PROJECT 1

EE654 - ELECTRONICS PACKAGING

ANAINA P (2024EEM1019)
ATHUL BABU (2024EEM1022)

March 16, 2025

The project is available on GitHub: project1.

The Figure 1 shows a 3D model of a copper interconnect in a stripline topology, designed and simulated using the HFSS field solver. The interconnect is embedded within a silicon dioxide dielectric material, providing controlled signal propagation. The structure consists of a central copper trace positioned between two conductive ground planes, forming a symmetric stripline configuration. Ports are assigned at four terminals to compute S-parameters over a frequency sweep of 1–10 GHz. The simulation captures signal transmission and reflection characteristics, providing insight into the interconnect's high-frequency performance.

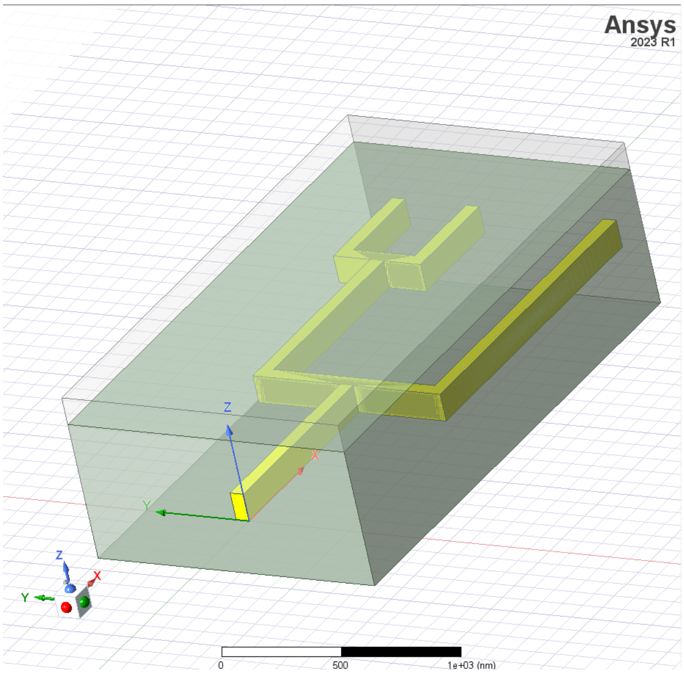

Figure 1: Model of the copper interconnect, surrounded by the dielectric and ground planes.

1 S- Parameter:

Figures 2, 3, 4, and 5 show the magnitude and phase variations of S_{11}, S_{21}, S_{31}, and S_{41} over frequency. The magnitude decreases with frequency due to increased dielectric and conductor losses, which result in higher signal attenuation at higher frequencies. Signal attenuation increases with frequency because of the skin effect, where higher frequencies cause current to concentrate near the conductor surface, increasing resistance and power dissipation. Additionally, dielectric losses rise with frequency due to polarization effects in the material. The phase also decreases as frequency increases due to the dispersive nature of the transmission medium, leading to phase delay accumulation over longer paths.

