Further consideration on 200G per lane CR electrical links

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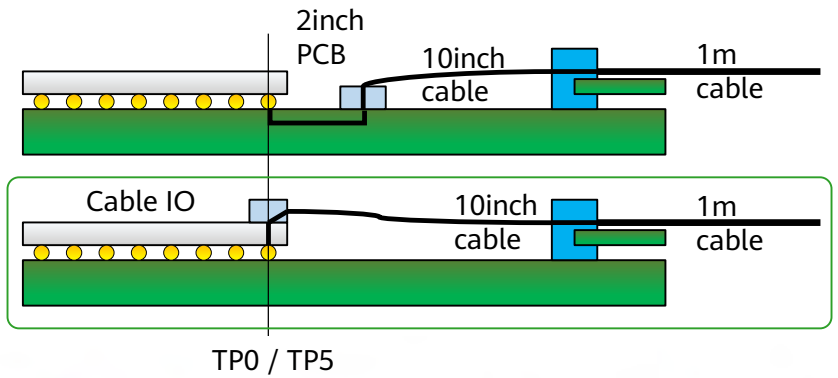
Background and motivations

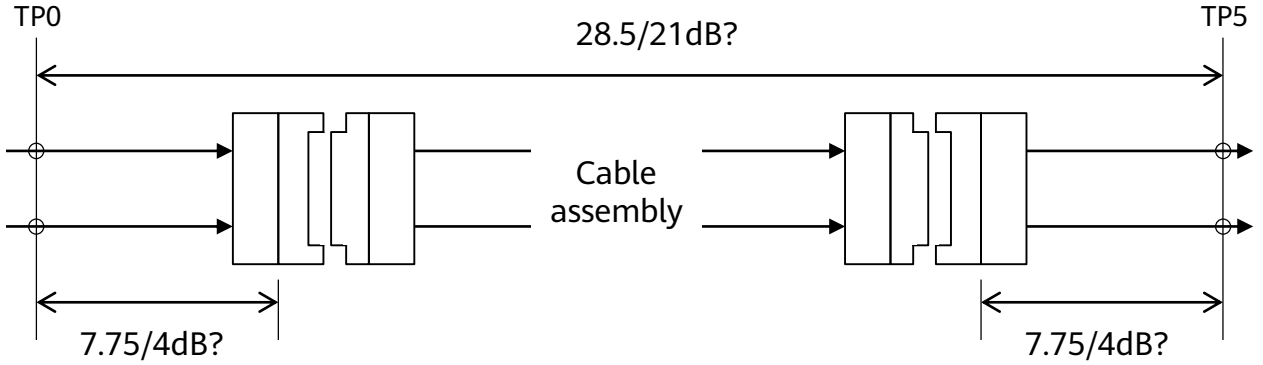
- 200G copper cable objectives are achievable with both PAM4 & SE PAM4 signaling.
  - Satisfy the “Commonality”, “Compatibility”, “Competitiveness” criteria.

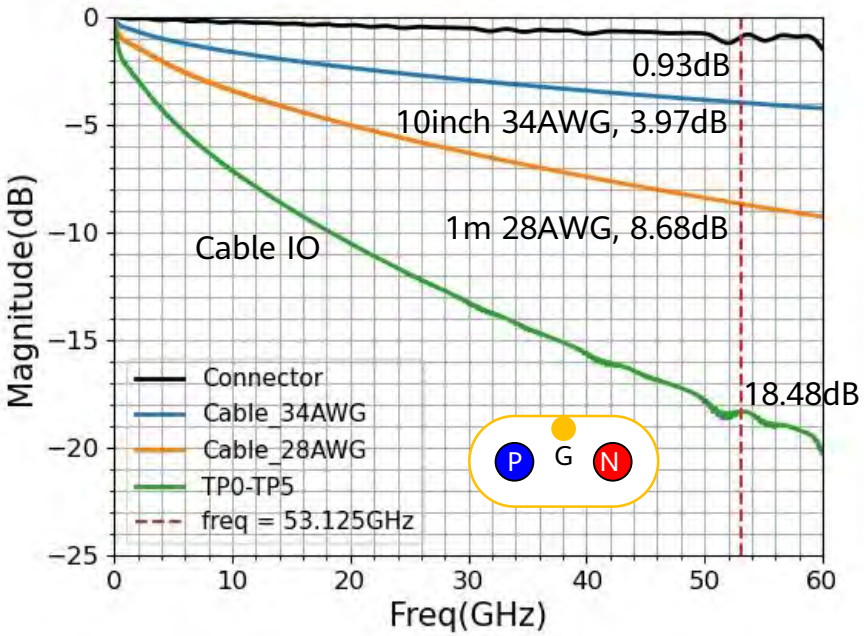
- Provide some data to show the insertion loss target for 1m copper cable link is achievable.
  - ~35dB@53GHz bump-to-bump.

