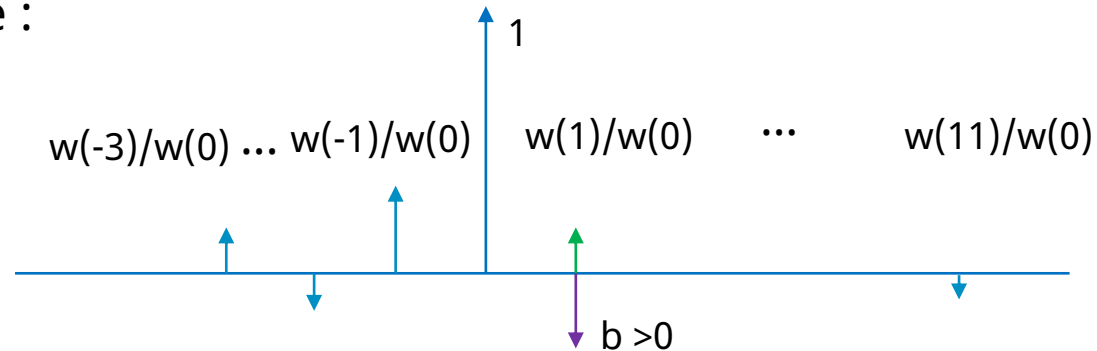
$$G_f(0) = G_d(0) \Rightarrow twf * wf(0) = twd * wd(0)$$



Examples of evolution of  $G = tw * w(0)$  for various TX BW and FFE - DFE tap configurations of ref equalizer

# Equivalence of FFE or FFE+DFE filters

When normalized to  $w(0)$ , the FFE or FFE+DFE filters achieve similar ISI removal, with an input signal to both filters of same amplitude :



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

As  $b(1) > 0$ ,  $w(1)/w(0)$  increases:  $\frac{wd(1)}{wd(0)} = \frac{wf(1)}{wf(0)} + b(1)$  **(A)**

With **(1)**  $Gf(0) * \sum_{i=-3}^{11} \frac{wf(i)}{wf(0)} = Gd(0) * \sum_{i=-3}^{11} \frac{wd(i)}{wd(0)} * \frac{1}{(1+b)}$

With **(2)** :  $Gf(0) = Gd(0) \Rightarrow \sum_{i=-3}^{11} \frac{wf(i)}{wf(0)} = \sum_{i=-3}^{11} \frac{wd(i)}{wd(0)} * \frac{1}{(1+b)}$

With **(3)**  $\sum wf(i) = \sum wd(i) = 1 \Rightarrow \frac{1}{wf(0)} = \frac{1}{wd(0)} * \frac{1}{(1+b)} \Rightarrow wd(0) = \frac{wf(0)}{(1+b)}$  **(B)**

