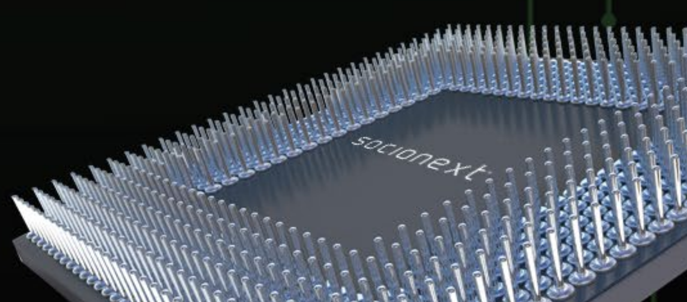
WHITE PAPER

As Serial Data Rates Continue to Increase, Pulse Amplitude Modulation (PAM-4) Delivers Significant Advantages



Note to readers:

A previous article entitled "The Evolution of SerDes Architecture and Advantages of ADC-DSP for High-Speed Serial Communications" discussed the limitations of NRZ (non-return to zero) data transmission for high loss channels and presented PAM4 (Pulse Amplitude Modulation) data transmission as a solution to serve the continued increase of serial data rates.

This second section of the series compares NRZ and PAM4 data transmission by simulating data transmission through a 29.8" backplane channel, with characteristics shown below in Figure 1.

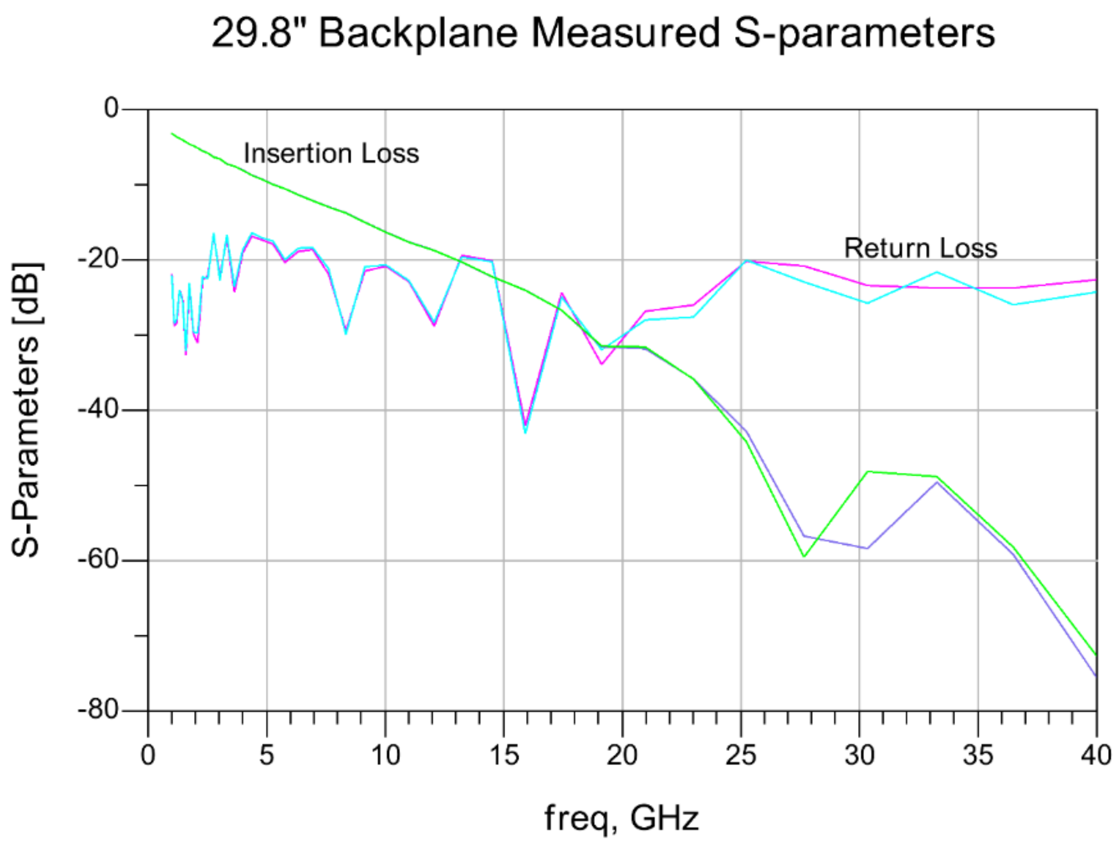


Figure 1. Measured characteristics of a 29.8" backplane channel. This channel is used to compare NRZ and PAM4 data transmission for different data rates.

