



The Programmable Solutions Company®

Stratix to DDR-II Memory Devices Interface Analysis

High Speed / End Applications Team
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Stratix to DDR-II Memory Interfaces Analysis

Revision History

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1 Introduction

This document presents the results of the simulation done for the SSTL-II I/O standard used in Double Data Rate (DDR-II) memory device interfaces designed by the Altera High Speed I/O / End Applications Team in San Diego. This document also recommends termination schemes based on the review of the simulation results. Agilent ADS is used for simulation and IBIS models of Stratix/Stratix GX devices and Micron DDR-II memories are used.

1.1 Background

The new DDR-II memory shows the a good acceptance in the industry and will replace its predecessor DDR-I which is very popular memory. Several boards that feature DDR memories are being designed both inside and outside Altera. Since DDR-II uses both the rising and falling edges of the clock, timing margin is reduced compared to traditional single-edge clocking systems. Thus it is important to have good signal integrity on the board. This, in turn, implies the termination scheme needs to be good to avoid reflections. The JEDEC specification for the SSTL-II standard (used by DDR-II memory interface) only provides general guidelines which may not always be the best choice to implement in a real system. Hence a need for a document which compares several termination schemes exists. This document aims to fulfill that need.

1.2 Simulation Overview

Simulations are performed using the ADS tool from Agilent. IBIS models are used to model the Stratix device and the Micron DDR memory device. The memory device used is DDR-II x16 SDRAM devices (part number Micron MT47H16M16FB). Simulation frequency is 200 MHz or 400 Mega Transfers per second. Simulation for both write and read cycles are performed for data bits since the bus is bidirectional. For the address bus, simulation for only the write direction is needed since the bus is unidirectional. The data is a point to point interface, while the address is a point to multipoint interface. This is because each address bit is serving more than one memory device.

The total routing length from the FPGA to the memory device is set to 6.0" which is a conservative estimate in the majority of systems.

The placement of parallel termination resistors at the ends of the line can be achieved in three modes: fly-by, non-fly-by and ODT (On Device Termination). In fly-by mode, the resistor is at the end of the transmission line and the connection to the device pin is made through a short stub off the transmission line. In non-fly-by configuration, the transmission line ends at the device pin, and the resistor is placed before the end of the transmission line is reached. In the ODT configuration, the termination relays inside the device and have two different values, 75 Ohms and 150 Ohms. For configurations which have parallel resistors at the source/destination pins, fly-by and non-fly-by topologies are achievable while laying out the board.

Figure 1-1 Non Fly-By (top), Fly-By (middle) and on device termination ODT (bottom) placement of parallel termination resistor. Figure 1-1 shows the fly-by versus non-fly-by placement

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of parallel resistors. In general fly-by placement is preferred over non-fly-by because the distance from the pin to the resistor is not very critical for fly-by placement. In the cases that follow, both fly-by and non-fly-by simulations are performed as much as possible.

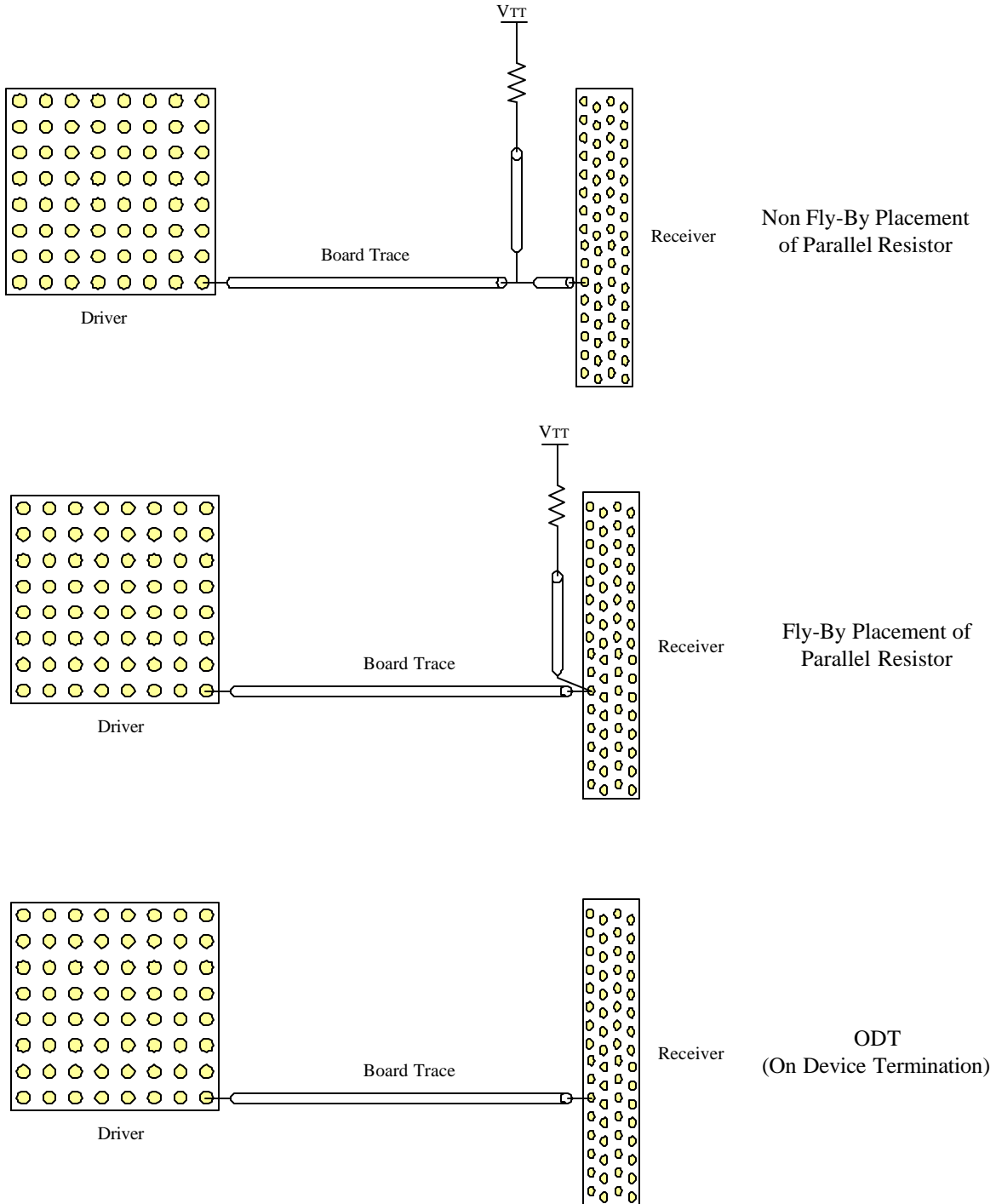


Figure 1-1 Non Fly-By (top), Fly-By (middle) and on device termination ODT (bottom) placement of parallel termination resistor.

2 Simulation Results

This section presents the results of the simulation for the data, address and clock interfaces using a variety of configurations.

2.1.1 Dual Series/Dual Parallel Termination (Fly-By)

This topology, depicted in Figure 2-1, requires two series resistors and two parallel resistors. The series resistors are needed to match the output impedance of the driver to the transmission line and the parallel resistor is the actual termination of the transmission line. The performance of this topology shows a similar response between the read and the write cycles due to its symmetric construction. The small differences between the read and write cycles are due to the differences in the driver/receiver characteristics models.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-2 Figure 2-3 and Figure 2-4 respectively. Looking at the waveforms, it is clear that the signal integrity is very good, however, the signal suffers from some attenuation due to the series resistors.

The eye closure at the Stratix during the read cycle is about 0.912 and the eye closure at the DDR-II during the write cycle is 0.922. These levels are good for SSTL-II and this scheme would work fine for the read and write cycles.

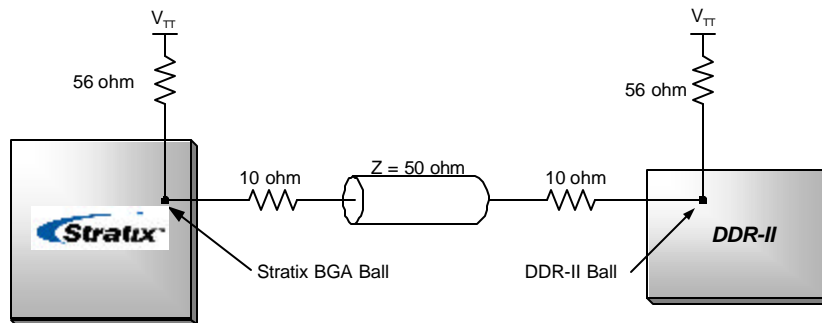


Figure 2-1 Dual Series/Dual Parallel Termination, Fly-By.

In order to understand the eye analysis plots some definition are required.

Eye Amplitude.- The “1” level mean subtracted from the “0” level mean.

Eye Height.- Is the inner bound of the eye.

Eye Closure.- Is the ratio of the Eye Height to the Eye Amplitude.

Eye Closure (dB).- $20\log(\text{Eye Closure})$

The jitter analysis plots should be read on the left scale the eye amplitude, on the right scale the frequency (number of hits) between the reference levels “A” and “B” for the read cycles, “D” and “E” for the write cycles. The cursors C1, C2, F1 and F2 set the boundaries for the total jitter during the read and write cycles respectively.

From the jitter analysis plots the total jitter during the write cycle is 83.3 pS and the total jitter during the red cycle is 100pS.

Stratix to DDR-II Memory Interfaces Analysis

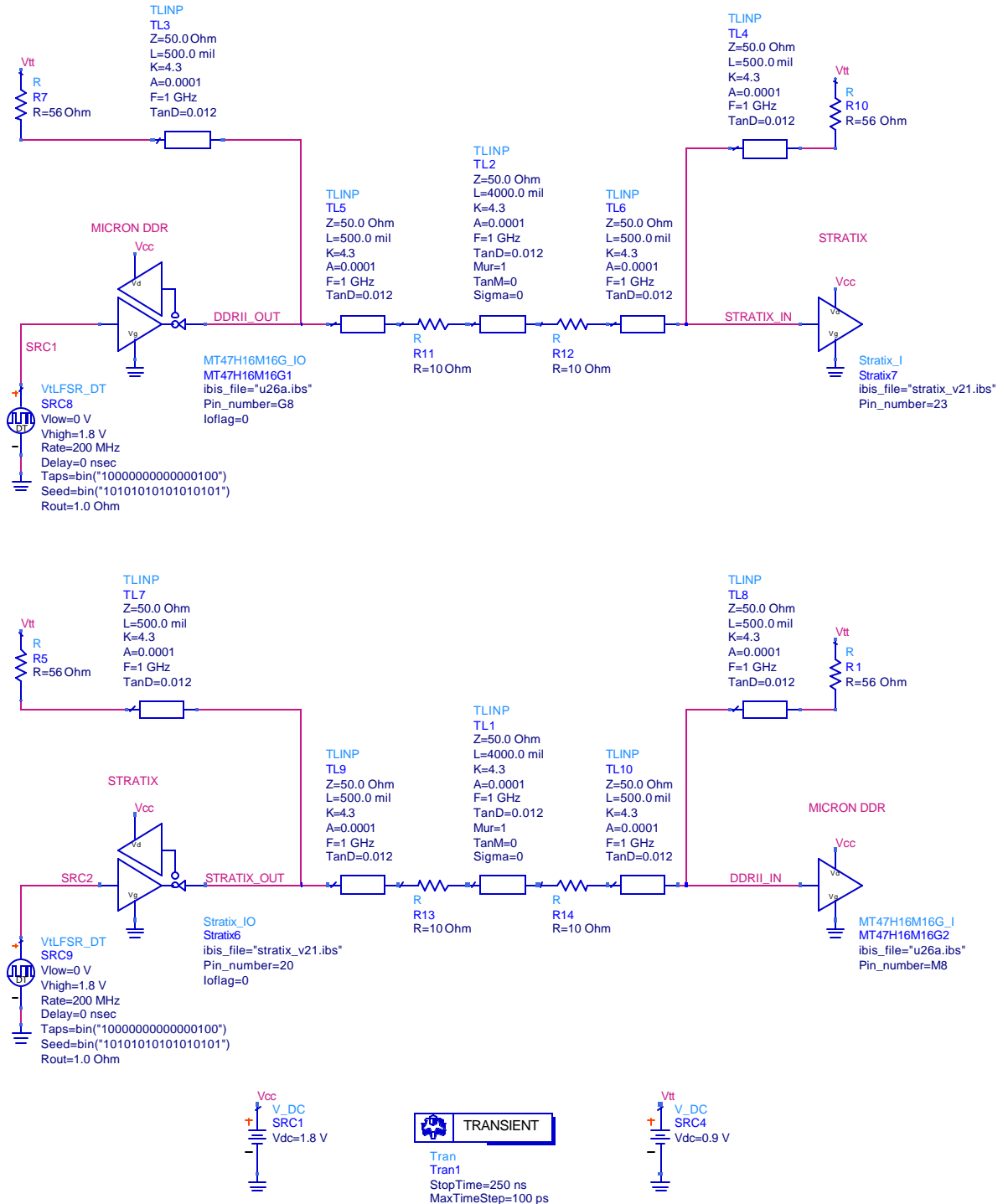


Figure 2-2 Dual Series/Dual Parallel Termination Simulation Setup (Fly-By).

Stratix to DDR-II Memory Interfaces Analysis

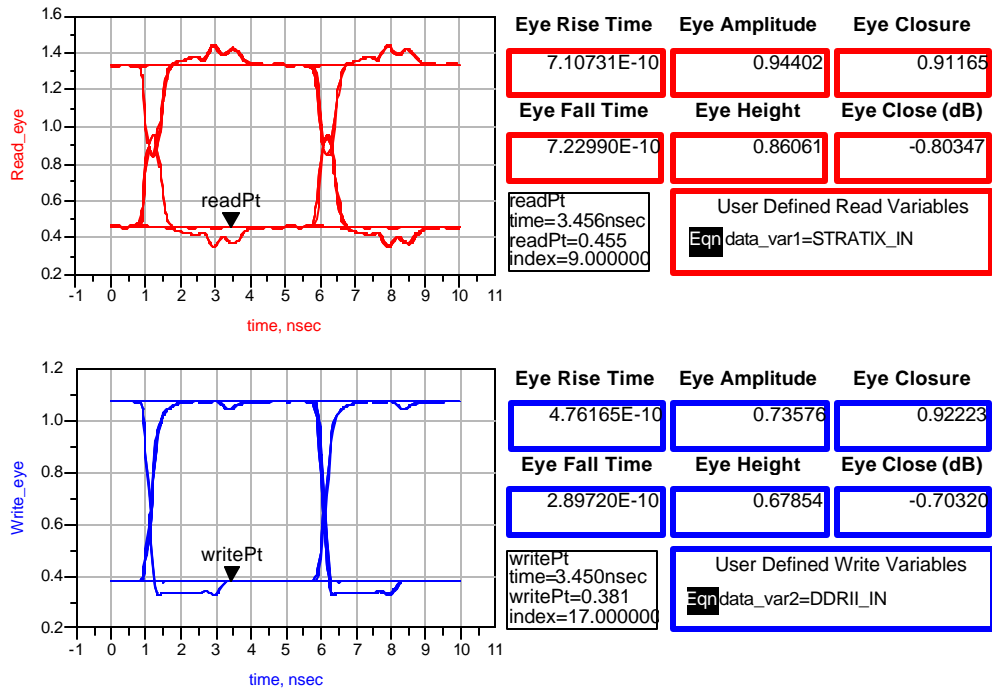


Figure 2-3 Dual Series/Dual Parallel Eye analysis Fly-By.

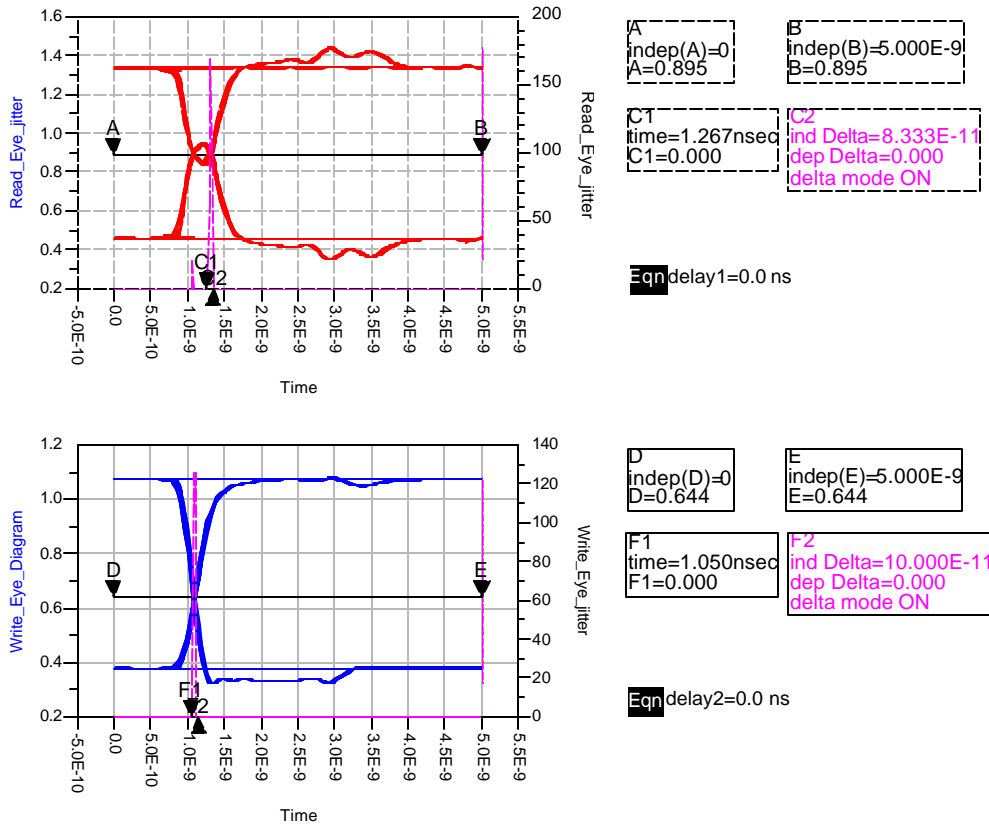


Figure 2-4 Dual Series/Dual Parallel Jitter Analysis Fly-By.

2.1.2 Dual Series/Dual Parallel Termination (Non-Fly-By)

This topology, depicted in Figure 2-5, requires two series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-6, Figure 2-7 and Figure 2-8 respectively. Looking at the waveforms, it is clear that the signal integrity is good, however, the signal suffers from the effects of a high impedance (open stub) at the DDR-II side during the write cycles and at the Stratix side during the read cycle. These open stubs (500 mils in simulation) represent an unterminated system which shows some degree of reflections during each cycle that creates an standing wave. This standing wave could be additive or subtractive depending on the delay and/or location of the discontinuity. The eye closure at the Stratix during the read is 0.895 and at the DDR-II during the write cycle is 0.927 respectively. The performances of this topology will warranties the functionality of the link during the read and write cycles.

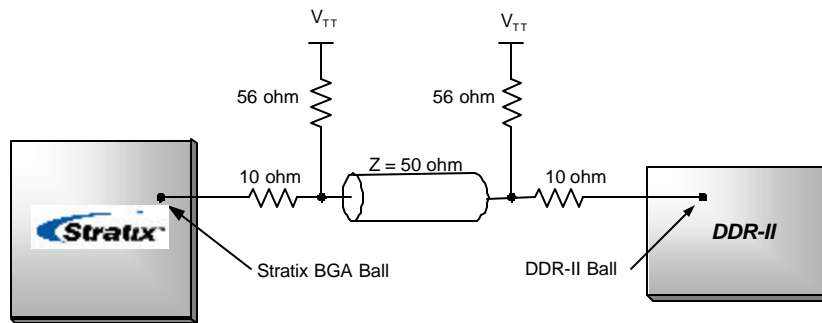


Figure 2-5 Dual Series/Dual Parallel Termination, Non-Fly-By.

