400G+ Pathfinding Using Backward-Compatible Orthogonal Signaling

Kandou Bus and Amazon Kuiper

400G+ Pathfinding Using Backward-Compatible Orthogonal Signaling

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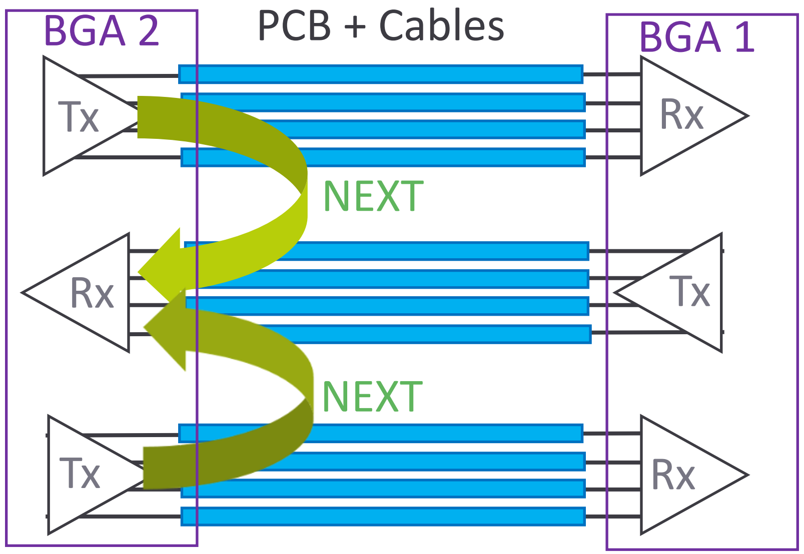
What We Will Cover

- Proposing a signaling method (EPAM) for OIF-400G applications in collaboration between Kandou and Amazon Kuiper.
- Studying configurations with 12 wires, grouped into 3 subgroups, analyzing NEXT impacts.
- Evaluating channel performance at scaled frequencies up to 200 Gbaud across various channel conditions.
- Comparing the EPAM signaling approach against standard PAM methods (PAM6) in terms of baudrate and signal integrity.
- Highlighting benefits of EPAM, including reduced frequency for equal throughput, superior ISI performance, and effective skew correction.
- Demonstrating that EPAM implementation closely parallels that of conventional PAM, simplifying adoption.
- Presenting detailed simulation results demonstrating advantages of EPAM in challenging channel environments.

EPAM: ENRZ combined with PAM signaling
ENRZ: Ensemble Non-Return to Zero
NEXT: Near-End Crosstalk

The Configuration

- We study 12 wires, grouped into 3 subgroups of 4 wires (2 lanes) each.
- The first and last subgroups are NEXT aggressors on the middle subgroup, the victim.
- We report on the performance of the victim subgroup.



