Improving TDECQ Reference Equalizer Tap Limits

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Overview

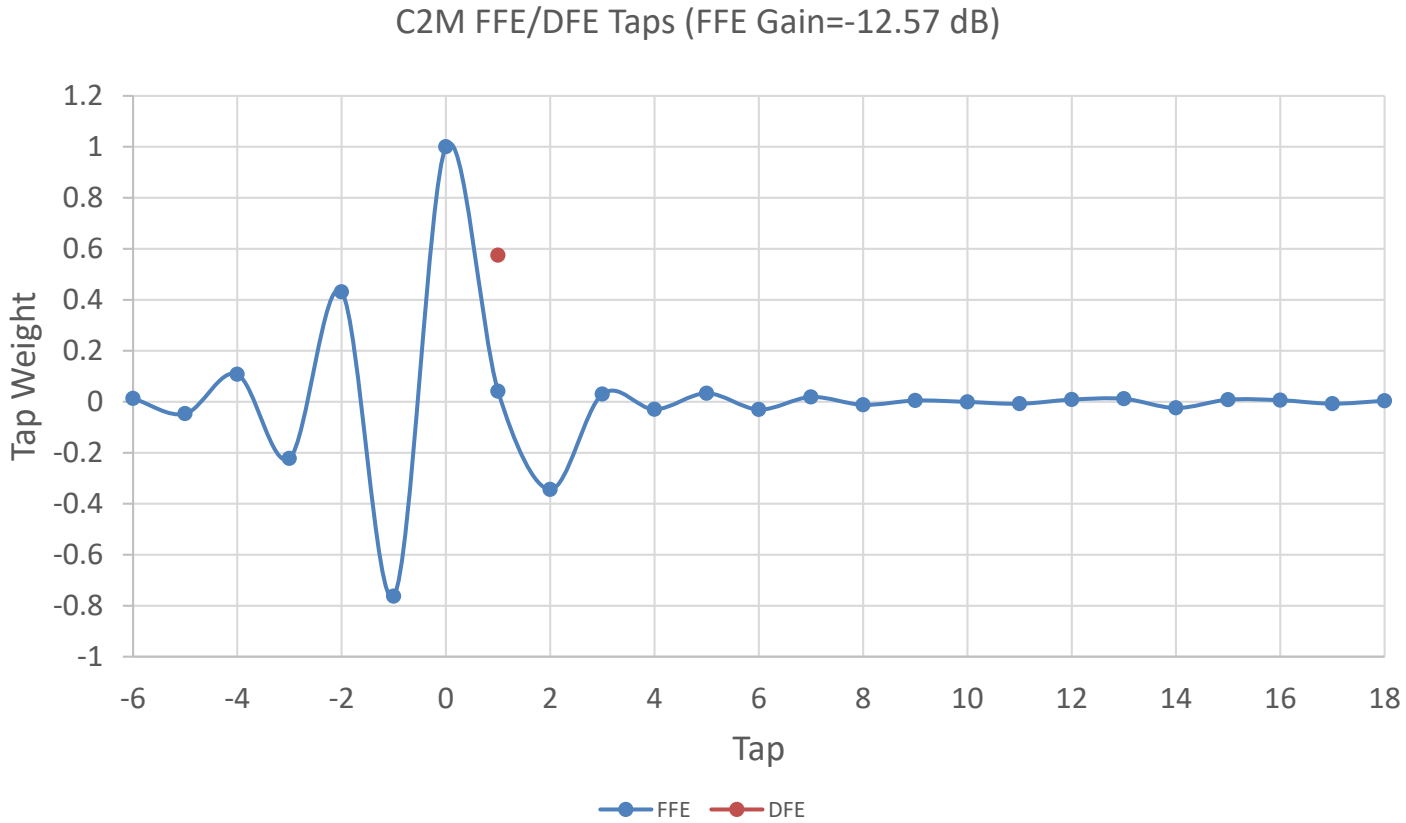
- Background on TDECQ equalizer
- Is there a benefit to control the tap weight so tightly
- Typical C2M equalizer tap weights
- Currently adopted FECo tap limits
- TECQ transmitter data with
- TECQ FECo vs FECi data
- Current and proposed tap limits
- Summary.

802.3bs/cd and 802.3db Equalizers

- **TDECQ 50G/100G SMF and 50G MMF equalizers in the 802.3bs/cd is**
  - 5 tap T-spaced (FFE), where the sum of the equalizer tap coefficients is equal to 1. Tap 1, tap 2, or tap 3, has the largest magnitude tap coefficient, which is constrained to be at least 0.8.
    - Implies TDECQ equalizer having 0, 1, or 2 pre-cursor
    - With sum of tap coefficient=1 implies the FFE has no gain/loss
    - Any combination of pre or post tap weight that satisfy unity gain is acceptable.
- **TDECQ 100G MMF equalizers in the 802.3db**
  - 9 tap T-spaced (FFE), where the arithmetic sum of the equalizer tap coefficients are equal to 1. Tap 1, tap 2, tap 3, or tap 4 has the largest magnitude tap coefficient, which is constrained to be at least 0.8. In addition 802.3db limits absolute value of C(7)<0.3, C(8)<0.2, and C(9)<0.1
    - Mandates TDECQ equalizer having 0, 1, or 2 pre-cursor
    - With sum of tap coefficient=1 implies the FFE has no DC gain/loss
    - Any combination of pre or post tap weight that satisfy unity gain is acceptable.