Stratix to DDR-II Memory Interfaces Analysis

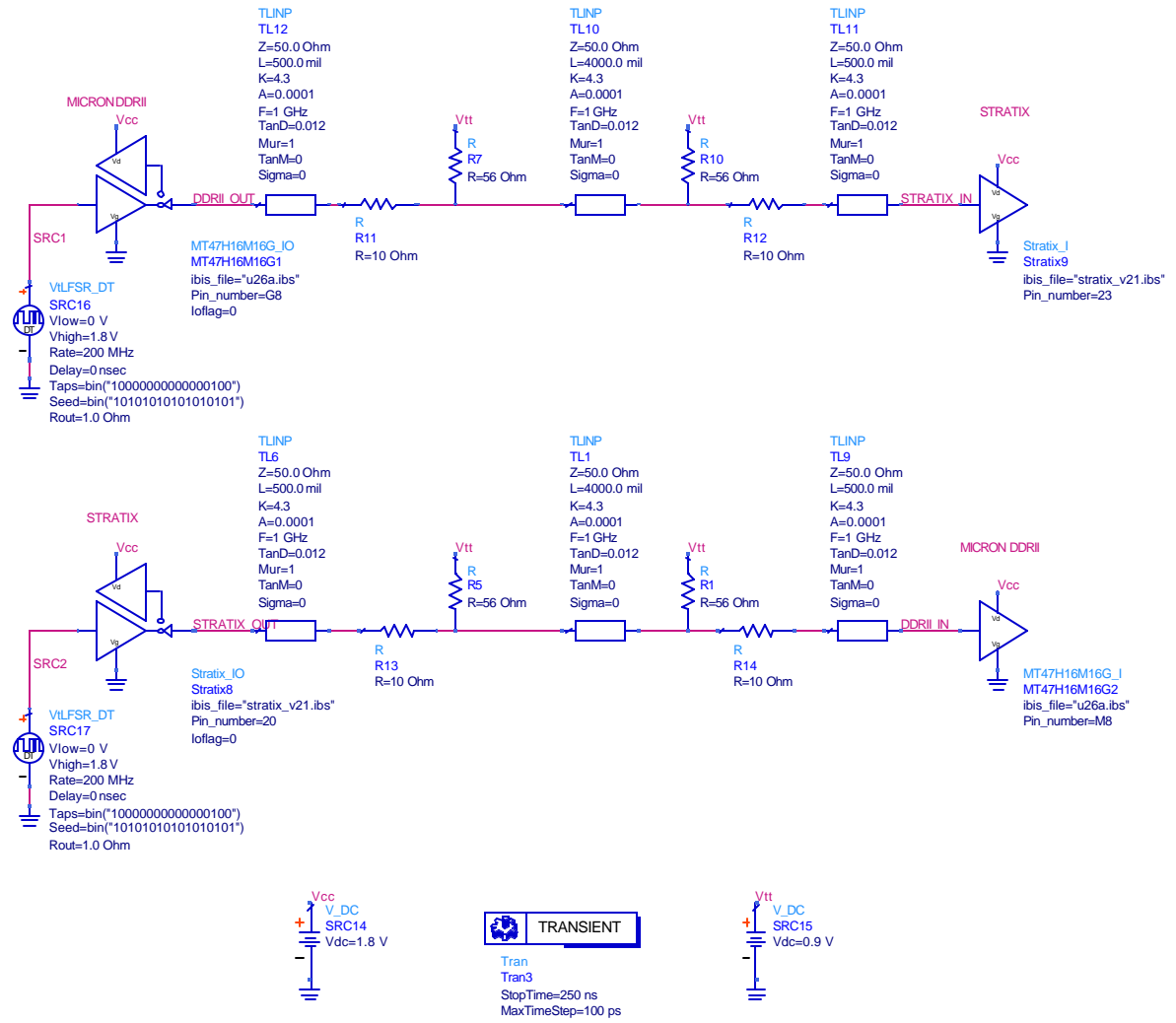


Figure 2-6 Dual Series/Dual Parallel Termination Simulation Setup Read/Write Cycles, Non Fly-By.

Stratix to DDR-II Memory Interfaces Analysis

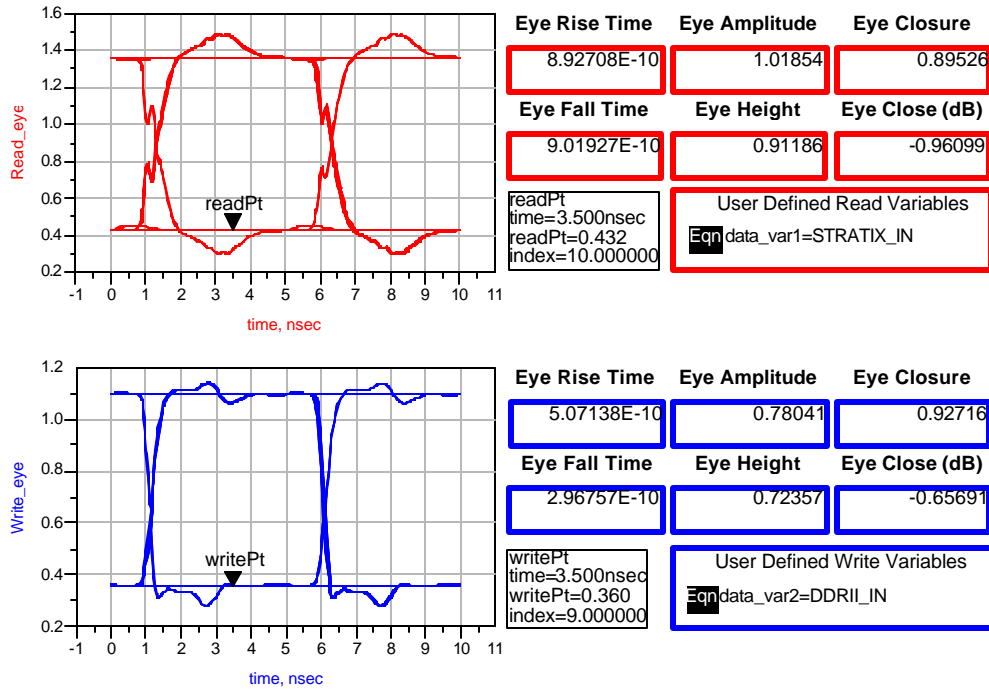


Figure 2-7 Dual Series/Dual Parallel Termination Simulation Eye Analysis, Non Fly-By

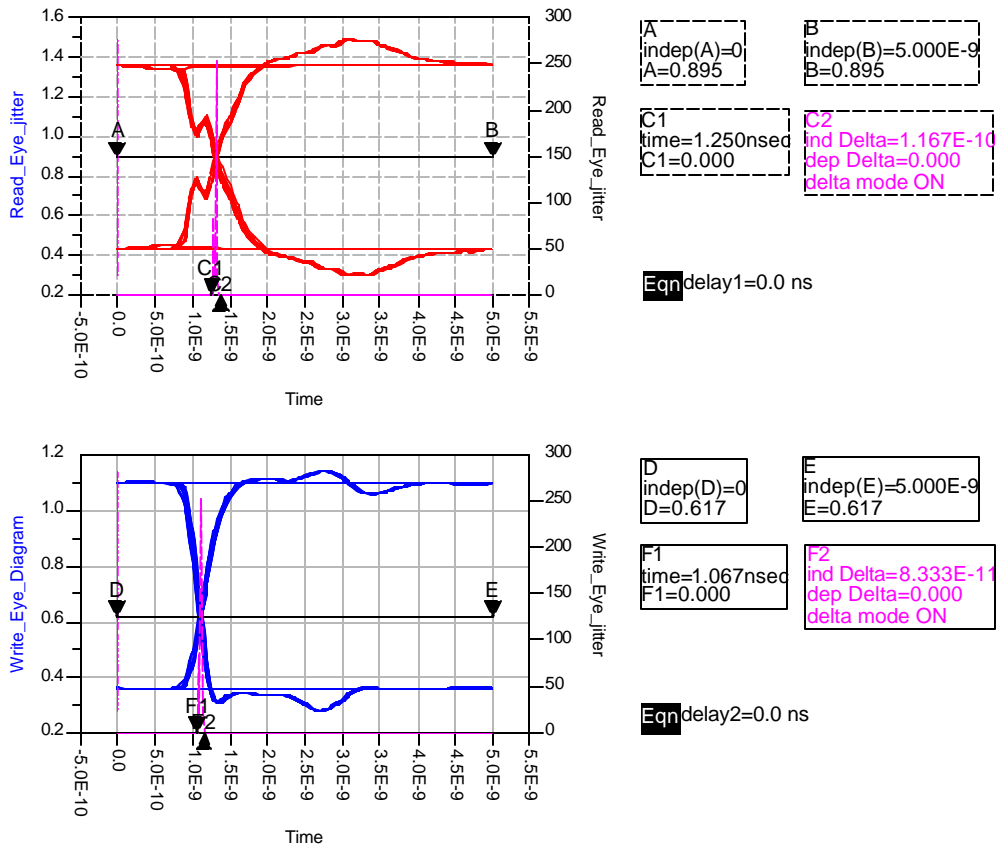


Figure 2-8 Dual Series/Dual Parallel Termination Simulation Jitter Analysis, Non Fly-By

2.1.3 Dual Parallel Termination (Fly-By)

This topology, depicted in Figure 2-9, requires two series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-10, Figure 2-11 and Figure 2-12 respectively. Looking at the waveforms, it is clear that the signal integrity is good, however, the signal suffers from the effects of the miss match between the driver device, Stratix or DDR-II, and the transmission line during the read or write cycles. The output impedance of an active device is in the order of 30 ohms that does not match the transmission line impedance of 50 ohms creating an standing wave.

The high impedance shown at the input of an active device makes the Fly-By option well suited for minimum components, good performance topology. The eye closure at the Stratix during the read cycle is 0.883 and at the DDR-II during the write cycle is 0.945 respectively. The performances of this topology will warranties the functionality of the link during the read and write cycles.

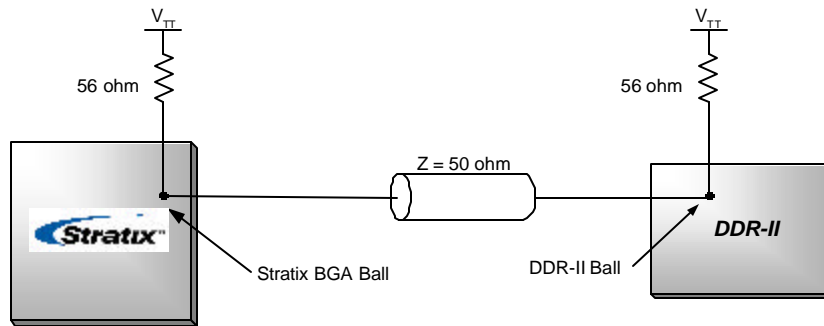


Figure 2-9 Dual Parallel Termination (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

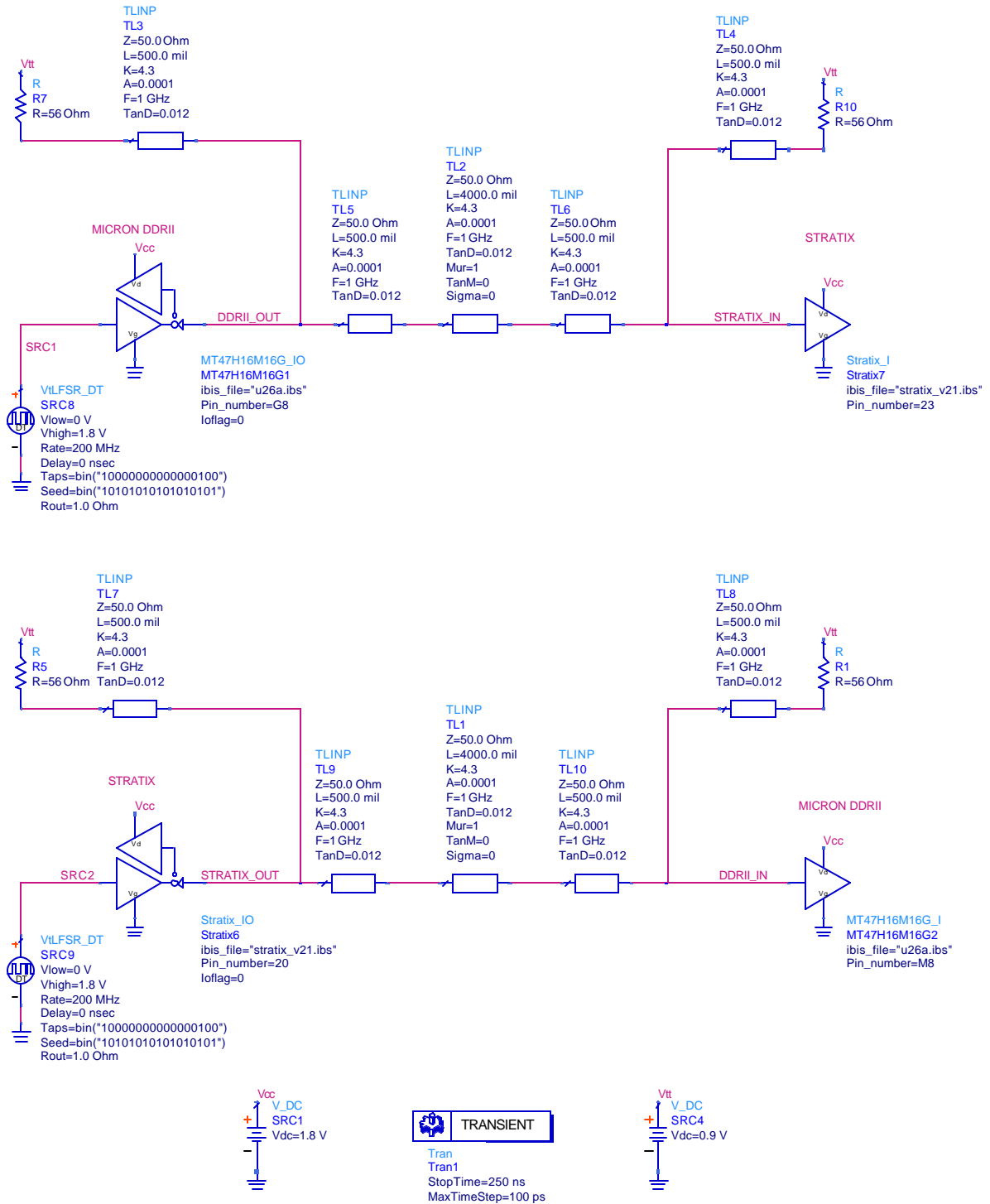


Figure 2-10 Dual Parallel Termination Simulation Setup Read/Write Cycles, Scheme 1.

Stratix to DDR-II Memory Interfaces Analysis

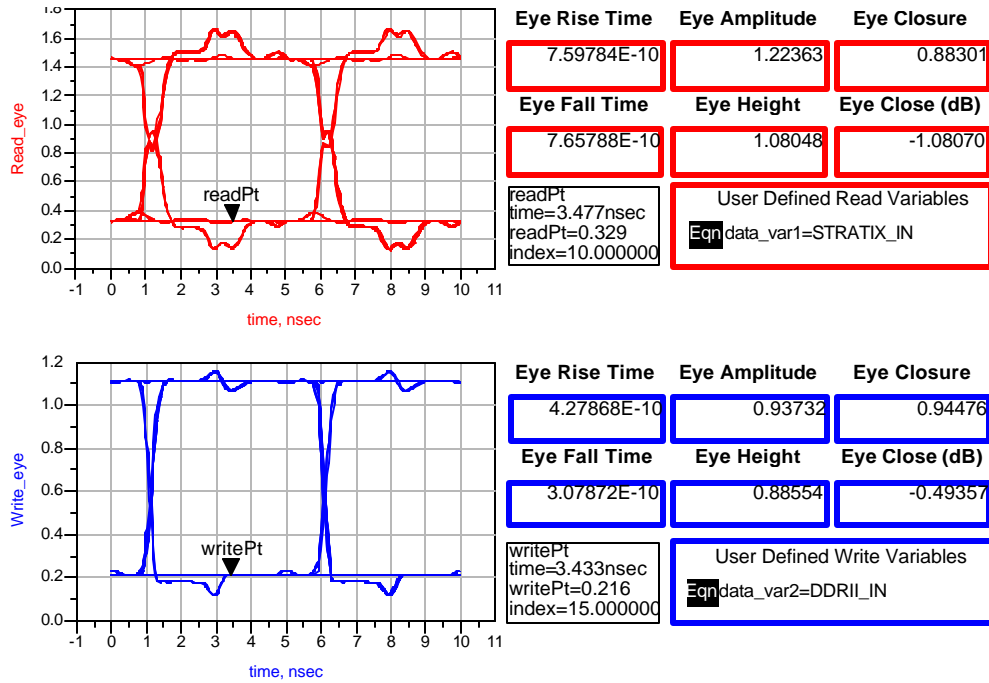


Figure 2-11 Dual Parallel Termination Eye Analysis, Fly-By.

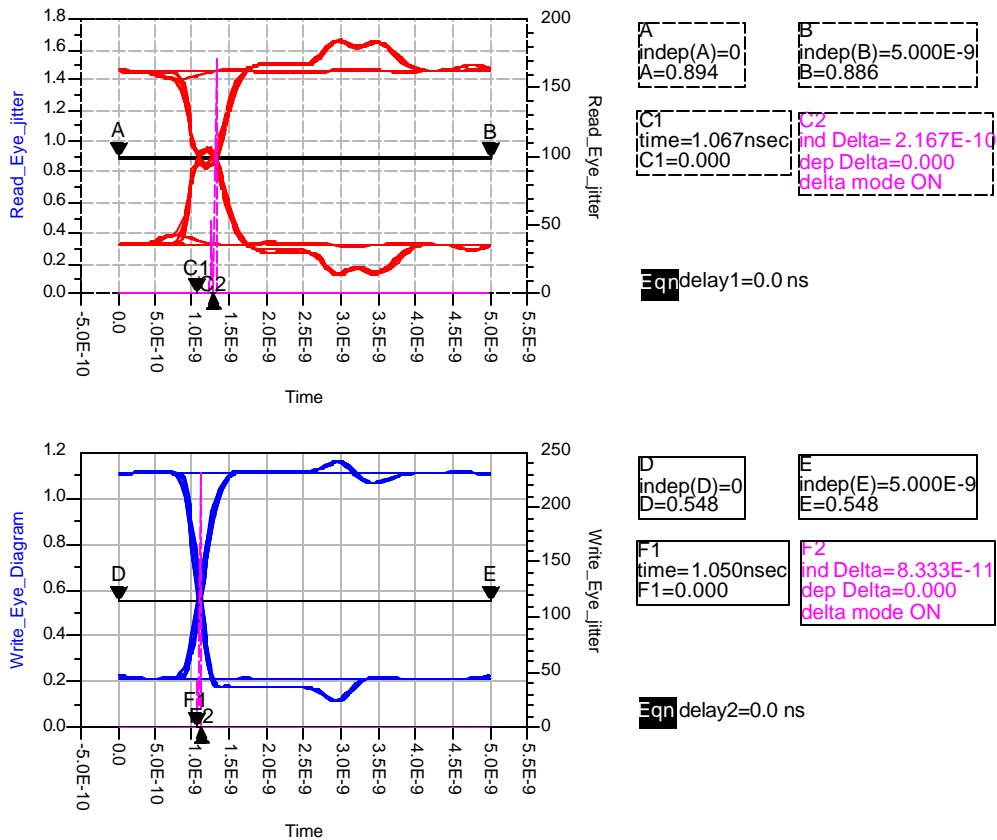


Figure 2-12 Dual Parallel Termination Jitter Analysis, Fly-By

2.1.4 Dual Parallel Termination (Non-Fly-By)

This topology, depicted in Figure 2-13, requires two series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-14, Figure 2-15 and Figure 2-16 respectively. Looking at the waveforms, it is clear that the signal integrity is good, however, the signal suffers from the effects of the open stub at the end of the transmission line during the read or write cycles. The input impedance of an active device is in the order of few Kohms that does not match the transmission line impedance of 50 ohms creating a standing wave.

This topology is recommended for systems where routing layers and components have to be kept to the minimum. The performance of this topology is similar to the Fly-by one but this required less routing and complexity. The most important parameters that have to be kept to the minimum is the distance from the termination resistor to the input of the device. The eye closure at the Stratix during the read cycle is 0.793 and at the DDR-II during the write cycle is 0.904 respectively. The performances of this topology will warranties the functionality of the link during the read and write cycles.