- Provide insights of single ended (SE) signaling to show how does the MIMO algorithm eliminate the intra-pair crosstalk.
  - Technical feasibility study can be found in lu_b400g_01b_210729.

Copper cable channel budget for PAM4







Parameter	IL@fn (dB)	
	100GEL	200GEL
Raw cable	8.85	7.0 (1m)
Paddle card + wire termination	1.35 (x2)	3.2 (x2)
Host PCB	6.875 (x2)	**10.3 (x2)**
Connector	1.6 (x2)	2.0 (x2)
Total loss (TP0-TP5)	**28.5**	**38**

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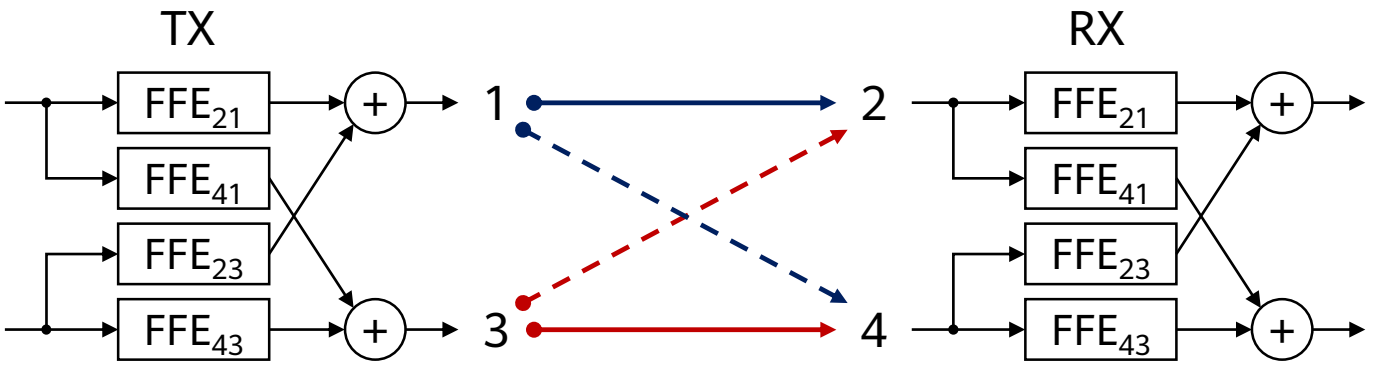
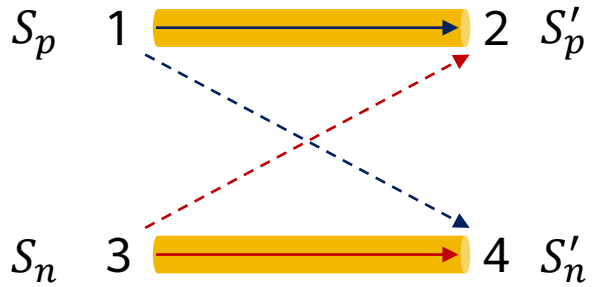
Parameter	IL@53G (dB)	Note
Raw cable	9.0	28 AWG, 1m
~~Paddle card + wire termination~~	1.0 (x2)	Can be greatly improved with cable connector.
Host Cable	**4.0 (x2)**	34 AWG, 10inch
Cable Connector	1.0 (x2)	
~~Host PCB (2inch)~~	2.5 (x2)	Can be greatly improved with cable IO.
~~Board connector~~	1.25 (x2)	
Total loss (TP0-TP5)	**28.5/21**	* 6.5/14dB for package.
* ~35dB@53GHz bump-to-bump		

Insights of single-ended signaling



$$\begin{bmatrix} t_{21} & t_{23} \\ t_{41} & t_{43} \end{bmatrix} \quad \begin{bmatrix} s_{21} & s_{23} \\ s_{41} & s_{43} \end{bmatrix} \quad \begin{bmatrix} r_{21} & r_{23} \\ r_{41} & r_{43} \end{bmatrix}$$



