CONSIDERATIONS ON AN 800G-FR4 BASELINE

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INTRODUCTION

- This presentation introduces some consideration for 800G-FR4 PMD specs regarding:
  - Reflections and TDECQ reference equalizer
  - FEC and optical link budget gain

- It proposes few modifications to the previously presented baseline in welch_3dj_03a_2305

TDECQ AND RF REFLECTION LOCATIONS

TDECQ with 5-tap FFE was developed for 26GBd, where 5UI would cover 188ps. At 113.4375GBs this would correspond to 21UI.

For every baudrate increase, margins are getting tighter, so we might need to revisit previously overlooked analysis or suboptimal specs that were supported by higher margins

From 100G to 200G per lane, reflections are:

- > 2x UI farther away for the same physical distance
- higher as signal transitions are faster

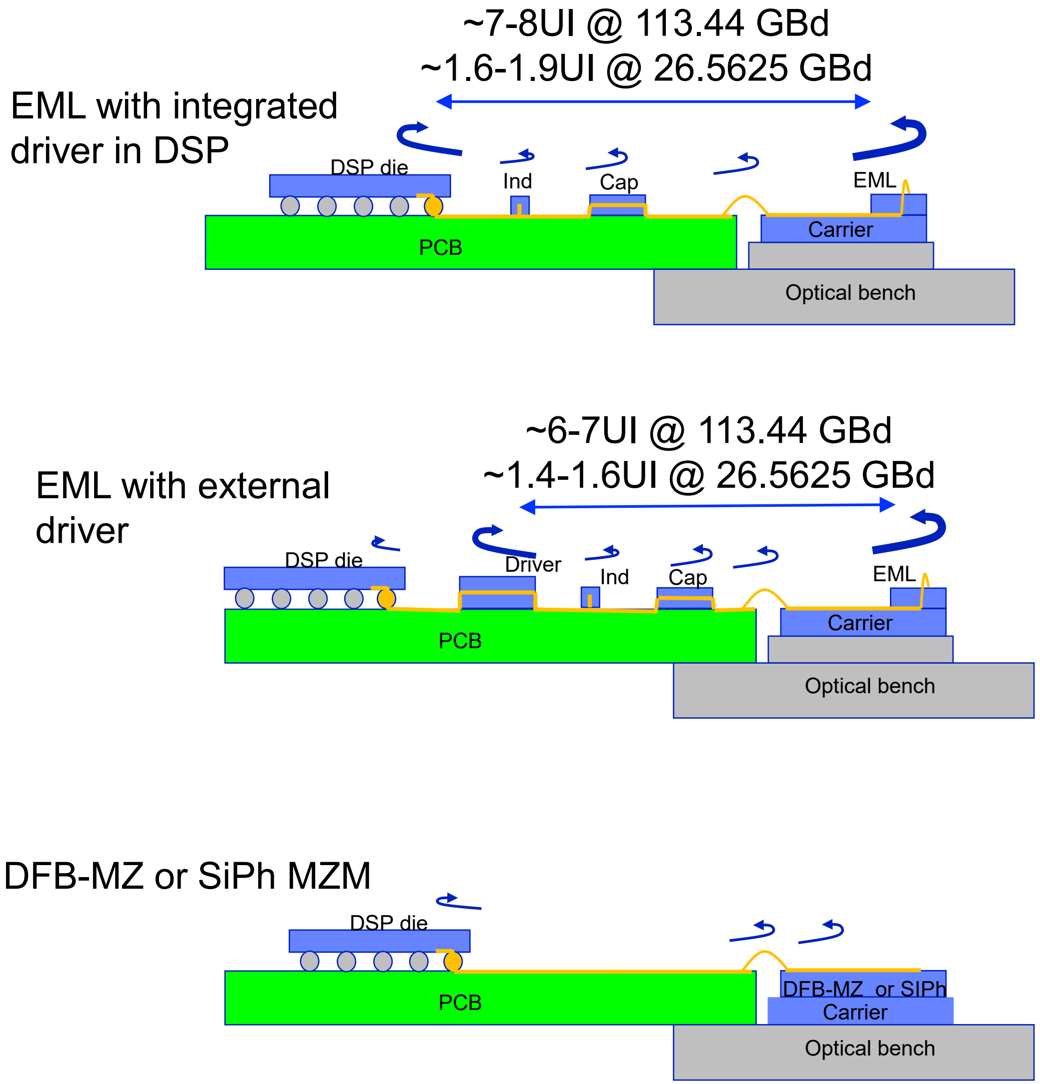
Rx DSPs include long enough FFE to deal with these reflections.

Each Tx technology/architecture has different requirements in terms of reference equalizer length

- EML-based Tx are more prone to suffer reflection due to the higher return loss in single ended EMLs
- DFB-MZ and SiPh MZM both have good return loss and could be have shorter distance reducing the severity and distance of reflections

To write specs that enable wider range of Tx technologies, we should consider updating TDECQ reference equalizer accordingly

Key RF reflection locations



TECQ VS REFERENCE EQUALIZER LENGTH

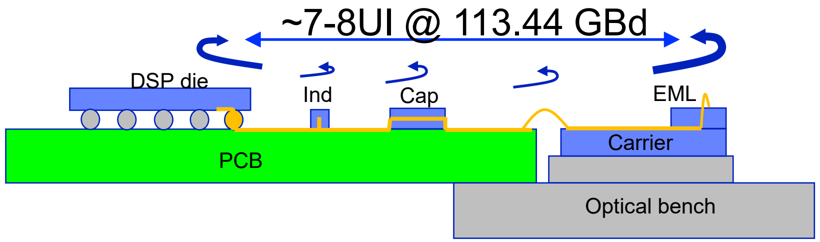
Simulation analysis on reference equalizer length requires 3D EM simulations of interconnects and circuit models of driver and EML

Rx equalizer tap coefficients are significant up to postcursor #15, corresponding to round trip from DSP to EML.