Typical 802.3dj C2M FFE Taps

- **Channel for the example illustrated below is Kareti SL No 10 with 32 dB bump-bump loss**
  - COM FFE uses normalized FFE taps and for this channel result in 12.57 dB of signal loss (unlike 802.3bs/cd/db TDECQ equalize that have unity gain)
  - Similar SerDes/DSP expect to handle at least ± 0.8 for taps near the main
  - To satisfy TDECQ equalizer unity gain as in 802.3bs/cd/db with strong 1st pre/post cursors the main tap typically ~1.6.



Adopted 802.3dJ TDECQ Tap Weight

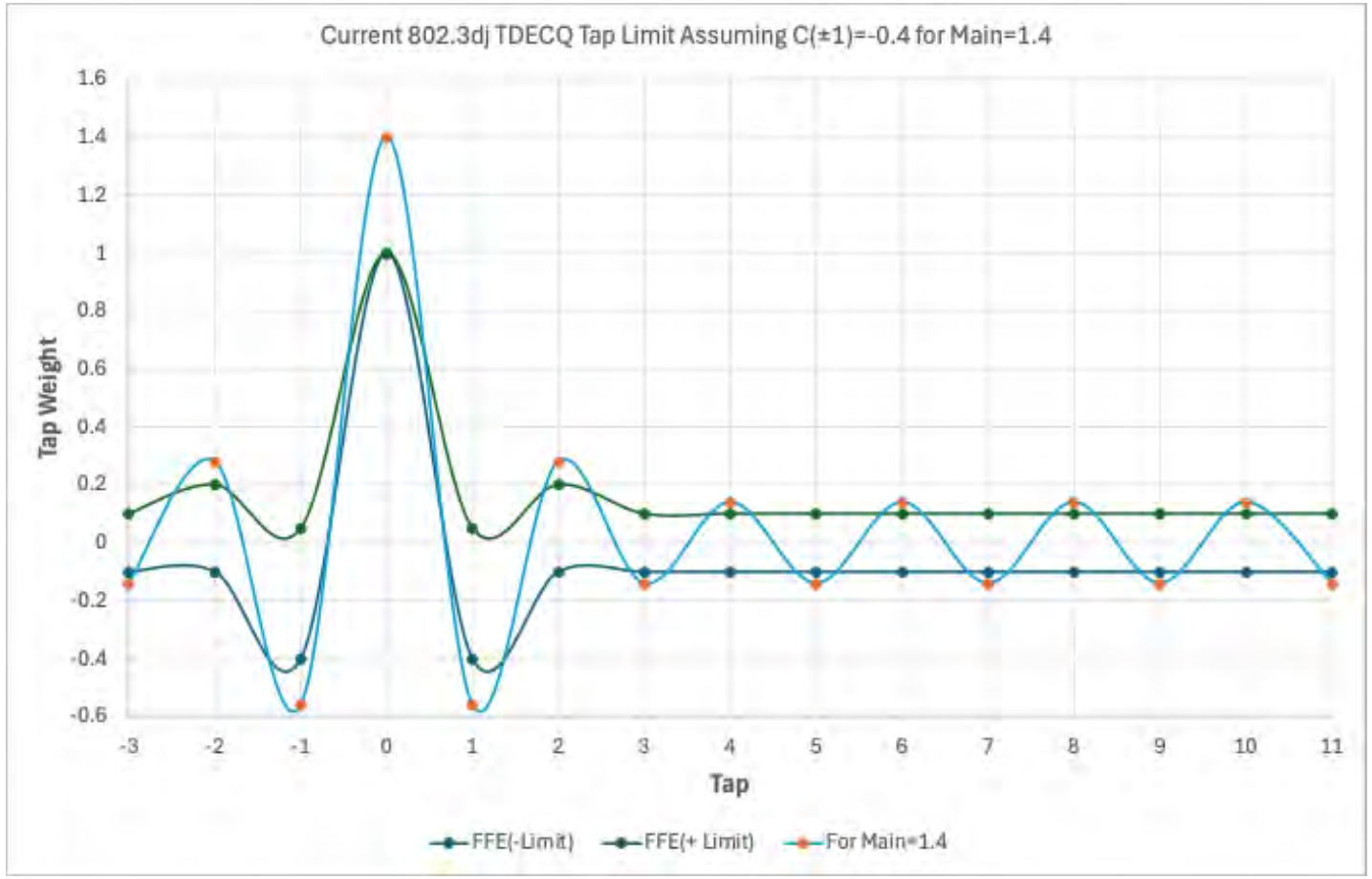
- **TDECQ tap weights were based on welch_3dj_01_2405 proposal with fixed 3 pre-cursors**
  - Table below show tap weights adopted per comments 324 and 325 but taps C(±1) are TBD.