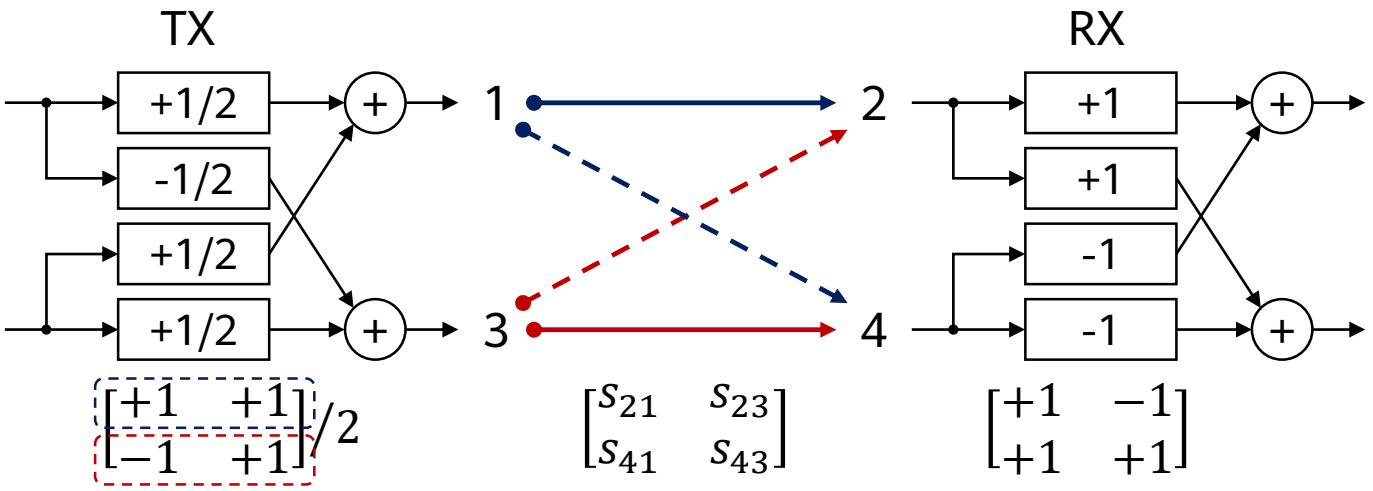
$$\begin{bmatrix} S'_p \\ S'_n \end{bmatrix} = \begin{bmatrix} s_{21} & s_{23} \\ s_{41} & s_{43} \end{bmatrix} \cdot \begin{bmatrix} S_p \\ S_n \end{bmatrix}$$

The overall transfer function of SE MIMO System.

$$\begin{bmatrix} r_{21} & r_{23} \\ r_{41} & r_{43} \end{bmatrix} \cdot \begin{bmatrix} s_{21} & s_{23} \\ s_{41} & s_{43} \end{bmatrix} \cdot \begin{bmatrix} t_{21} & t_{23} \\ t_{41} & t_{43} \end{bmatrix}$$

Two coupled single-ended (SE) channels

Insights of single-ended signaling (Cont'd)



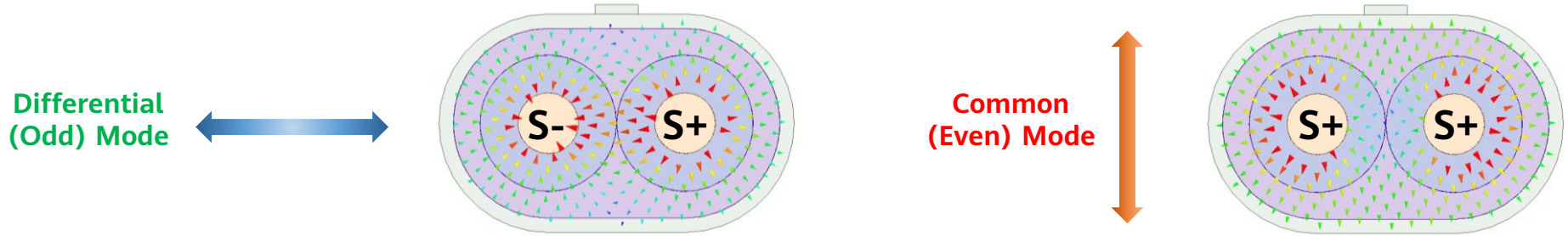
- SE MIMO is actually achieving mode/spatial division multiplexing.
- The common and differential modes are physically orthogonal.