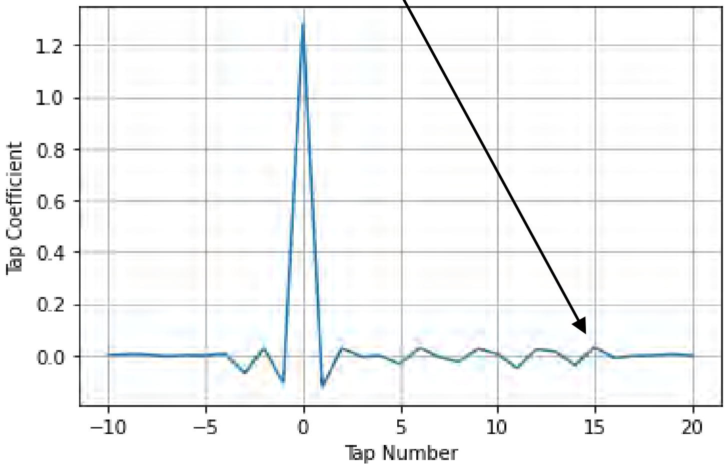
Shorter length on the reference equalizer FFE results on higher residual ISI, and therefore higher TDECQ

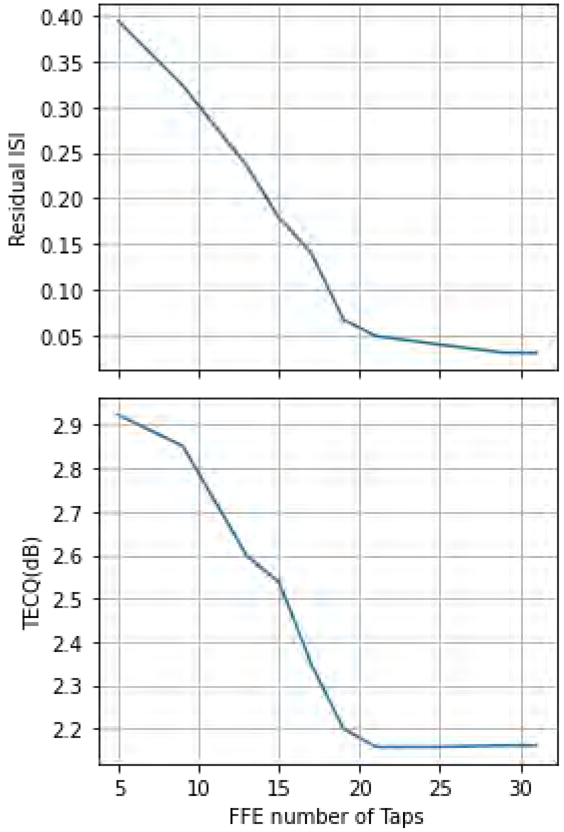
Beyond 19 -tap FFE, TDECQ value plateaus

Case of EML with integrated driver in DSP



Simulation on EML-based 800G-FR4 module @ 113.4375GBd and BER = 3.5e-3





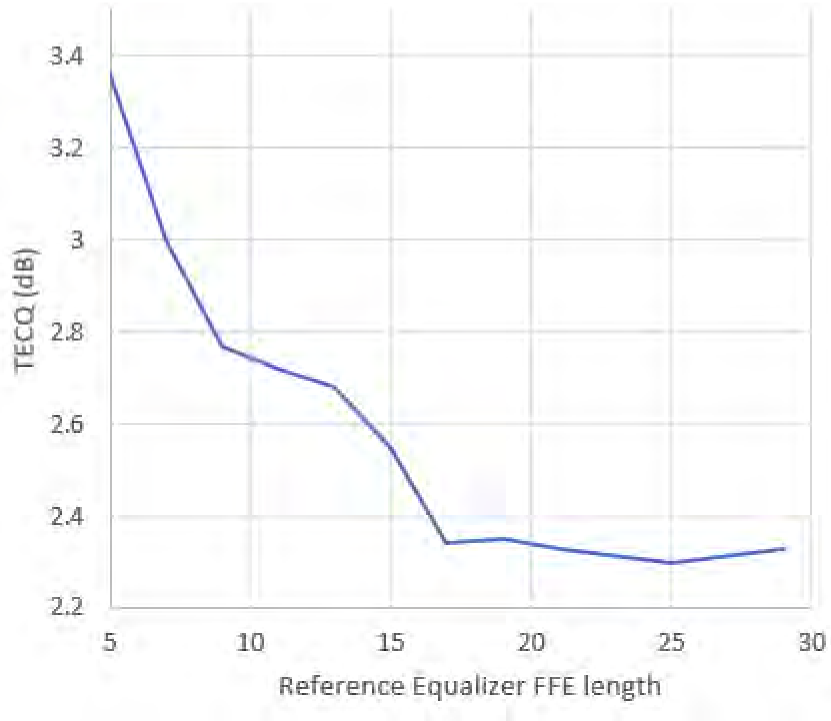
TECQ VS REFERENCE EQUALIZER LENGTH

Experimental TECQ measurement show similar trend when sweeping reference equalizer length.

Notice that the PMD is running at 106.25GBd. When running at 113.4375GBd the FFE length required would correspond to ~7% longer for the same round-trip reflection.