	Symbol	Min	Max	Units
Feedforward equalizer (FFE) length	N_b		15	UI
Maximum FFE pre-cursors			3	UI
Maximum FFE post-cursors			13	UI
FFE main tap coefficient limit		0.9	2.5	-
Normalized FFE coefficient limits†	bb(n)			
n = -3		-0.1	0.1	
n = -2		-0.1	0.2	
n = -1		TBD ~~-0.4~~	0.05	
n = 1		TBD ~~-0.4~~	0.05	-
n = 2		-0.1	0.2	
n ≥ 3		-0.1	0.1	
FFE Gain‡		1	1	-

† Measured relative to the main tap
‡ The sum of FFE Coefficients must equal one

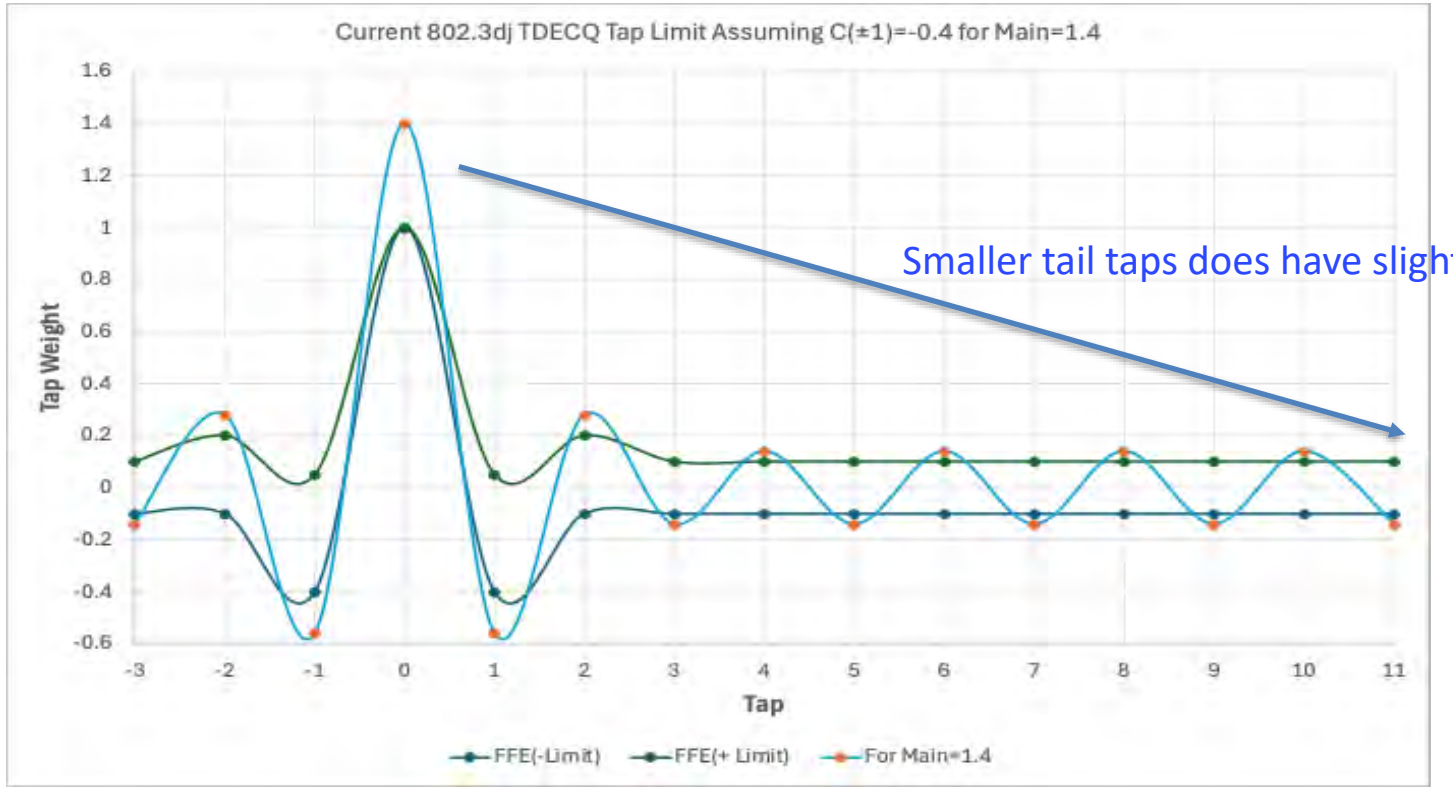
Current 802.3dj Tap Range

- **TDECQ pre/post cursors taps are relative main tap in percentage**
  - For Main tap of 1.4 which is typical for the measured data in this contribution and a C(±1)=0.4 currently TBD some of the transmitter require tap C(1) >0.56 (40% of main).



