

A Preliminary Study of Modulation and FEC for 400 Gb/s per Lane NPC Channels

Xiang He, Shuangxing Dai, Hao Ren, Xuebo Wang
Huawei Technologies

Background/Introduction

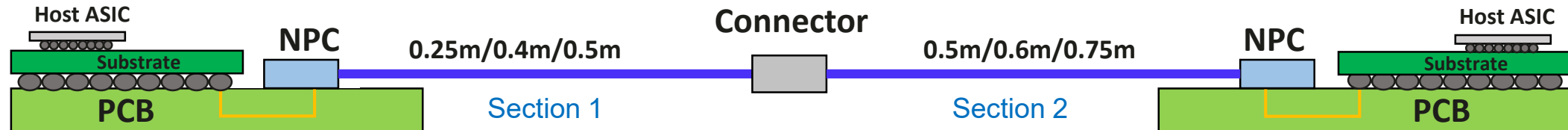
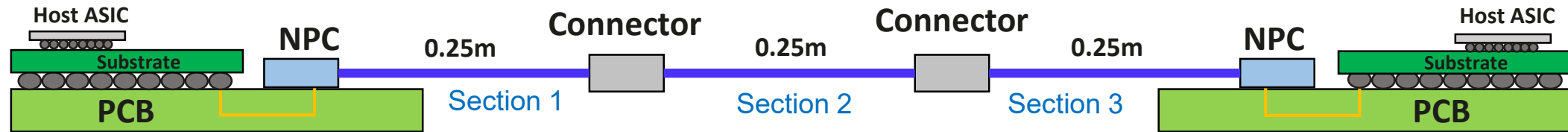
- Industry is exploring 400G/lane electrical interfaces to address AI data center bandwidth growth.
- C2M, C2C, and CR channels have been contributed within this group, with bandwidth limitations suggesting the need for PAM6 or PAM8 signaling at 400G/lane.
- CPC channel demonstrations at the OCP Global Summit (last week) showed feasibility beyond 100 GHz bandwidth.
- This work presents our new NPC (Near-Package Copper) channels:
 - S-parameter (s4p) channel data contributed along with this presentation.
- Channel simulations evaluated PAM4, PAM6, and PAM8 modulation formats.
 - Newly defined Block Error Ratio metric applied to assess modulation performance.
- Briefly explored longer RS-FEC options for higher-order modulations.