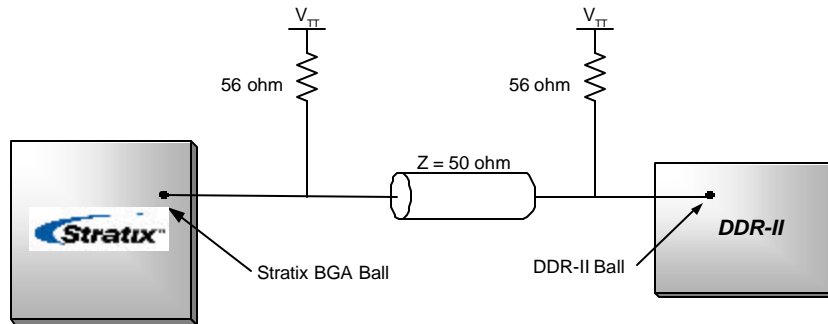


Figure 2-13 Dual Parallel Termination Non Fly-by

Stratix to DDR-II Memory Interfaces Analysis

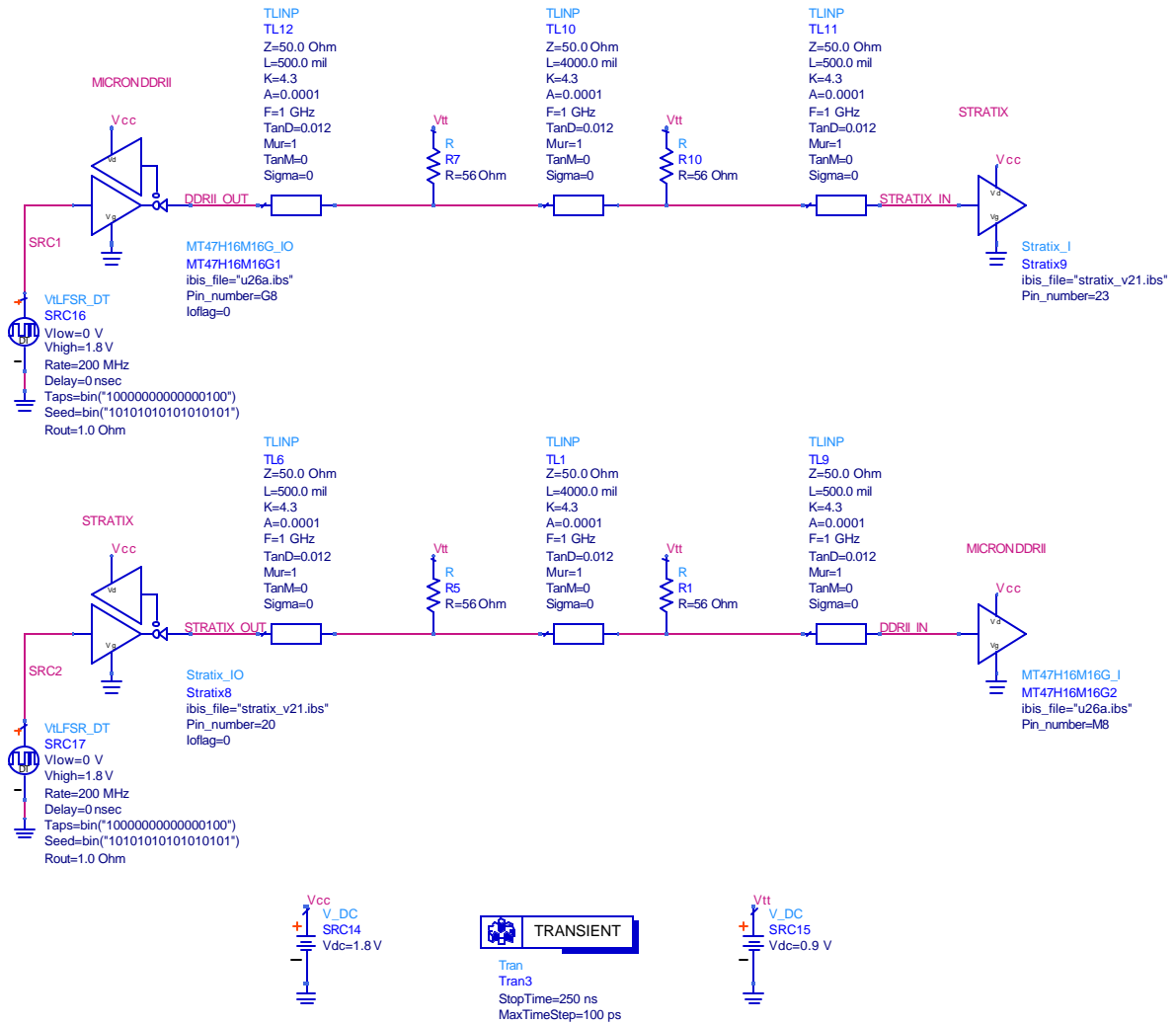


Figure 2-14 Dual Parallel Termination Simulation Setup Read/Write Cycles, Non Fly-By.

Stratix to DDR-II Memory Interfaces Analysis

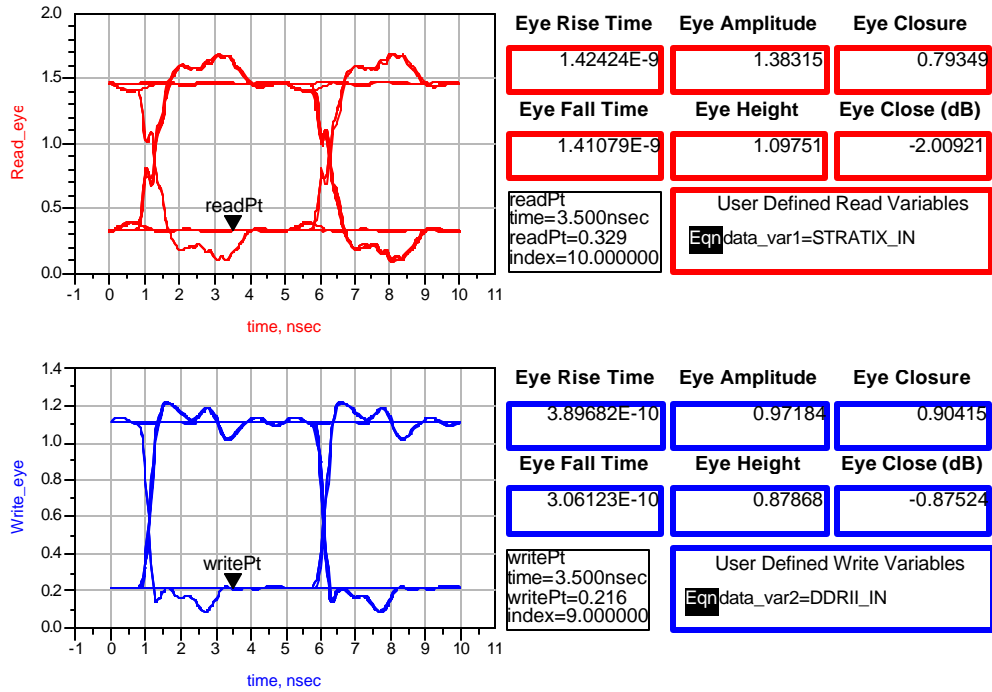


Figure 2-15 Dual Parallel Termination Eye Analysis Results, Non Fly-By

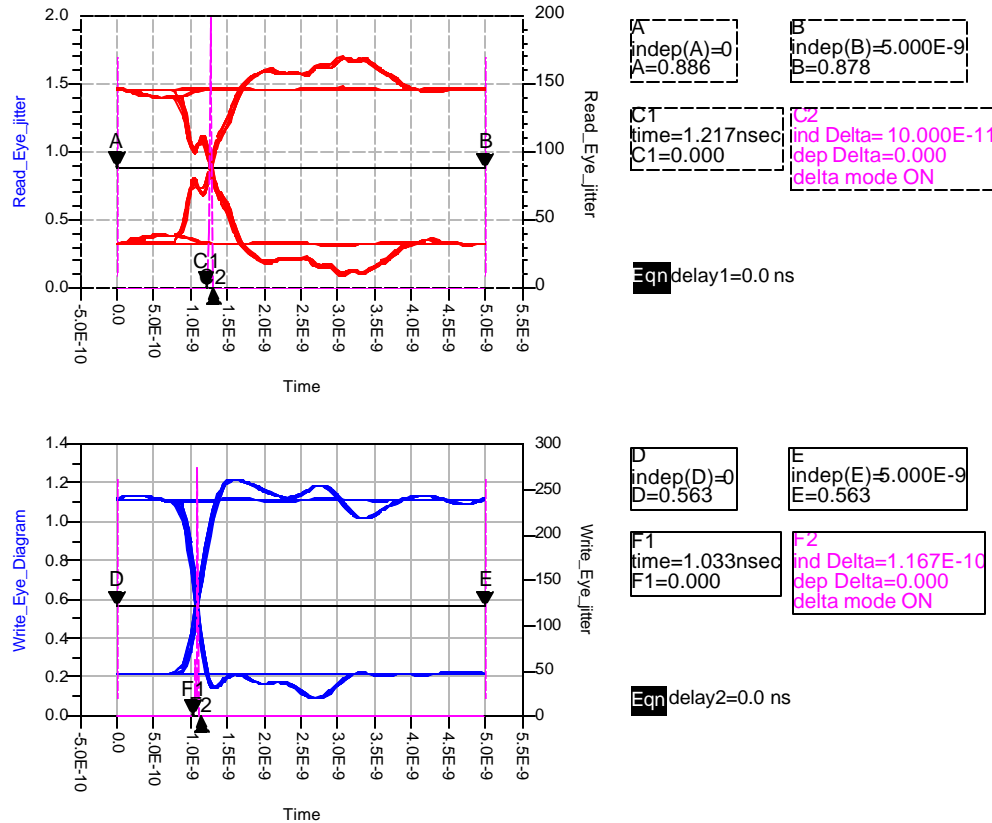


Figure 2-16 Parallel Termination Jitter Analysis Results, Non Fly-By.

2.1.5 Near End Single Series / Dual Parallel Termination (Fly-By)

This topology, depicted in Figure 2-17, requires one series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-18, Figure 2-19 and Figure 2-20 respectively. This topology is useful when output drive strength or output impedance of both devices is different. The addition of one resistor makes this topology asymmetrical, so the performance during the read/write cycles will be different adding flexibility to the system. This characteristic can be used to optimized one of the read or write cycles. Looking at the waveforms, it is clear that the signal integrity during the write cycle is better than the read cycle. The high impedance shown at the input of an active device makes the Fly-By option well suited for minimum components, good performance and low sensitivity to termination resistor location. The eye closure at the Stratix during the read cycle is 0.850 and at the DDR-II during the write cycle is 0.956 respectively. The performances of this topology will warrant the functionality of the link during the read and write cycles.

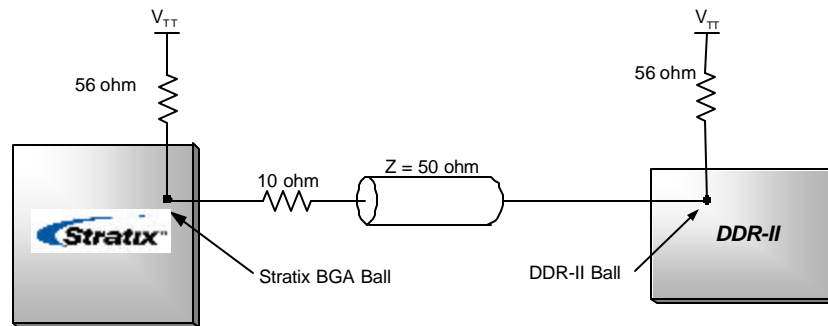


Figure 2-17 Near End Single Series / Dual Parallel Termination (Fly-By).

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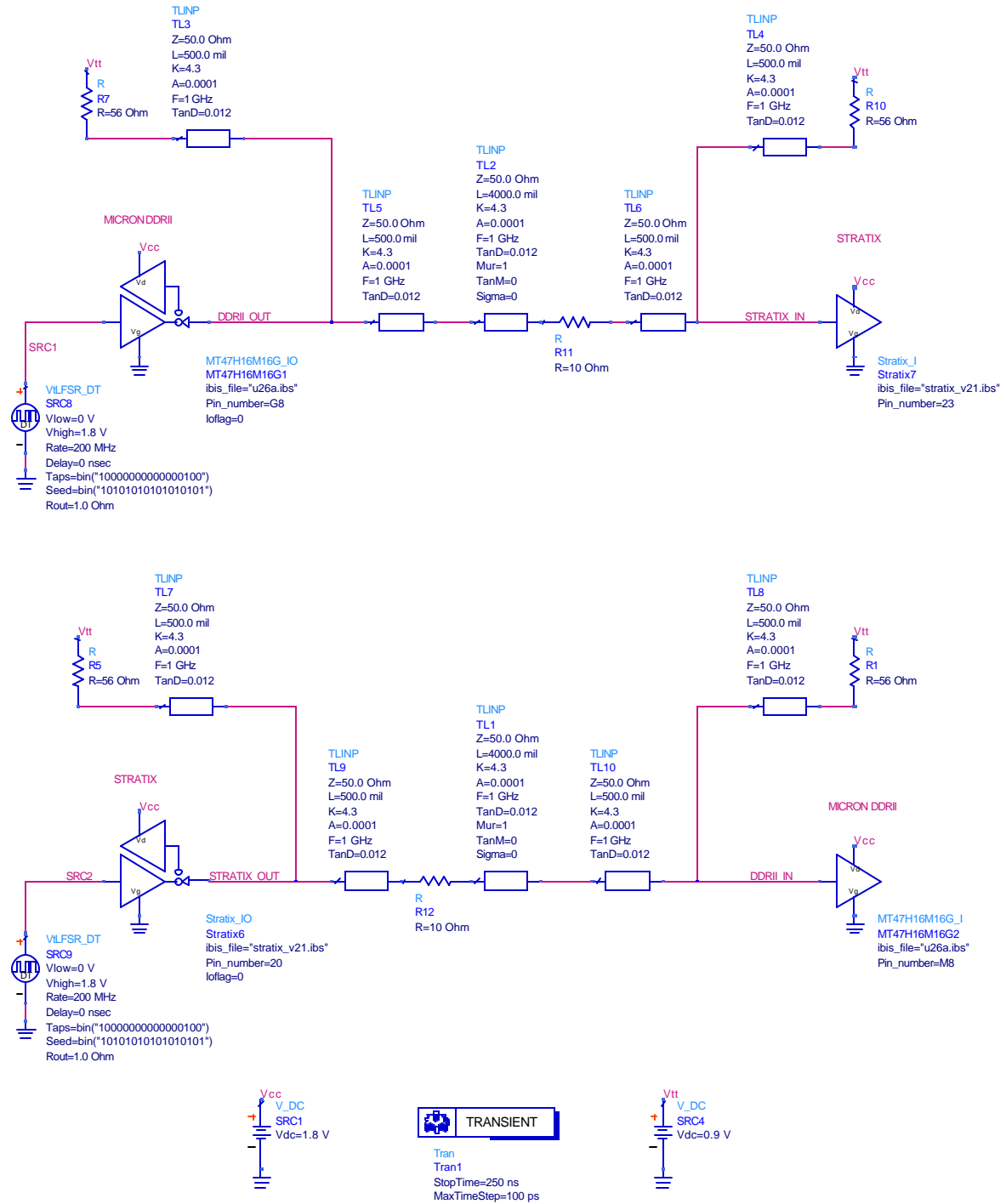


Figure 2-18 Near End Single Series / Dual Parallel Termination Simulation Setup Read/Write Cycles (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

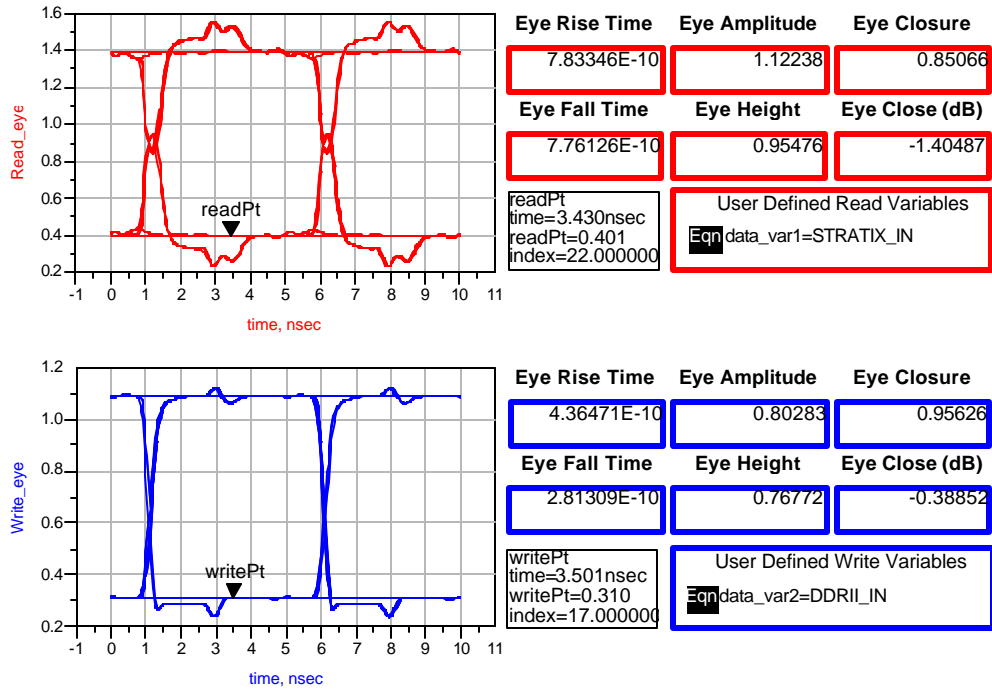


Figure 2-19 Stratix Near End Single Series / Dual Parallel Termination Eye Analysis Results

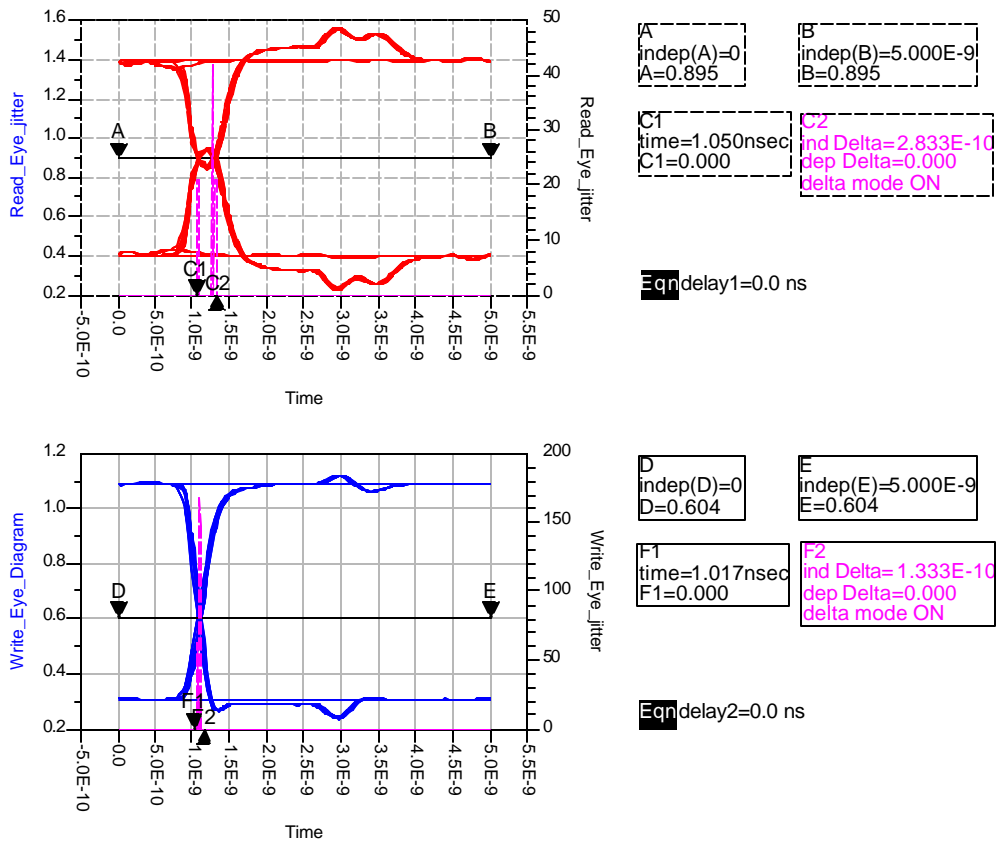


Figure 2-20 Stratix Near End Single Series/Dual Parallel Termination Jitter Analysis Results

2.1.6 Near End Single Series / Dual Parallel Termination (Non-Fly-By)

This topology, depicted in Figure 2-21, requires one series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-22, Figure 2-23 and respectively. This topology and the previous one are useful when output drive strength or output impedance of both devices is different. The addition of one resistor makes this topology asymmetrical, so the performance during the read/write cycles will be different. This characteristic can be used to optimized one of the read or write cycles. Looking at the waveforms, it is clear that the signal integrity during the write cycle is better than the read cycle.

The approach depicted in Figure 2-21 is an option when the routing in high density areas makes the previous topology difficult to achieve. The most important parameter that has to be considered to minimize undesired standing waves is the distance from the termination resistor to the input of the device. The eye closure at the Stratix during the read cycle is 0.870 and at the DDR-II during the write cycle is 0.924 respectively. The performances of this topology will warrant the functionality of the link during the read and write cycles.