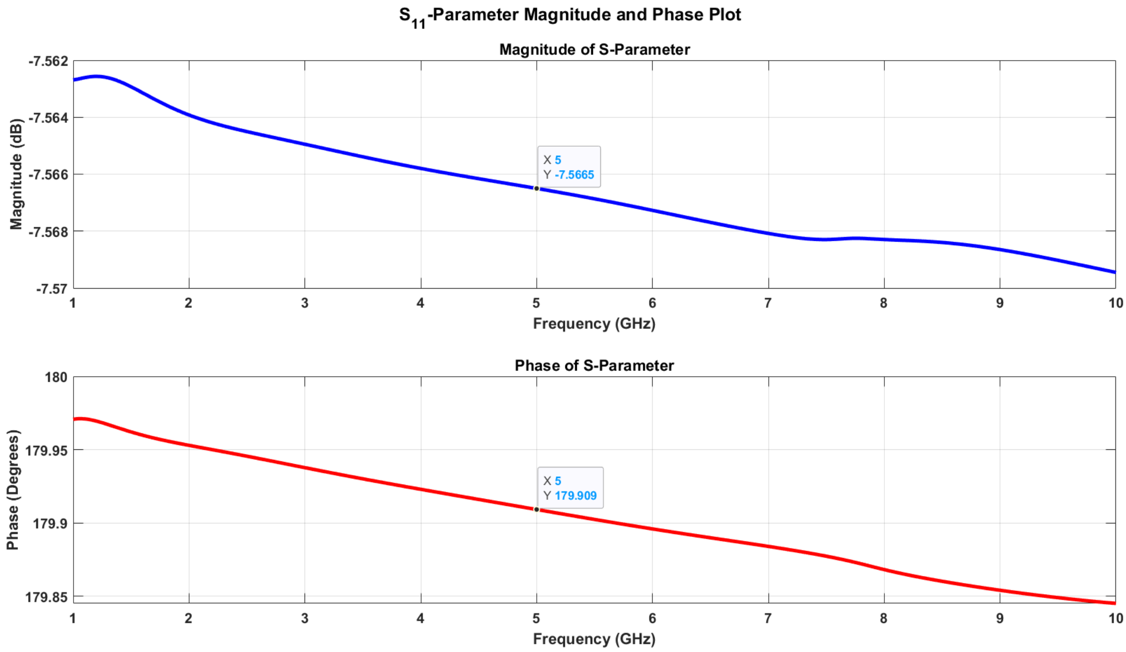

Figure 2: Magnitude and phase plot of S_{11} parameter

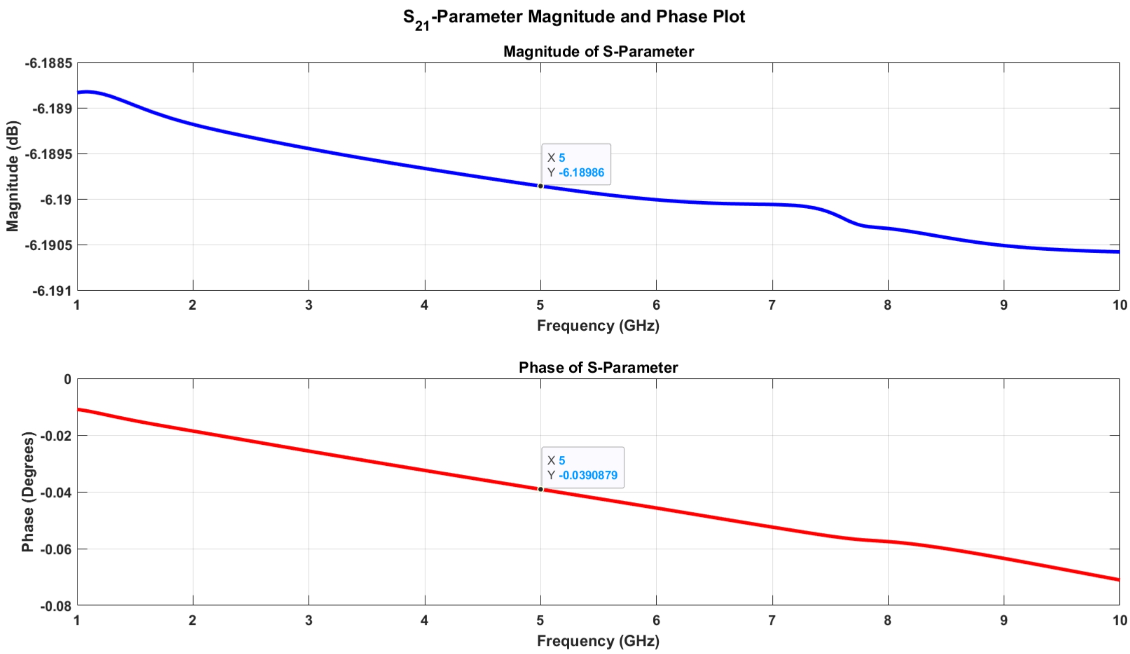

Figure 3: Magnitude and phase plot of S_{21} parameter

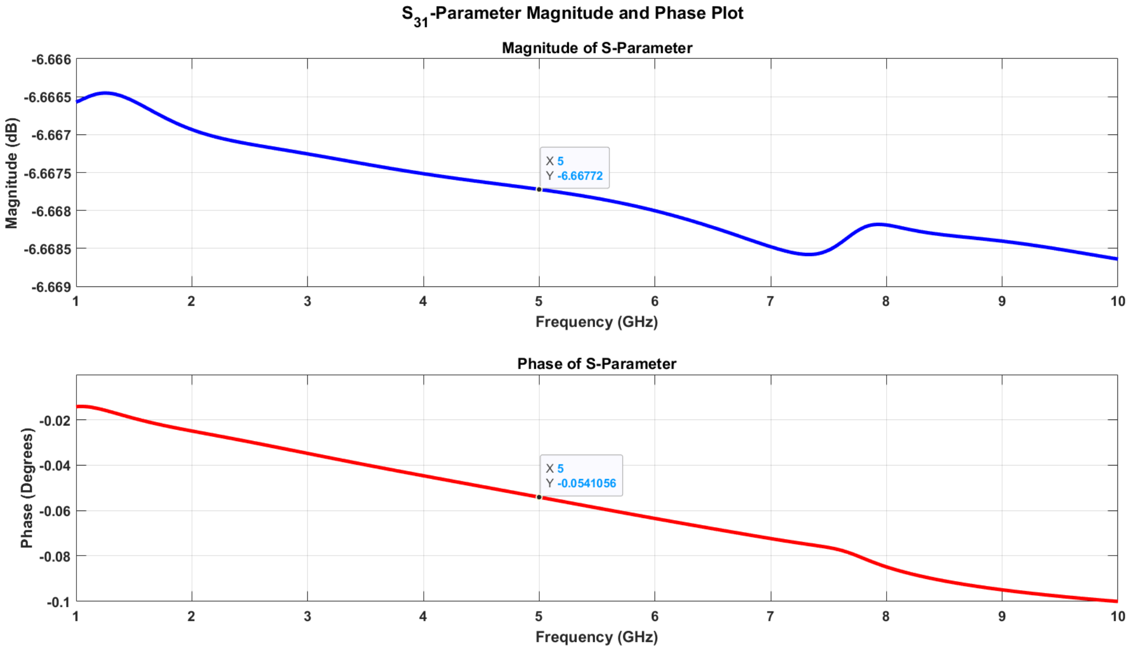

Figure 4: Magnitude and phase plot of S_{31} parameter

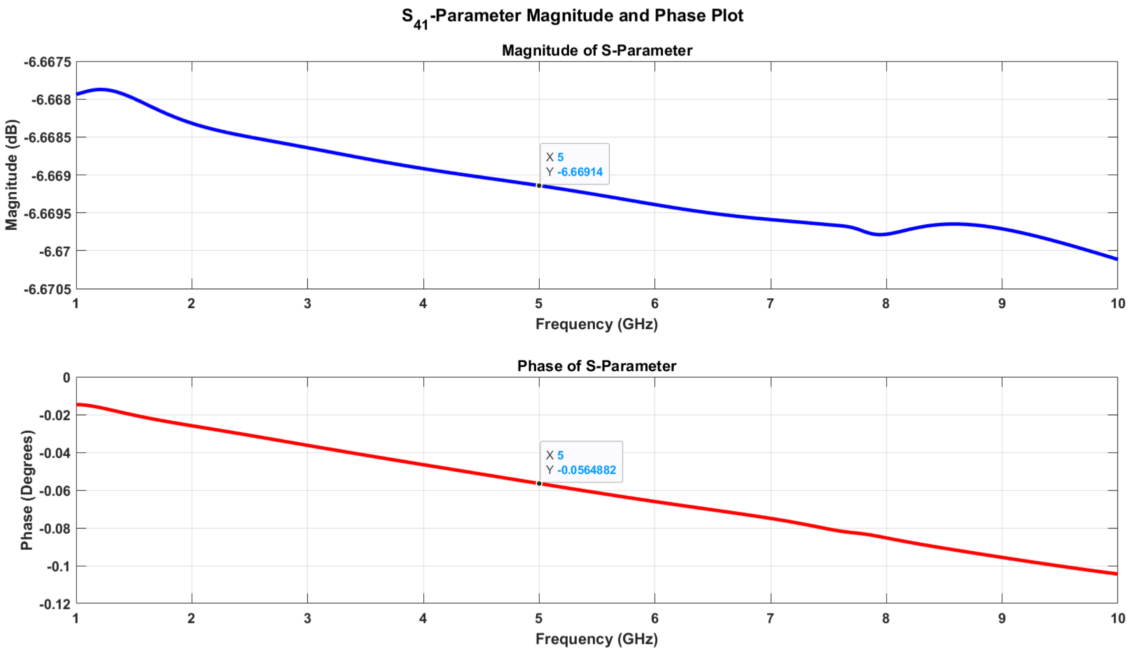

Figure 5: Magnitude and phase plot of S_{41} parameter

- The S-parameter results provide insight into the signal distribution and losses within the structure. The reflection coefficient, S_{11}, has a magnitude of -7.57 dB, indicating that a small fraction of the input signal is reflected due to impedance mismatches at Terminal 1. This suggests a moderate level of impedance matching, with most of the signal transmitted forward.
- The transmission coefficients, S_{21}, S_{31}, and S_{41}, represent the fraction of the input signal that reaches Terminals 2, 3, and 4, respectively. S_{21} has the highest magnitude

(-6.19 dB), indicating that Terminal 2 receives the largest portion of the transmitted signal. This is expected, as Terminal 2 is positioned along the main transmission path, experiencing lower splitting losses.

- On the other hand, S_{31} and S_{41} have slightly lower magnitudes (-6.67 dB), as they correspond to terminals located in the branched section of the structure. The reduction in magnitude is due to signal splitting, additional transmission path losses, and potential impedance mismatches at the branching point.
- S_{11} has a phase of approximately 179.9°, indicating that the reflected signal is nearly out of phase with the incident signal. This suggests that the impedance mismatch at Terminal 1 causes significant phase inversion upon reflection.
- S_{21} has a phase of -0.0391°, meaning that the signal reaching Terminal 2 experiences minimal phase shift. Since Terminal 2 is directly along the main transmission path, the signal maintains its original phase with negligible delay.
- S_{31} and S_{41} have phase values of -0.0541° and -0.0565°, respectively. These slightly more negative values indicate minor additional delays due to the longer path lengths and potential impedance mismatches at the branching junction. The small negative values suggest that the signals at Terminals 3 and 4 are slightly delayed compared to the signal at Terminal 2, which aligns with the physical structure.

