Discussion on FFE and DFE Coefficients Calculation in COM

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Outline

- COM and channels used in this analysis
- Non-Monotonic COM performance by increasing FFE tap number
- Root cause and ways to improve
- Discussion & next step
- Summary

COM Tool Adopted

- COM 2.41
  - Adopted COM ver2.41 (Link) released by Richard Mellitz
  - Adopted the following parameters proposed by Richard for “100 G KR PAM4 DFE1 FFE(3,1,24)”
    - T1config_com_ieee8023_93a=100GEL-KR_DFE1_RxFFE3-24.xls
    - T1config_com_ieee8023_93a=100GEL-KR_DFE1_RxFFE3-20.xls
    - T1config_com_ieee8023_93a=100GEL-KR_DFE1_RxFFE3-16.xls
    - T1config_com_ieee8023_93a=100GEL-KR_DFE1_RxFFE3-12.xls
  - PKG length = 30 mm
- COM 2.41a
  - Modified from COM 2.41 by extending the dimension of FV by 2
  - Details in latter pages

Channels in this Simulation

Ch. ID	Description
A	Mellitz, Ideal Transmission Lines for Backplane$_{*1}$ (Link)
B	Mellitz, Initial BP – Best case Tachyon BP, 3'' IL15to16 (Link)
C	Mellitz, Initial BP – Best case Tachyon BP, 13'' IL25to26 (Link)
D	Mellitz, Cabled BP & PCB Design Impact Using 112G Ready Connectors, Opt1_24dB$_{*2}$ (Link)
E	Mellitz, Cabled BP & PCB Design Impact Using 112G Ready Connectors, Opt1_28dB$_{*3}$ (Link)

*1. Adopt the "Backplane channel" for analysis
*2. Adopt the channel of "CaBP_BGAVia_Opt1_24dB.zip"
*3. Adopt the channel of "CaBP_BGAVia_Opt1_28dB.zip"

Expectation – COM increases when FFE tap increases

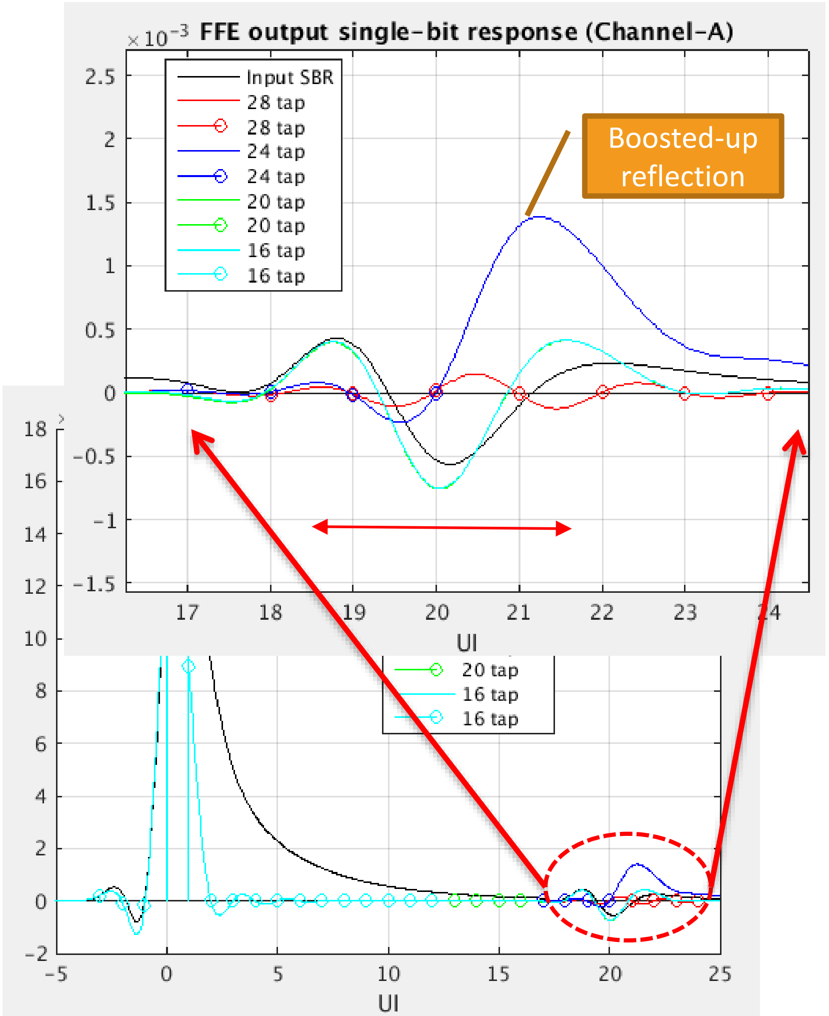
- It's intuitive that COM values increases when FFE tap increases
- However, we found it's NOT true for COM 2.41
- Take Channel A as an example to do analysis