$$\begin{bmatrix}+1 & +1\\ -1 & +1\end{bmatrix}\cdot\begin{bmatrix}s_{21} & s_{23}\\ s_{41} & s_{43}\end{bmatrix}\cdot\frac{1}{2}\cdot\begin{bmatrix}+1 & -1\\ +1 & +1\end{bmatrix}=$$

$$\frac{1}{2}\cdot\begin{bmatrix}+s_{21}+s_{23}+s_{41}+s_{43} & \overbrace{-s_{21}+s_{23}-s_{41}+s_{43}}^{\approx 0}\\ \underbrace{-s_{21}-s_{23}+s_{41}+s_{43}}_{\approx 0} & +s_{21}-s_{23}-s_{41}+s_{43}\end{bmatrix}\approx\frac{1}{2}\cdot\begin{bmatrix}\text{Common (Even) Mode}: +s_{21}+s_{23}+s_{41}+s_{43} & 0\\ 0 & \text{Differential (Odd) Mode}: +s_{21}-s_{23}-s_{41}+s_{43}\end{bmatrix}$$

$$s_{21}\approx s_{43},\ s_{23}\approx s_{41}$$

Physical picture of single-ended signaling



RX CHANNEL TX

$$\begin{bmatrix} +1 & +1 \\ -1 & +1 \end{bmatrix} \cdot \begin{bmatrix} s_{21} & s_{23} \\ s_{41} & s_{43} \end{bmatrix} \cdot \frac{1}{2} \cdot \begin{bmatrix} +1 & -1 \\ +1 & +1 \end{bmatrix} =$$

Common mode (Even mode)

$$\frac{1}{2} \cdot \begin{bmatrix} +s_{21} + s_{23} + s_{41} + s_{43} & -s_{21} + s_{23} - s_{41} + s_{43} \\ -s_{21} - s_{23} + s_{41} + s_{43} & +s_{21} - s_{23} - s_{41} + s_{43} \end{bmatrix}$$

≈ 0 (Common mode) ≈ 0 (Differential mode)

Differential mode (Odd mode)

$$s_{21} \approx s_{43}, s_{23} \approx s_{41}$$

Single-ended to differential conversion

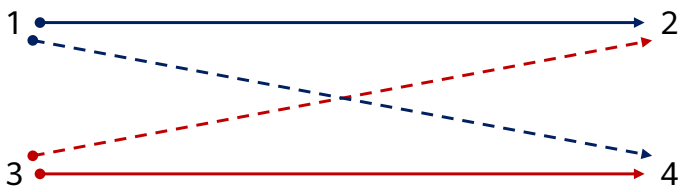
$$sdd11 = \frac{1}{2} \cdot (s_{11} - s_{13} - s_{31} + s_{33})$$

$$sdd12 = \frac{1}{2} \cdot (s_{12} - s_{14} - s_{32} + s_{34})$$

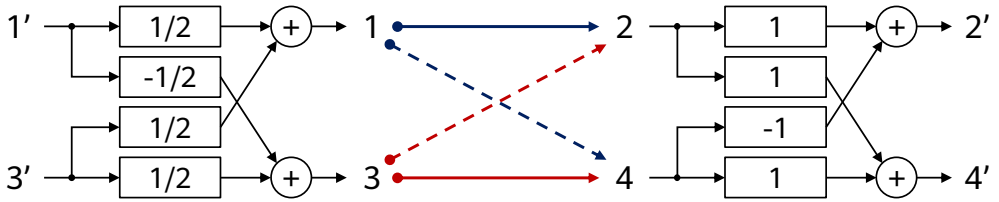
$$sdd21 = \frac{1}{2} \cdot (s_{21} - s_{23} - s_{41} + s_{43})$$