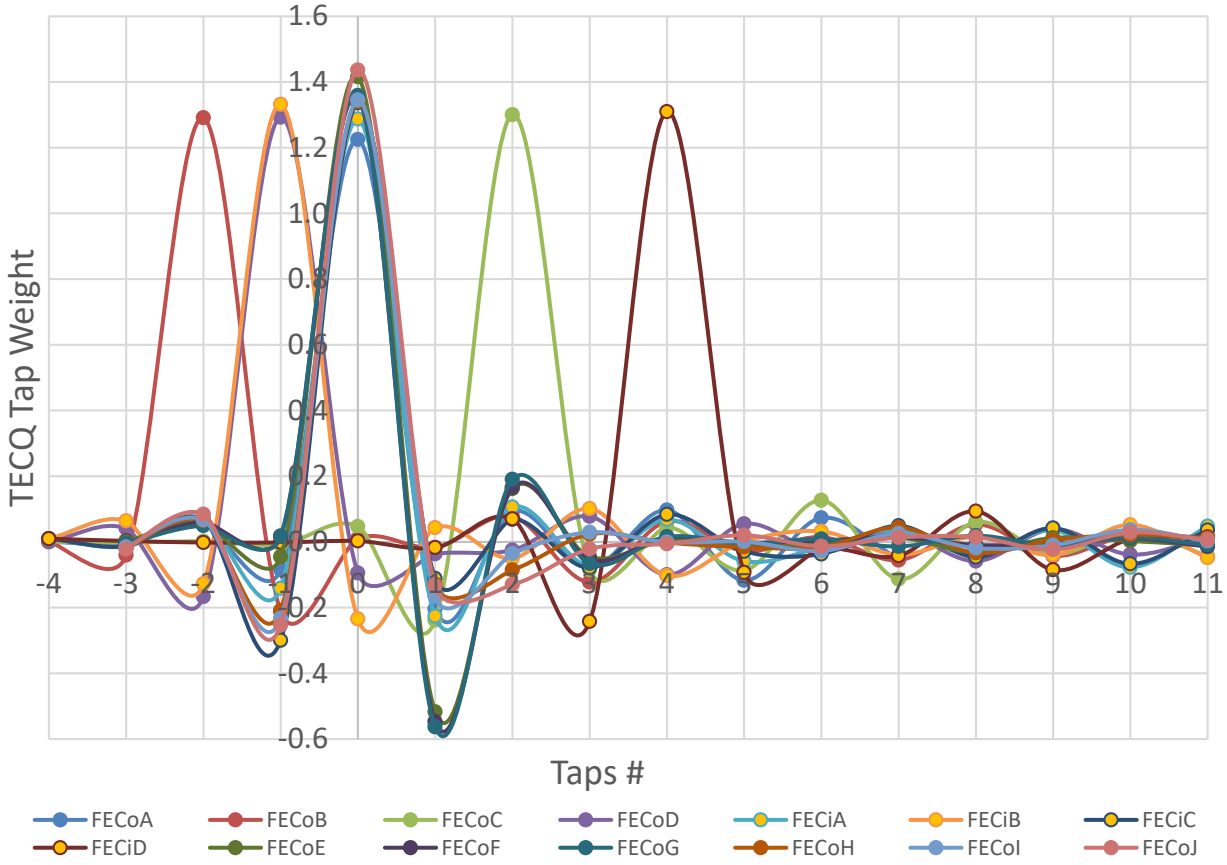
Is there an Advantage to Tightly Limit the Taps

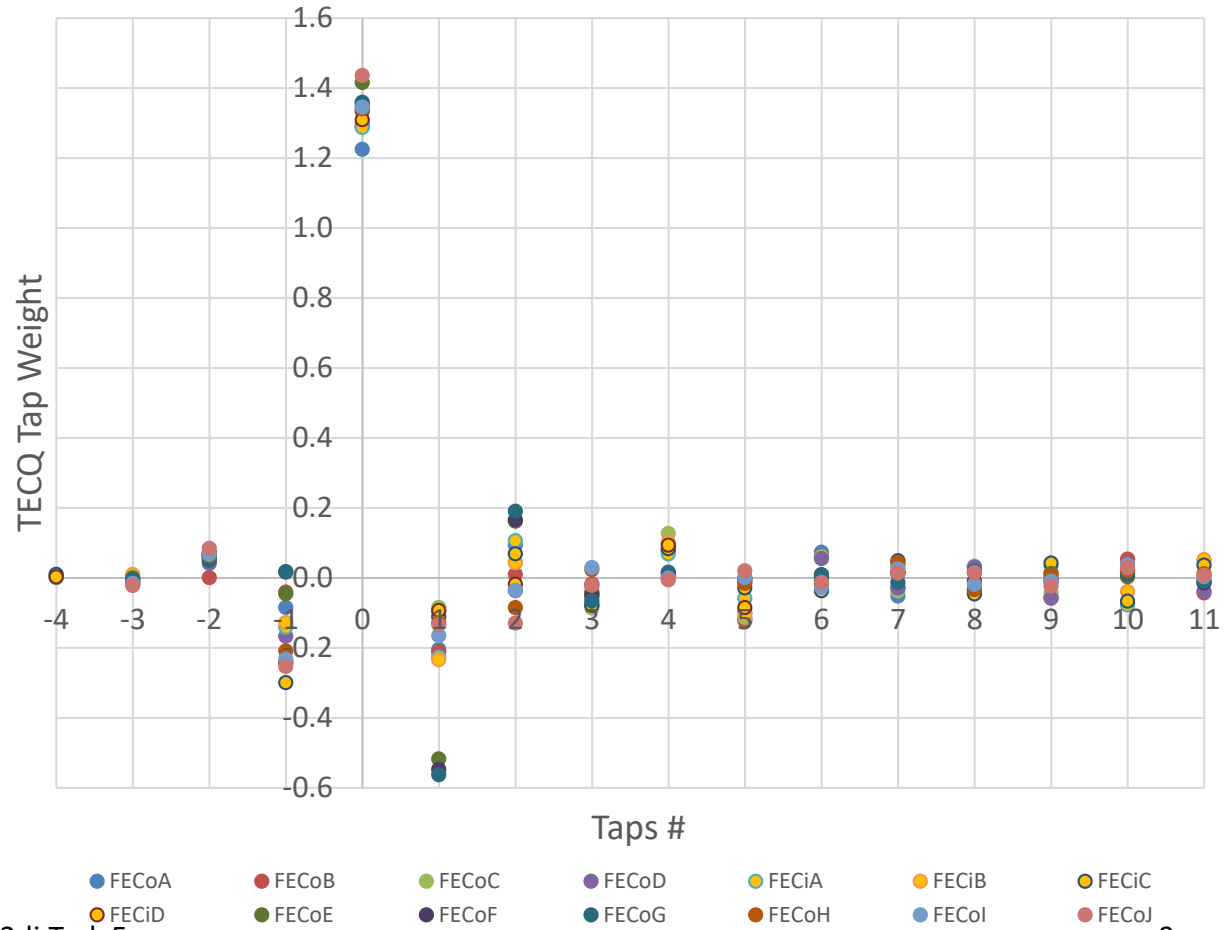
- **Having some tap limits on the tail taps does have small power advantage**
  - Tap weight should be compared in the context of ADC resolution which is ~0.02
  - FFE tap limit should be determined based on worst case optics response given limited power advantage reducing tap weights!