Channel Topologies

Pkg: 92 Ω , 15mm

Cable: 92 Ω

Pkg: 92 Ω , 25mm



PCB Trace: 1 inch

PCB Trace: 1 inch

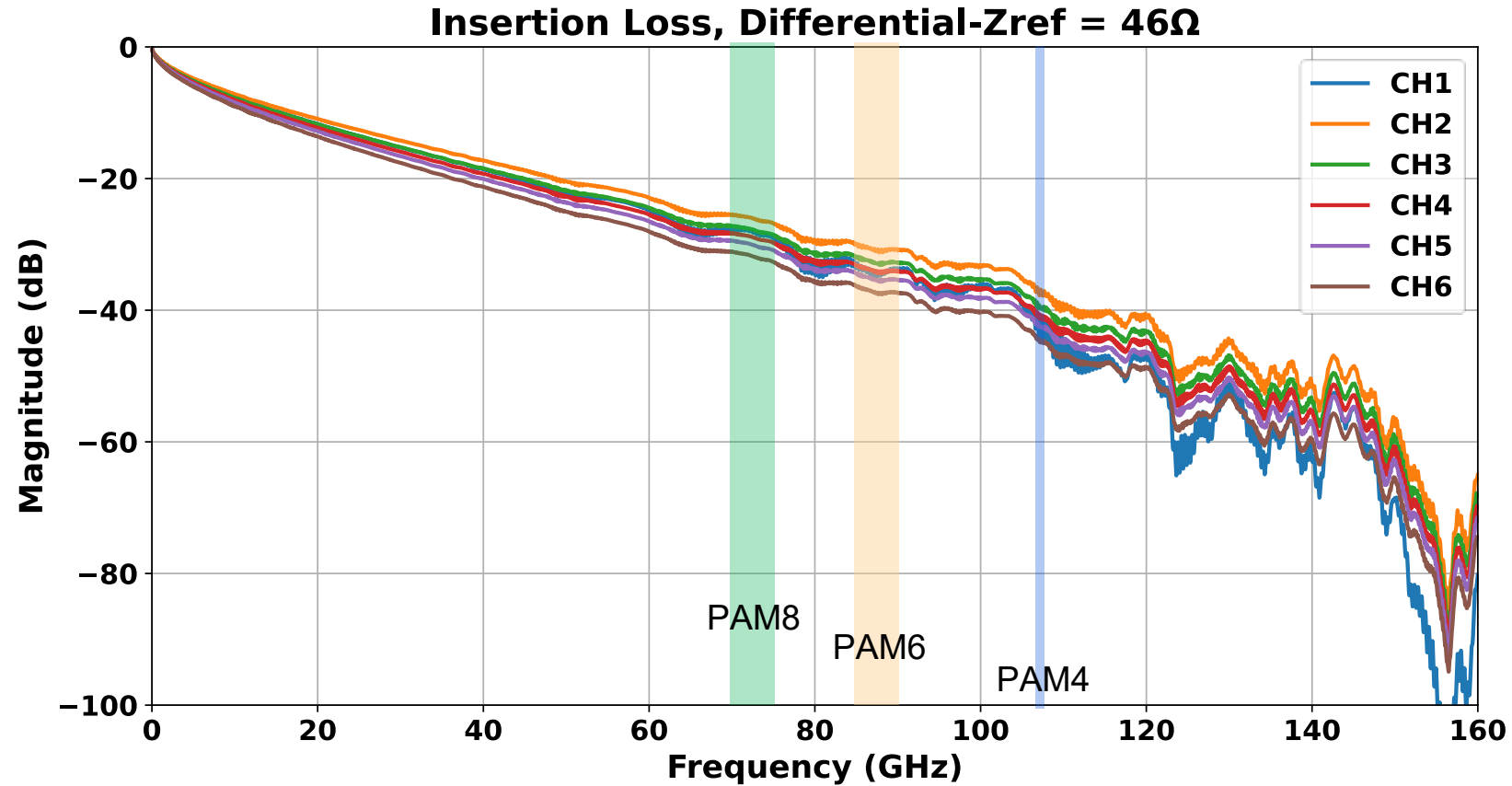
- All data and channels provided in this contribution are simulation based.
- Two types of NPC channels are presented.
- Variable length from 0.75m to 1.25m.
- Bump-to-bump loss varying from 37dB to 44dB.

Channel Files

Channel #	File Name	Section 1	Section 2	Section 3	Overall Length	IL (dB) @106.25GHz
CH1	pkg_15mm_25mm_hdi_1inch_npc_0p25m_0p25m_0p25m_thru1.s4p	0.25m	0.25m	0.25m	0.75m	41.3
CH2	pkg_15mm_25mm_hdi_1inch_npc_0p25m_0p5m_thru2.s4p	0.25m	0.5m	/	0.75m	36.5
CH3	pkg_15mm_25mm_hdi_1inch_npc_0p4m_0p5m_thru3.s4p	0.4m	0.5m	/	0.9m	38.3
CH4	pkg_15mm_25mm_hdi_1inch_npc_0p5m_0p5m_thru4.s4p	0.5m	0.5m	/	1.0m	40.0
CH5	pkg_15mm_25mm_hdi_1inch_npc_0p5m_0p6m_thru5.s4p	0.5m	0.6m	/	1.1m	41.2
CH6	pkg_15mm_25mm_hdi_1inch_npc_0p5m_0p75m_thru6.s4p	0.5m	0.75m	/	1.25m	43.6

- Files can be found at https://www.ieee802.org/3/ad_hoc/E4AI/public/channel/index.html

Frequency Domain Responses



Simulation Configuration

- For each channel, we simulated channel performance for different modulations at different data rates.
 - PAM4 @ 425 Gb/s, for RS(544,514) FEC with hard decision MLSE.
 - PAM6 @ 425 Gb/s, for RS(544,514) FEC with hard decision MLSE.
 - PAM6 @ 453 Gb/s, assuming a soft-decision Inner FEC (128,120) is used.
 - PAM8 @ 425 Gb/s, for RS(544,514) FEC with hard decision MLSE.
 - PAM8 @ 453 Gb/s, assuming a soft-decision Inner FEC (128,120) is used.
- For this simulation, crosstalk is scaled from a measured 224G channel with similar topology.
 - More data including crosstalk model is underway.
- CTLE peaking for PAM6 and PAM8 is adjusted to include Inner FEC.