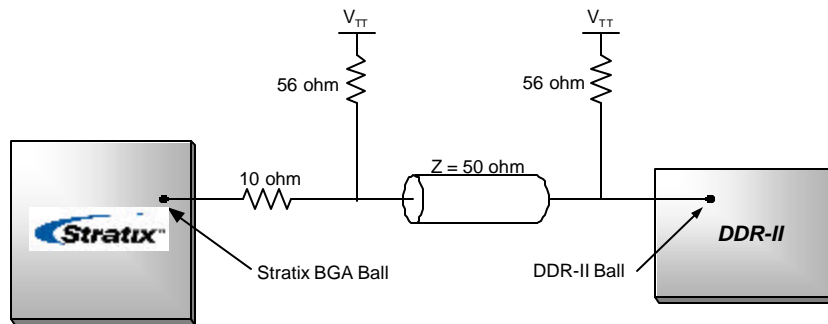


Figure 2-21 Near End Single Series / Dual Parallel Termination (Non-Fly-By)

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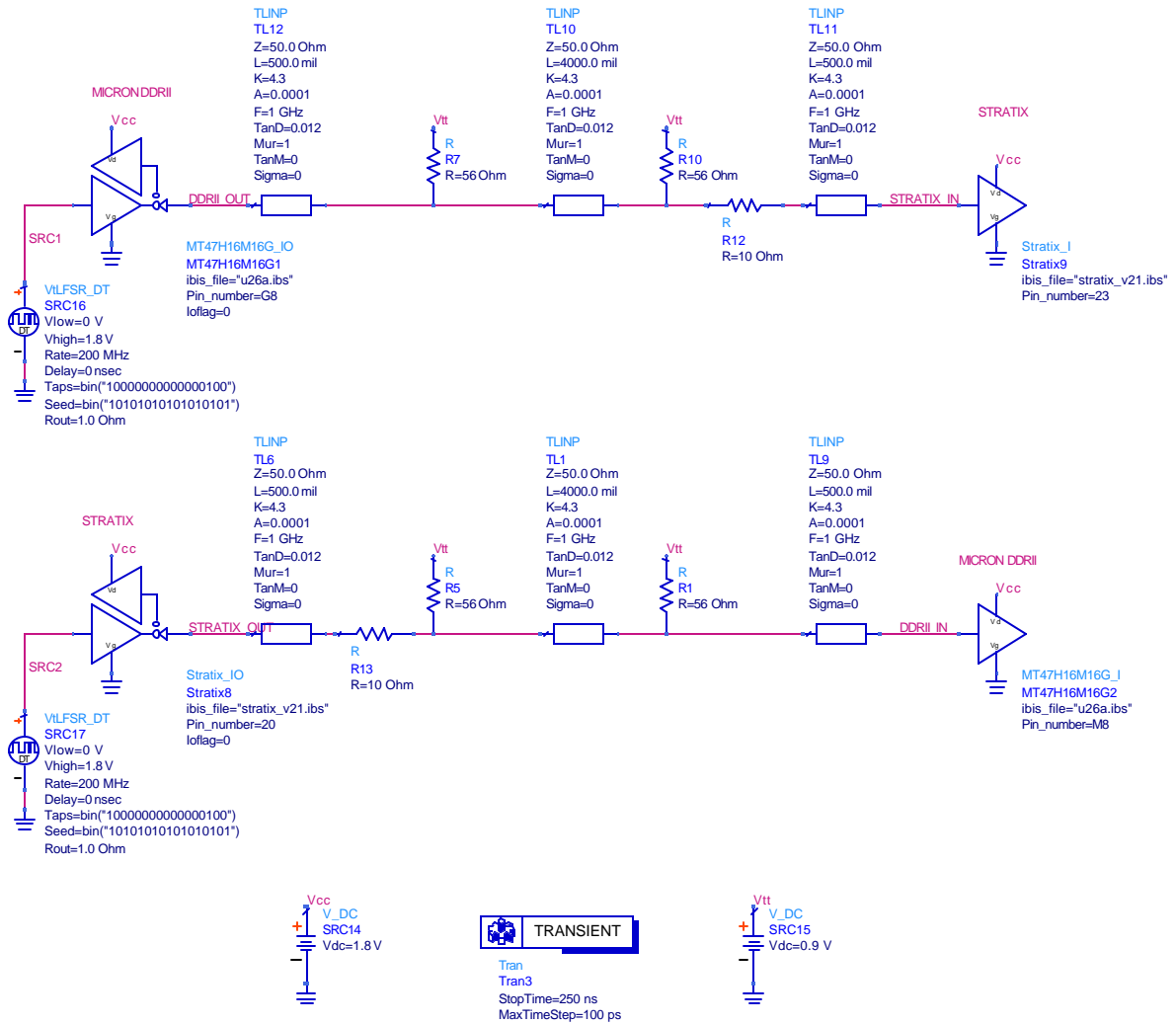


Figure 2-22 Near End Single Series/Dual Parallel Termination Simulation Setup Read/Write Cycles , (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

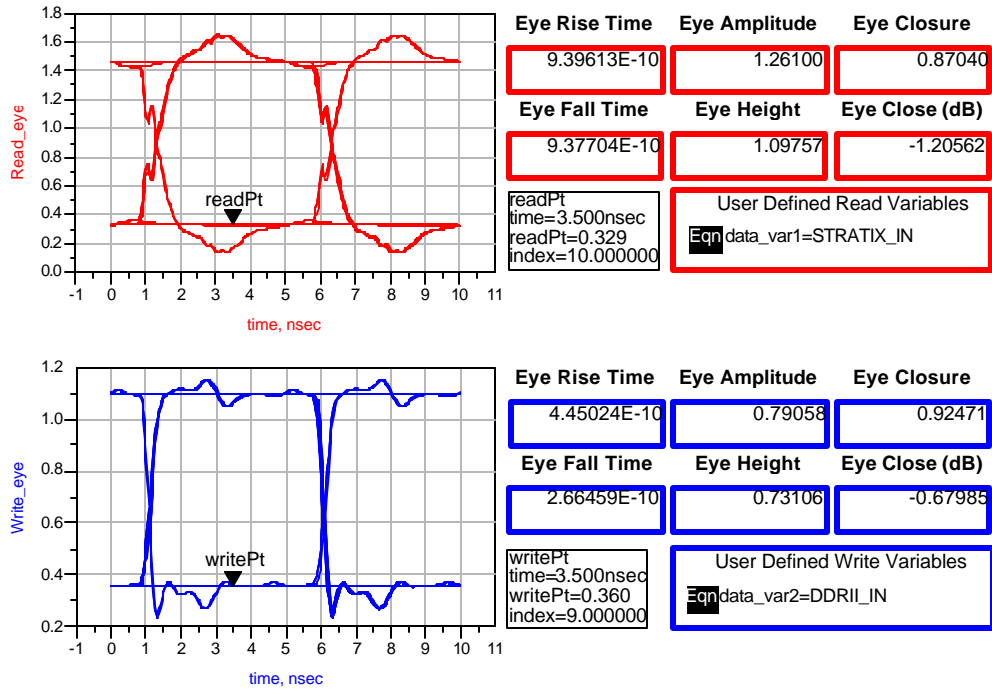


Figure 2-23 Near End Single Series / Dual Parallel Termination Eye Analysis Results, Non Fly-By.

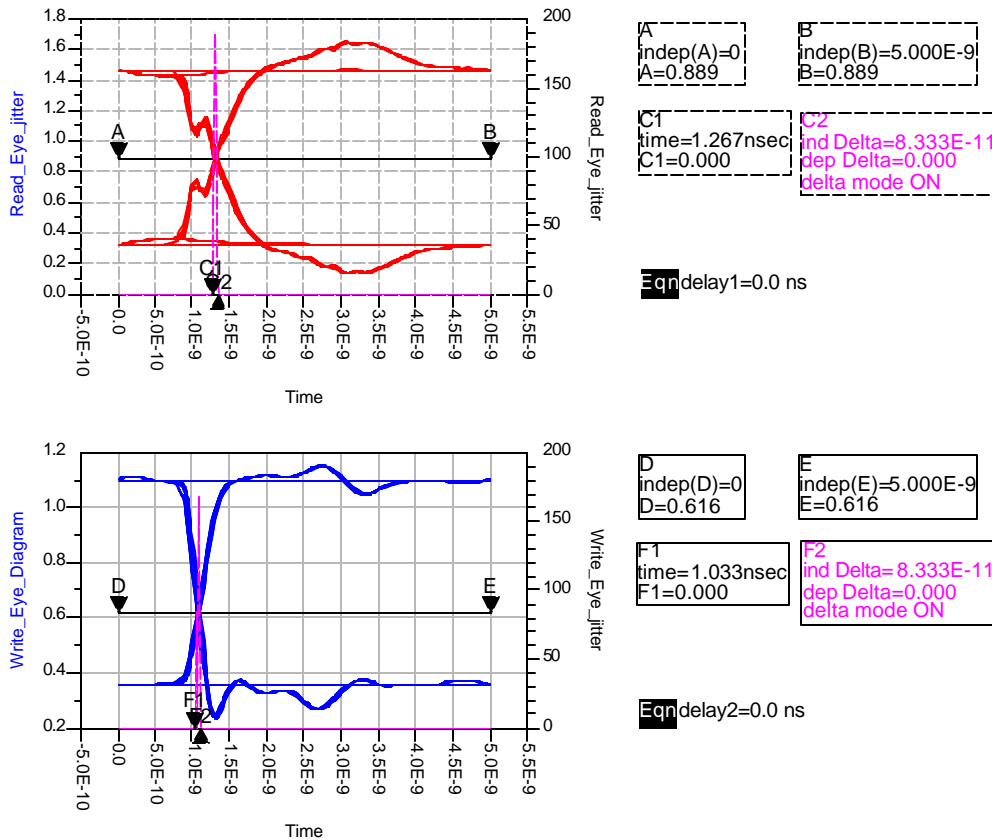


Figure 2-24 Near End Single Series / Dual Parallel Termination Jitter Analysis Results, Fly-By.

2.1.7 Far End Single Series / Dual Parallel Termination (Fly-By)

This topology, depicted in Figure 2-25, requires one series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-26, Figure 2-27 and Figure 2-28 respectively. This topology is useful when output drive strength or output impedance of both devices is different. The addition of one resistor makes this topology asymmetrical, so the performance during the read/write cycles will be different. This characteristic can be used to optimized one of the read or write cycles. Looking at the waveforms, it is clear that the signal integrity during the read cycle is better that the write cycle.

The high impedance shown at the input of an active device makes the Fly-By option well suited for minimum components, good performance and low sensitivity topology. The eye closure at the Stratix during the read cycle is 0.940 and at the DDR-I during the write cycle is 0.976 respectively. The performances of this topology will warranties the functionality of the link during the read and write cycles.

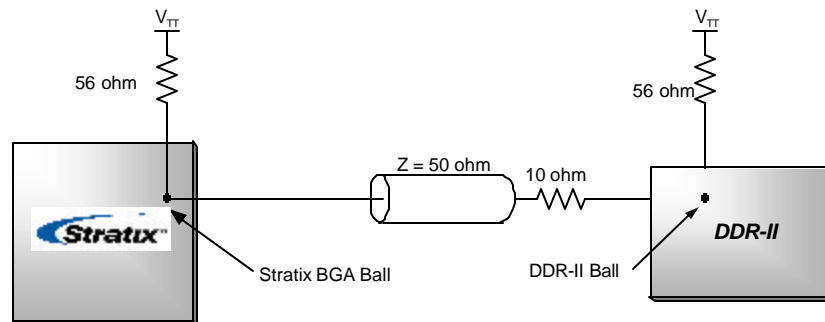


Figure 2-25 Far End Single Series / Dual Parallel Termination (Fly-By)

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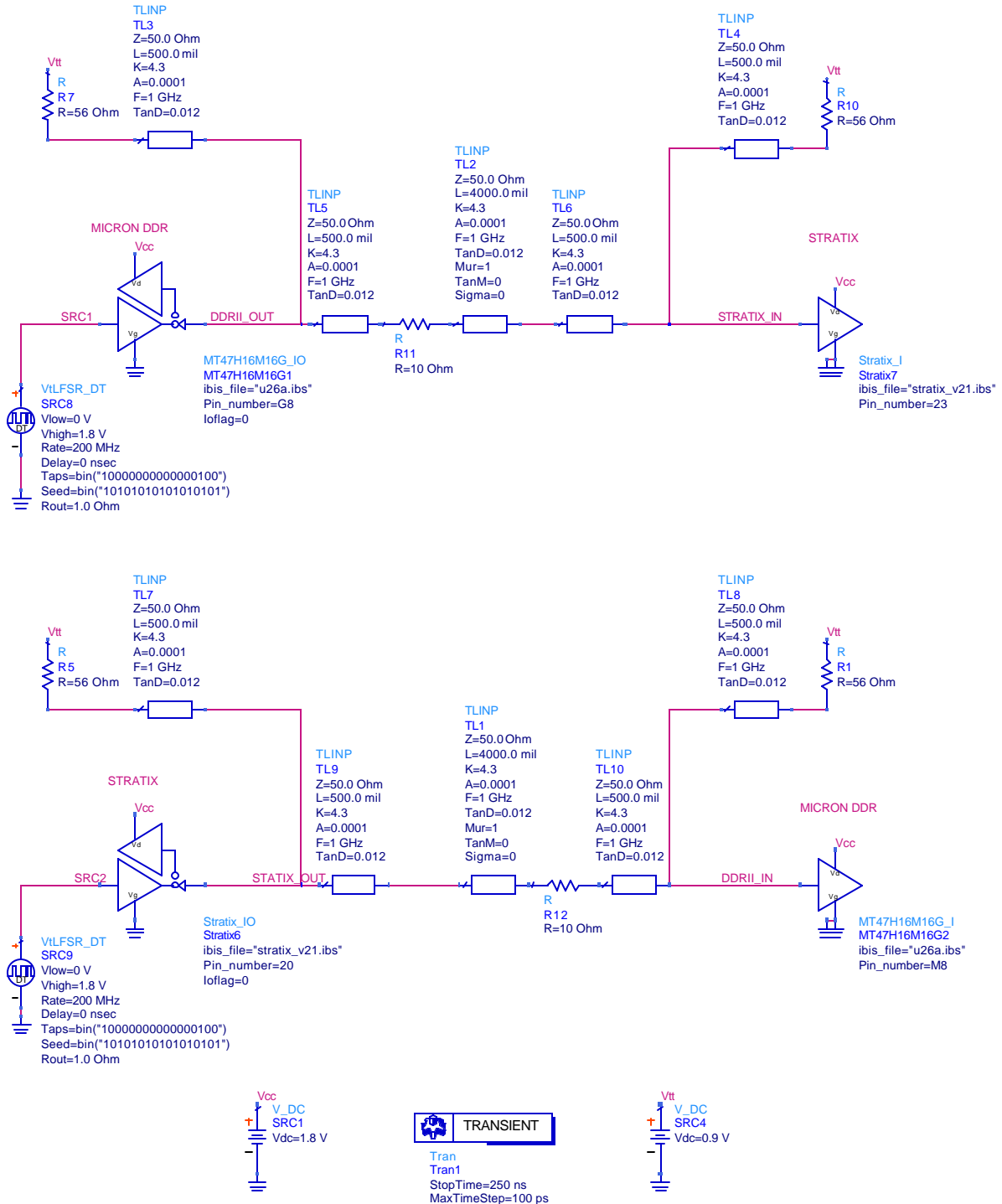


Figure 2-26 Far End Single Series / Dual Parallel Termination Simulation Setup Read/Write Cycles (Fly-By)

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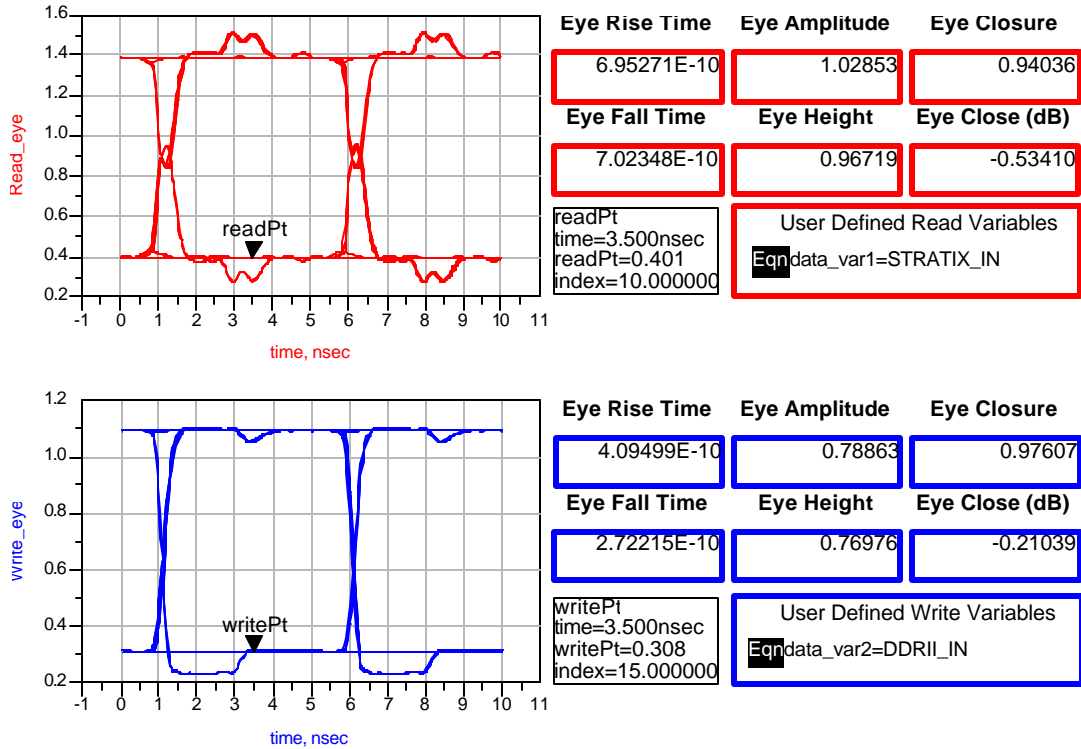


Figure 2-27 Near End Single Series / Dual Parallel Termination Eye Analysis Results, Fly-By

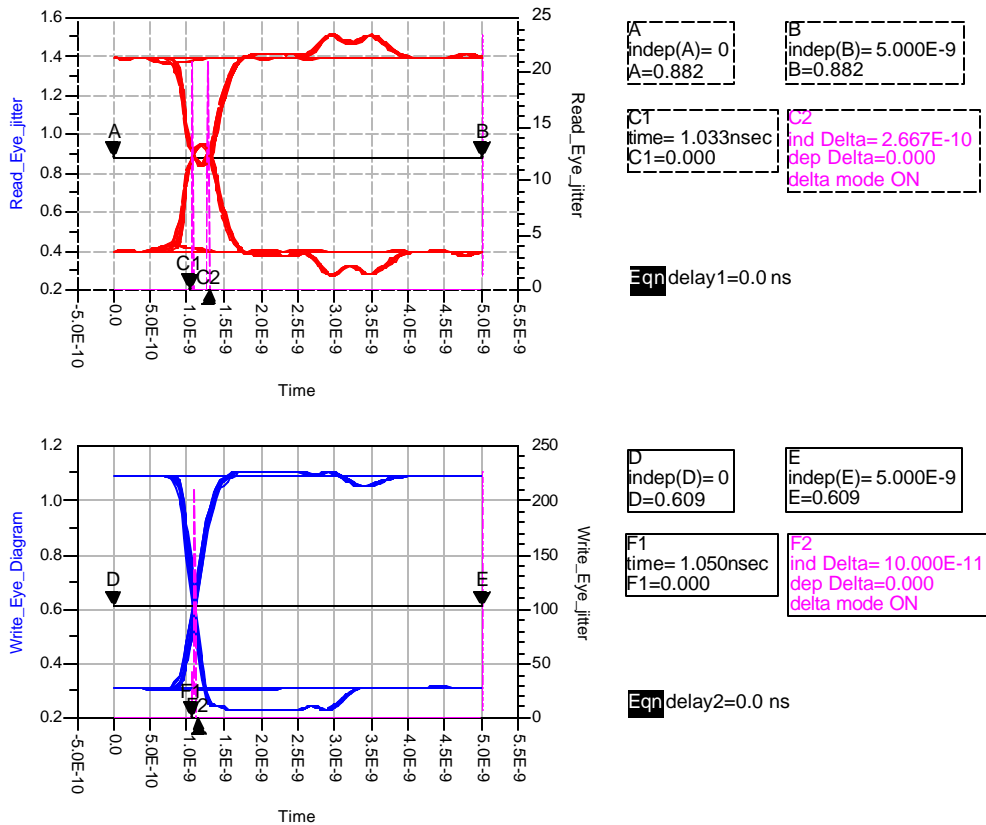


Figure 2-28 Far End Single Series / Dual Parallel Termination Jitter Analysis Results, Fly-By

2.1.8 Far End Single Series / Dual Parallel Termination (Non-Fly-By)

This topology, depicted in Figure 2-29, requires one series resistors and two parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-30, Figure 2-31 and Figure 2-32 respectively. This topology and the previous one are useful when output drive strength or output impedance of both devices are different. The addition of one resistor makes this topology asymmetrical, so the performance during the read/write cycles will be different. This characteristic can be used to optimized one of the read or write cycles. Looking at the waveforms, it is clear that the signal integrity during the write cycle is better than the read cycle. The approach depicted in Figure 2-29 is an option when the routing in high density areas makes the previous topology difficult to achieve. The most important parameter to consider is the distance from the termination resistor to the input of the device in order to minimize undesired standing waves. The eye closure at the Stratix during the read cycle is 0.820 and at the DDR-II during the write cycle is 0.905 respectively. The performances of this topology will warranties the functionality of the link during the read and write cycles.