Propose to use 17-tap FFE on reference equalizer baseline

Measured TDECQ on EML-based 800G-FR4 module @ 106.25GBd and BER = 3.5e-3



REFERENCE EQUALIZER LENGTH IMPLICATIONS ON TX+RX

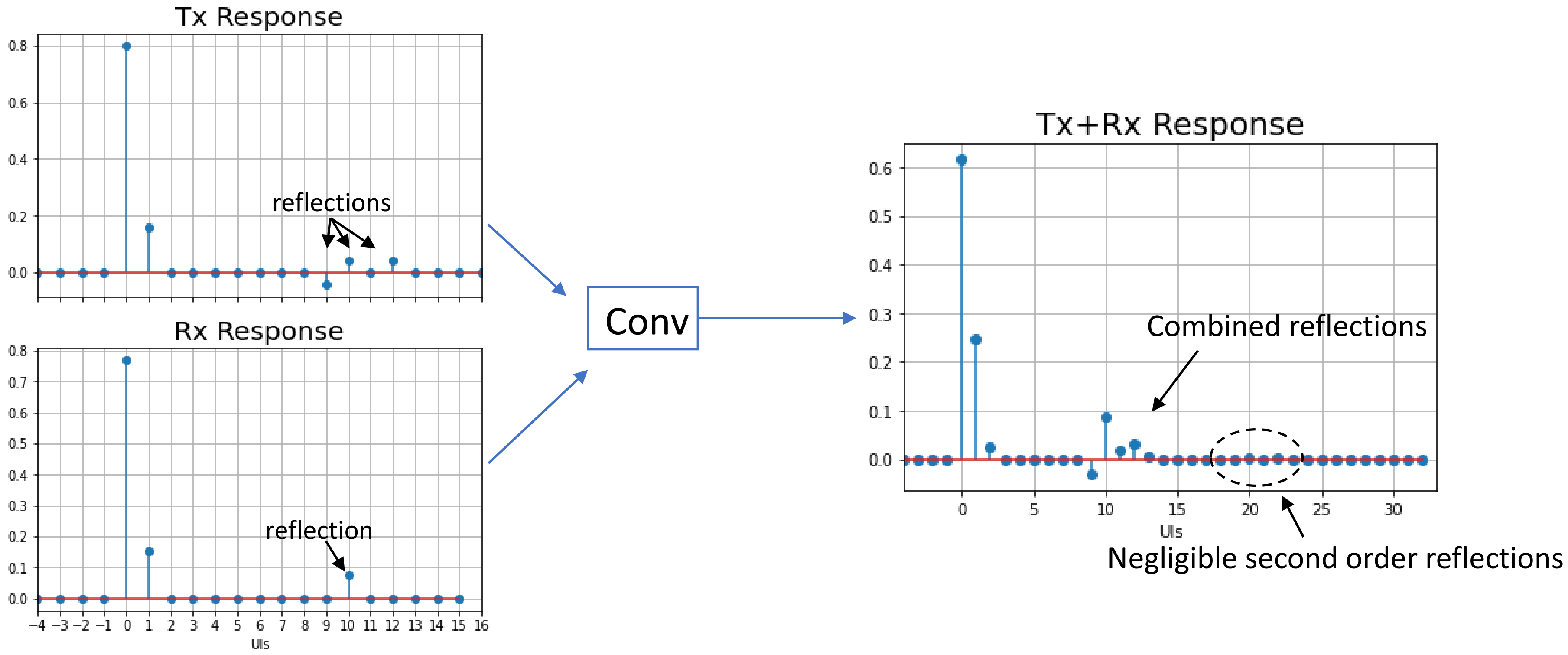
The next four slides try to explain why:

- More taps in reference receiver does not mean less taps are available for Rx path equalization.
- There is no split in the Rx DSP taps on what is used to equalize Tx and Rx.
- The Rx DSP will equalize the combined response. ‘Near’ and ‘far’ taps are available to equalize both Tx and Rx channels.
- Shorter TDECQ reference equalizer is not an effective way to protect the Rx.

Example:

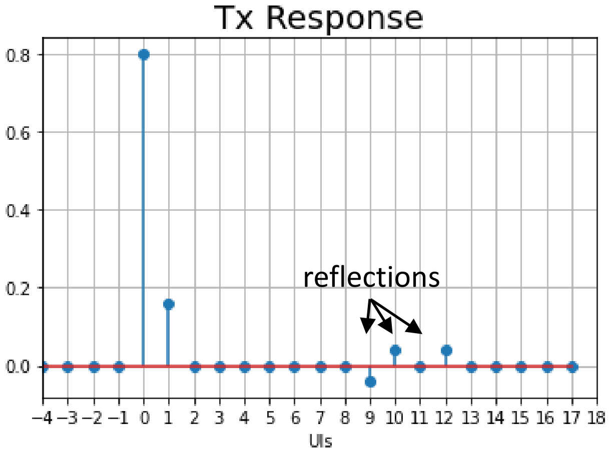
Tx:
5% reflection at 9,10 and 12UI

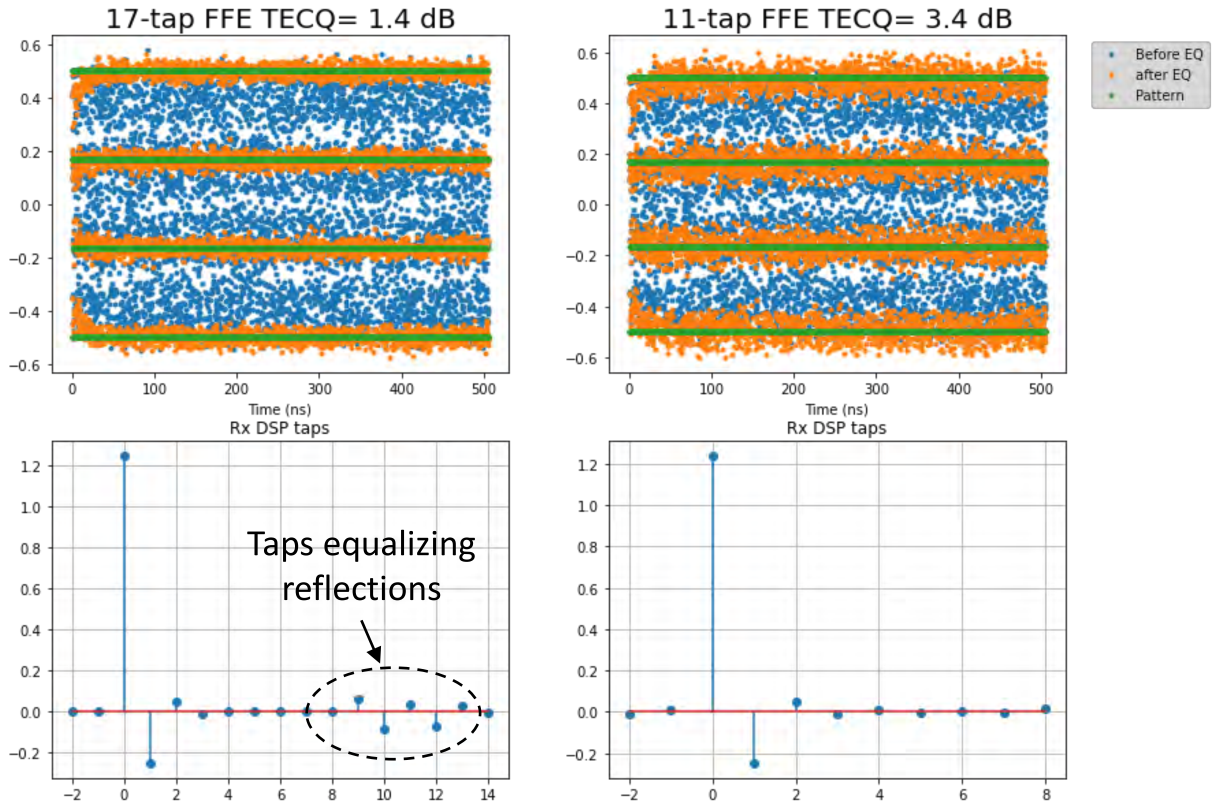
Rx:
10% reflections at 10UI



EXAMPLE: TDECQ FFE LENGTH ON TX

- Small reflections when not equalized will generate residual ISI that can rapidly degrade TDECQ
- Small values in Rx FFE are enough to greatly reduce the penalty





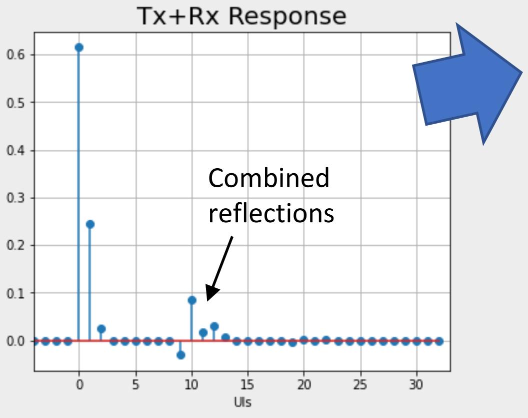
- 17-tap TDECQ can equalize the signal by using postcursors 9,10 and 12
- 11-tap TDECQ cannot equalize these reflections and would reject this transmitter
- Is the shorter reference equalizer protecting the Rx?
- If the Rx has another reflection, can I still use those 'far' taps for Rx?

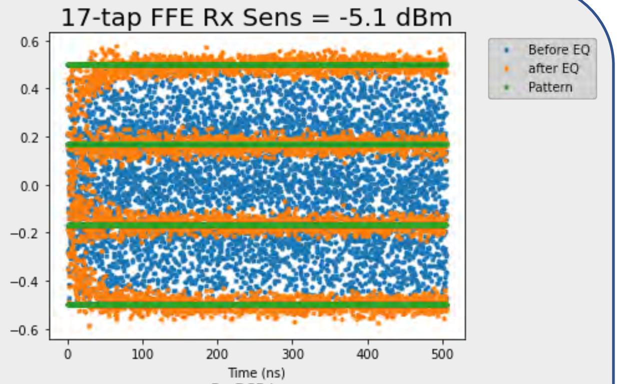
EXAMPLE: TDECQ FFE LENGTH ON TX+RX

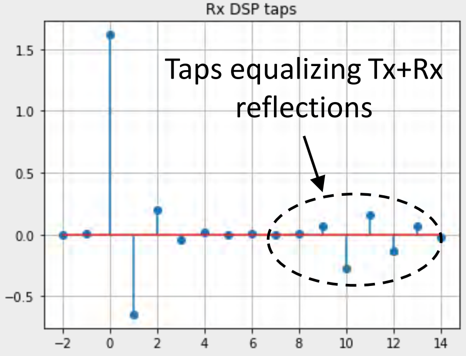
- Do we need to save the FFE taps for the Rx? Can the Rx equalize both Tx and Rx at the same time?
- This slide simulates Rx performance with the Tx from previous slide, and compare with the same Tx without reflection

Case1:

- Tx <u>with</u> reflections
- Rx with reflections

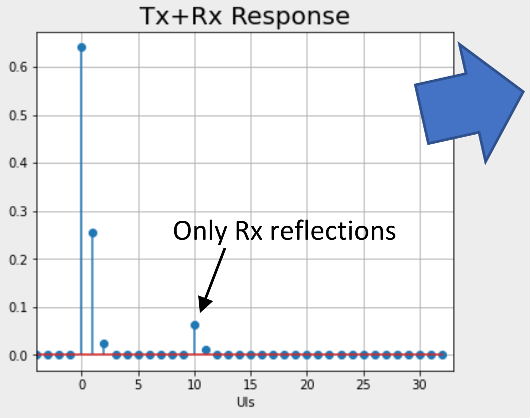


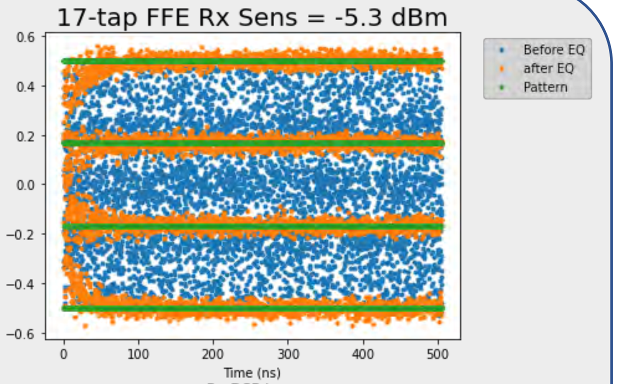


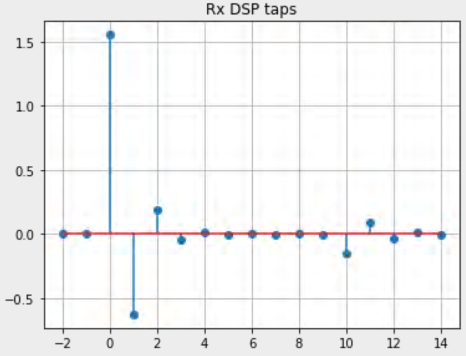


Case2:

- Tx <u>without</u> reflections
- Rx with reflections







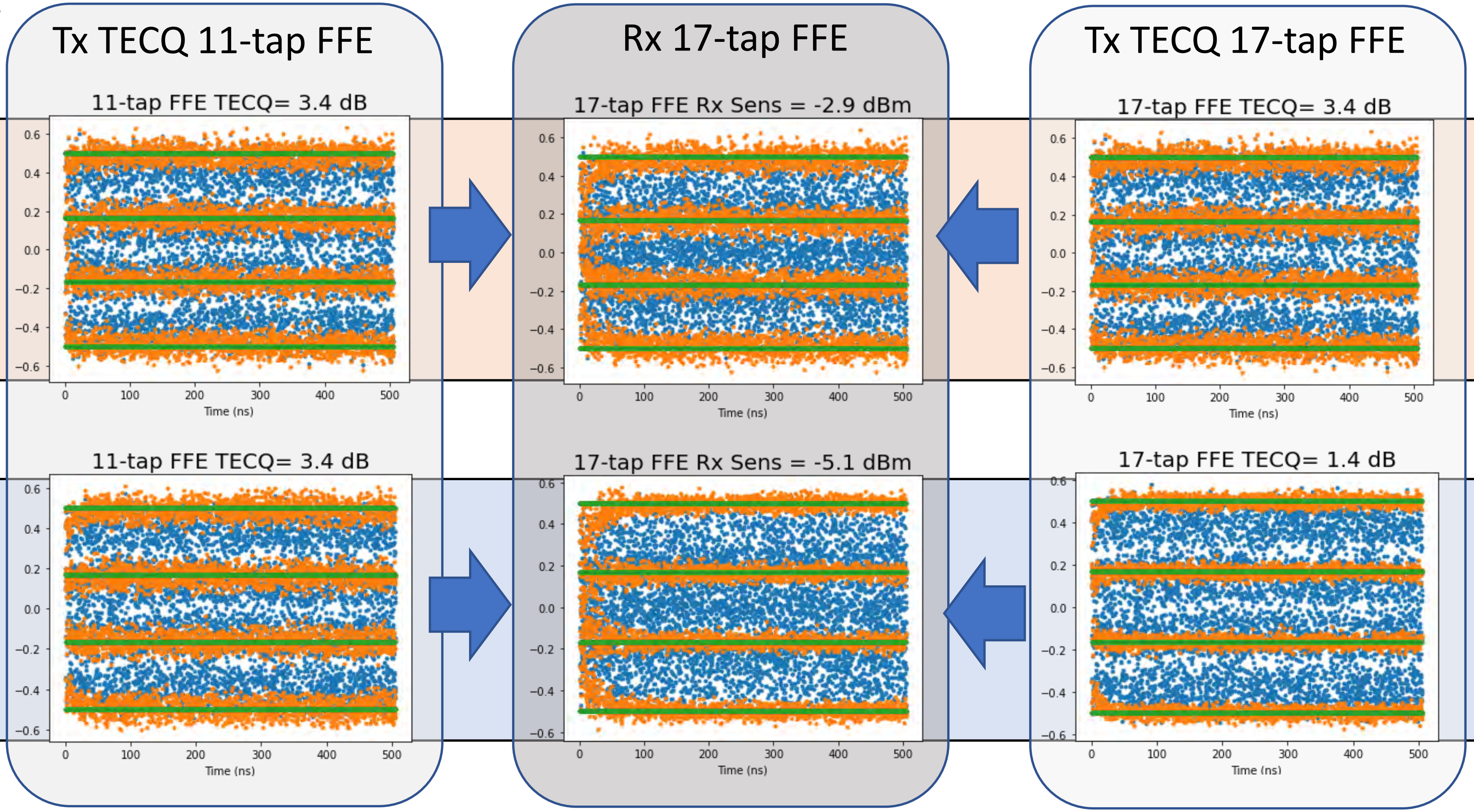
- Minimal difference on Rx Sensitivity from Tx reflections. Rx reflections get equalized even though Tx has similar reflections
- We could limit the absolute value of ‘far’ taps on TDECQ (i.e. <10%) to ensure negligible second-order reflections (10%*10% = 1%), and a minimum tap weight available for the Rx channel

PROBLEM OF SHORTER TDECQ FFE: TX MISCLASSIFICATION

Example of Tx misclassifications using two transmitters with same TECQ:

Tx1:
- No reflection
- ~3dB more noise than Tx2

Tx2: (same than previous slide)
- 5% reflections at 9,10&12UI
- Low Noise



- 17-tap TDECQ better predicts the impact of Tx1 and Tx2 in Rx Sensitivity
- 11-tap TDECQ could reject Tx2 which causes no harm on Rx, while passing Tx1 which causes higher sensitivity penalty
- Shorter FFE TDECQ will either overreject good Txs (such as Tx2), or underreject bad Txs (such as Tx1)

FEC AND RX SENSITIVITY CONSIDERATIONS

Theoretical BER for a PAM4 signal assuming uniform noise, ISI-free Tx with equal level spacing can be described by:

$$BER = \frac{3}{8}\,\mathrm{erfc}\left(\frac{Q}{\sqrt{2}}\right)$$

where

$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0}$$

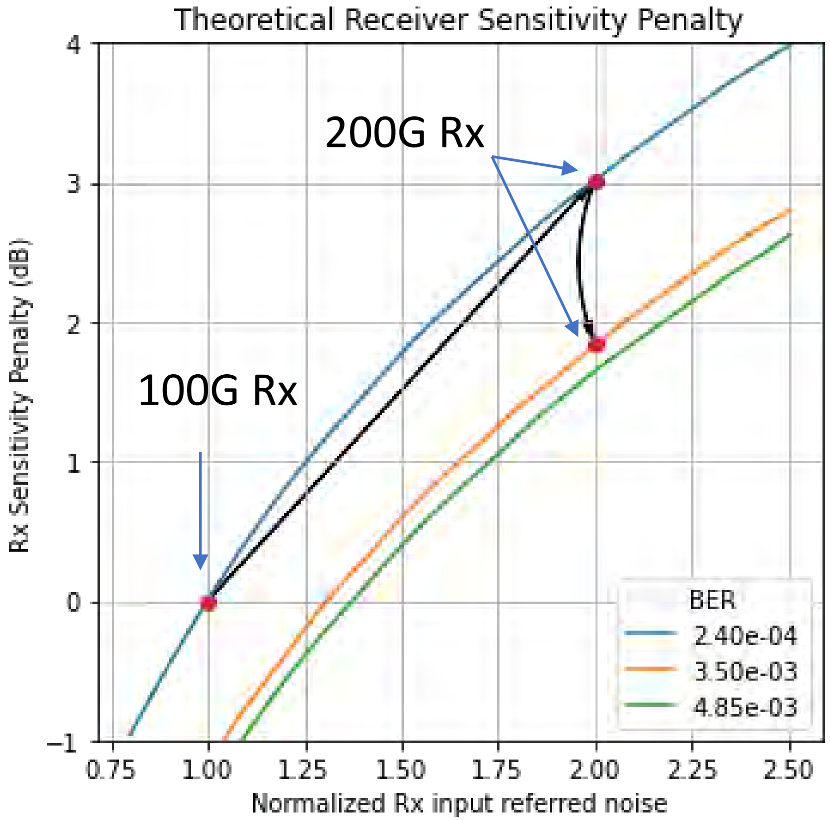
The equation can be used to analyze impact of BER and Rx noise on Rx sensitivity

Total Rx input referred noise of 200G is expected to be ~2x of 100G. This is due to:

- ~1.4x with the same IRN density and just doubling the BW
- ~1.4x from higher IRN density to achieve higher BW TIA

This results on ~3 dB optical penalty, assuming same responsivity.

Moving from 2.4e-4 (KP4) to ~3.5e-3 (KP4+SFEC) results in ~ 1.1dB higher optical link budget, reducing some of the burden of doubling the speed.



FEC AND RX SENSITIVITY CONSIDERATIONS

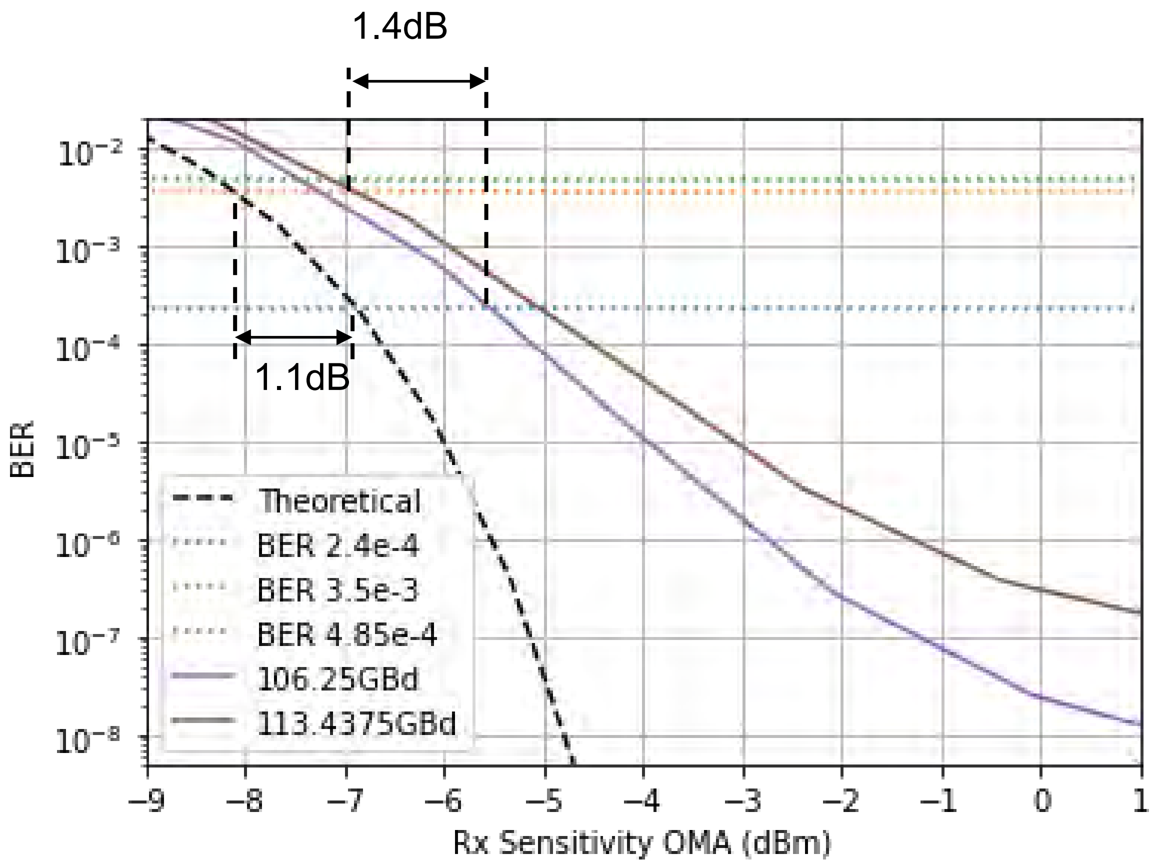
On a realistic optical link, the shallower waterfall makes the optical link power budget gain from 2.4e-4 to 3.5e-3 larger than theoretical 1.1dB.

On the other hand, overhead reduces gain by ~0.3dB at BER 3.5e-3

Overall, the total expected gain in link power budget from using concatenated FEC is ~1.4dB

This is in line with results presented in parthasarathy_3dj_01_2303

The results differ from welch_3dj_01a_230206 that showed negligible FEC gain



TX BASELINE PROPOSAL

Building from option B on welch_3dj_02_2305:

TDECQmax:
3.4dB until there is evidence that it needs to be reduced.