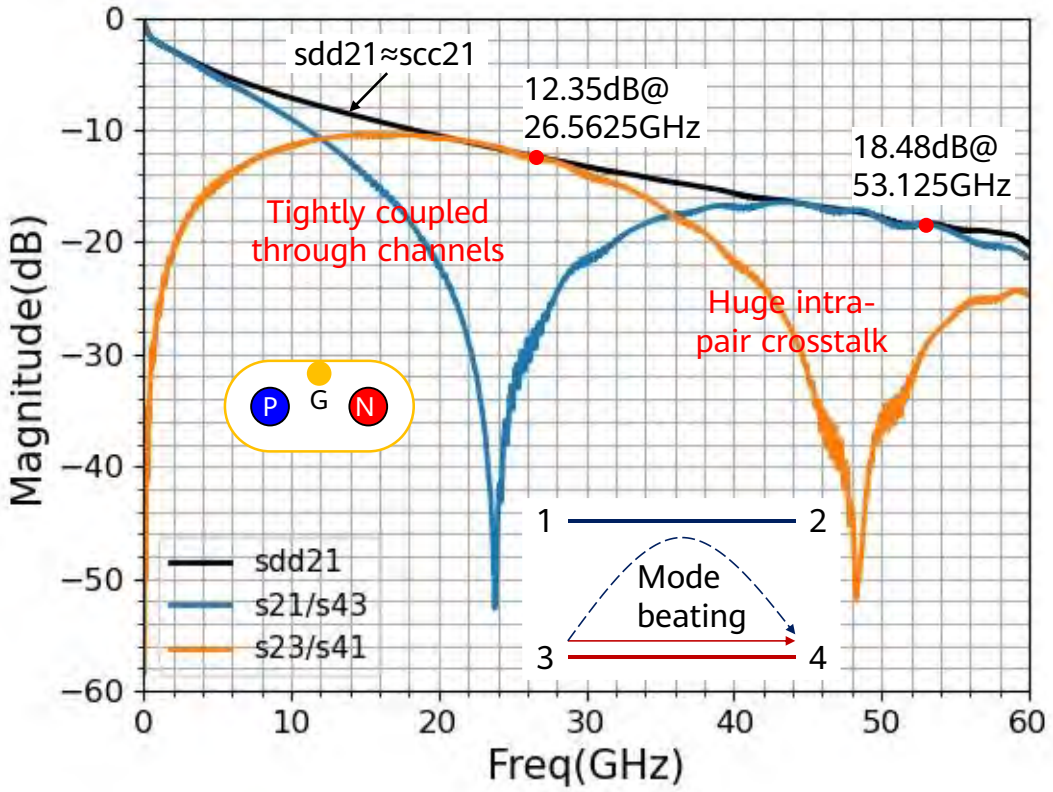
$$sdd22 = \frac{1}{2} \cdot (s_{22} - s_{24} - s_{42} + s_{44})$$

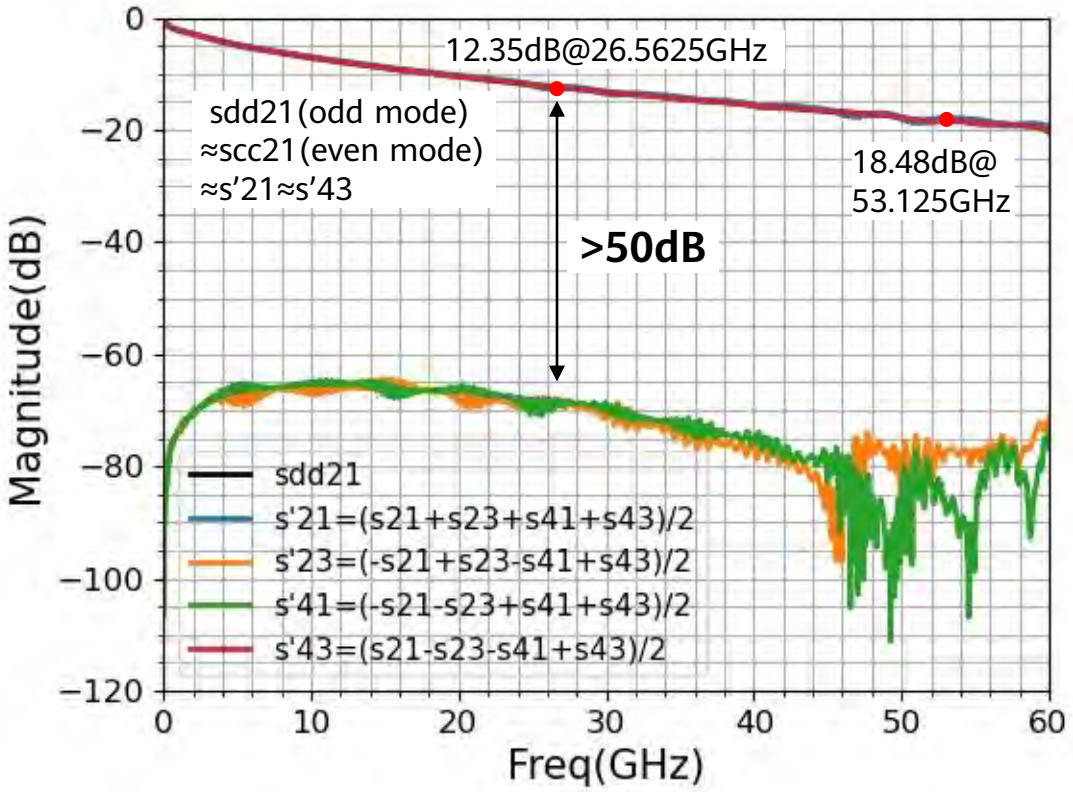
Frequency domain picture of single-ended signaling