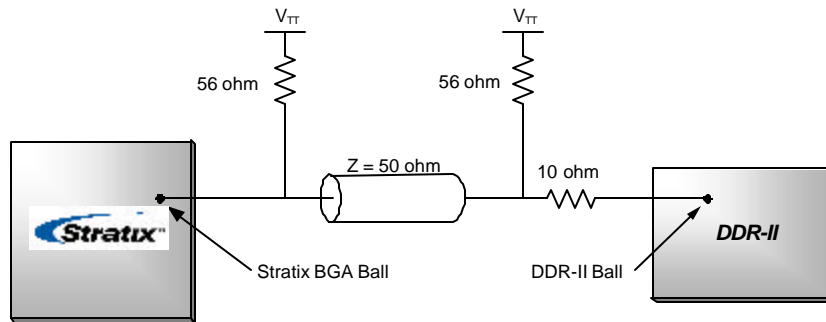


Figure 2-29 Far End Single Series / Dual Parallel Termination (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

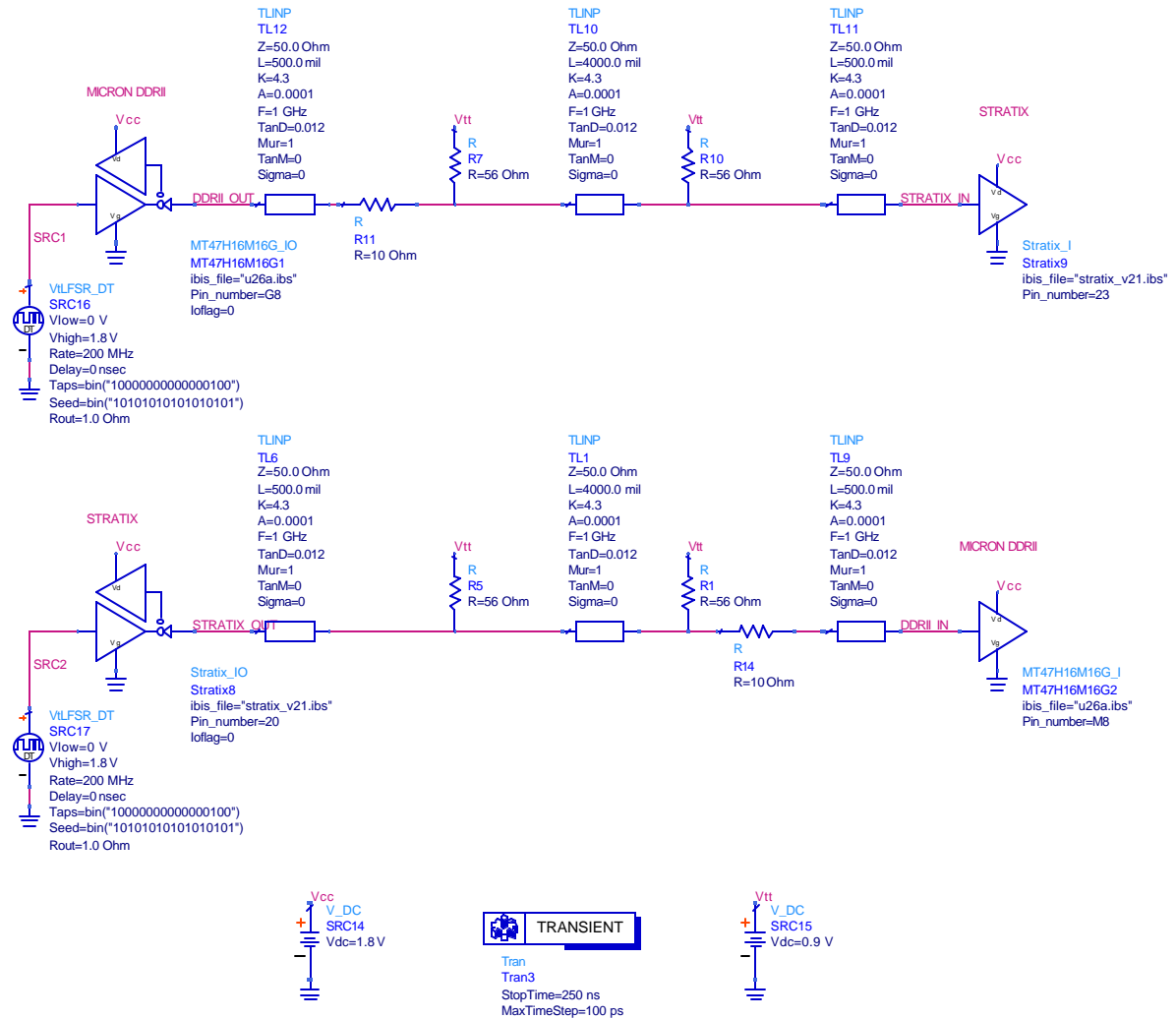


Figure 2-30 Far End Single Series / Dual Parallel Termination Simulation Setup Read/Write Cycles, Non Fly-By

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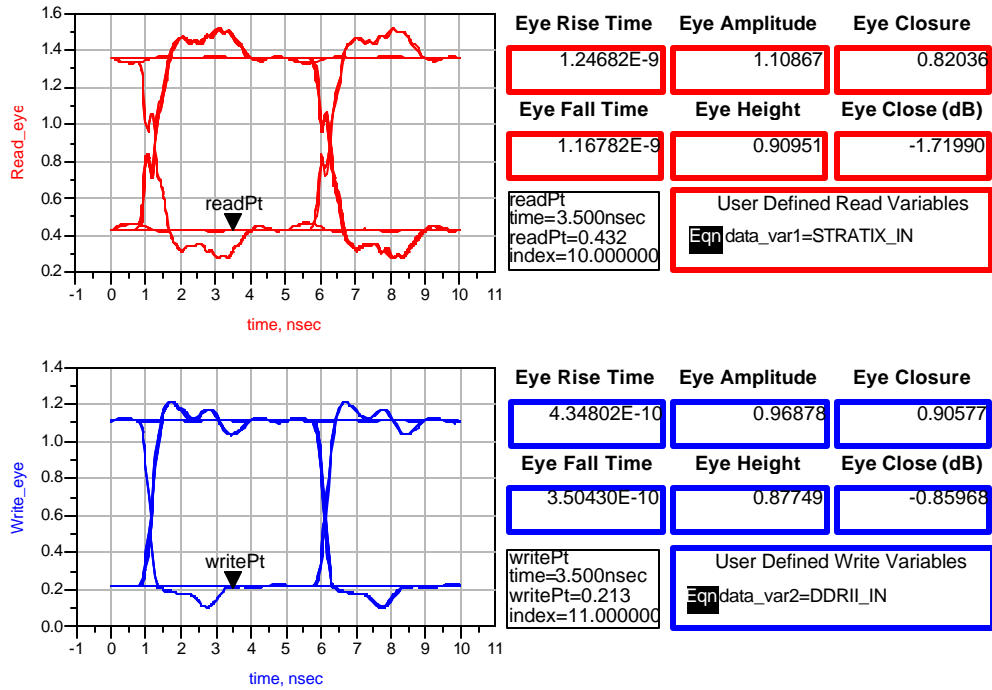


Figure 2-31 Far End Single Series / Dual Parallel Termination Eye Analysis Results, Non Fly-By.

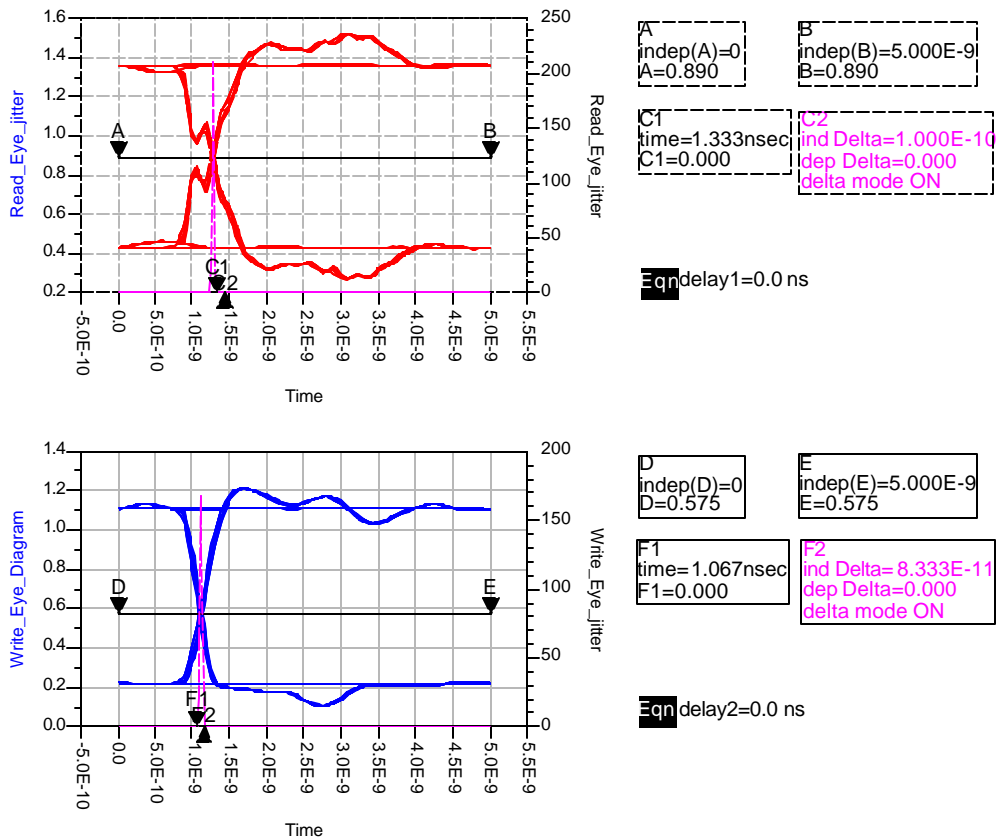


Figure 2-32 Far End Single Series / Dual Parallel Termination Jitter Analysis Results, Non Fly-By

2.1.9 Single Near End Series / Far End Parallel Termination, (Fly-By)

This topology, depicted in Figure 2-33, requires one series resistors and one parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-34, Figure 2-35 and Figure 2-36 respectively.

The approach depicted in Figure 2-33 is an option when unidirectional signals, low component count and short distances are the goal. The series resistor should be located close to the driver and the parallel termination close to the destination (receiver). Looking at the waveforms, it is clear that the signal integrity during the write cycle is much better than the read cycle making this configuration especially well suited for write cycles. The use of this topology in bi-directional transmission lines requires the verification of the min/max input voltage at the device. The eye closure at the Stratix during the read cycle is 0.582 and at the DDR-I during the write cycle is 0.824 respectively. The performances of this topology will warranties the functionality of the link during for write cycles.

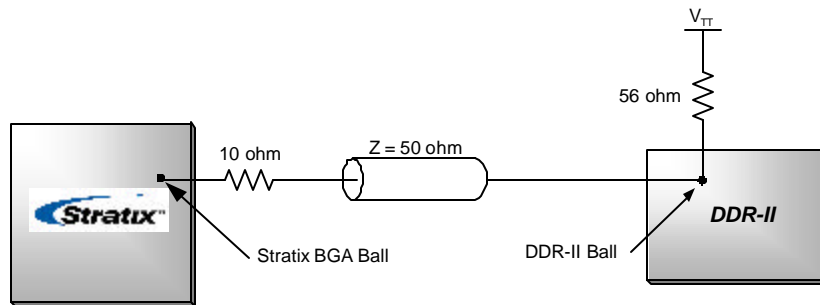


Figure 2-33 Single Near End Series / Far End Parallel Termination (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

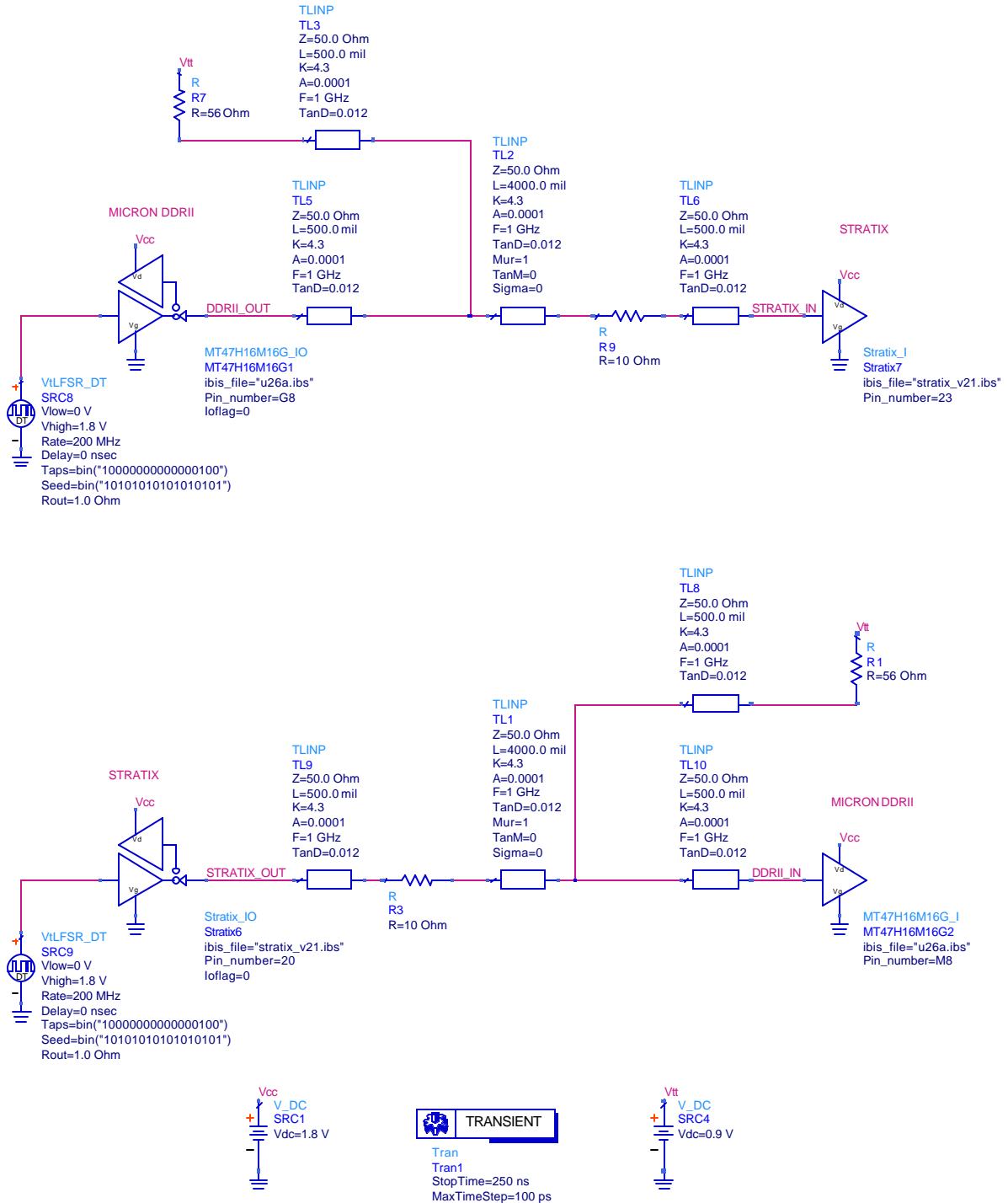


Figure 2-34 Single Near End Series / Far End Parallel Termination Simulation Setup Read/Write Cycles (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

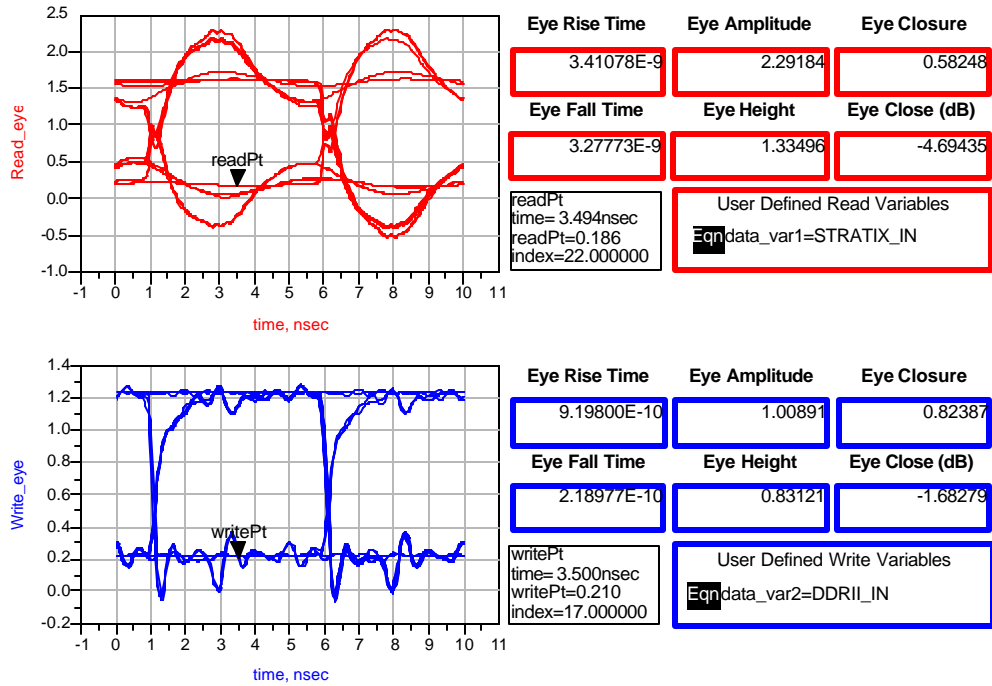


Figure 2-35 Single Near End Series / Far End Parallel Termination Eye Analysis Results, Fly-By.

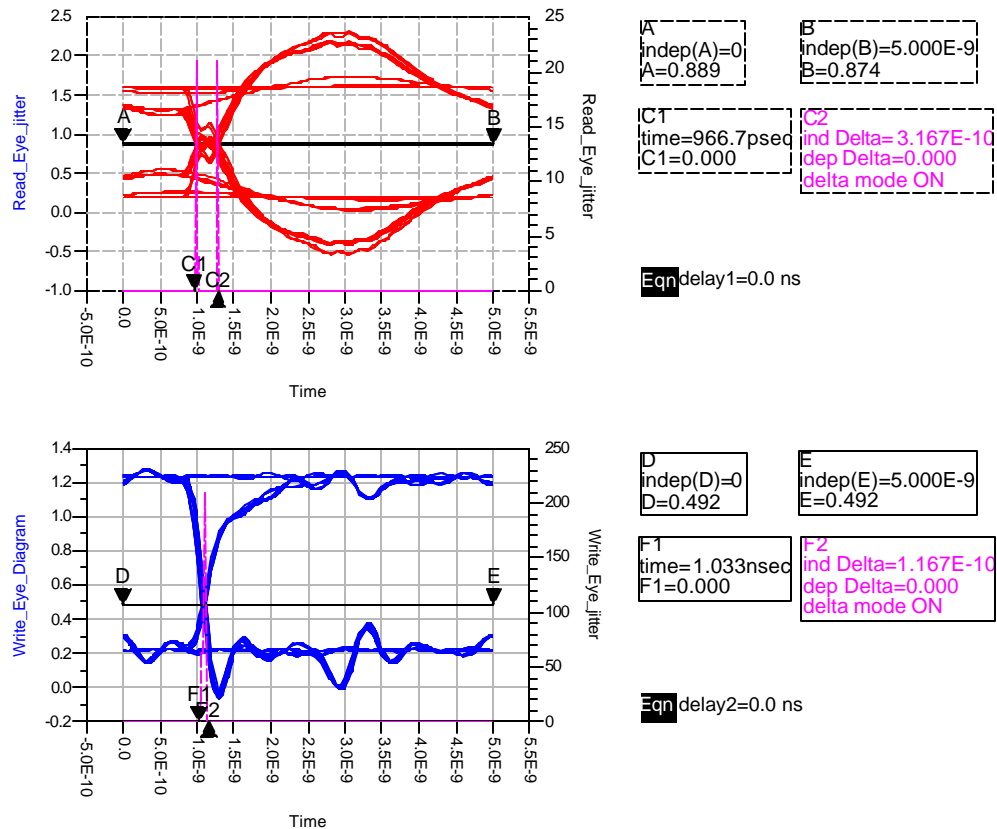


Figure 2-36 Single Near End Series / Far End Parallel Termination Jitter Analysis Results, Fly-By

2.1.10 Single Near End Series / Far End Parallel Termination (Non-Fly-By)

This topology, depicted in Figure 2-37, requires one series resistors and one parallel resistors.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-38, Figure 2-39 and Figure 2-40 respectively.