Reference equalizer:
Suggest baseline with 17tap

welch_3dj_02_2305

Description	800GBASE-FR4	Unit
Signaling rate, each lane (Range)	112.5 -113.4375 ± 50 ppm	GBd
Modulation Format	PAM4	
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Side-mode suppression ratio (SMSR), (min)	30	dB
Average launch power, each lane (max)	4.9	dBm
Average launch power, each lane (min)	-1.6	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane(max)	4.8	dBm
Outer Optical Modulation Amplitude (OMA_{outer}), each lane(min)† for TDECQ < 1.3dB for 1.3 dB ≤ TDECQ ≤ 2.9 dB 1.4dB <= TDECQ <= 3.4dB	 1.2 -0.2 ~~-0.1~~+TDECQ	 dBm dBm
Transmitter and dispersion eye closure (TDECQ), each lane (max)†	2.9 3.4	dB
TECQ (max)†	2.9 3.4	dB
| TDECQ - TECQ| (max)†	1.9	dB
Average launch power of OFF transmitter, each lane (max)	-15	dBm
Extinction ratio, each lane, (min)	3.5	dB
Transmitter transition time (max)	8	ps
Transmitter over/under-shoot (max)	22	%
RIN_x OMA (max)	-139	dB/Hz
Optical return loss tolerance (max)	17.1	dB
Transmitter reflectance (max)	-26	dB

† Measured with ~~FFE9~~ FFE17 reference equalizer with tap weight restrictions of +/ to the main tap), and SER = ~~9.7e-3~~ 7e-3

RX BASELINE PROPOSAL

Building from option B on welch_3dj_02_2305:

SECQmax:
3.4dB until there is evidence that it needs to be reduced.

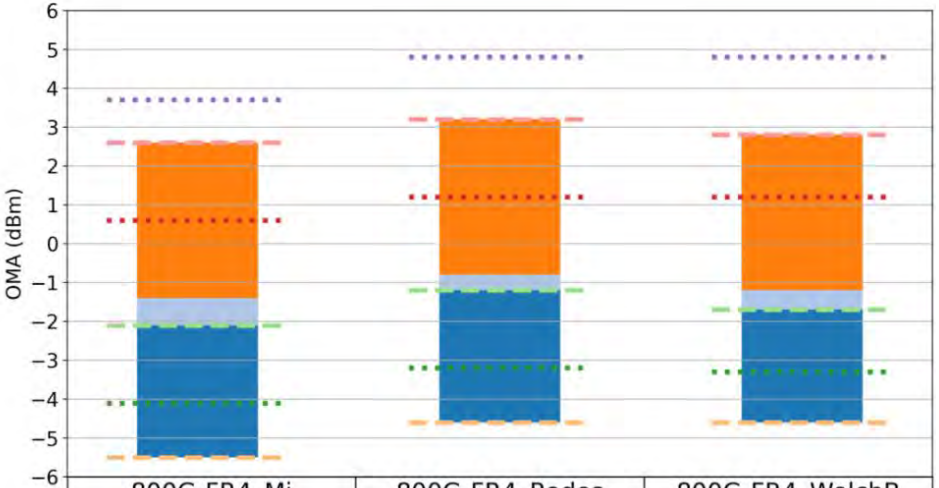
Reference equalizer for SECQ:
Suggest baseline with 17tap

welch_3dj_02_2305

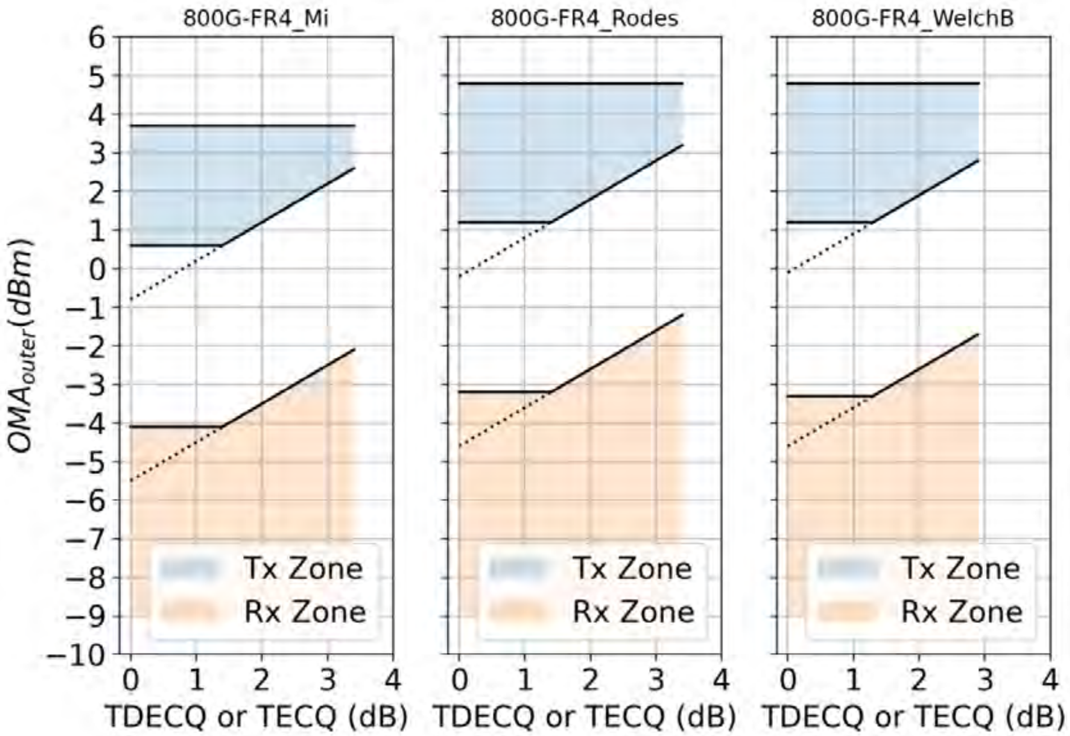
Description	800GBASE-FR4	Unit
Signaling rate, each lane (Range)	112.5 -113.4375 ± 50 ppm	GBd
Modulation Format	PAM4	
Lane wavelengths (range)	1264.5 to 1277.5 1284.5 to 1297.5 1304.5 to 1317.5 1324.5 to 1337.5	nm
Damage threshold, each lane	5.9	dBm
Average receive power, each lane (max)	4.9	dBm
Average receive power, each lane (min)	-5.6	dBm
Receive power, each lane (OMA_{outer}) (max)	4.8	dBm
Receiver reflectance (max)	-26	dB
Receiver sensitivity (OMA_{outer}), each lane (max)		
for TECQ < 1.3dB	-3.3 3.2	dBm
for 1.3 dB ≤ TECQ ≤ 2.9 dB 1.4dB <= TDECQ <= 3.4dB	-4.6 + TECQ	dBm
Stressed receiver sensitivity (OMA_{outer}), each lane (max)†	-1.7 -1.2	dBm
Conditions of stressed receiver sensitivity test:		
SECQ†	2.9 3.4	dB
OMA_{outer} of each aggressor lane	1.9	dBm