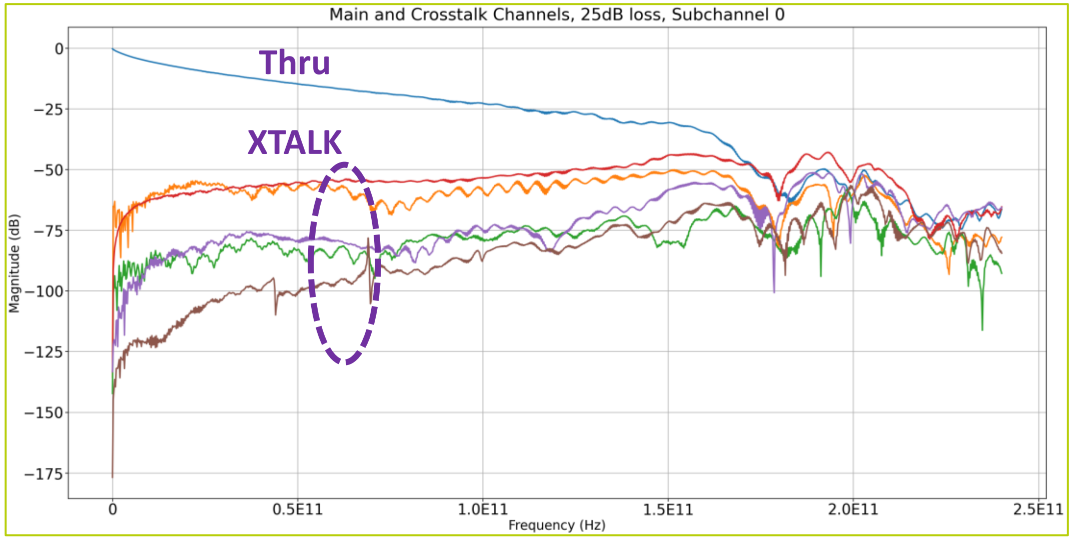
The Channels

- We extracted 5 different channels with different losses at 50 Gbaud:
  - List of channels: 25dB, 25dB with more XTLK, 27 dB, 29 dB, 31 dB
- On the next slides we include the channel response for the 25dB channel and the 25 dB channel with more XTLK in differential modes.
- For our simulations we scale the channels linearly to 4x the frequency to arrive at channels with corresponding losses at 200 Gbaud.
  - This is an optimistic assumption but may work well for comparing different signaling methods.
- We assume no connectors in this version.
- We also assume a skew of < 1ps among the wires.
  - Can be accomplished using Kandou's skew-correction algorithms.

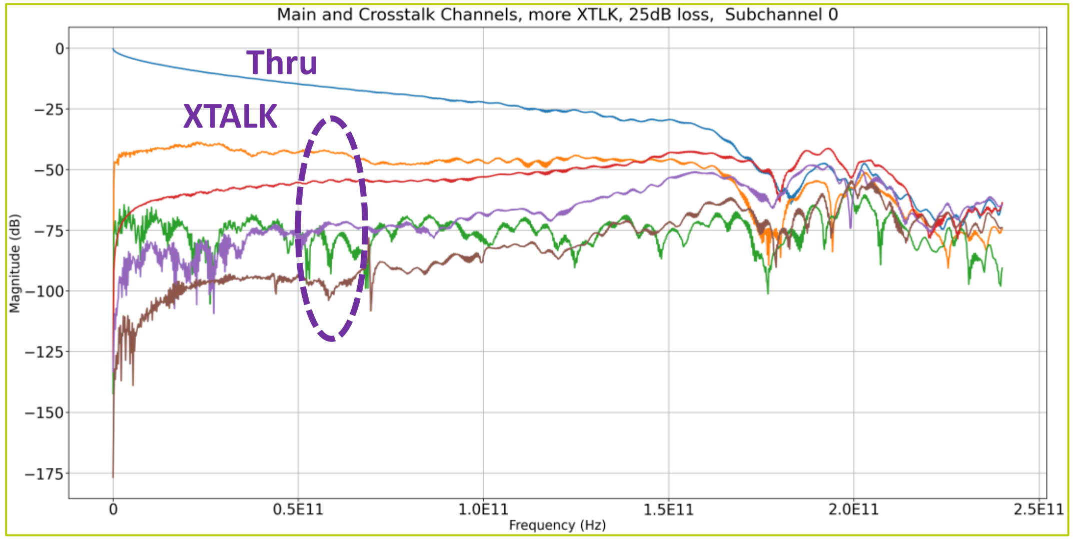
XTALK: Crosstalk

25 dB Channel, Diff Mode, Varying XTLK

25dB Channel, Normal XTLK



25dB Channel, Increased XTLK



EPAM

- In EPAM transmission we encode 3 incoming PAM-signals into multi-level values on 4 wires and transmit them.
  - Encoding is done either in analog, or with a DAC.
  - Encoding is a linear operation accomplished by the orthogonal matrix

$$H = \begin{pmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{pmatrix}.$$

  - Modeling the PAM signals as values between -1 and +1, the transmitted values on the wires are

$$(w_0, w_1, w_2, w_3) = (0, v_0, v_1, v_2) * H * \tfrac{1}{3},$$

- At the receiver the operation is reversed by multiplying the received wire values with H/2.
- All these operations can be performed efficiently with analog or mixed signal circuits.

Why EPAM?

- EPAM transmits 3 signals on 2 differential lanes instead of 2 signals for regular PAM.
  - Lowers the frequency of the transmission by 33% for the same overall throughput
- To achieve the same throughput, increase on two differential lanes a higher PAM order is needed.
  - For example, the throughput of EPAM4 on 4 wires is the same as that of differential PAM8.
- But higher PAM modulation leads to smaller vertical and horizontal opening of the eye due to the number of levels, and more importantly, due to (residual) ISI.
- In this presentation we present simulation results for EPAM3, PAM6, and EPAM4 to quantify these advantages.
  - EPAM3 has 25% higher baudrate than PAM6, and PAM6 has ~20% higher baudrate than EPAM4.
  - As we will see, EPAM4 performs best among these signaling methods, but not only due to the lower baudrate, but also due to better (residual) ISI performance.
  - Case in point: despite the higher baudrate, EPAM3 performs better than PAM6 because of its superior ISI performance.