The approach depicted in Figure 2-37 is an option when unidirectional signals, low component count and short distances are the goal. The series resistor should be located close to the driver and the parallel termination close to the destination (receiver). Looking at the waveforms, it is clear that the signal integrity during the write cycle is much better than the read cycle making this configuration especially well suited for write cycles. The use of this topology in bi-directional transmission lines requires the verification of the min/max input voltage at the device. The eye closure at the Stratix during the read cycle is 0.588 and at the DDR-II during the write cycle is 0.825 respectively. The performances of this topology will warranties the functionality of the link during for write cycles.

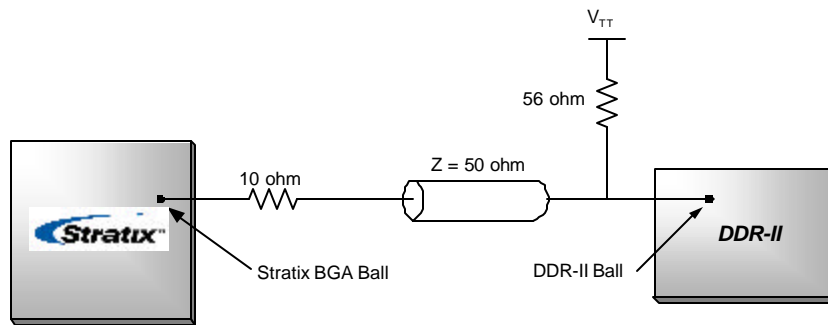


Figure 2-37 Single Near End Series / Far End Parallel Termination (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

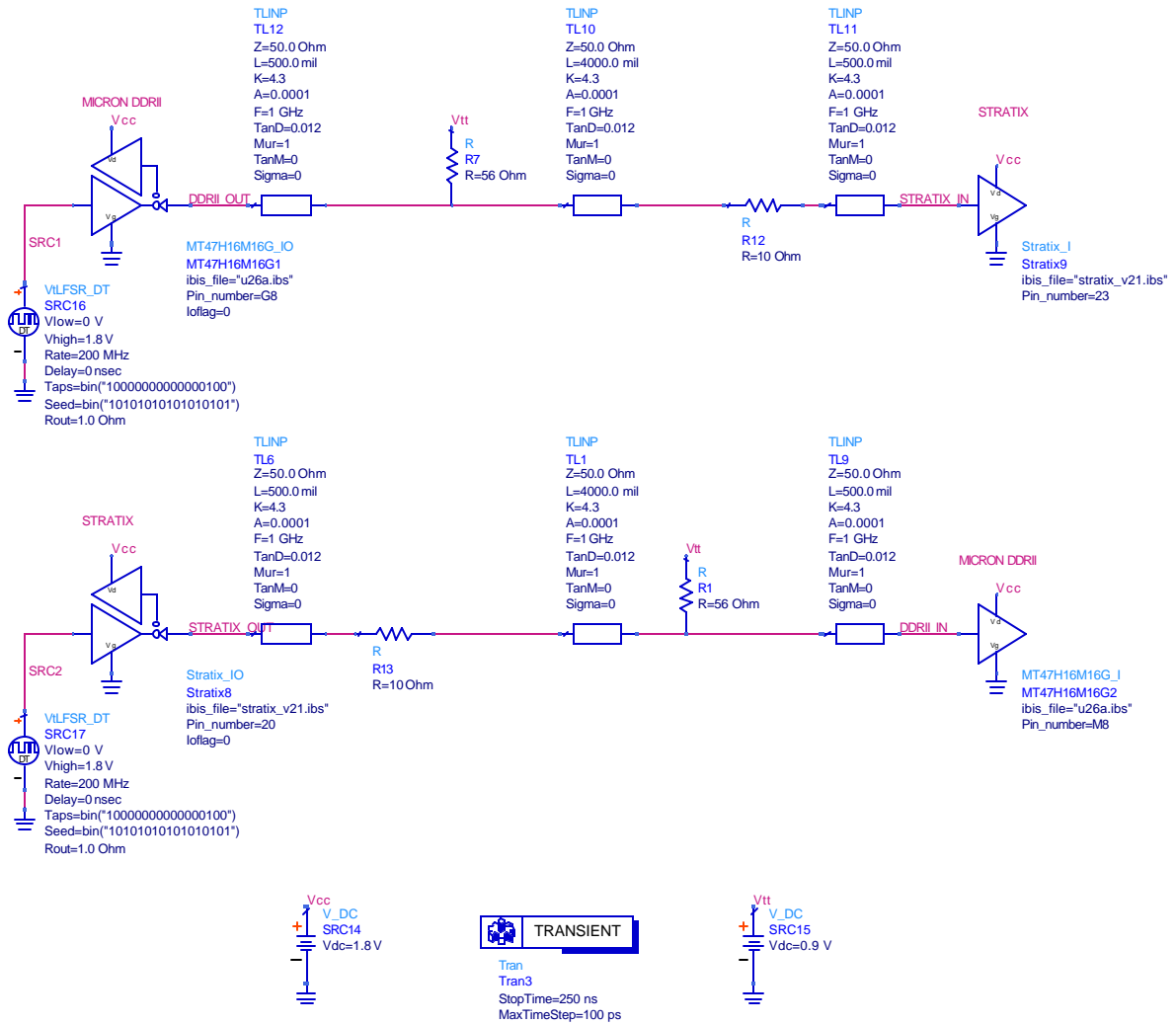


Figure 2-38 Single Near End Series/Far End Parallel Termination Simulation Setup Read/Write Cycles (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

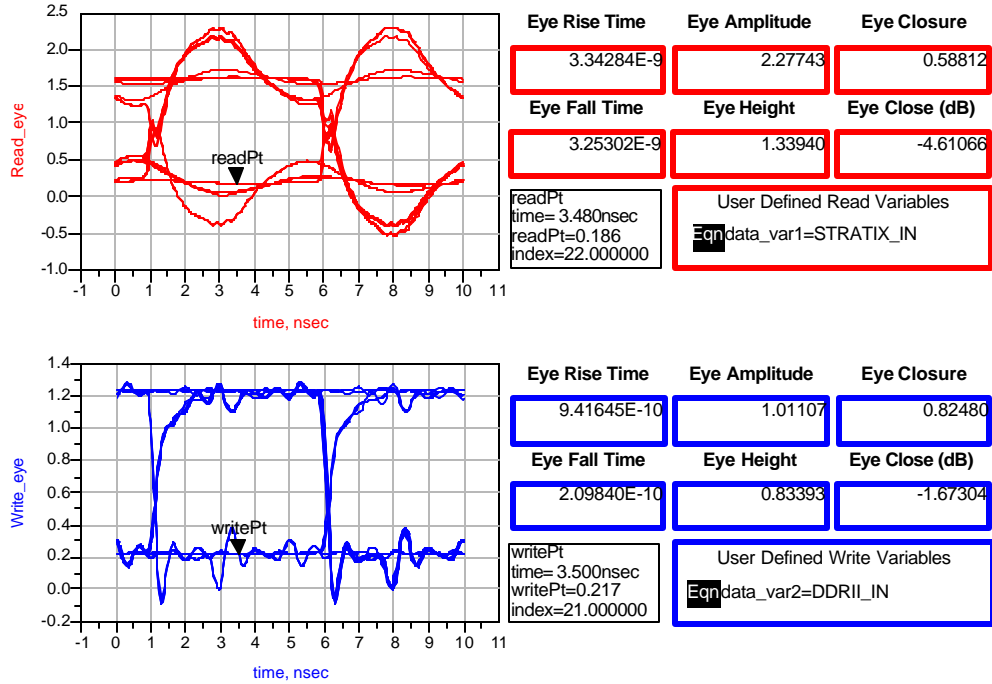


Figure 2-39 Single Near End Series / Far End Parallel Termination Eye Analysis Results.

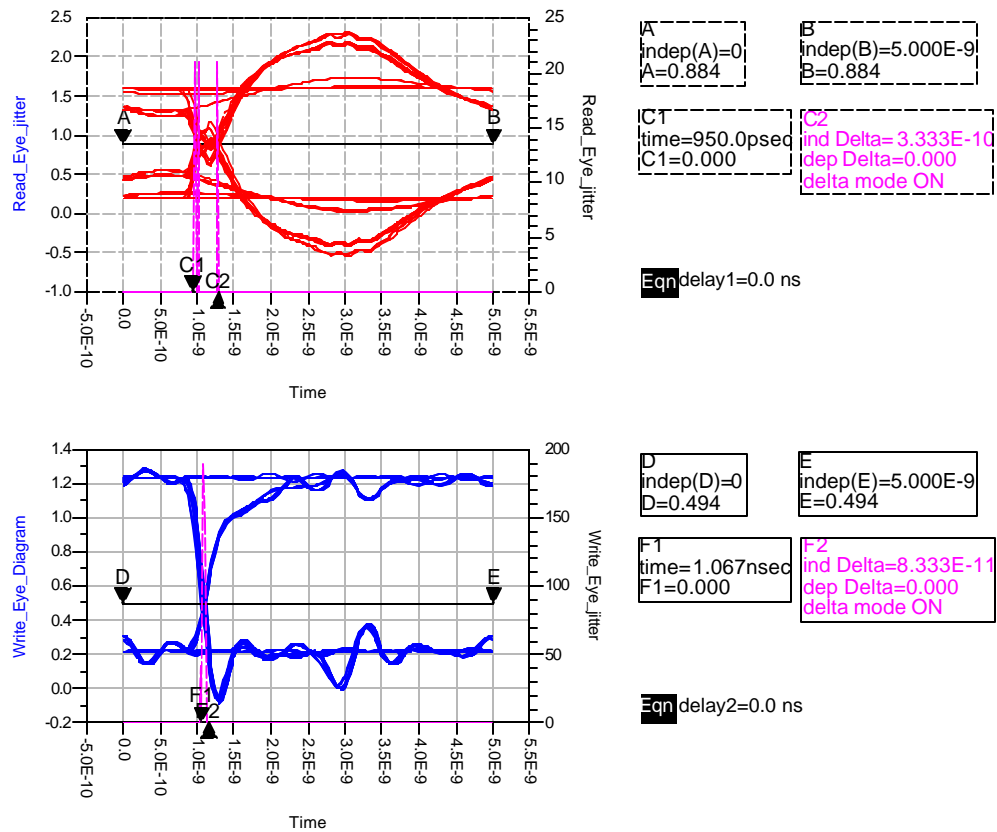


Figure 2-40 Single Near End Series / Far End Parallel Termination Jitter Analysis Results.

2.1.11 Single Far End Series / Far End Parallel Termination, (Fly-By)

This topology, depicted in Figure 2-41, requires two series resistors and one parallel resistor.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-42, Figure 2-43 and Figure 2-44 respectively.

The approach depicted in Figure 2-41 would work fine for “write” direction only, but overall due to the poor performance of the read direction, this scheme should be avoided. In addition the component count is higher with any improve in performance. The eye closure at the Stratix during the read cycle is 0.921 and at the DDR-II during the read cycle is 0.636 respectively. The performances of this topology will warranties the functionality of the link during for read cycles but with very limited performance during the write cycles.

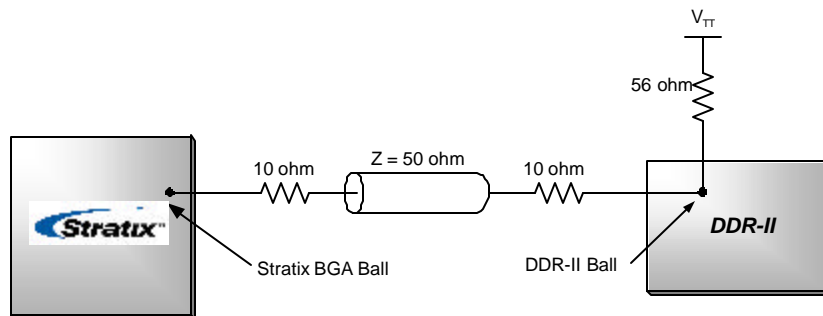


Figure 2-41 Single Near End Series / Far End Parallel Termination, (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

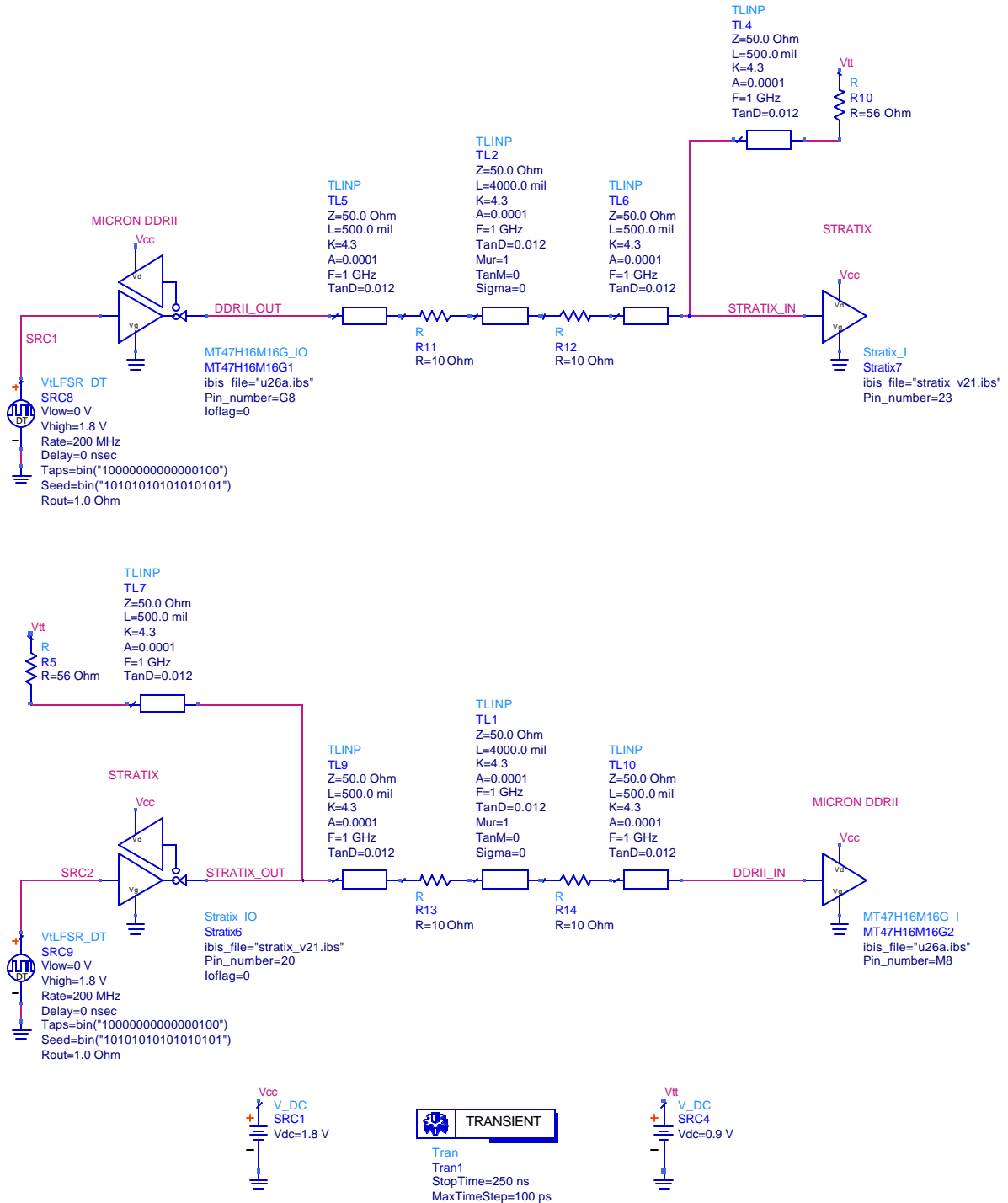


Figure 2-42 Single Near End Series/Far End Parallel Termination Simulation Setup Read/Write Cycles , (Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

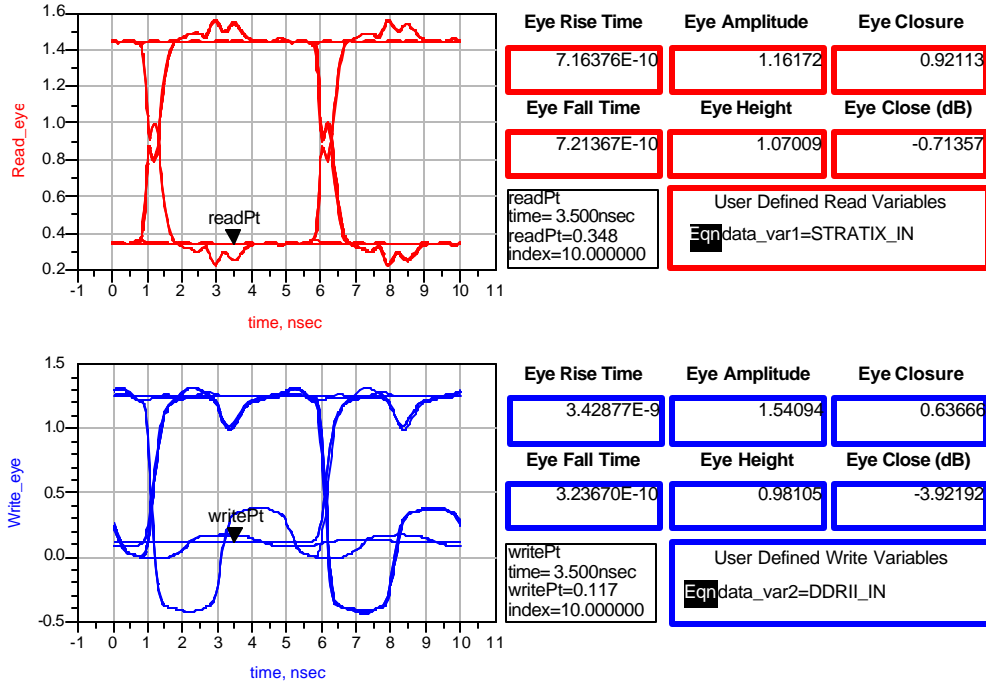


Figure 2-43 Single Near End Series / Far End Parallel Termination Eye Analysis Results, Fly-By

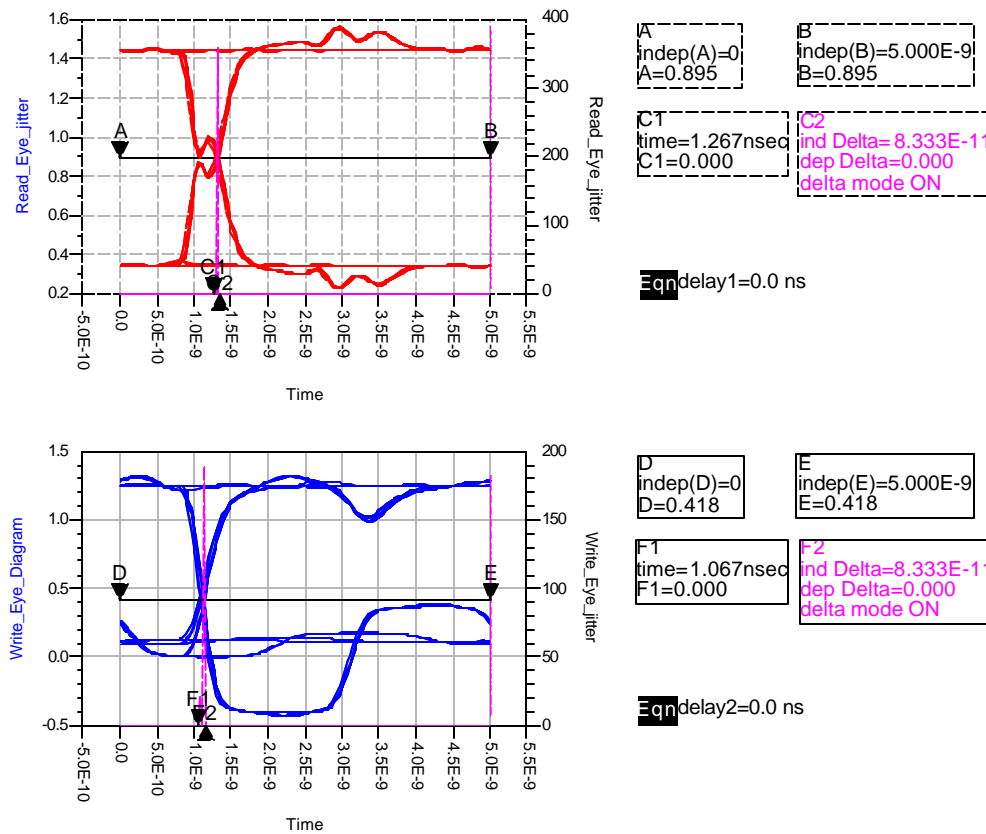


Figure 2-44 Single Near End Series / Far End Parallel Termination Jitter Analysis Results, Fly-By

2.1.12 Dual End Series / Near End Parallel Termination, (Non-Fly-By)

This topology, depicted in Figure 2-45, requires two series resistors and one parallel resistor.