COM Values by ver. 2.41

Channel	16-tap FFE	20-tap FFE	24-tap FFE	28-tap FFE
A	2.65 dB	2.66 dB	**2.26 dB**	5.55 dB
B	-0.38 dB	-0.29 dB	0.10 dB	0.59 dB
C	-1.92 dB	-1.94 dB	**-1.83 dB**	-1.47 dB
D	2.51 dB	2.51 dB	3.26 dB	5.11 dB
E	2.08 dB	2.08 dB	**1.79 dB**	4.38 dB

Non-Monotonic Behavior of COM 2.41 – Varying FFE Tap

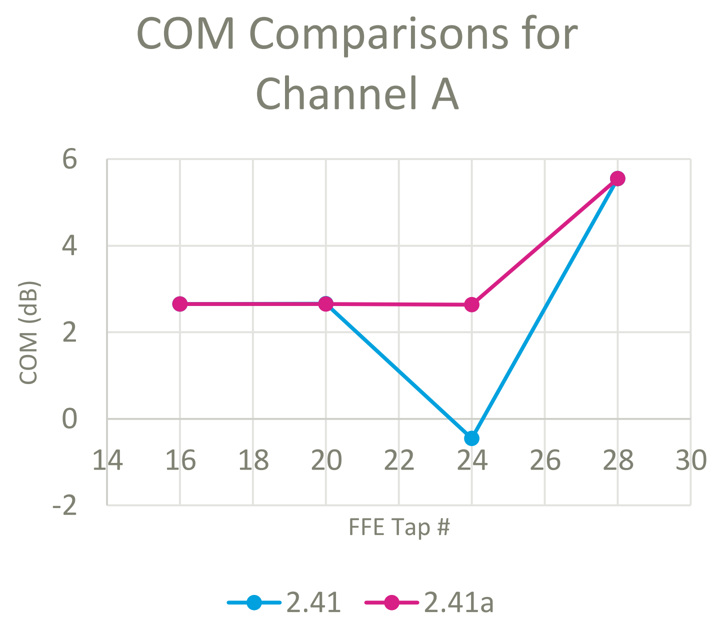
- Apply same TxFFE & CTLE for all cases
  - TxFFE = [0 0.05 -0.2 0.75 0], gdc = -10, gdc2 = -2
- From 'Input SBR', there is reflection during 19 ~ 21 UIs after main cursor
- For 16-tap & 20-tap cases
  - Not cover 'reflection': COM ~= 2.7 dB
- For 28-tap cases
  - Overall 'reflection' is covered: COM ~= 5.6 dB
- For 24-tap cases
  - Due to some 'reflection' is NOT covered in the 'FV'*1, it's boosted up by FFE
  - COM value degrades to ~= -0.45 dB < 2.7 dB (20-tap)
- Question: is this the true behavior of Receiver?