# Evolution of FFE taps with DFE

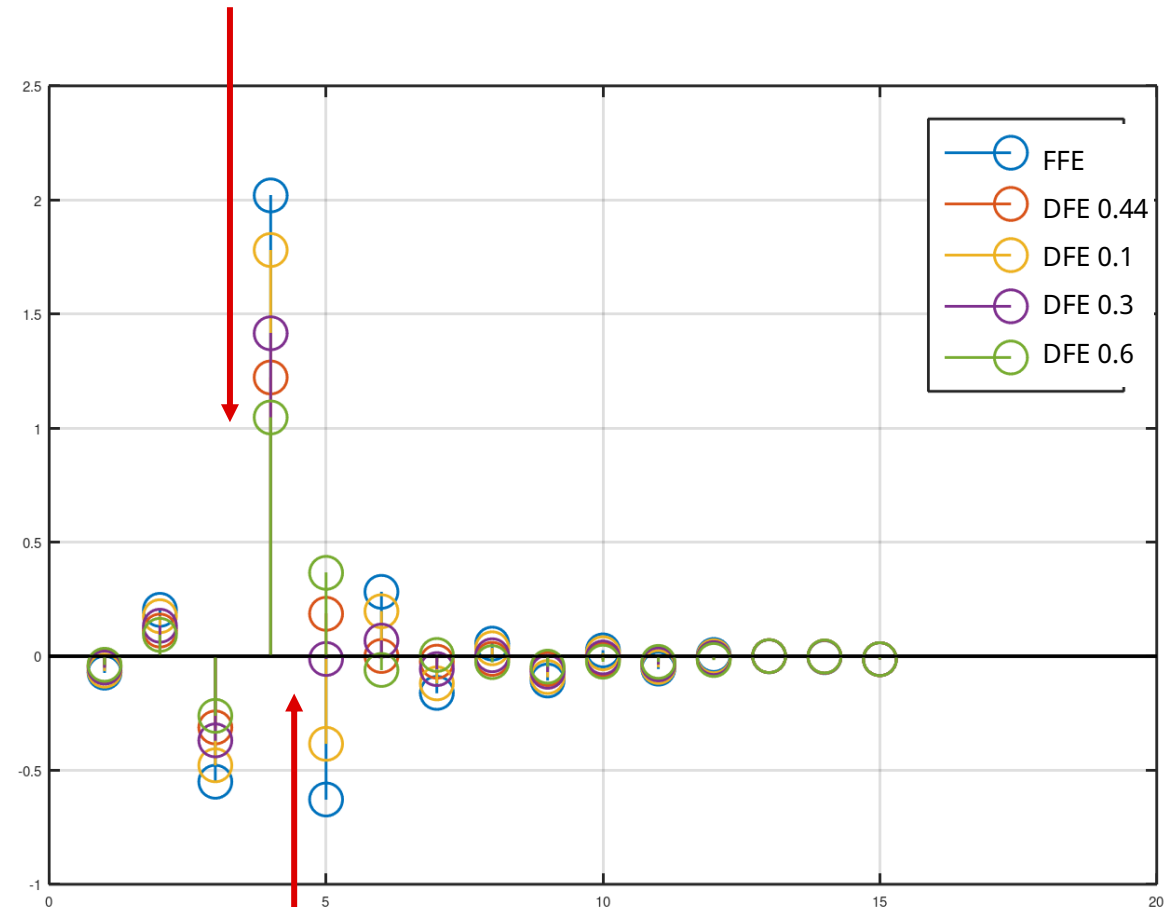
- 1)  $w_f(\mathbf{0})$  is main tap of ffe equalizer
- 2)  $w_d(\mathbf{0})$  is main tap of ffe of ffe+dfe equalizer  
 $b(\mathbf{1})$  is DFE tap

$$(B) \quad w_d(\mathbf{0}) = \frac{w_f(\mathbf{0})}{1 + b(\mathbf{1})}$$

Main tap  $w(\mathbf{0})$  reduces inversely proportionally to DFE tap  $b(\mathbf{1})$  increase

$$(A) \quad \frac{wd(\mathbf{1})}{wd(\mathbf{0})} = \frac{wf(\mathbf{1})}{wf(\mathbf{0})} + b(\mathbf{1})$$

Main tap  $w(\mathbf{0})$  reduces as  $b(\mathbf{1})$  increase



Postcursor  $w(\mathbf{1})$  increases as  $b(\mathbf{1})$  increase

# Proposed tap limit changes to D3.1 specification

With  $b_{\max} = 0.33$ ,

First postcursor min limit  $\frac{w(1)}{w(0)}$  of -0.6 should be increased to  $-0.6 + b_{\max} = -0.27$

Main tap limit max limit  $w(0)$  of 2.5 should be reduced to  $-2.5 / (1 + b_{\max}) = 1.8797 \approx 1.9$

# Proposed editorial changes to D3.1

Table 180–16—Reference equalizer tap coefficients

0.8	1.9
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-0.27	0.2
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Parameter	Symbol	Value	
		Minimum	Maximum
Number of feed-forward taps	$N_w$	15	
Number of pre-cursor feed-forward taps	—	0	3
Main tap coefficient limit	$w(0)$	0.8	2.5
Normalized feed-forward tap 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-cursor tap coefficient difference limit: $ w(1)/w(0) - b(1) - w(-1)/w(0) $	—	—	0.25
Feed-forward tap DC gain <sup>a</sup>	—	1	
Number of feedback taps	$N_b$	1	
Feedback tap coefficient limit <sup>b</sup>	$b(1)$	0	0.33

<sup>a</sup> The sum of all 15 feed-forward tap coefficients,  $w(i)$ .

<sup>b</sup> The feedback tap coefficient  $b(1)$  is referenced to  $OMA_{TDECQ}/2$  (see 180.9.6.4 for definition of  $OMA_{TDECQ}$ ).

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# Conclusion / Recommendation

With the updated DFE normalization in draft 3.1, we derived the expected relationship of the FFE main tap and first postcursor values with the DFE tap  $b(1)$ .

Taking into account the maximum DFE  $b_{\max}$  value of 0.33, we propose to update the max limit of the main FFE tap  $w(0)$  from 2.5 to 1.9

Taking into account the maximum DFE  $b_{\max}$  value of 0.33, we propose to update the min limit of the first postcursor FFE tap  $\frac{w(1)}{w(0)}$  from -0.6 to -0.27

Thank you