The ADS test setup, eye analysis and jitter analysis for the read/write cycles are shown in Figure 2-46, Figure 2-47 and Figure 2-48 respectively.

The approach depicted in Figure 2-45 would work fine for “read” direction only, but overall due to the poor performance of the write direction, this scheme should be avoided. In addition the component count is higher with any improve in performance. The eye closure at the Stratix during the read cycle is 0.632 and at the DDR-II during the read cycle is 0.877 respectively. The performances of this topology will warranties the functionality of the link during for write cycles but with very limited performance during the read cycles.

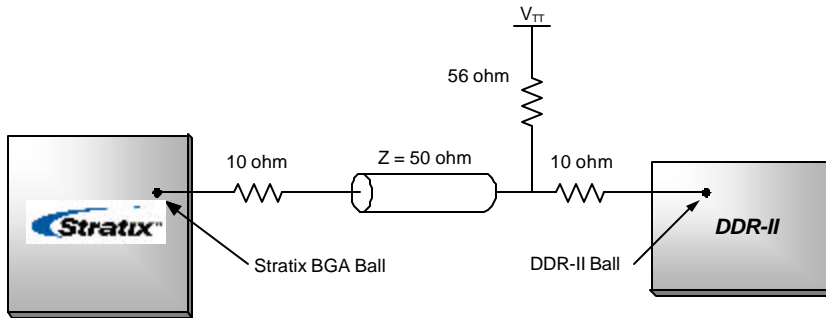


Figure 2-45 Single Far End Series / Far End Parallel Termination, (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

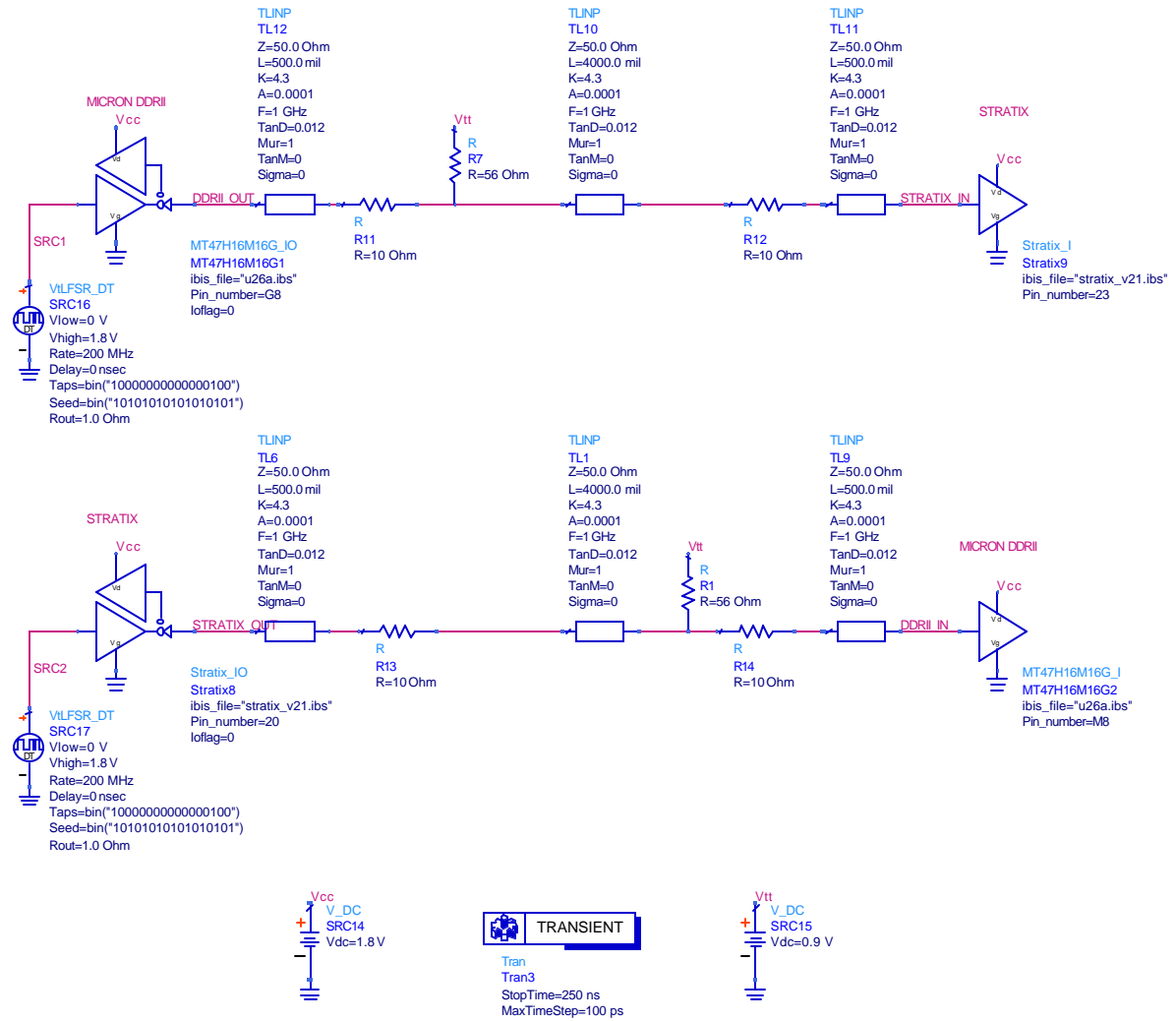


Figure 2-46 Single Near End Series/Far End Parallel Termination Simulation Setup Read/Write Cycles, (Non-Fly-By)

Stratix to DDR-II Memory Interfaces Analysis

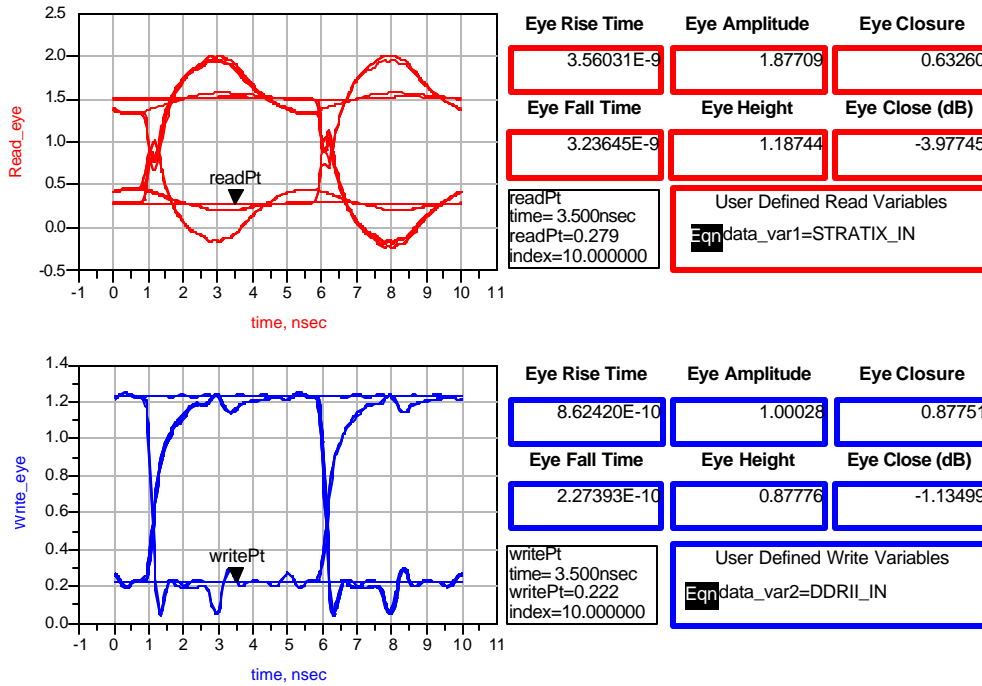


Figure 2-47 Single Near End Series / Far End Parallel Termination Eye Analysis Results

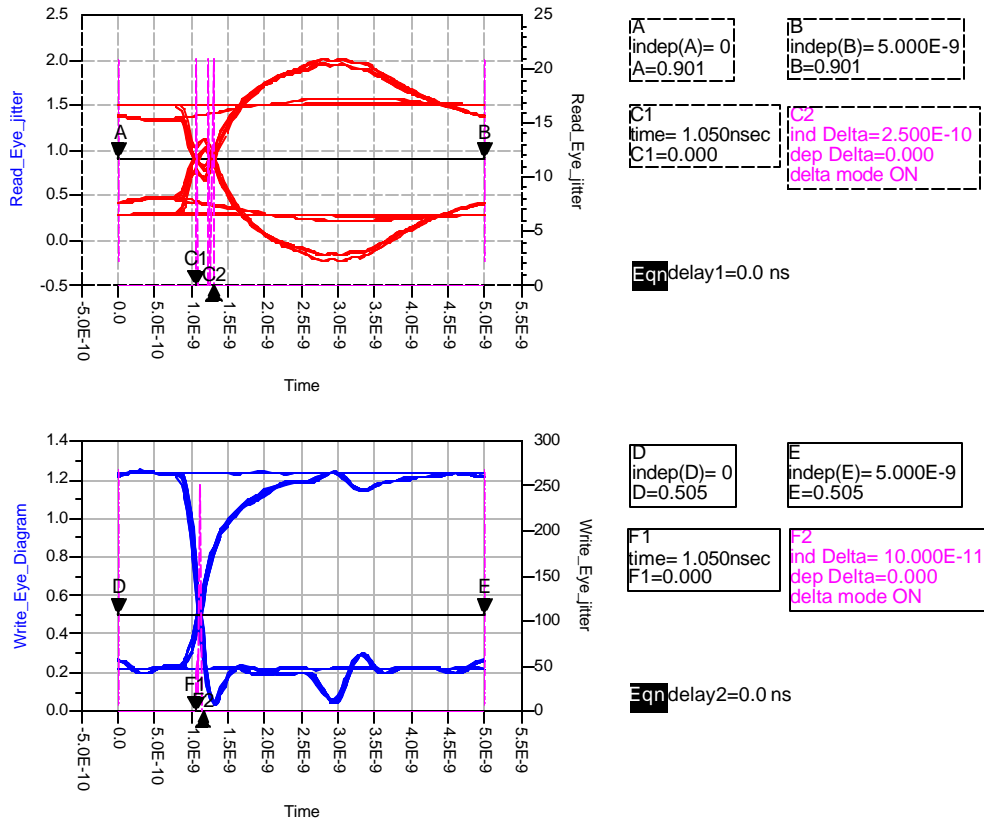


Figure 2-48 Single Near End Series / Far End Parallel Termination Jitter Analysis Results

2.1.13 SSTL-II Multi load Address

The address bus and clocks are often shared among several DDR devices on the board, so it is harder to achieve good signal integrity on the address bus. This section shows a typical address bit routing topology and a proposed termination scheme.

Figure 2-49 shows the block diagram of this address scheme. Figure 2-50 shows the ADS test setup and Figure 2-51 shows the simulated waveform at the DDR-II memory balls. While there is overshoot and undershoot, the overall eye closure is about 0.503 at the DDR-II device terminals.

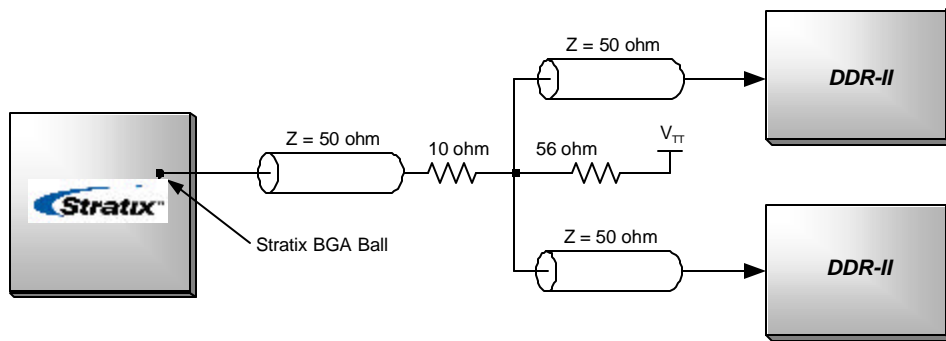


Figure 2-49 Stratix-DDR-II Address Interface, Write.

Stratix to DDR-II Memory Interfaces Analysis

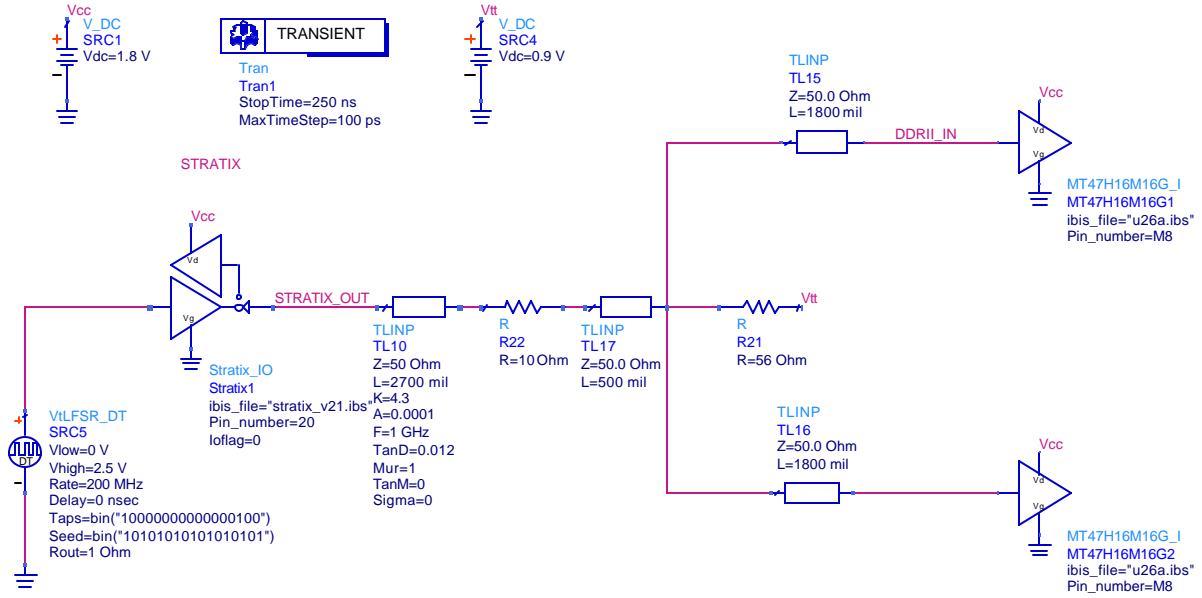


Figure 2-50 Stratix-DDR-II Address Interface, Simulation Setup

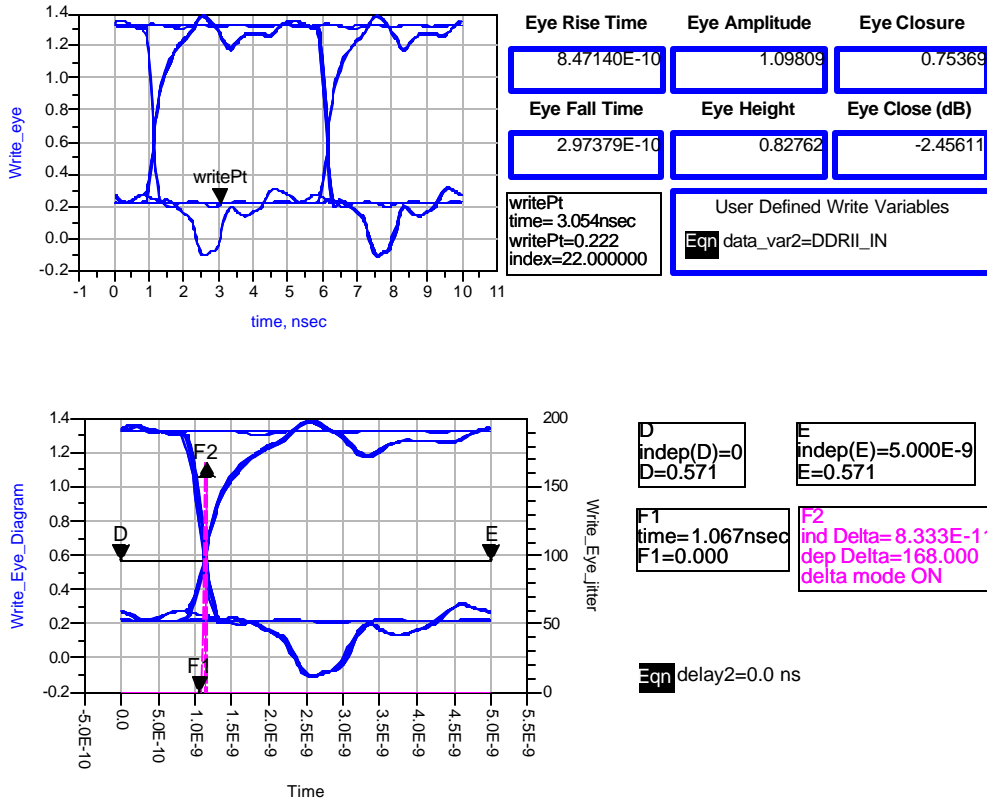


Figure 2-51 Stratix-DDR-II Address Interface, Simulation results.

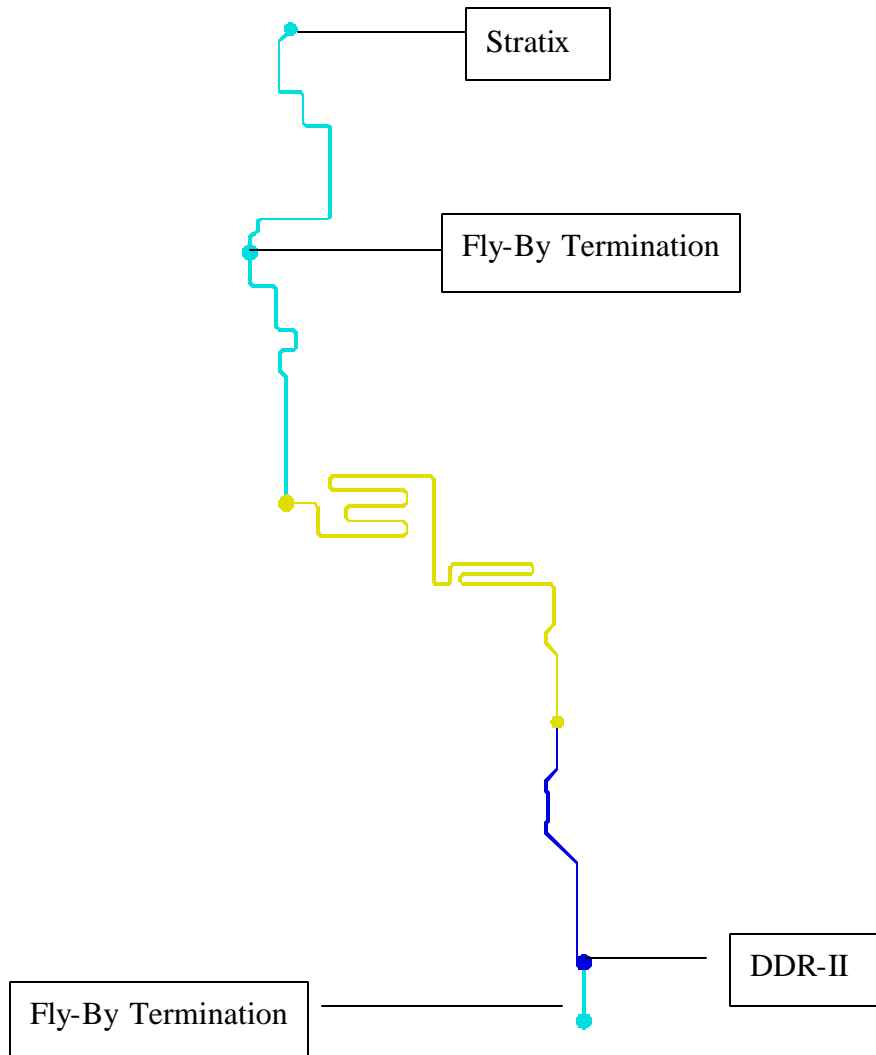
3 POST LAYOUT SIMULATIONS

When the layout is complete, a post layout simulation is performed on the critical sections of the board to ensure there are no major signal integrity problems. Based on the results of the post-layout simulation, any changes required are incorporated in the layout and the layout is released to the fabrication house for board manufacturing.