FECo and FECi TECQ Data

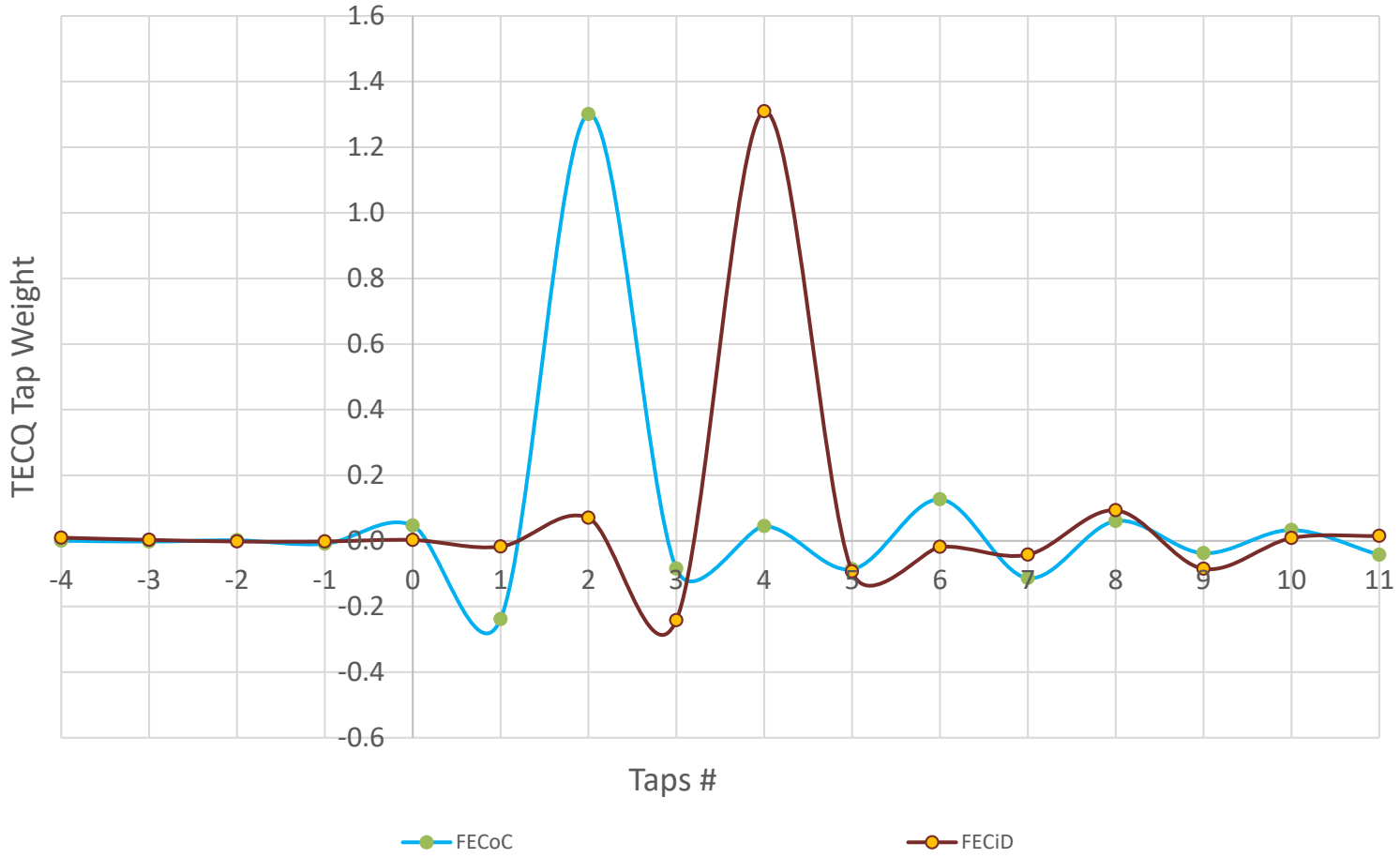
- **Original tap positions and after aligning all the main to tap #5 (4 pre-cursors)**
  - Main position for the data shown varied from tap #3 to tap #9
  - Forcing all transmitters to a fixed 3 pre-cursors will result in some TECQ penalty!