S-Parameter	**Magnitude at 5 GHz (dB)**	**Phase at 5 GHz (degree)**
S_{11}	-7.5665	179.909
S_{21}	-6.1899	-0.0391
S_{31}	-6.6677	-0.0541
S_{41}	-6.6691	-0.0565

Table 1: Comparison of S-Parameter Magnitudes and phases at 5 GHz

2 Eye Diagram:

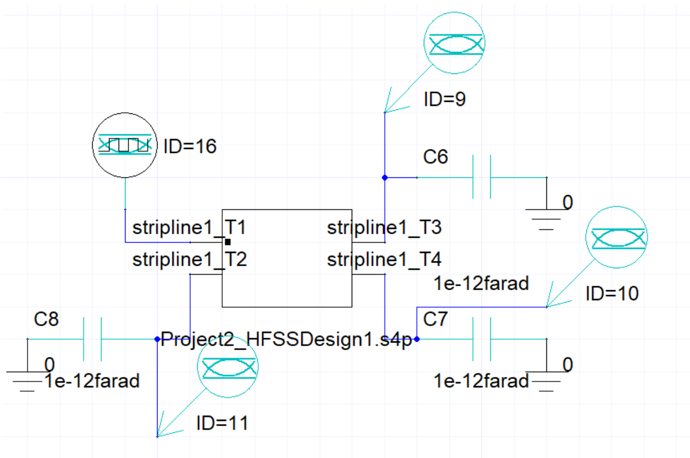

Figure 6: Circuit setup for simulating eye diagrams with a PRBS input source

The input source used in the simulation is a Pseudo-Random Binary Sequence (PRBS), which generates a random bit stream to emulate real-world data transmission. PRBS helps analyze signal integrity and assess the impact of inter-symbol interference (ISI) on the eye diagram.

- Eye height represents the voltage margin available for signal detection, where a larger value indicates better noise immunity and improved signal integrity.
- Eye width defines the time duration in which the signal can be accurately sampled, with a wider width signifying reduced timing jitter and better data recovery.
- Eye SNR ratio measures the quality of the signal relative to noise, with a higher ratio ensuring clearer distinction between logic levels.
- Eye-opening factor quantifies the overall openness of the eye diagram, considering both height and width, where a higher value suggests improved signal performance and a lower bit error rate.

2.1 For 1 Gbps data rate:

Figure 7 shows the eye diagram at Terminal 2 for 1 Gbps, while Table 2 presents the corresponding eye diagram parameters, including eye height, eye width, eye SNR ratio, and eye-opening factor, which help evaluate the signal integrity and data transmission quality.

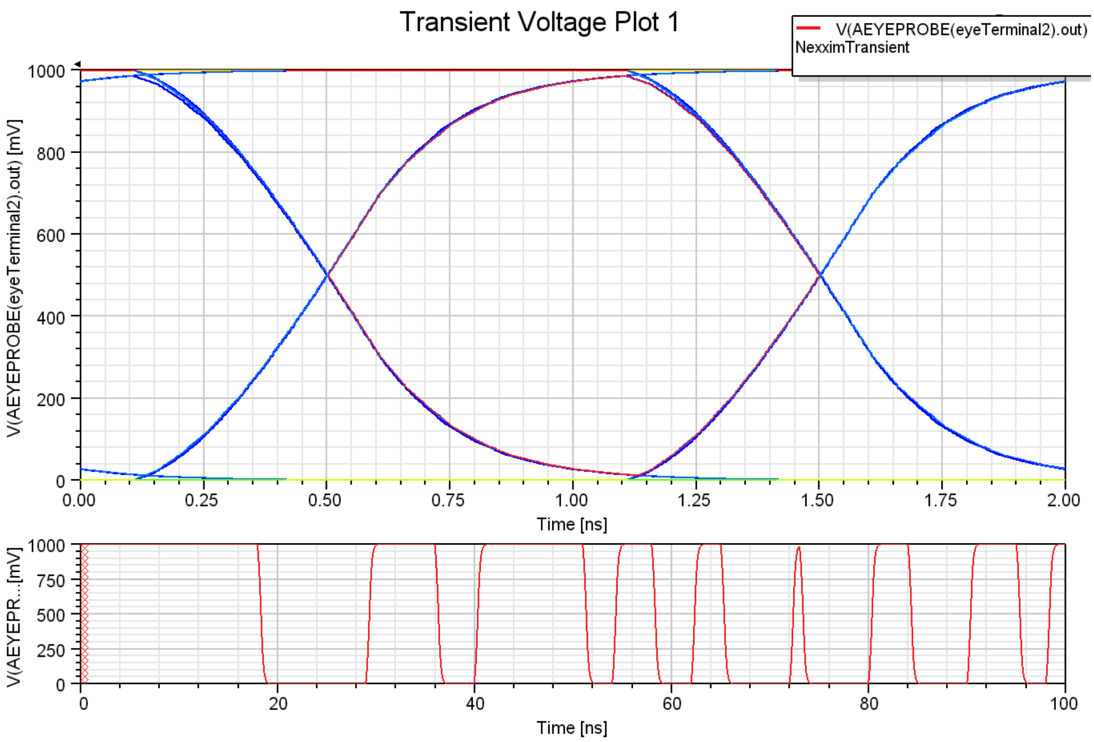

Figure 7: Eye diagram plotted at terminal 2 for 1 Gbps

Parameter	Value
Eye Height (mV)	911.433
Eye Width (ns)	0.9889
Eye SNR Ratio (SI)	39.2729
Eye-Opening Factor (SI)	0.9745

Table 2: Eye diagram parameters at Terminal 2 for 1 Gbps

Figures 8 and 9 illustrate the eye diagrams at Terminals 3 and 4 for a data rate of 1 Gbps, providing insights into signal integrity at these locations. The corresponding parameters, presented in Tables 3 and 4, include eye height, eye width, eye SNR ratio, and eye-opening factor, which help assess the quality of data transmission and overall signal performance at these terminals.