EPAM Implementation

- EPAM can be implemented in essentially the same way as PAM as we will see later.
- EPAM is susceptible to skew in the group of 4 wires, but Kandou has various algorithms for correcting the skew in mission mode.
  - It should be noted that differential methods like PAM6 also are susceptible to skew, especially at high data rates.
  - At the same time, they don't allow for similar skew correction mechanisms as EPAM.
- EPAM uses the common mode of the differential pairs in the 4-wire interface.
- Care must be taken to ensure that all channel elements equally handle both the differential and common-mode components of differential pairs.
  - This consideration is particularly important for connectors, as they frequently (though not always) degrade common-mode performance.
- To drive our point home, our extracted channels don't contain connectors in the path.

The Signaling Methods

EPAM3

- Throughput = 400 Gb/s/diff-pair
- Baudrate = 200 Gbaud
- Nyqvist = 100 GHz
- UI = 5 ps
- Loss at Nyqvist = 25 dB
- 600 mV p2p
- One gain stage of 6 dB
- Extensive equalization
- 2 mV rms noise
- 200 fs-rms Rj
- 2 ps Dj
- 2ps rise time.

PAM6

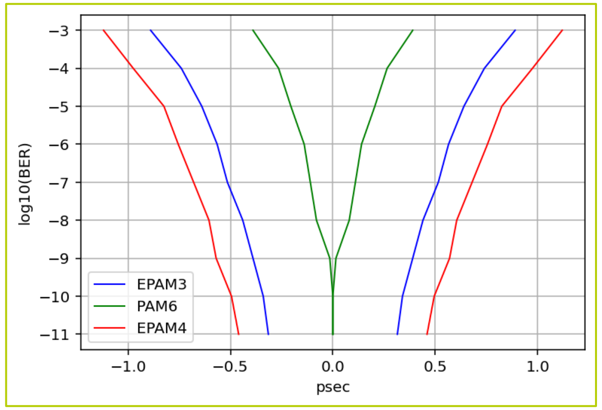
- Throughput = 400 Gb/s/diff-pair
- Baudrate = 160 Gbaud
- Nyqvist = 80 GHz
- UI = 6.25 ps
- Loss at Nyqvist = 18 dB
- 600 mV p2p
- One gain stage of 6 dB.
- Extensive equalization
- 2 mV rms noise
- 200 fs-rms Rj
- 2 ps Dj
- 2ps rise time.

EPAM4

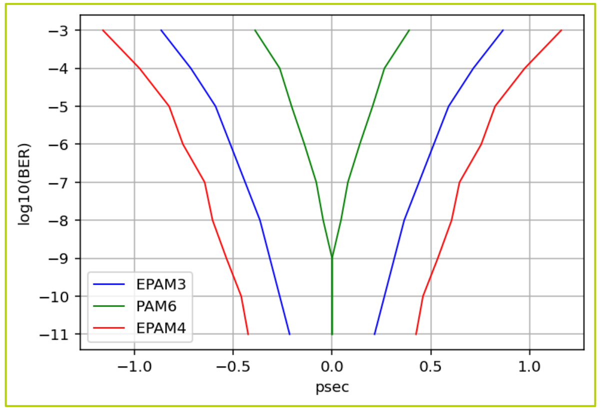
- Throughput = 400 Gb/s/diff-pair
- Baudrate = 132 Gbaud
- Nyqvist = 66 GHz
- UI = 7.58 ps
- Loss at Nyqvist = 16 dB
- 600 mV p2p
- One gain stage of 6 dB
- Extensive equaliztion
- 2 mV rms noise
- 200 fs-rms Rj
- 2 ps Dj
- 2ps rise time

Horizontal Bathtub Comparison (1)