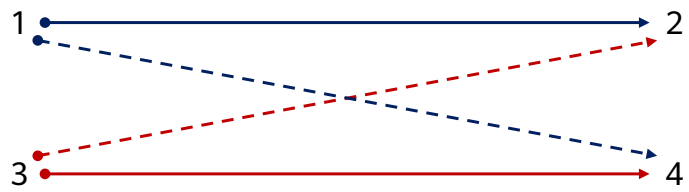
Transmission with intrinsic ‘odd and even’ modes.

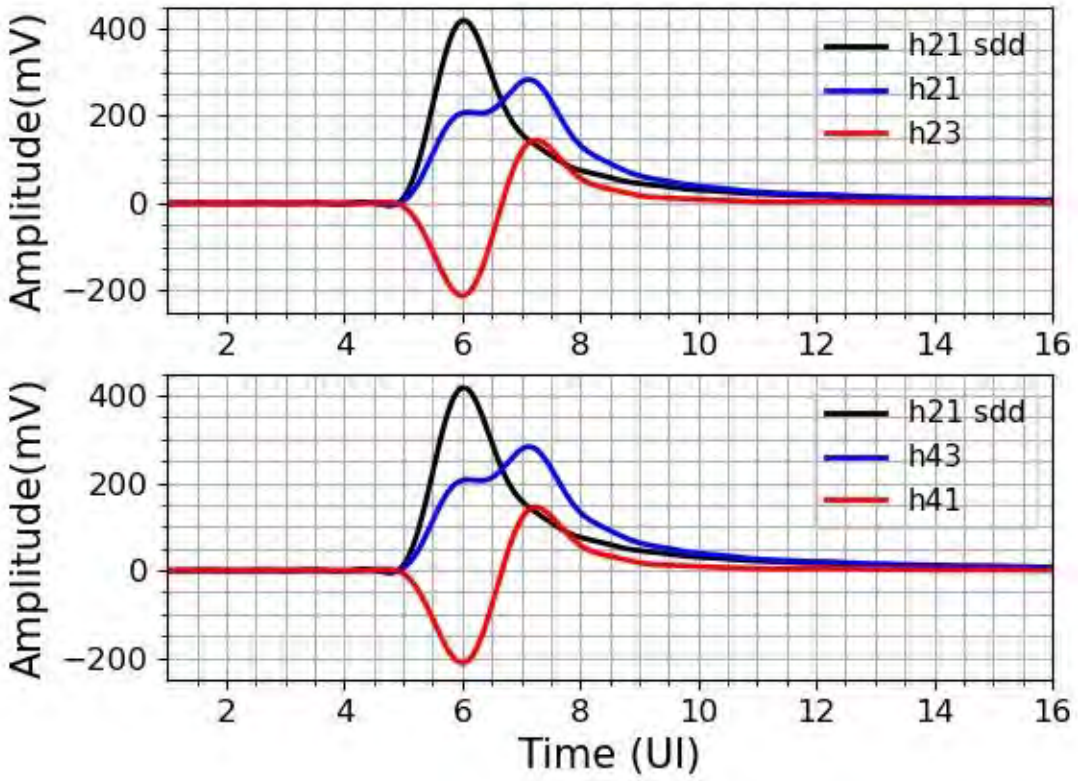




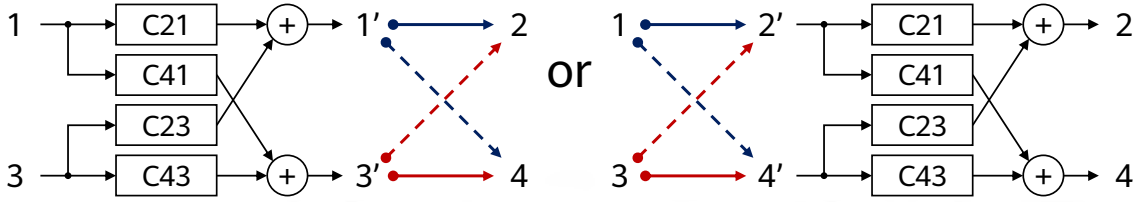