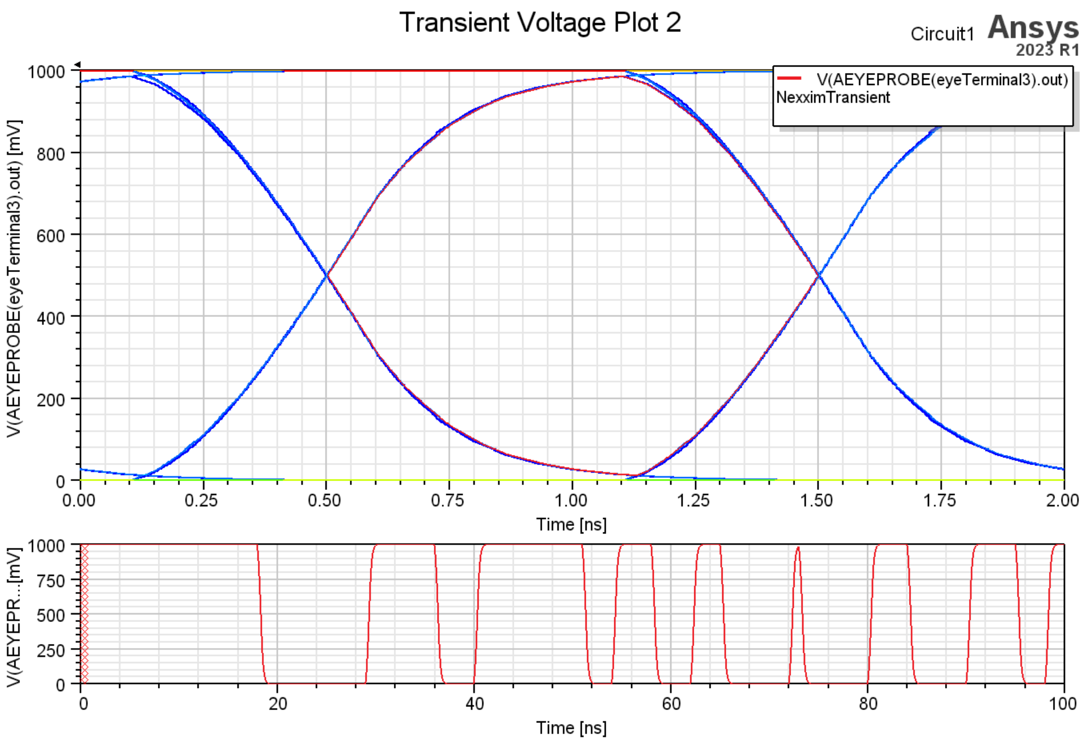

Figure 8: Eye diagram plotted at terminal 3 for 1 Gbps

Parameter	Value
Eye Height (mV)	912.477
Eye Width (ns)	0.989
Eye SNR Ratio (SI)	39.75
Eye-Opening Factor (SI)	0.9748