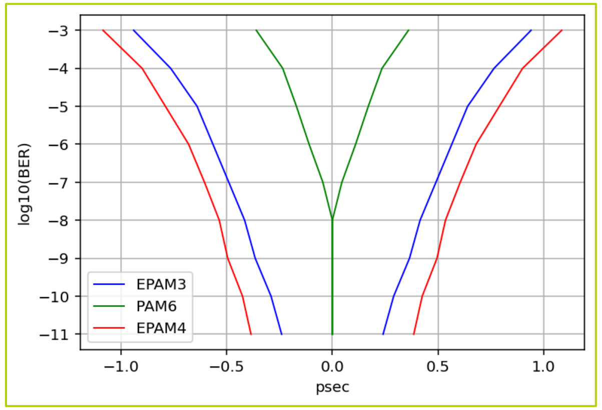
25dB Channel

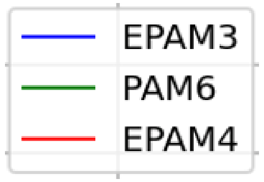


25dB Channel with more XTLK

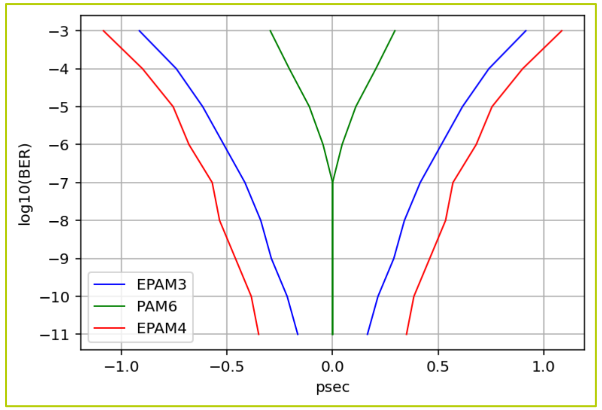


27dB Channel