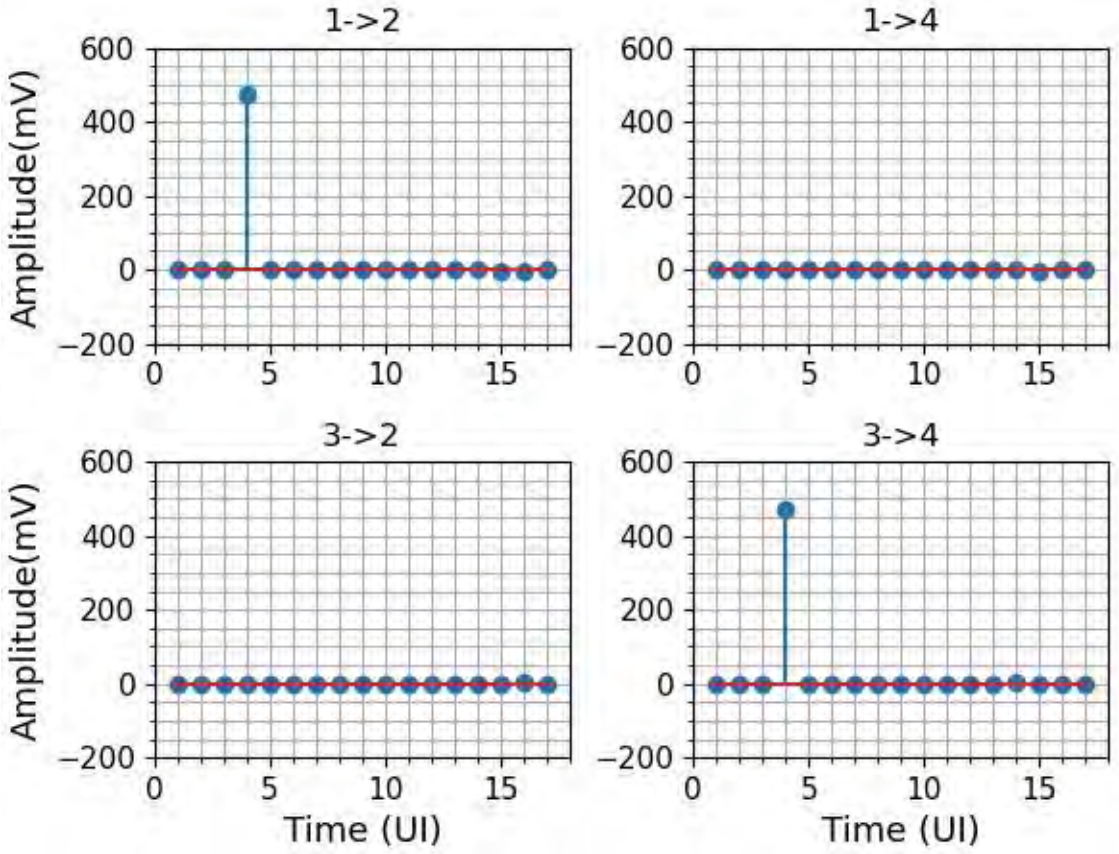
Time domain picture of single-ended signaling



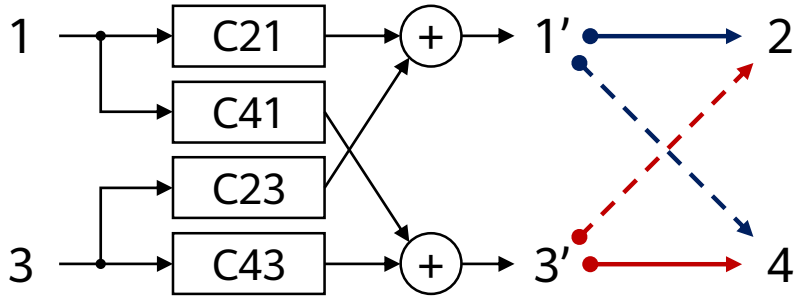


Transmission with two 'orthogonal compound' modes.