† Measured with ~~FFE9~~ FFE17 reference equalizer with tap weight restrictions of +/- to the main tap), and SER = ~~9.7e-3~~ 7e-3

POWER BUDGET COMPARISON OF PROPOSALS



	800G-FR4_Mi	800G-FR4_Rodes	800G-FR4_WelchB
OMAmax(dBm)	3.7	4.8	4.8
OMA-TDECQ(dBm)	-0.8	-0.2	-0.1
OMAmin@TDECQmax(dBm)	2.6	3.2	2.8
OMAmin(dBm)	0.6	1.2	1.2
SRS(dBm)	-2.1	-1.2	-1.7
Unstressed Rx Sens (dBm)	-4.1	-3.2	-3.3
RSnominal (TECQ=0dB)(dBm)	-5.5	-4.6	-4.6
Optical Loss(dB)	4.0	4.0	4.0
Additional Penaties(dB)	0.7	0.4	0.5
TDECQmax(dB)	3.4	3.4	2.9
PowerBudget(dB)	8.1	7.8	7.4



In general, the power budget spec proposals are similar:

- *WelchB* has lower TDECQ compared to the other two
- *Mi* has lower Rx Nominal sensitivity compared to the other two

CONCLUSIONS

- Propose reference equalizer with 17-tap FFE to enable a wider range of transmitter implementation
  - Shorter equalizer will unnecessarily overreject transmitter
  - Small unequalized reflections can cause large TDECQ degradation
  - Introducing tap weight limits in reference equalizer could enable longer FFE TDECQs while allowing only limited reflection equalization on TDECQ

- More Rx data is required to better estimate TDECQmax. The proposal is to maintain the same 3.4dB used in 100G/lane and revise this number based on Rx measurements evidence.

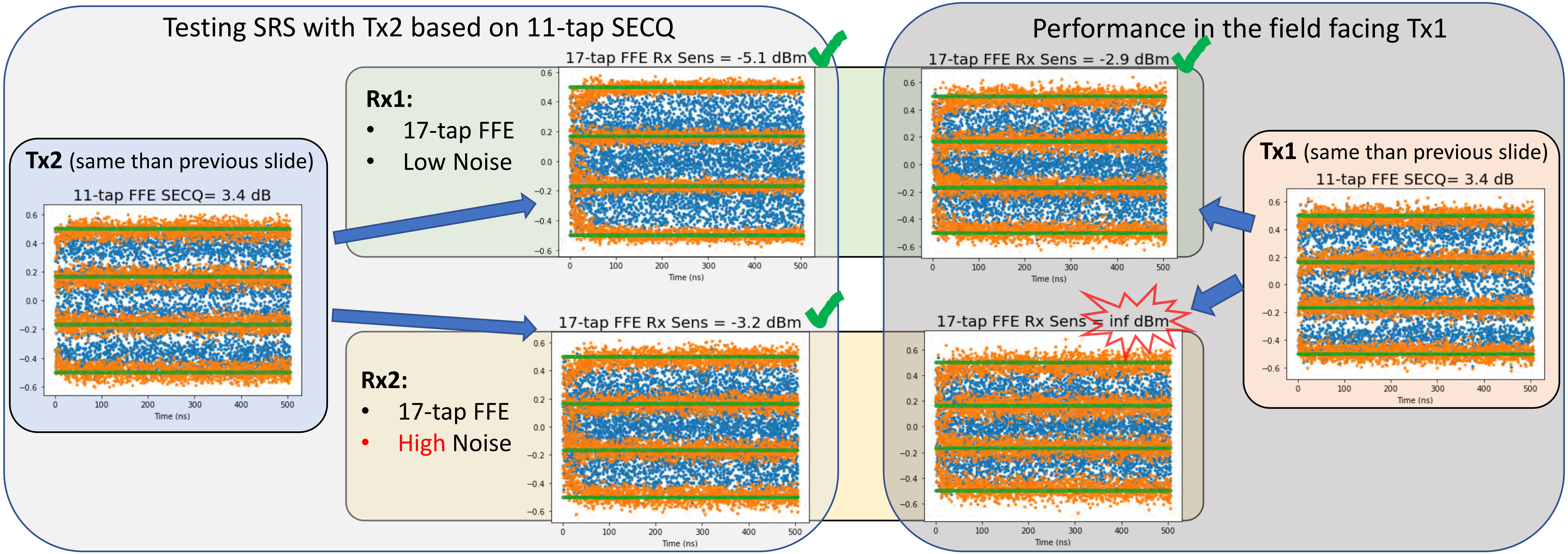
- Inner Code provides ~1.4dB extra optical link including overhead based on simulations

- Propose the following changes on baseline in welch_3dj_02_2305
  - TDECQ max = 3.4 dB
  - Reference equalizer: 17-tap FFE

Thank you

APPENDIX: SECONDARY PROBLEM OF SHORTER TDECQ FFE: RX MISCLASSIFICATION

- This example shows SRS testing of the same Rx from previous slide, plus an additional Rx with high noise
- Both Txs in slide#9 are valid SRS test sources when using 11-tap SECQ (SECQmax = 3.4dB).



- 11-tap SECQ will pass SRS test for both, Rx1 and high-noise Rx2
- When Rx2 faces Tx1 in the field, it will have poorer performance and compromise the link
- Shorter FFE SECQ could allow for bad receivers, such as Rx2, to pass the SRS test, which will fail in the field