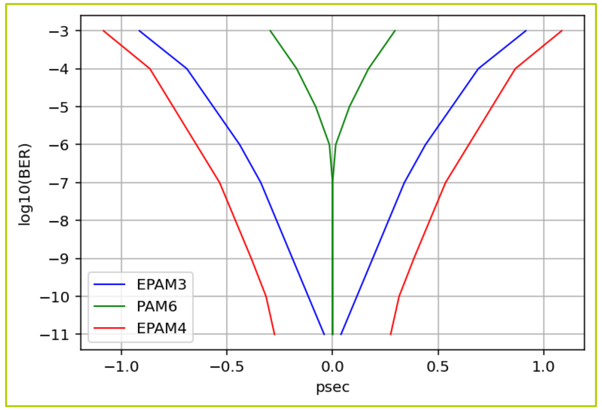




29dB Channel

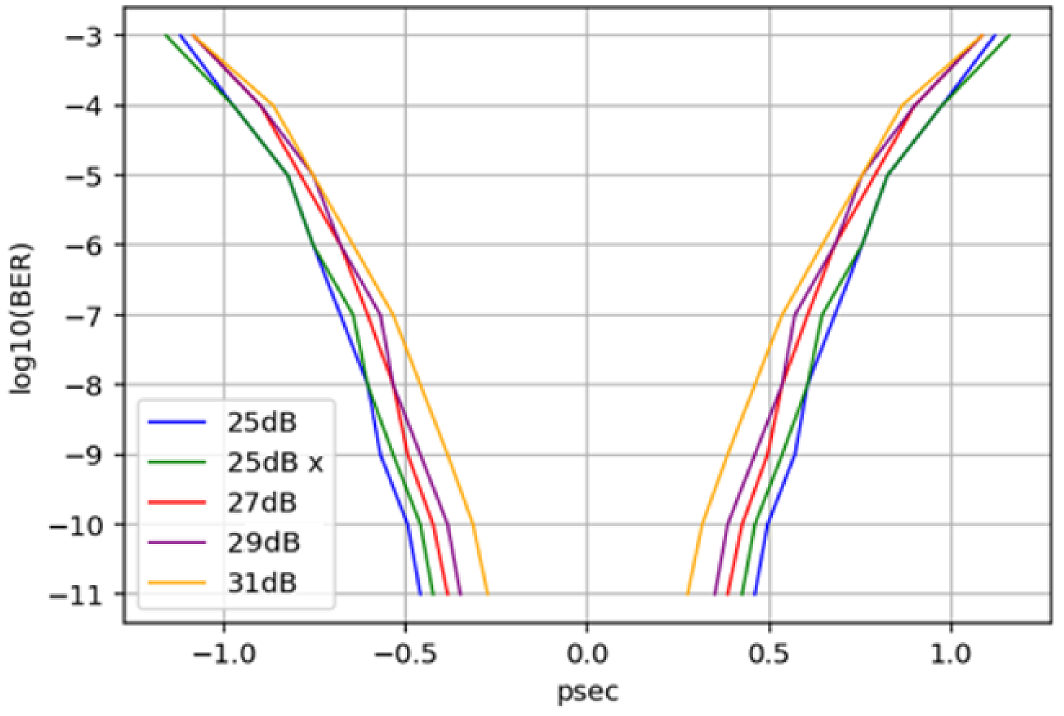


31dB Channel

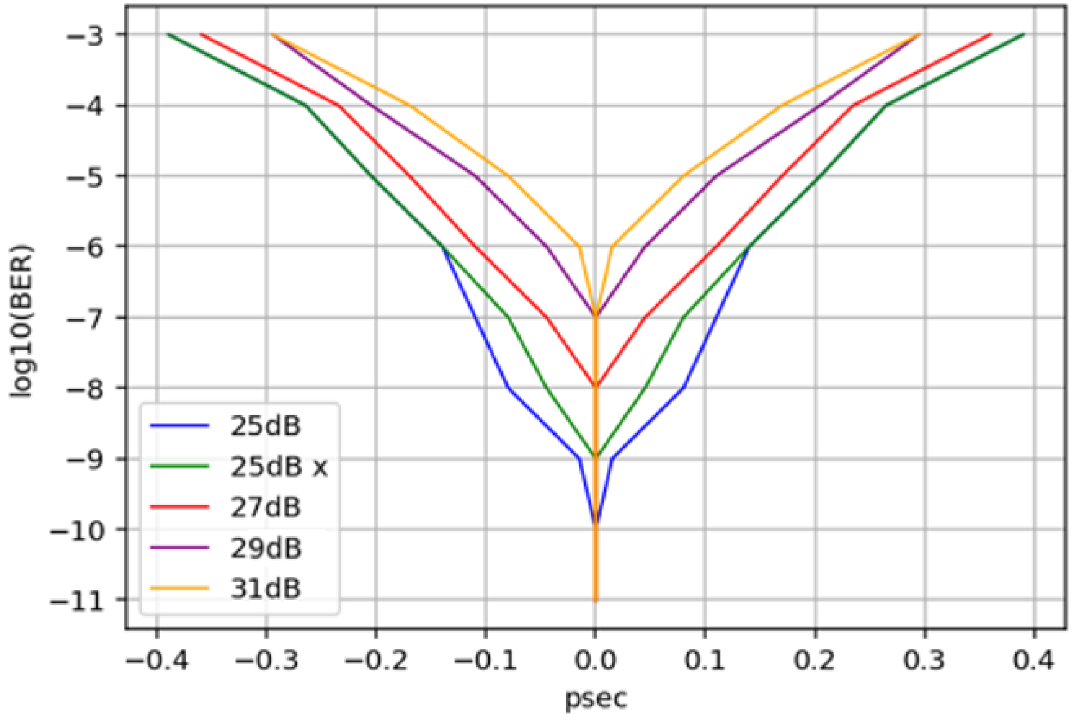


Horizontal Bathtub Comparison (2)