Table 3: Eye diagram parameters at Terminal 3 for 1 Gbps

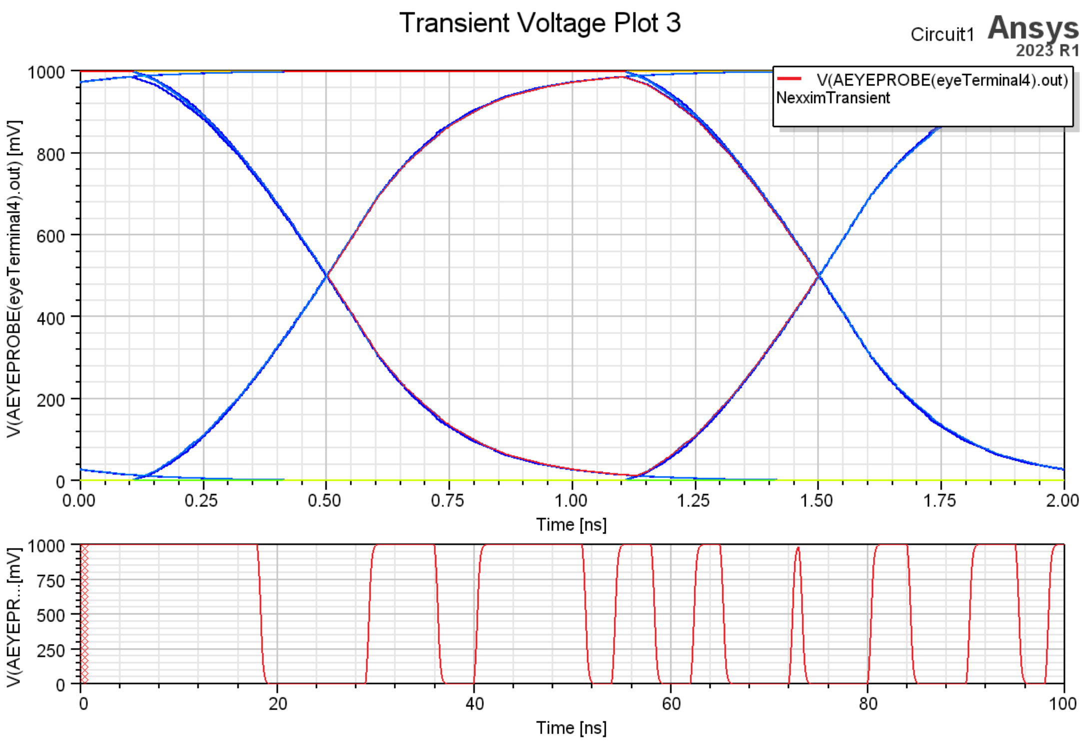

Figure 9: Eye diagram plotted at terminal 4 for 1 Gbps

Parameter	Value
Eye Height (mV)	912.476
Eye Width (ns)	0.989
Eye SNR Ratio (SI)	39.75
Eye-Opening Factor (SI)	0.9748

Table 4: Eye diagram parameters at Terminal 4 for 1 Gbps

2.2 For 10 Gbps data rate:

The stop time for plotting an eye diagram should typically be long enough to capture multiple periods of the signal to generate a statistically meaningful pattern. A good rule of thumb is:

$$T_{\text{stop}} \geq 100 \times T_{\text{bit}}$$

where:

- T_{stop} = Total simulation stop time
- T_{bit} = Bit period

For a 10 Gbps signal with a unit interval of 100 ps, a rise or fall time of 500 ps is too slow since it exceeds the bit period, making 500 ps unsuitable for high-speed operation. So a rise/fall time of 50 ps is considered for the simulation of 10 Gbps data rate.