The post layout simulation process requires the Gerbers files of all active layers on the board, the actual permittivity, loss tangent and thickness of the all dielectrics layers, the copper thickness in every layer as long as the relevant solder mask information.

3.1 DDRII DQ0

The post-layout simulations for the DDRA DQ0 in based on the S-Parameters of the data path from the Stratix I/O to the DDR-I I/O pin. The S-Parameters were obtained from 10MHz to 2GHz and included as a black box in the simulation set up shown in Figure 3-1 Near End Single Series / Dual Parallel Termination (Fly-By) used in DQ0 DDR-II U1..



Stratix to DDR-II Memory Interfaces Analysis

Figure 3-1 Near End Single Series / Dual Parallel Termination (Fly-By) used in DQ0 DDR-II U1.

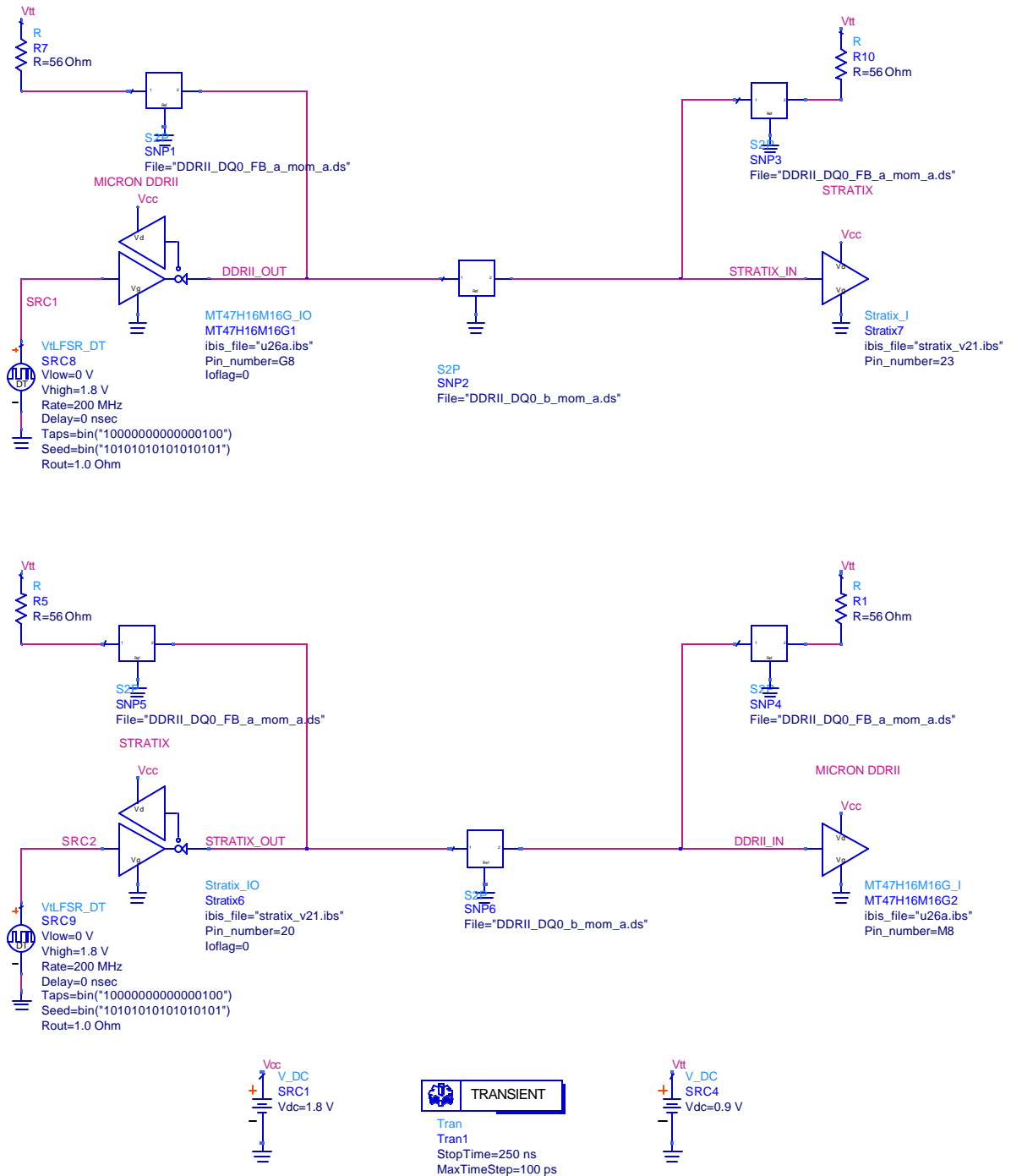


Figure 3-2 Near End Single Series / Dual Parallel Termination (Fly-By) post-layout simulation setup used in DQ0 DDR-II U1.

Stratix to DDR-II Memory Interfaces Analysis

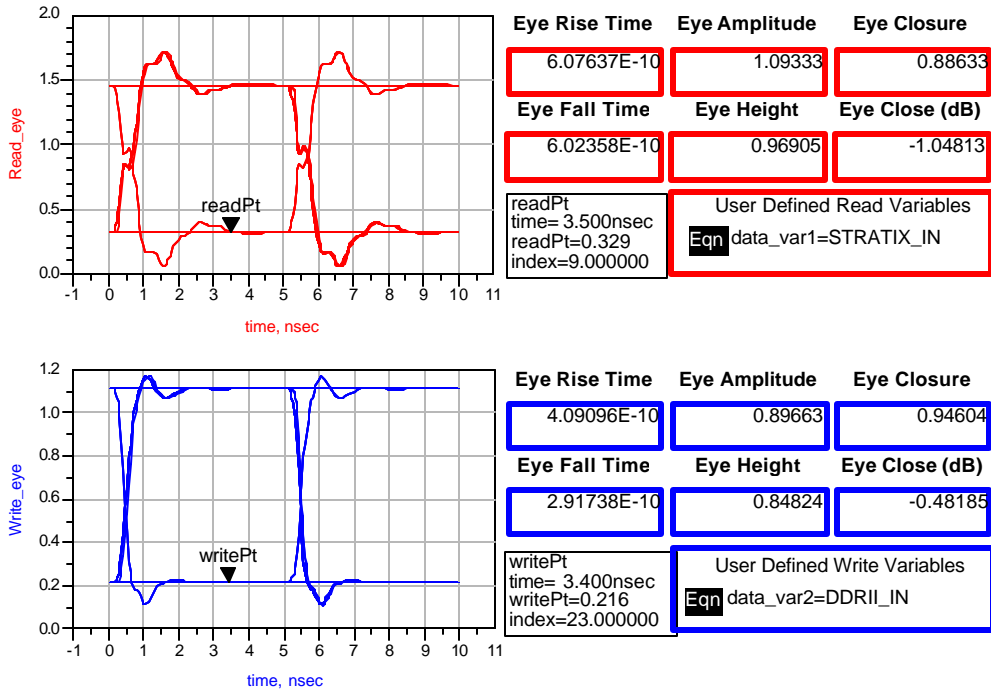


Figure 3-3 Near End Single Series / Dual Parallel Termination (Fly-By) used in DQ0 DDR-II U1, eye analysis.

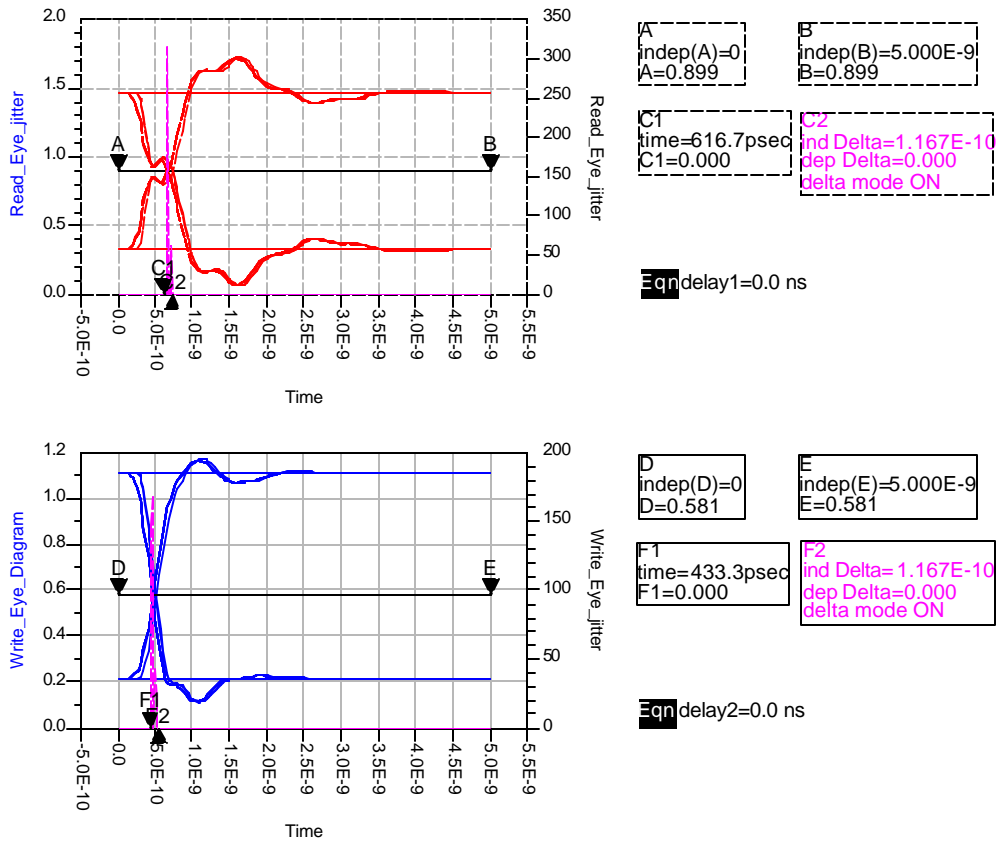


Figure 3-4 Near End Single Series / Dual Parallel Termination (Fly-By) used in DQ0 DDR-II U1, jitter analysis.

3.2 DDRII_A0

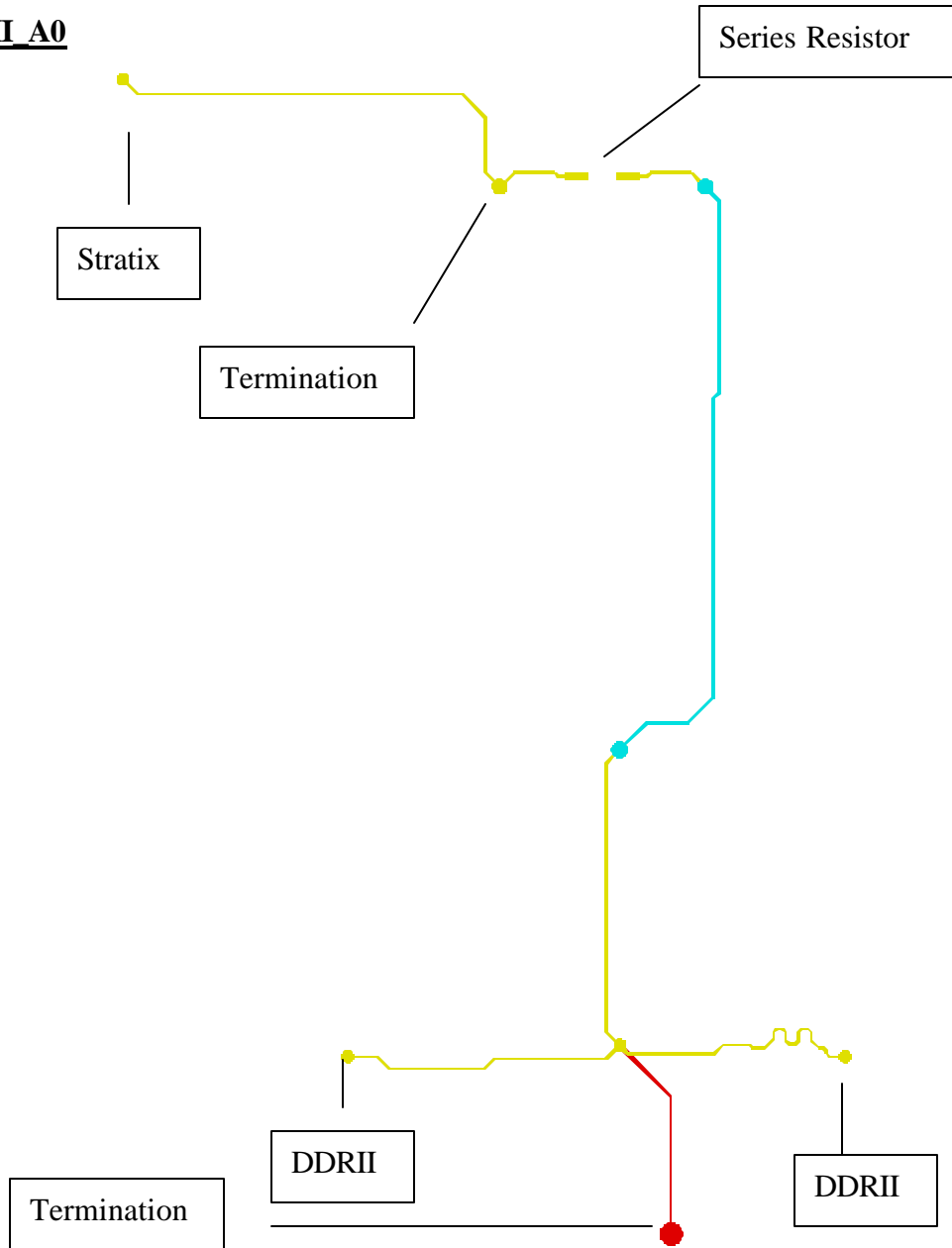


Figure 3-5 Near End Single Series / Dual Parallel Termination (Non Fly-By) used in A0 DDRII.

Stratix to DDR-II Memory Interfaces Analysis

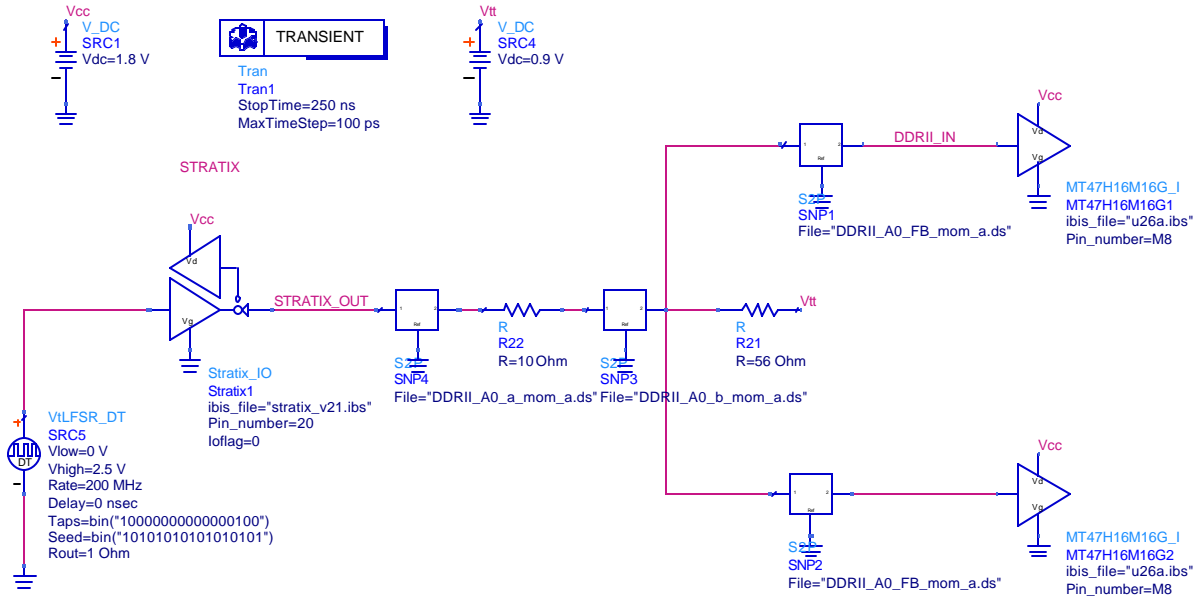


Figure 3-6 Near End Single Series / Dual Parallel Termination (Fly-By) post-layout simulation setup used in A0 DDR-II U1.

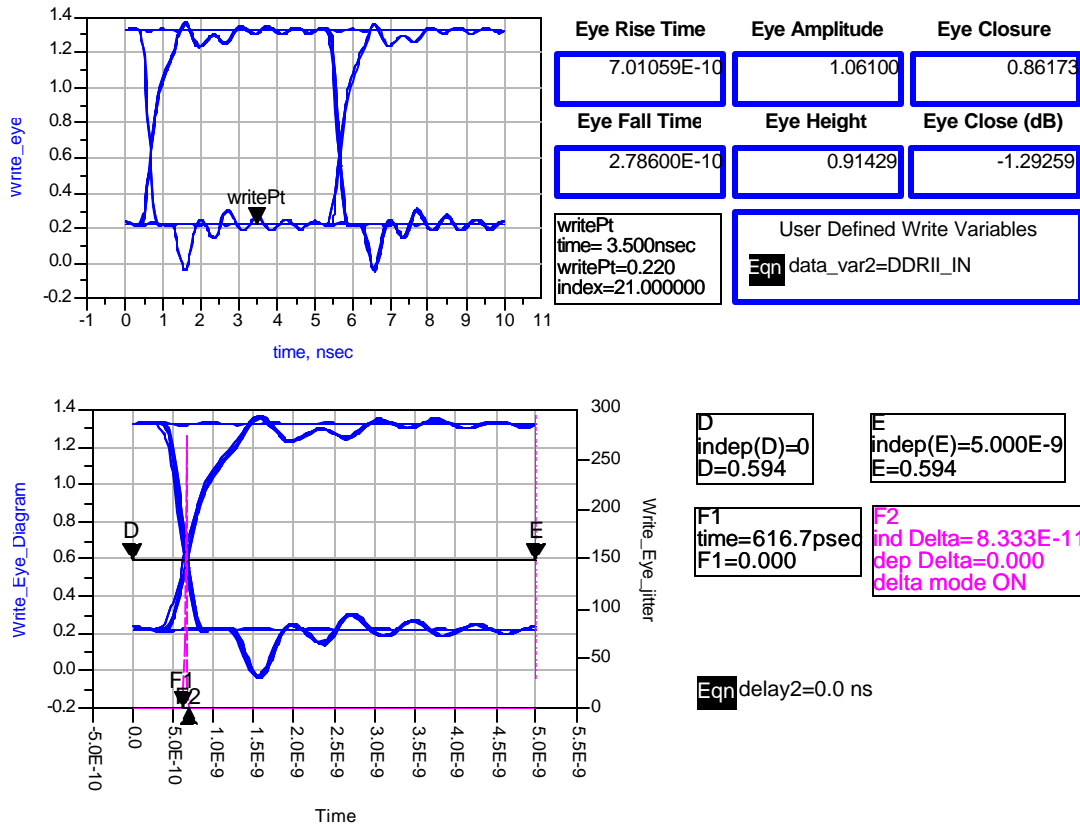


Figure 3-7 Near End Single Series / Dual Parallel Termination (Fly-By) used in A0 DDR-II U1/U2, eye analysis/jitter analysis.

4 CONCLUSION

Based on the simulation results, the following schemes show the best performance for Stratix to DDR-II memory device bi-directional buses:

- 2.1.1 Dual Series/Dual Parallel Termination (Fly-By)
- 2.1.2 Dual Series/Dual Parallel Termination (Non-Fly-By)
- 2.1.3 Dual Parallel Termination (Fly-By)
- 2.1.4 Dual Parallel Termination (Non-Fly-By)

Based on the simulation results, the following schemes show the best performance for Stratix to DDR-II memory device unidirectional buses:

- 2.1.9 Single Near End Series / Far End Parallel Termination, (Fly-By)
- 2.1.10 Single Near End Series / Far End Parallel Termination (Non-Fly-By)

The best scheme based on performance/component ratio appears to be 2.1.5. The Stratix Memory Board 2 (SMB2) uses this topology for bidirectional signaling and for unidirectional signals.

5 FURTHER WORK

These simulations should correlate with the measurements.