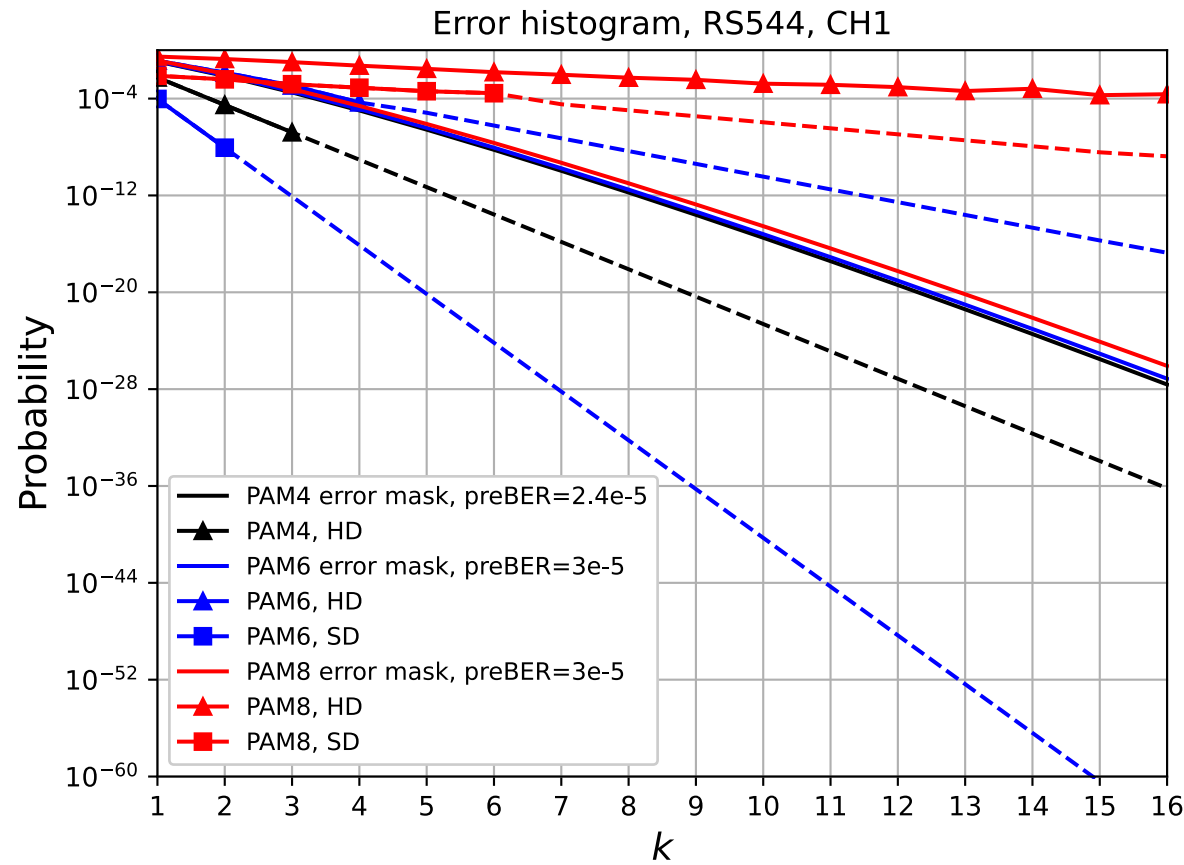
Overview of Simulation Results

CH #		PAM4@425Gb/s	PAM6@425Gb/s	PAM6@453Gb/s	PAM8@425Gb/s	PAM8@453Gb/s
CH1	Insertion Loss	41.3dB	33.1dB	33.6dB	27.7dB	29.5dB
	BER (w/MLSE)	1.11E-6	3.92E-5	1.19E-4	3.66E-4	4.53E-4
CH2	Insertion Loss	36.5dB	30.0dB	30.9dB	25.6dB	27.2dB
	BER (w/MLSE)	<1E-9	1.47E-5	2.04E-5	1.91E-4	1.21E-4
CH3	Insertion Loss	38.3dB	32.0dB	32.9dB	27.4dB	29.1dB
	BER (w/MLSE)	5.75E-9	7.84E-6	1.22E-5	1.94E-4	1.27E-4
CH4	Insertion Loss	40.0dB	33.2dB	34.2dB	28.5dB	30.2dB
	BER (w/MLSE)	8.2E-9	3.83E-6	9.97E-6	1.63E-4	1.00E-4
CH5	Insertion Loss	41.2dB	34.4dB	35.5dB	29.7dB	31.4dB