While visual comparison of eye diagrams provides a qualitative indication of transmission quality, a quantitative metric of data transmission also is required. To address this need, IEEE 802.3 Standards Annex 93A was developed to create a figure of merit known as channel operating margin, or "COM". The calculation of COM accounts for transmitter characteristics, receiver characteristics, equalization, channel S-parameters, jitter, crosstalk, and noise. While this calculation includes many parameters, COM can also be simply thought of as the ratio of signal amplitude to noise amplitude:

$$COM = 20*\log(As/Ani) \quad [dB] \qquad \text{Eq (1)}$$

In the formula, "As" is the signal amplitude and "Ani" is the noise amplitude. COM is measured in dB and a higher value of COM indicates higher transmission quality. Most standards require a minimum COM value of 3dB.

The automated calculation of COM is very detailed. Analysis is performed using the SerDes Toolbox in the MATLAB tool suite. The simulation schematic used for the COM calculation is shown in Figure 2. The channel is calculated from the impulse response of the S-parameters shown in Figure 1.

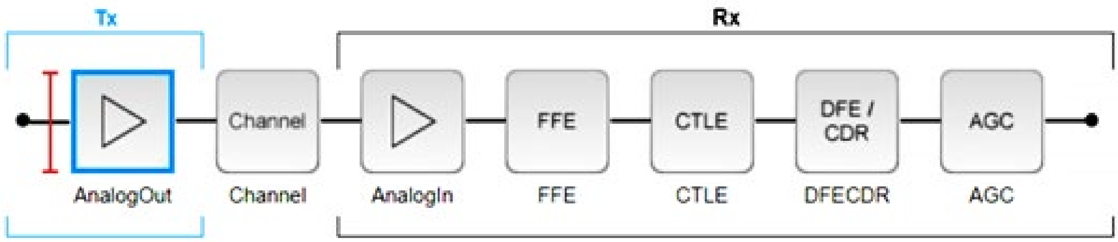


Figure 2. **Simulated schematic used for the calculation of Channel Operating Margin (COM)**

All equalization, FFE (feed forward equalizer), CTLE (continuous time linear equalization) and DFE (decision feedback equalizer) are placed in the receiver, and the optimal settings are calculated for each data rate. NRZ and PAM4 transmission are simulated for 25, 32, 50, 56 and 64G data rates. The simulations are performed using the StatEye methodology, which is based on calculating the eye diagram and bit error rate (BER) contours from the convolution of the impulse response of the transmission system with a random data stream. This method is much faster than using bit-by-bit simulation and allows for system optimization in just a few minutes.

Table 1 captures a summary of the results of these simulations, and Figures 3 through 7 show the statistical eye diagrams. PAM4 signaling has one-third of the spacing between levels when compared with NRZ, and as a result has a 9.5dB lower signal to noise ratio (SNR). As a rule of thumb, 3dB is added to this figure to account for other transmission impairments. Despite the reduced SNR, PAM4 has half the Nyquist frequency when compared to NRZ, and therefore experiences lower channel loss. In cases where the difference in channel loss is greater 12.5dB, PAM4 signaling will have an advantage. This is clearly seen in Table 1. At 25G, NRZ has a clear advantage. For 32G signaling, the values of COM are comparable. However, for data rates greater than 50G, PAM4 clearly has an advantage. For 64G signaling (PCIe Gen6), the COM for NRZ is 2.55dB, which is less than the required minimum of 3dB. At 64G, NRZ transmission is not feasible, and PAM4 is required.

Table 1: Comparison of Channel Operating Margin (COM) for NRZ and PAM4 Transmission through a 29.8” Backplane

Data Rate [Gbps]	COM for NRZ [dB]	COM for PAM4 [dB]	Channel Loss at Nyquist for NRZ [dB]	Channel Loss at Nyquist for PAM4 [dB]
25	15.49	13.63	19.1	11.1
32	12.50	11.91	24.2	13.5
50	5.66	7.81	42.2	19.1
56	3.80	6.71	57.6	21.5
64	2.55	4.54	48.4	24.2