Horizontal Bathtub EPAM4

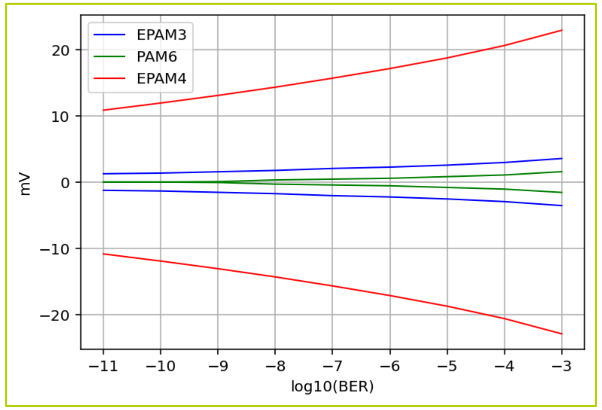


Horizontal Bathtub PAM6

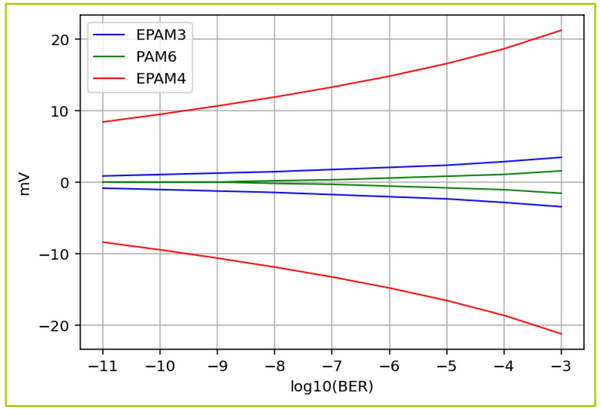


Vertical Bathtub Comparison

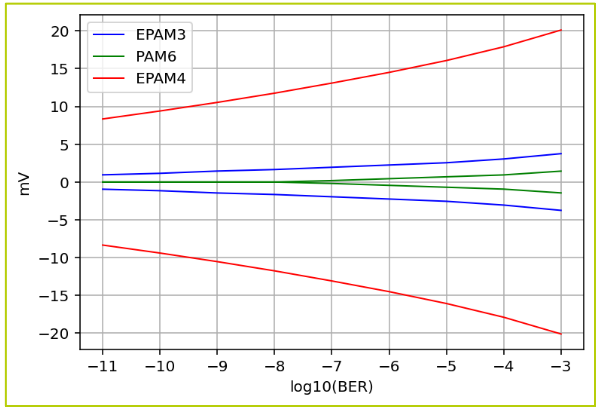
25dB Channel

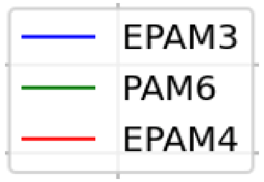


25dB Channel with more XTLK

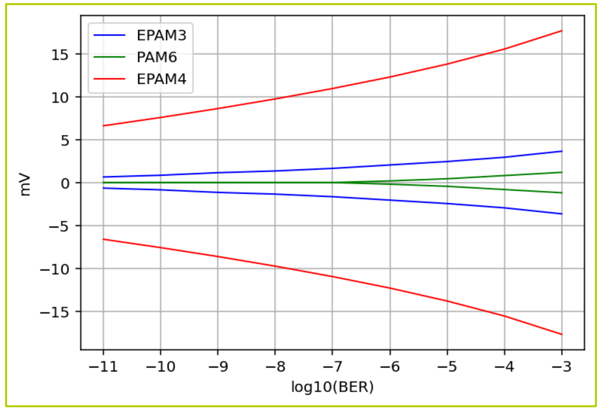


27dB Channel

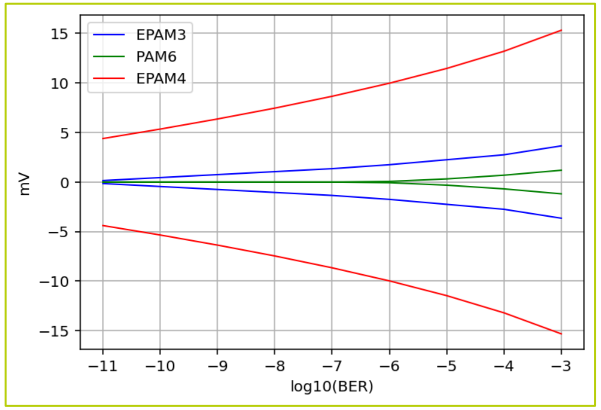




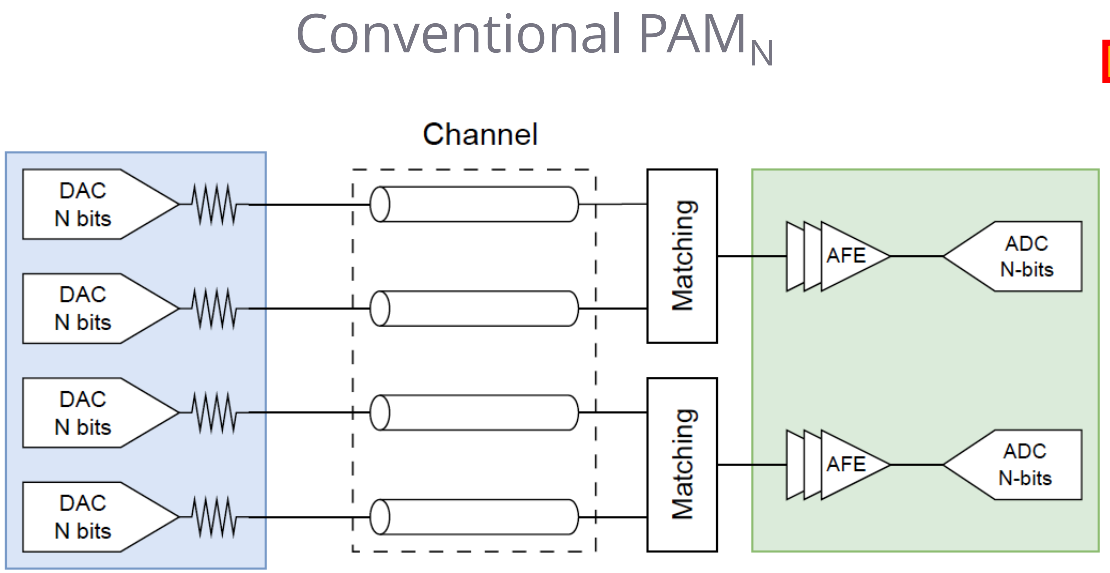
29dB Channel

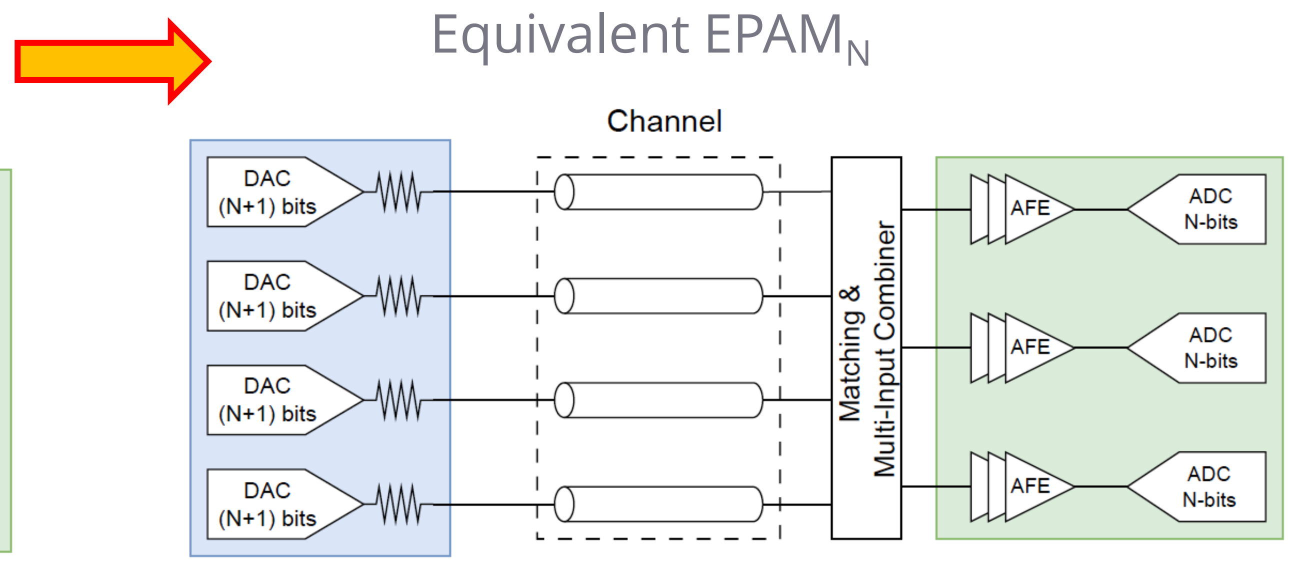


31dB Channel



Backwards Compatibility to 200GigE





- The conventional PAM_N receiver and transmitter circuits can be reused to implement the corresponding E PAM_N , with the same margin and 50% more throughput.

Summary

	EPAM4	PAM6	EPAM3
Baudrate	134 Gbaud	160 Gbaud	200 Gbaud
Horizontal opening @ 1E-6	20%	4%	14%
Vertical opening @ 1E-6	29.6 mV	1.13 mV	4.1 mV
Skew correction	Required	Recommended	Required
Backwards compatibility	Yes	Yes	Yes

- EPAM4 is the clear winner in this comparison in terms of baudrate and signal integrity.
- Despite its higher baudrate, EPAM3 performs better than PAM6 due to its superior ISI performance.
- EPAM seems to be the right choice of signaling if combined with careful selection of connectors.

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