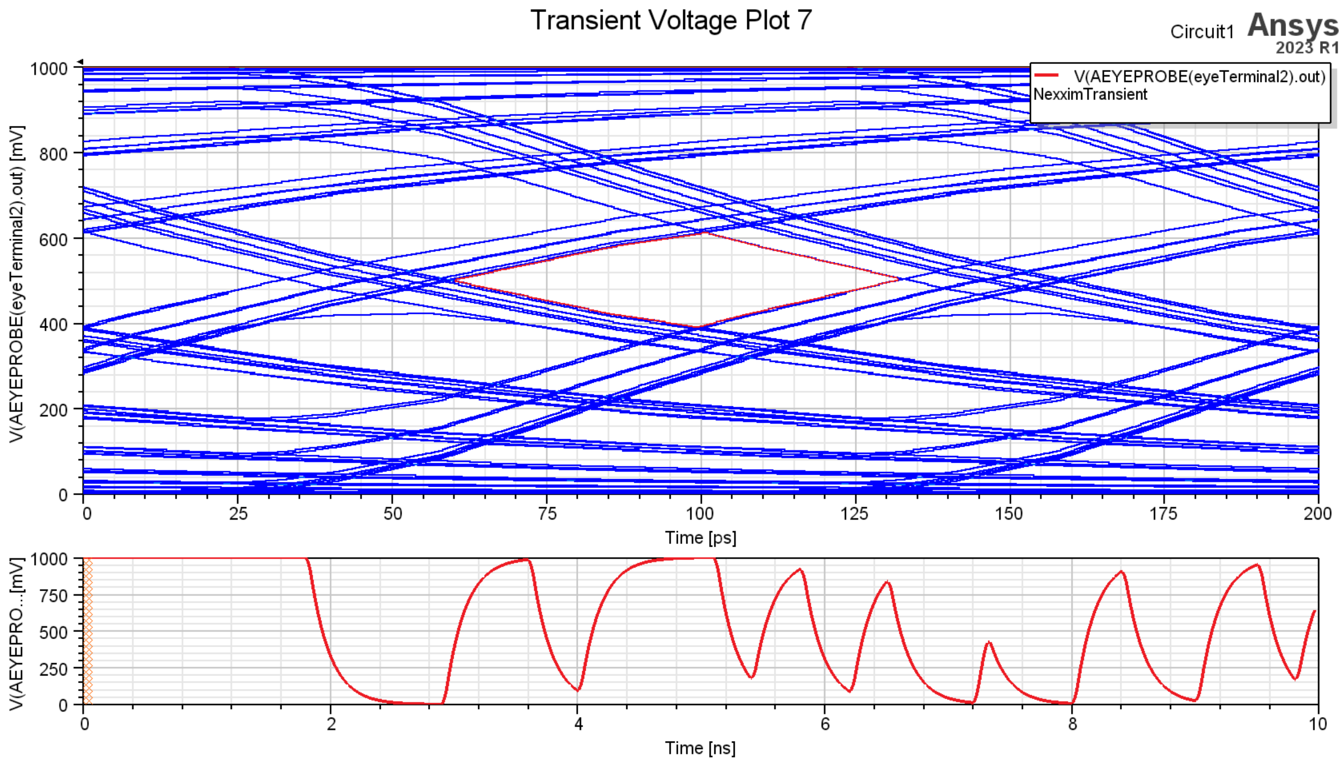

Figure 10: Eye diagram plotted at terminal 2 for 10 Gbps

Figures 10, 11, and 12 illustrate the eye diagrams at Terminals 2, 3, and 4 for a data rate of 10 Gbps, providing insight into signal integrity at higher transmission speeds. The corresponding parameters, presented in Tables 5, 6, and 7, show a notable reduction in eye height and width compared to lower data rates, indicating increased signal degradation. The lower eye SNR ratio and eye-opening factor across all terminals suggest higher noise levels, reduced voltage margins, and timing distortions, which can lead to increased bit errors. These results highlight the impact of interconnect losses and jitter on high-speed data transmission, emphasizing the need for signal integrity optimization techniques.

Parameter	Value
Eye Height (mV)	217.755
Eye Width (ps)	44.403
Eye SNR Ratio (SI)	2.35
Eye-Opening Factor (SI)	0.5745

Table 5: Eye diagram parameters at Terminal 2 for 10 Gbps

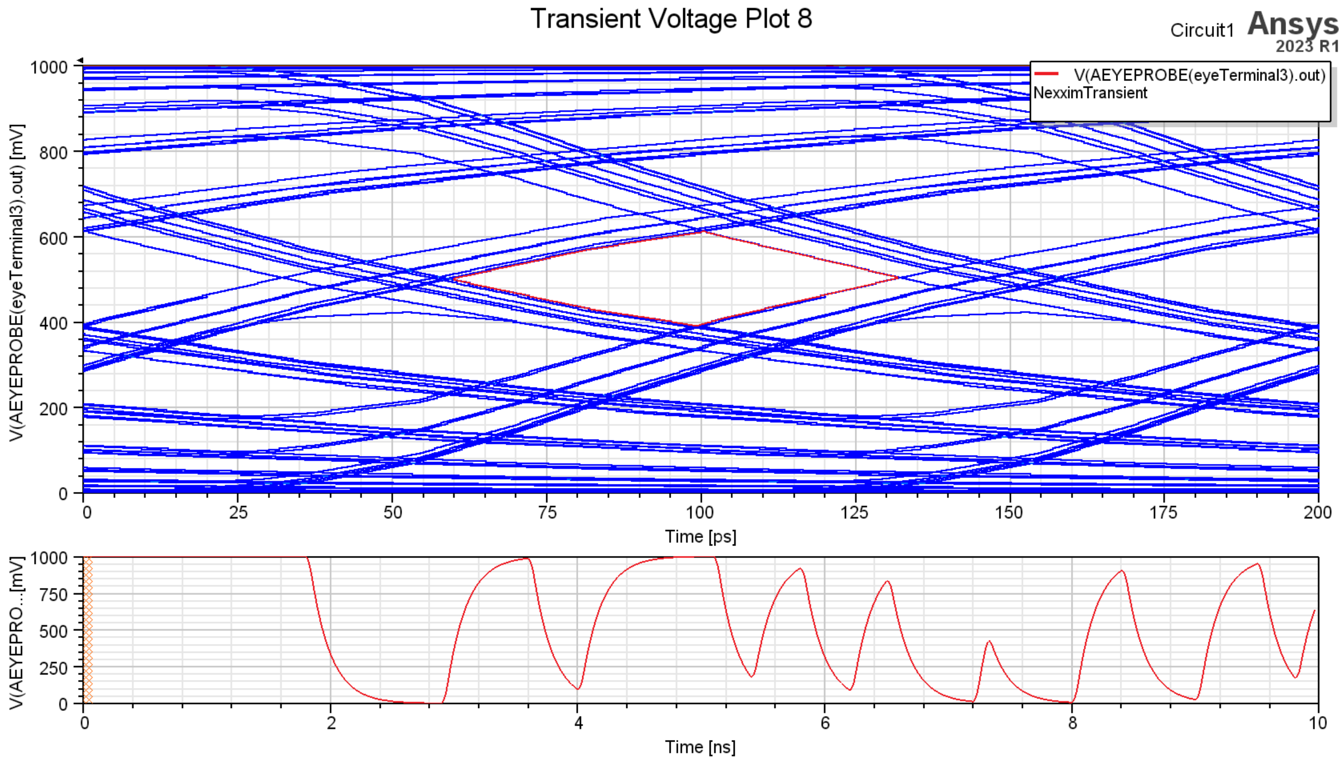

Figure 11: Eye diagram plotted at terminal 3 for 10 Gbps

Parameter	Value
Eye Height (mV)	215.752
Eye Width (ps)	44.288
Eye SNR Ratio (SI)	2.346
Eye-Opening Factor (SI)	0.5738