*1. Refers to Page 7 of "Mellitz_3ck_01_0718.pdf" for details of the 'forcing vector (FV)'

Solution (2.41a) – Modifications from COM 2.41

- Apply same TxFFE & CTLE for all cases
  - TxFFE = [0 0.05 -0.2 0.75 0], gdc = -10, gdc2 = -2
- In order to avoid 'non-monotonic behavior', we tried COM 2.41a
  - Take FFE with 24 taps as an example
  - Range of coefficients to be calculated [Pre, Main, Post] = [3, 1, 20]
  - Range of forcing vector (FV) is extended from [3, 1, 20] to [3, 1, 20+2], on purpose of considering overall reflections when calculating FFE/DFE coefficients
- Results
  - We can find COM value monotonic increases by increasing FFE tap number for Channel A
  - However, it can't apply generally to solve issues for other channels



Link: SBR of 2.41a

COM 2.41a Results

COM Values by ver. 2.41a				
Channel	**16-tap FFE**	**20-tap FFE**	**24-tap FFE**	**28-tap FFE**
A	2.65 dB	2.65 dB	2.90 dB	5.55 dB
B	-1.56 dB	-0.21 dB	0.18 dB	**-0.26 dB**
C	-2.72 dB	-2.65 dB	-2.51 dB	-2.40 dB
D	1.57 dB	**1.46 dB**	2.90 dB	5.16 dB
E	2.67 dB	**2.57 dB**	**2.30 dB**	3.26 dB

- By 'zero-forcing' approach adopted in COM 2.41 (& 2.41a as well)
  - Crosstalk and noise not count in calculating FFE & DFE coefficients
  - May not result in 'optimal' FFE/DFE coefficients
- Question: any alternative approaches?

Discussion & Next Step

- What alternative ways are feasible for FFE/DFE calculation?
- Exhausted search
  - Not feasible!
  - 24-tap FFE with maximum absolute value of 0.2 and resolution of 0.05 requires $(2*0.2/0.05+1)^{24}$ ~= 1e23 candidates to be calculated
- Some adaptation to reduce the complexity
  - Maybe too implementation-specific & difficult to reach consensus
- Some closed-form solution is suggested
  - Such as "Salz SNR" used by Broadcom$_{*1}$
    - Need to modify it to finite-tap version
  - Maybe MMSE-DFE$_{*2}$

*1. Page 3 of "healey_100GEL_01_0318.pdf"
*2. Reference: Book by John M. Cioffi

Summary

- By adopting ‘zero-forcing’ approach to calculate FFE/DFE coefficients in COM 2.41, we found
  - COM performance doesn’t monotonic increase when FFE tap increases
  - Can’t solve this issue even by extending forcing vector (FV) dimension
- Suggest to consider alternative approach to calculate FFE/DFE coefficients
  - Some closed-form preferred, such as Salz SNR, MMSE-DFE