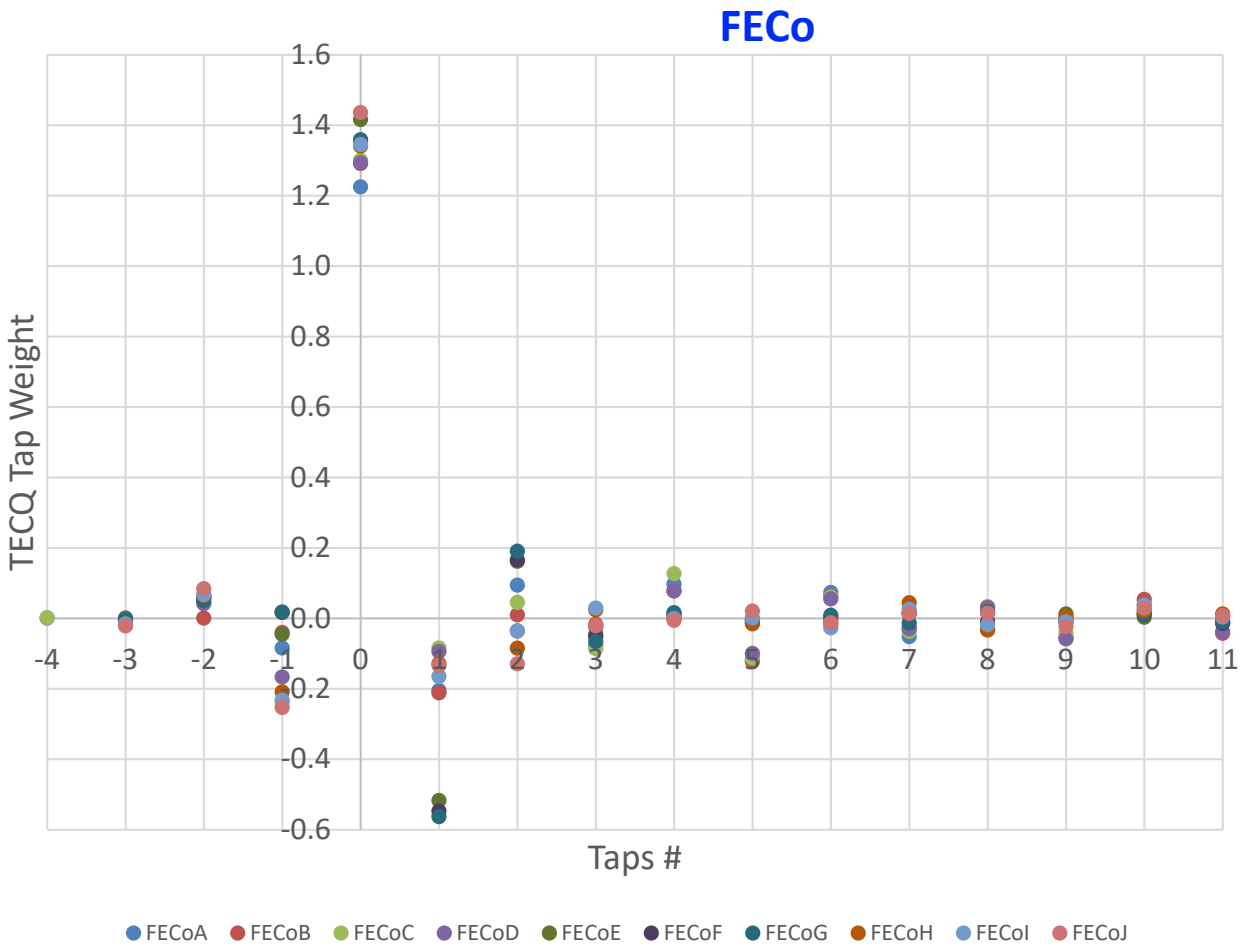
Minimum # of Pre-Cursor Taps

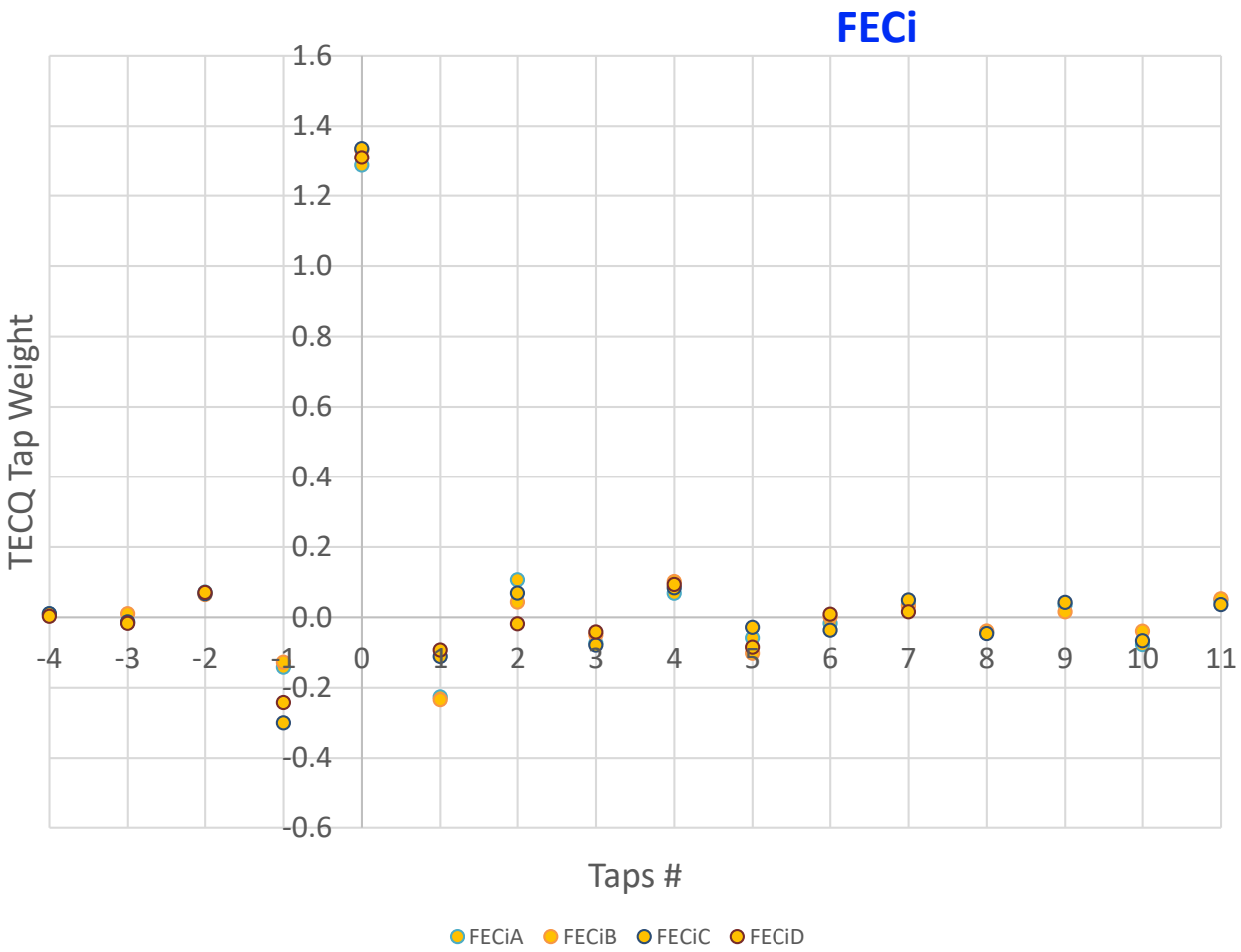
- **Two transmitters on previous page that # of pre-cursors were highest shown below**
  - Even though FECoC TX optimized with 6 pre-cursors and FECiD TX with 8 pre-cursors a forced 3 tap pre-cursors should have negligible TDECQ penalty.



FECo vs FECi Tap Weight

- **FECo and FECi equalizer tap weights are very similar and may have the same limit.**



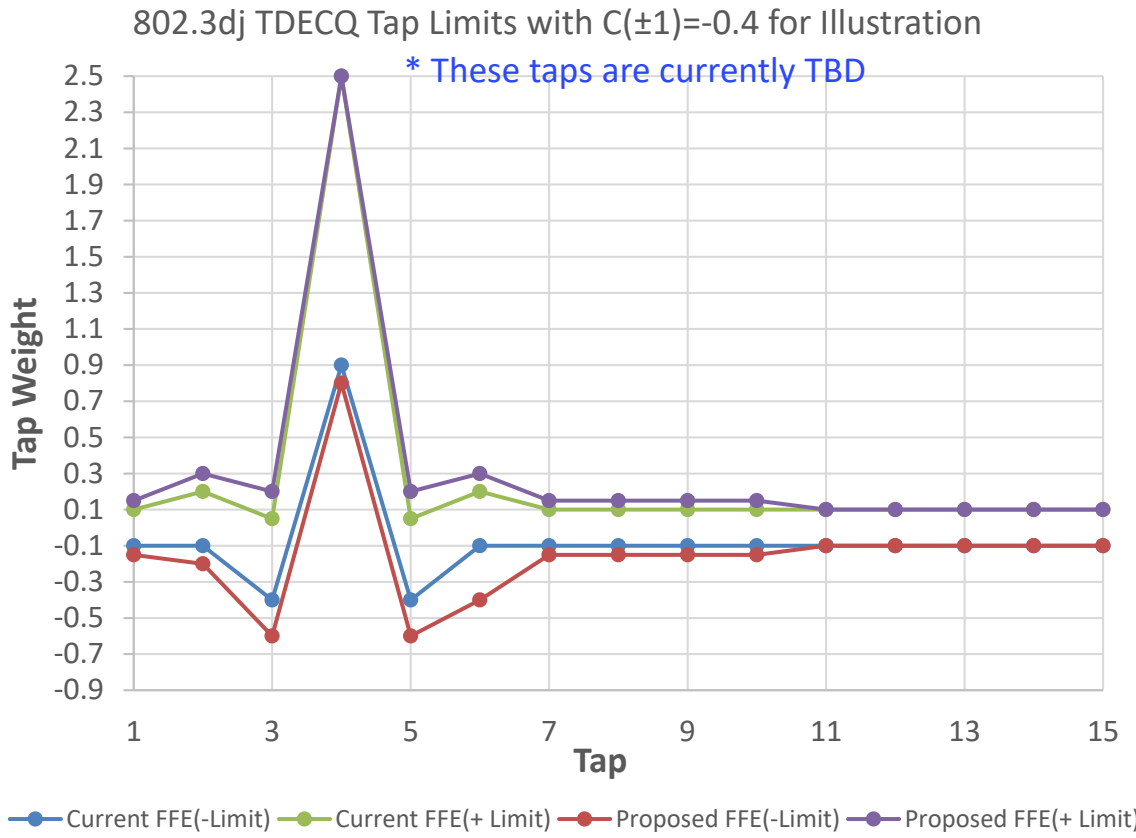


Current vs Proposed Tap Limit

- **Same FECo limit applies to FECi tap weight**
  - Given the capability of DSP and negligible cost there is no reason to tightly control the taps where good transmitter may fail and complicate the TDECQ procedure
  - Current tap limits are for normalized to main=1 with 3 pre-cursors (** main tap aren't normalized and show the range)
  - Proposed tap limits are normalized illustration below is for 3 pre-cursors (see next page how the main tap varies).