Table 6: Eye diagram parameters at Terminal 3 for 10 Gbps

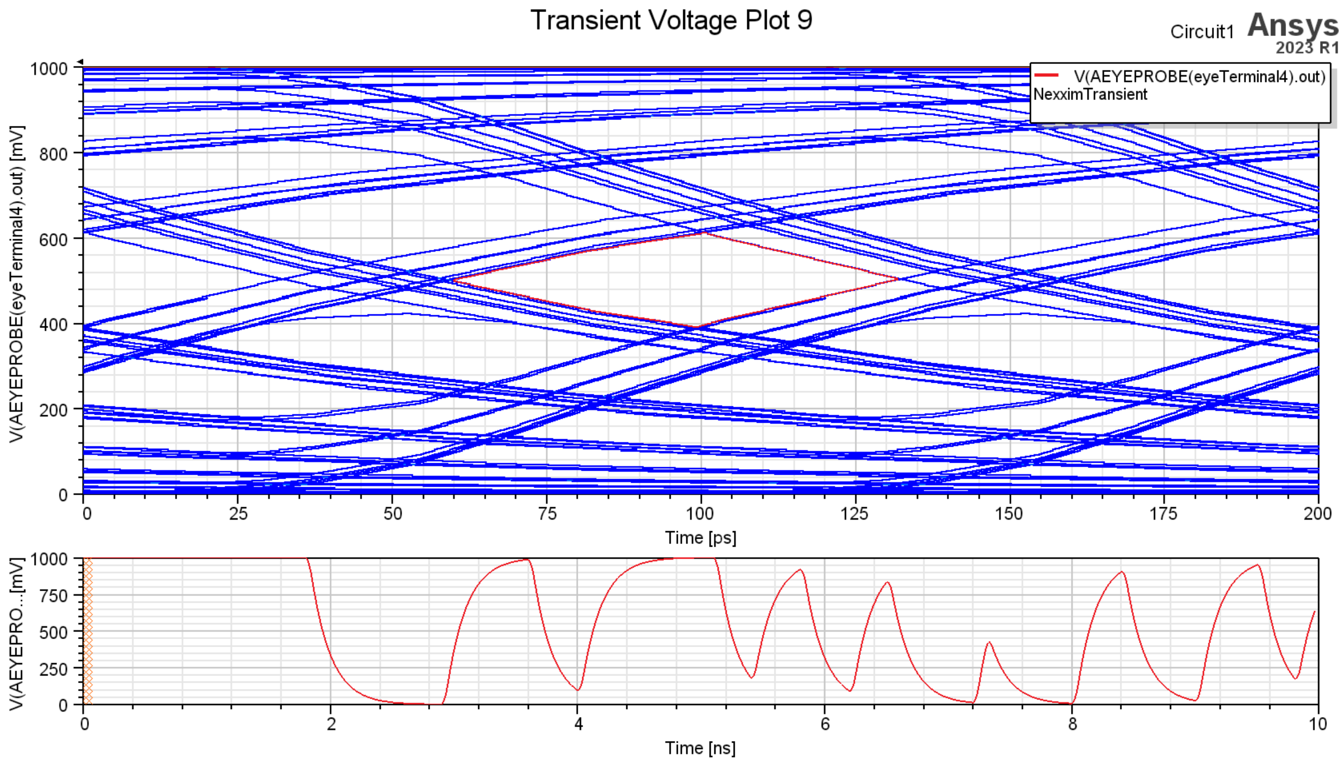

Figure 12: Eye diagram plotted at terminal 4 for 10 Gbps

Parameter	**Value**
Eye Height (mV)	215.752
Eye Width (ps)	43.928
Eye SNR Ratio (SI)	2.346
Eye-Opening Factor (SI)	0.5737

Table 7: Eye diagram parameters at Terminal 4 for 10 Gbps

- At 1 Gbps, the eye diagrams exhibit larger eye height and width, indicating better signal integrity with lower noise interference and minimal distortion. The higher eye SNR ratio and eye-opening factor confirm stable data transmission with reduced bit errors.
- At 10 Gbps, a significant reduction in eye height and width is observed, leading to increased signal degradation. The lower eye SNR ratio and eye-opening factor indicate higher noise levels and reduced timing margins, making the system more susceptible to bit errors.
- As data rate increases, the signal experiences higher attenuation due to skin effect and dielectric losses, which cause greater amplitude reduction at higher frequencies.
- Higher data rates lead to increased inter-symbol interference (ISI), where signal pulses spread over multiple bit periods, causing distortion and reduced eye opening.

- The increased frequency content in high-speed signals results in greater dispersion effects, where different frequency components of the signal propagate at different velocities, further distorting the waveform.

- The differences between 1 Gbps and 10 Gbps emphasize the need for signal integrity enhancements such as equalization, advanced filtering techniques, and optimized interconnect design to mitigate losses and maintain reliable high-speed data transmission.