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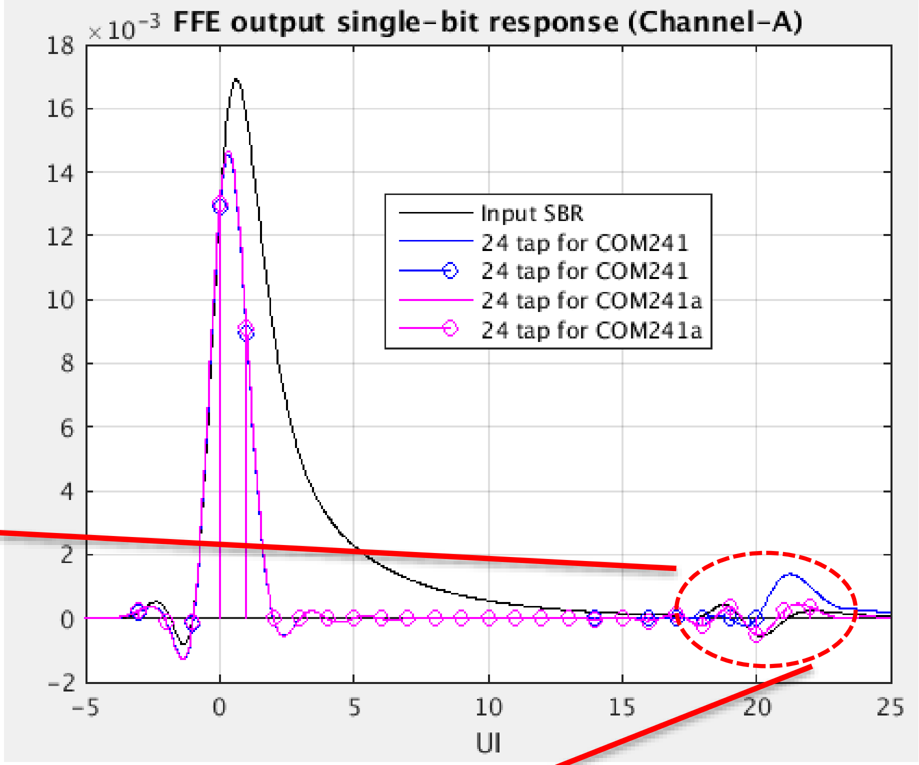
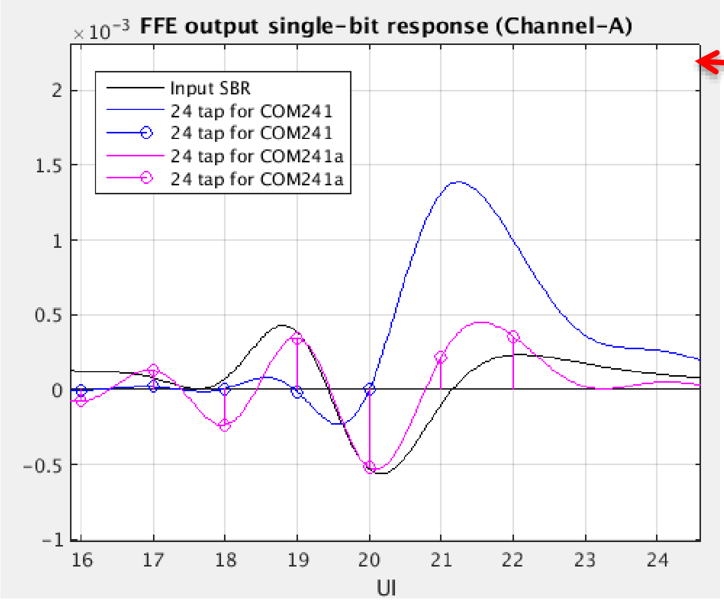
Extending FV length by 2 – The Effects

- By same TxFFE & CTLE
- By extending 2 taps for FV range, the SBR after FFE shows smaller residue ISI comparing to COM 2.41





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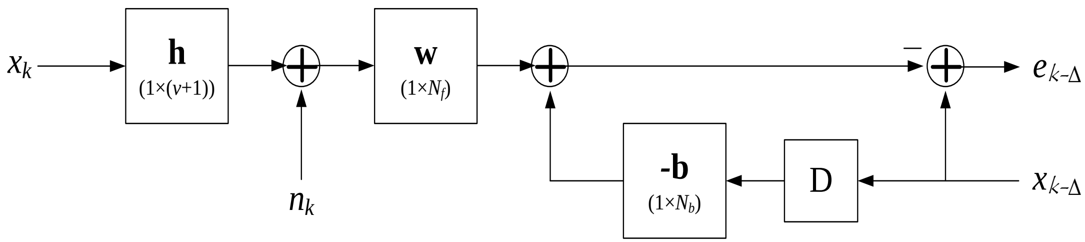
Formula of MMSE solution for FFE/DFE



$$\mathbf{w} = \mathbf{1}_\Delta^* \mathbf{P}^* \left(\mathbf{P}\mathbf{P}^* - \mathbf{P}\mathbf{J}_\Delta \mathbf{J}_\Delta^* \mathbf{P}^* + \frac{1}{\varepsilon_x} \mathbf{R}_{\mathbf{nn}} \right)$$

$$\mathbf{b} = \mathbf{w}\mathbf{P}\mathbf{J}_\Delta \qquad \sigma_e^2 = \varepsilon_x \left(1 - \mathbf{w}\mathbf{P}\mathbf{1}_\Delta\right)$$

$$SNR_{biased\,MMSE-DFE} = \frac{\varepsilon_x}{\sigma_e^2} = \frac{1}{1 - \mathbf{w}\mathbf{P}\mathbf{1}_\Delta}$$

- References
  - Book by John M. Cioffi
    - https://web.stanford.edu/group/cioffi/book/
  - Details in Chapter 3.7.4 FIR MMSE-DFE
- We may try to adopt MMSE approach to calculate
  - FFE and DFE coefficients