	BER (w/MLSE)	4.38E-8	3.66E-6	5.61E-6	1.81E-4	1.59E-4
CH6	Insertion Loss	43.6dB	36.3dB	37.5dB	31.3dB	33.2dB
	BER (w/MLSE)	1.15E-7	3.12E-6	5.61E-6	2.24E-4	2.00E-4

Detailed data is shown in the backup slides.

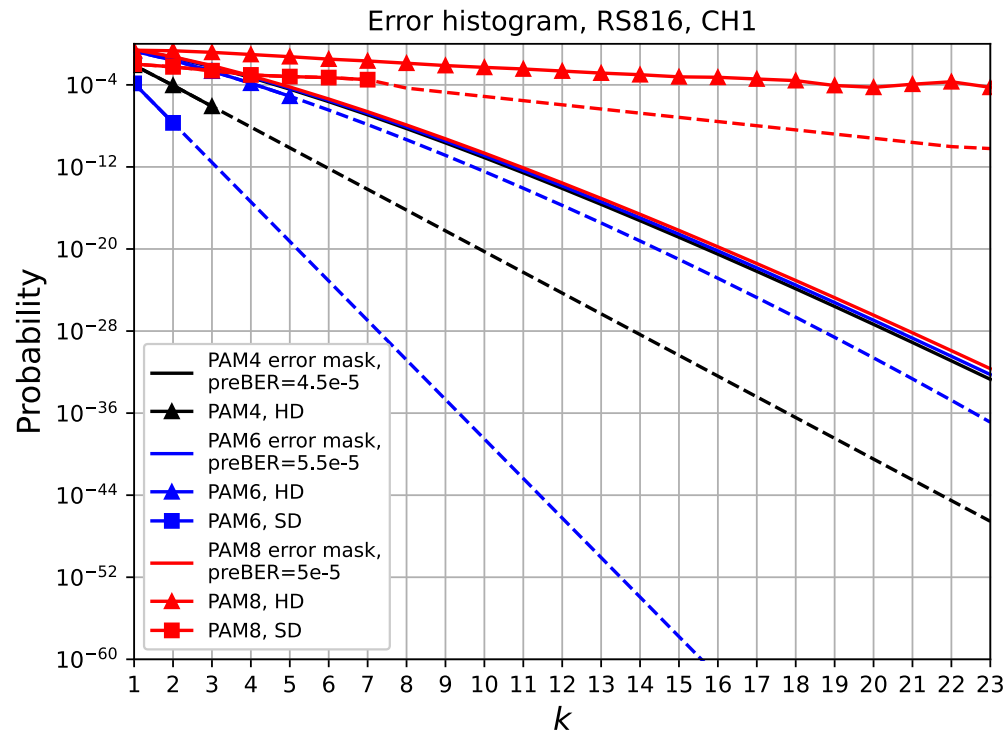
Block Error Ratio Evaluation for CH1

- We plotted the error statistics for CH1 using block error ratio method using RS(544,514).



- PAM4 performance is excellent, passing the error mask with broad margin.
- PAM6 using RS(544,514) only cannot pass the error mask.
 - PAM6 using Inner FEC has best performance.
- PAM8 using RS(544,514) with or without Inner FEC cannot meet KER requirement.