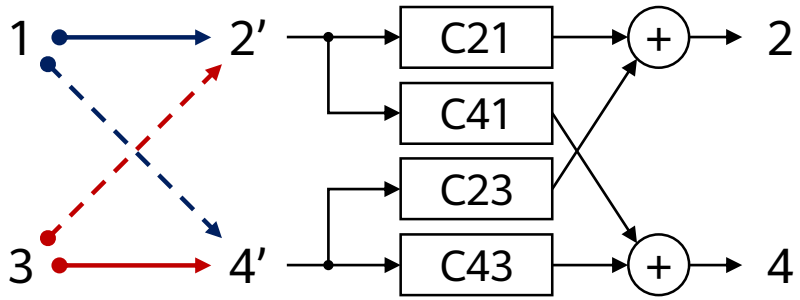


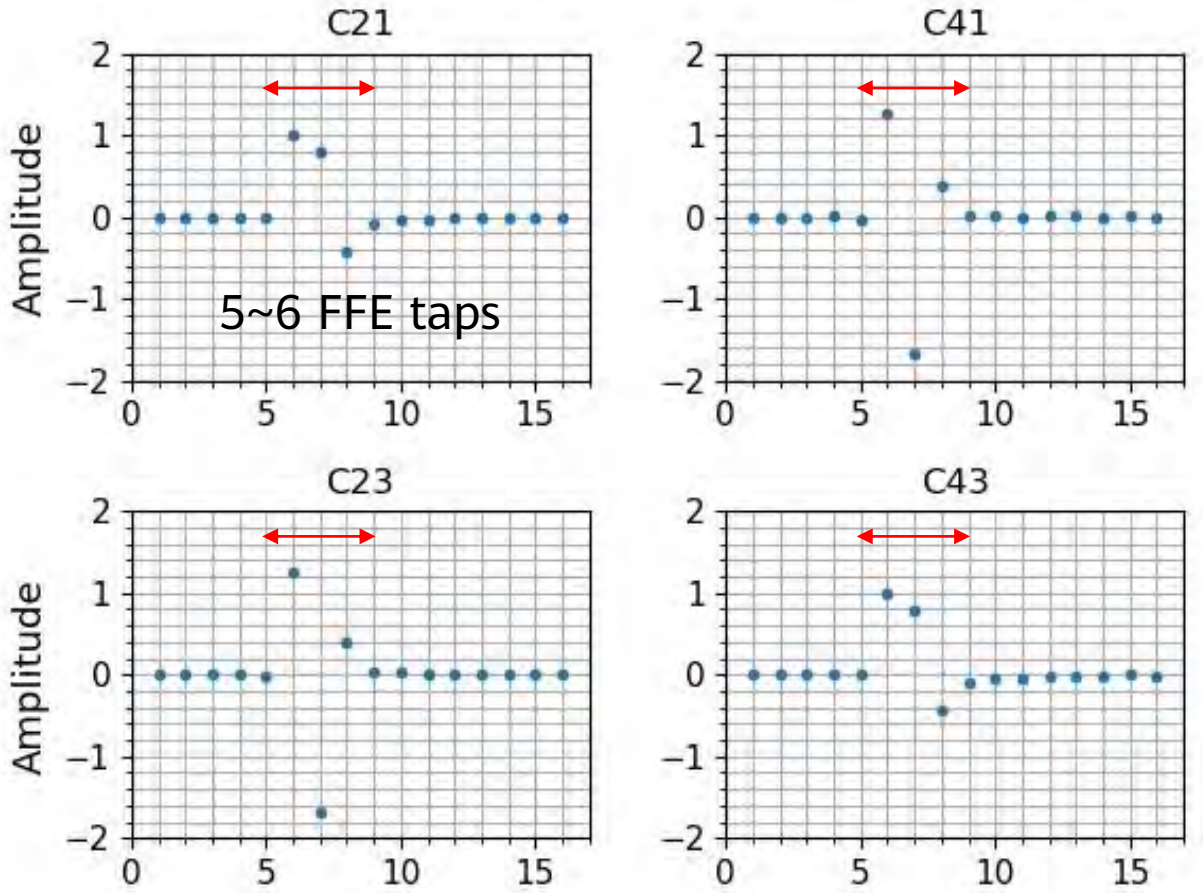


SE MIMO coefficients



or





Summary and recommendation

- 200G CR & KR objectives are achievable for PAM4.
  - TP0~TP5 loss of <28.5dB for on-board cable connector solution;
  - TP0~TP5 loss of <21.0dB for cable IO solution.

- SE PAM4 works well for tightly coupled differential pairs.
  - SE MIMO is actually achieving mode/spatial division multiplexing.
  - The intra-pair crosstalk can be easily removed by “MIMO” algorithm.
    - Benefits from the “Orthogonality” of “Modes”.

- **N*200G (N=4, 2, 1), CR PHYs are proposed as objectives.**

Thanks!
Q&A