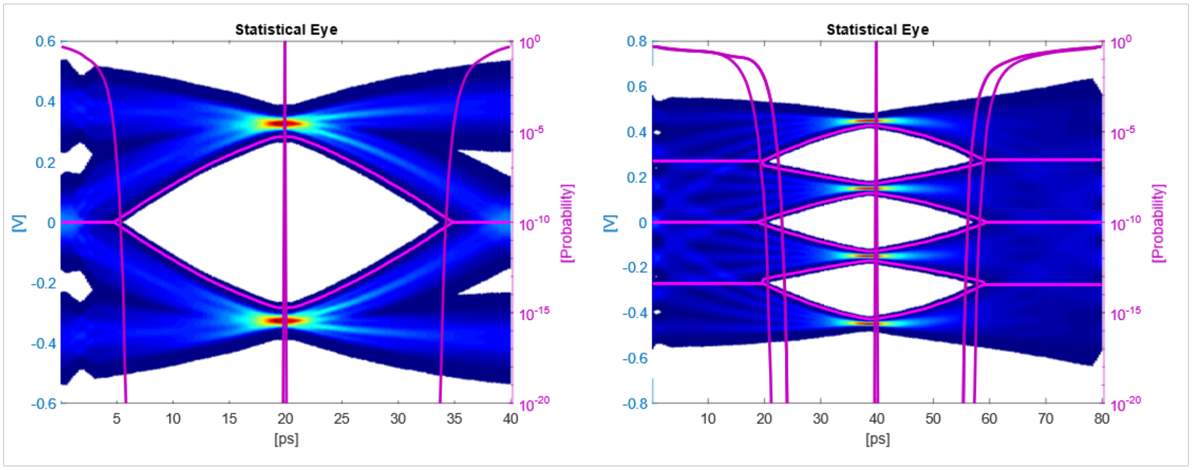


Figure 3. NRZ and PAM4 Eye Diagrams for 25Gbps Transmission. The difference in channel loss at the Nyquist frequency is 8dB, so NRZ transmission is advantageous.

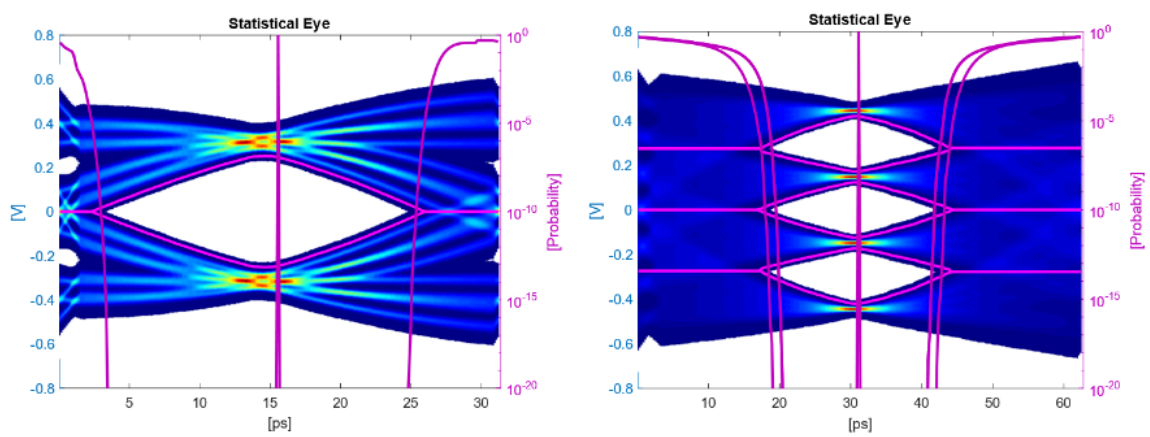


Figure 4. NRZ and PAM4 Eye Diagrams for 32Gbps Transmission. The difference in channel loss is 10.7dB, so NRZ and PAM4 transmission have comparable values of COM.

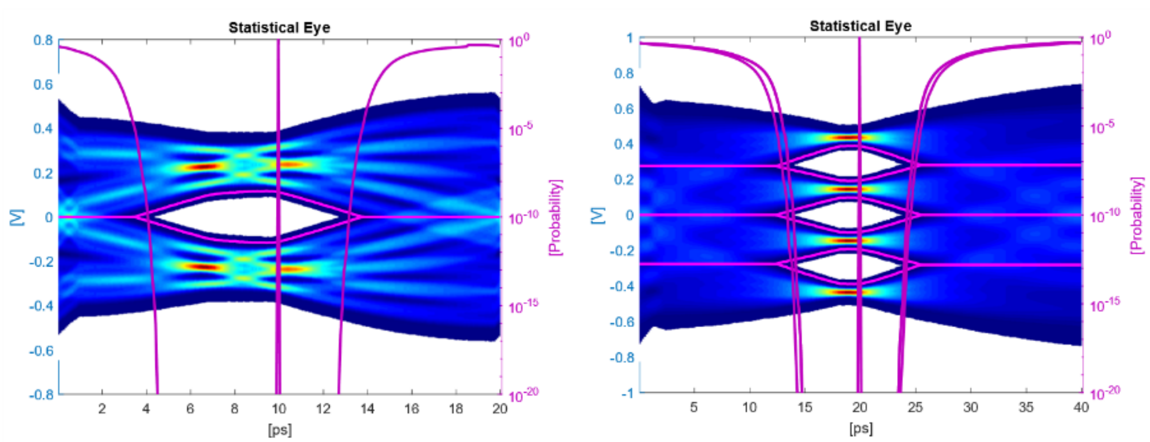


Figure 5. NRZ and PAM4 Eye Diagrams for 50Gbps Transmission. The difference in channel loss is 23.2dB, so PAM4 transmission is advantageous.