Longer RS-FEC May Help



- A RS(816,(771+1)) with the same overhead as RS(544,514) is used to evaluate the same data in the previous slide.
 - It can correct 22 symbols per codeword.
 - Error mask was created following the similar method as for RS(544,514), extending bins to 23.
- With this longer RS-FEC, PAM6 can pass the error mask without the need of Inner FEC.
 - Longer RS-FEC may require less area and power compared to RS(544,514) plus an Inner FEC
- PAM8 still failed with or without Inner FEC.

FEC code	Overhead	Burst tolerance (4xCW Interleaving)	Baudrate (@PAM4)	Pre-FEC BER (AWGN)	Area	Latency(ns) 400G@1.25GHz
RS(544,514)	5.8%	600 bits	212.5G	2.9E-4	1.0x	55
RS(576,514)	12.1%	1240 bits	225G	1.3E-3	2.5x	84
RS(816,(771+1))	5.8%	880 bits	212.5G	4.6E-4	1.3x	79
RS(1088,1028)	5.8%	1200 bits	212.5G	5.8E-4	3.0x	112

Summary

- Preliminary simulation results are presented on NPC channels under-development supporting >106.25 GHz bandwidth.
- PAM4, PAM6, and PAM8 signaling over these channels are evaluated.
 - PAM4 shows feasible performance at 400 Gb/s per lane.
 - PAM6 may require stronger FEC (e.g., Inner FEC or longer RS-FEC) to meet target BER/KER.
 - PAM8 exhibits limited margin and lowest performance.
- Additional channel data and refined equalization/FEC analysis will be contributed in upcoming meetings.

Thank you!

Backup slides - Simulation configuration and results for CH1 and CH2

		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH1	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	41.3dB	33.1dB	33.6dB	27.7dB	29.5dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.89	0.47	0.59	0.45	0.59
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	1.11E-6	3.92E-5	1.19E-4	3.66E-4	4.53E-4
	BER (after Inner FEC)	/	/	5.41E-8	/	7.18E-6
		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH2	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	36.5dB	30.0dB	30.9dB	25.6dB	27.2dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.89	0.31	0.38	0.33	0.45
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	<1E-9	1.47E-5	2.04E-5	1.91E-4	1.21E-4
	BER (after Inner FEC)	/	/	<1E-9	/	1.02E-7

Backup slides - Simulation configuration and results for CH3 and CH4

		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH3	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	38.3dB	32.0dB	32.9dB	27.4dB	29.1dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.80	0.36	0.42	0.31	0.50
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	5.75E-9	7.84E-6	1.22E-5	1.94E-4	1.27E-4
	BER (after Inner FEC)	/	/	<2.5E-9	/	1.57E-7
		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH4	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	40.0dB	33.2dB	34.2dB	28.5dB	30.2dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.77	0.40	0.45	0.40	0.51
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	8.2E-9	3.83E-6	9.97E-6	1.63E-4	1.00E-4
	BER (after Inner FEC)	/	/	<2.5E-9	/	4.13E-7

Backup slides - Simulation configuration and results for CH5 and CH6

		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH5	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	41.2dB	34.4dB	35.5dB	29.7dB	31.4dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.81	0.42	0.51	0.32	0.56
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	4.38E-8	3.66E-6	5.61E-6	1.81E-4	1.59E-4
	BER (after Inner FEC)	/	/	<2.5E-9	/	5.90E-7
		PAM4	PAM6	PAM6,SD	PAM8	PAM8,SD
CH6	Data rate	425Gbps	425Gbps	453Gbps	425Gbps	453Gbps
	Insertion Loss	43.6dB	36.3dB	37.5dB	31.3dB	33.2dB
	ICN@bump, mV	0.7	0.5	0.55	0.37	0.42
	Alpha	0.81	0.51	0.6	0.46	0.58
	Precoding	ON	OFF	OFF	OFF	OFF
	BER (w/MLSE)	1.15E-7	3.12E-6	5.61E-6	2.24E-4	2.00E-4
	BER (after Inner FEC)	/	/	<2.5E-9	/	8.41E-7