Tap	Current FFE(-Limit)	Current FFE(+ Limit)	Proposed FFE(-Limit)	Proposed FFE(+ Limit)
1	-0.1	0.1	-0.15	0.15
2	-0.1	0.2	-0.2	0.3
3	-0.4 *	0.05	-0.6	0.2
4	0.9 **	2.5 **	0.9 **	2.2 **
5	-0.4 *	0.05	-0.6	0.2
6	-0.1	0.2	-0.4	0.3
7	-0.1	0.1	-0.15	0.15
8	-0.1	0.1	-0.15	0.15
9	-0.1	0.1	-0.15	0.15
10	-0.1	0.1	-0.15	0.15
11	-0.1	0.1	-0.1	0.1
12	-0.1	0.1	-0.1	0.1
13	-0.1	0.1	-0.1	0.1
14	-0.1	0.1	-0.1	0.1
15	-0.1	0.1	-0.1	0.1

Blue indicate taps are the same
Keeping tail tap small does offer some power saving.



How to Define TDECQ Equalizer with Varying Main Position

- **The # of pre-cursors for the data in this contribution varied from 2 to 8 taps**
  - IEEE 802.3bs/cd/db all allowed main tap position to vary
  - Given IEEE 802.3dj TDECQ equalizer is only 15 taps to better fit the data recommend main tap position to vary from tap 3 to 7 (2 to 6 pre-cursors)
    - COM C2M analysis indicate 5-6 pre-cursors taps are needed
  - Table illustrates main tap varying from tap #3 to tap #7
  - When main tap moves to left additional tail taps limits to ±0.1 and when main tap shifts to the right additional pre-cursors taps limited to ±0.15
  - If preferred to go with fixed main position, for most of data in this contribution 3 fixed pre-cursors expect to have negligible TDECQ penalty.

Tap	Proposed FFE(-Limit) with main tap #3	Proposed FFE(+ Limit) with main tap #3	Limit) with main tap #7	Proposed FFE(+ Limit) with main tap #7
1	-0.2	0.3	-0.15	0.15
2	-0.6 *	0.2 **	-0.15	0.15
3	0.8	2.2	-0.15	0.15
4	-0.6	0.2	-0.15	0.15
5	-0.4	0.3	-0.2	0.3
6	-0.15	0.15	-0.6 *	0.2 **
7	-0.15	0.15	0.8	2.2
8	-0.15	0.15	-0.6	0.2
9	-0.15	0.15	-0.4	0.3
10	-0.1	0.1	-0.15	0.15
11	-0.1	0.1	-0.15	0.15
12	-0.1	0.1	-0.15	0.15
13	-0.1	0.1	-0.15	0.15
14	-0.1	0.1	-0.1	0.1
15	-0.1	0.1	-0.1	0.1

Highlighted cell indicate range of main tap.

*C(-1)=-0.6 over range of main may have value of -0.48 to 1.32.

**C(-1)=0.2 over range of main may have value of 0.16 to 0.44.

Summary

- **Having some tap limits for DJ TDECQ equalizer would be an improvement over 802.3bs/cd where tap weight can be very large as long equalizer has unity gain**
  - Previously only 802.3db limited tail taps C(7)≤±0.3, C(8)≤±0.2, C(9) ≤ ±0.1)
  - 802.3bs/cd/db all allow main tap to have limited float instead of having fix # of pre-cursors
- **Normalized FFE taps results in OMA loss and may result in unnecessary changes in TDECQ oscilloscope algorithm but is not an issue for DSP/Equalizer**
  - Current TDECQ oscilloscope tap optimization doesn't consider tap weights for convergence
  - If tap weight are set very tight, then the TDECQ algorithm must be modified to include tap limits in convergence algorithm, and we would need to increase tap limits for longer reach PMDs
- **For reference C2M adopted equalizer has 5 pre-cursors taps and CR/KR expected to have 6 pre-cursors taps**
- **Recommendations on tap weight for FECo and FECi**
  - Based on this data, the TDECQ equalizer and tap weights should be the same for both FECo and FECi
  - Given similar DSP/Eq that will be used for both C2M and optical DSP/Eq there is room for further tap weight relaxation
  - Reduce main tap range from 0.9-2.5 to 0.9-2.2
  - Relax tap weight per limits on page 12
  - Pre-cursors taps
    - Option I – stay with fixed 3 pre-cursors
    - Option II - Main tap position vary from tap #3 to tap #7 (as illustrated on page 12 and 13) allowing the equalizer to have 2 to 6 pre-cursors taps.

Thank you!

Backup slide

- **Normalized FFE taps results in OMA loss which may complicate the TDECQ procedure**
  - As long as equalizer DC loss is constrained then it doesn't matter for the hardware DSP/equalizer.