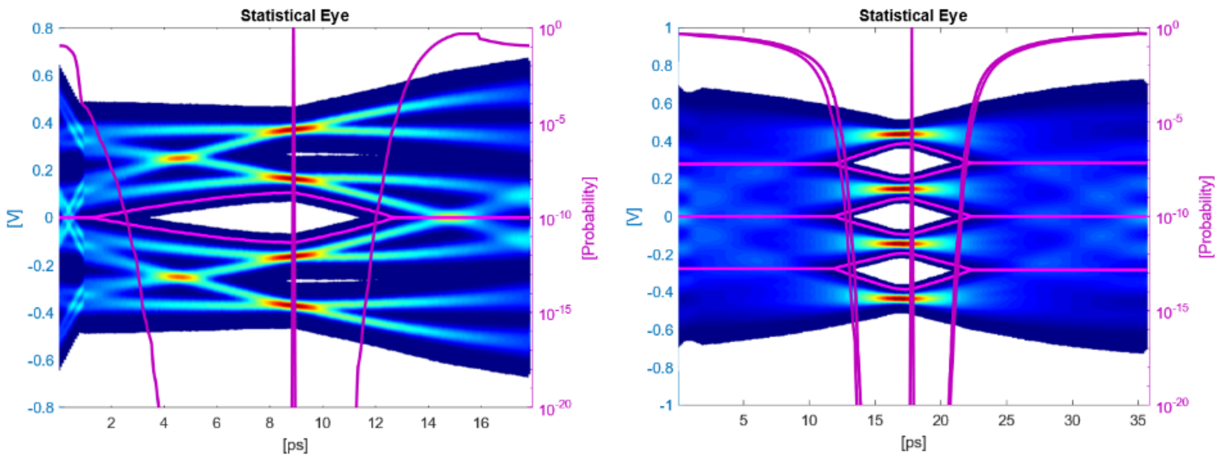


Figure 6. NRZ and PAM4 Eye Diagrams for 56Gbps Transmission. The difference in channel loss is 31.1dB, so PAM4 transmission is advantageous.

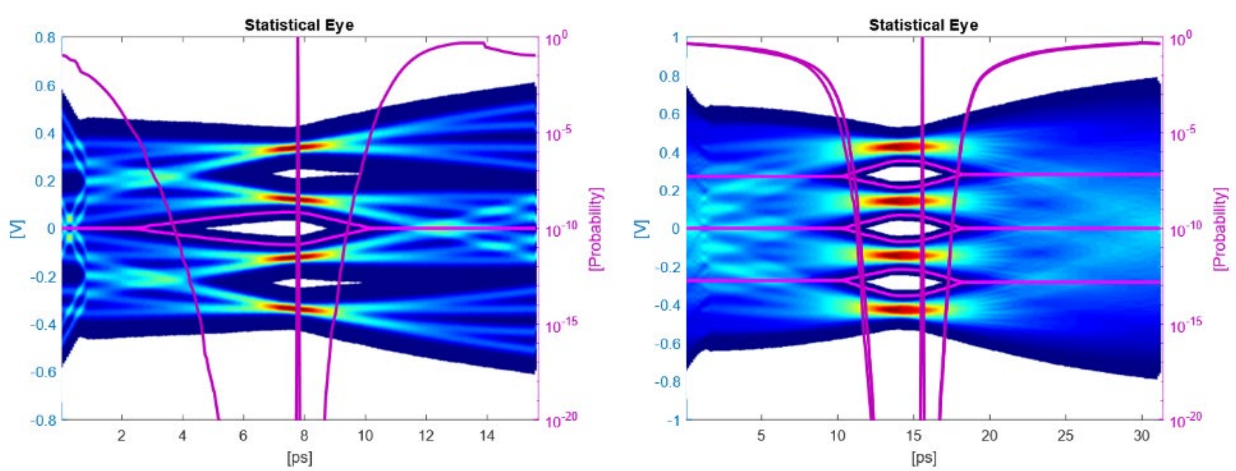


Figure 7. NRZ and PAM4 Eye Diagrams for 64Gbps Transmission. The difference in channel loss is 24.2dB, so PAM4 transmission is advantageous. In this case, the COM for NRZ is less than 3dB, so NRZ data transmission is not feasible for this channel.

Higher level modulation formats such as PAM4, are required for continued increase in serial data rates; however, this necessitates a change in SerDes architecture, in particular with the clock recovery circuit. This method was discussed in the first article in this series, in which an ADC-DSP SerDes architecture is required. A subsequent article will discuss ADC-DSP SerDes implementation.

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