ECEN 5224: Week 11 Lab Report

Part 1: Eye Simulation of Differential Pair using Siemens HyperLynx

Hyounjun Chang

Objective of Lab: Explore signal integrity of differential signals using Eye Diagram simulations of T-termination using Keysight ADS.

Summary of Experiment: A T-termination schematic with differential driver was created in Keysight ADS. Results of an eye diagram (for single-ended and differential) were compared with no skew and 0.2ns skew for one of the lines. Correct T-termination minimizes reflections, which lead to clean eyes. A small amount of skew can be handled, as long as termination is proper.

A differential driver with 50 ohm termination lines (12 inches, or 1.8ns delay) on both ends were created. A T-termination schematic was created with R1 = 48.3 ohm and R2 = 1.7 ohm, with PCB trace = 9.2mils and spacing = 18.4mils (2x width), since the measured differential impedance was equal to 96.7 ohms. Three 1 megaohm resistors were added to measure differential signal and simulate high-impedance load.

$$R_1 = \frac{R_{diff}}{2} = 48.3ohm \;\; Z_{comm} = 25ohm = \frac{1}{2} * R_1 + R_2 \;\; R_2 = 1.7ohm$$

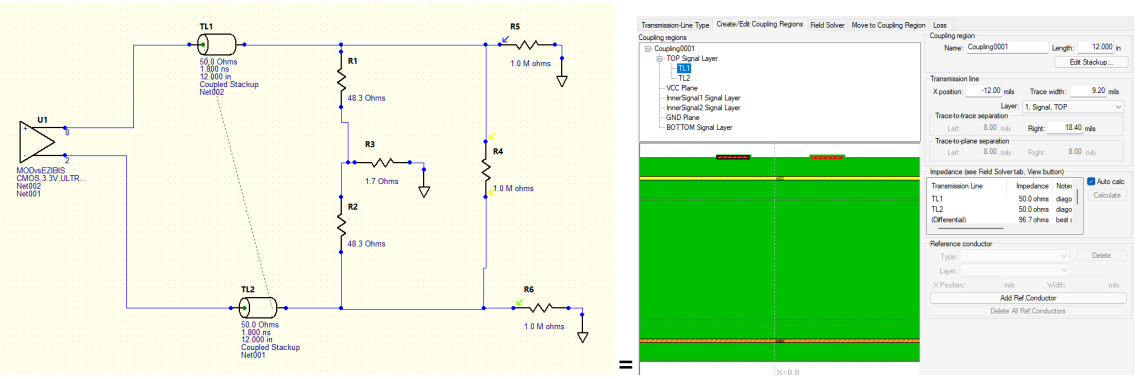

Figure 1: Schematic (Left) and stack-up of PCB (right). The circuit is T-terminated with R1 = 48.3 Ohms and R2 = 1.7 ohms. Differential Impedance is 96.7 Ohms (Not quite 100 ohms), despite each t-line being 50 ohms. 1 Megaohm resistors were added to the right to simulate high impedance load and to measure differential voltage.

Since the lines are lossy, there is more “noise” in the receiver end of the signal. However, without skew (additional delay in one-end), the eye diagram is very clean on both ends of the receiver, with the eye height being over 5V for the receiver. However, there is a slight decrease in eye height between driver and receiver. The eye width was above 900ps for all signals (receiver/driver).

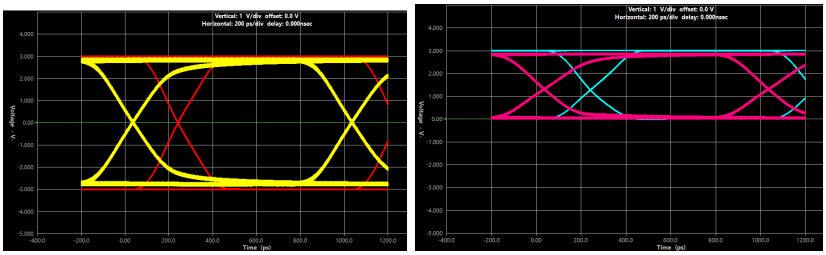

Figure 2: Eye Diagrams of differential signal (Left, Red: Driver, Yellow: Receiver) and single-ended signal (Right, Light Blue: Driver, Pink: Receiver)

T-Termination, 0ns skew, 1Gbps	Eye Height (V)	Eye Width (ps)
Driver (single)	2.99	938
Receiver (single)	2.58	945
Differential Driver	5.98	987

Differential Receiver	5.17	978

Figure 3: Table for Eye Diagram for no delay with T-termination

One additional transmission transmission line 0.2ns delay was added on the positive-end of the driver to create some skew. All other parts were kept the same for comparison.

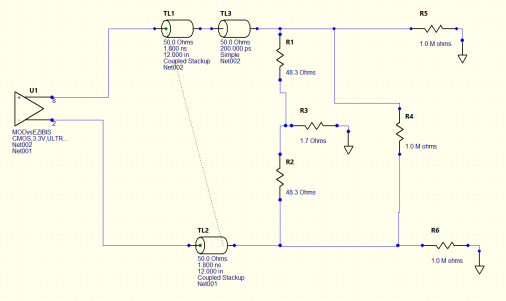

Figure 4: Same schematic but with 0.2ns delay added on one-end for skew

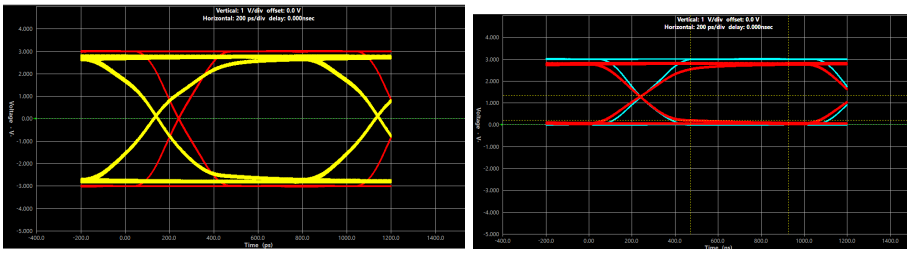

Figure 5: Eye Diagrams of differential signal with 0.2ns skew on one channel (Left, Red: Driver, Yellow: Receiver) and single-ended signal (Right, Light Blue: Driver, Red: Receiver)

Even with skew added, T-termination correctly terminates common signal and differential signal. Eye height decrease in the receiver signal was miniscule (5.17V vs 5.13V), and the eye width is still above 900ps for all signals. This leads to a clean eye. Shape of the eye has changed with the 0.2ns skew, due to “slower rise time”, but at 1Gbps this does not affect the eye height or width.

T-Termination, 0.2ns Skew, 1Gbps	Eye Height (V)	Eye Width (ps)
Driver (single)	2.97	938
Receiver (single)	2.55	946
Differential Driver	5.95	985
Differential Receiver	5.13	959

Figure 6: Table for Eye Diagram for 0.2ns delay on one end with T-termination

Conclusion for Lab: Differential signals have two components: differential and common. T-terminations can be created with some calculations by matching both differential impedance and common impedance based upon odd/even mode. If a circuit is properly terminated with T-terminations, there are minimal reflections, which lead to clean eyes even with slight skew, although it may lead to greater rise or fall times.

ECEN 5224: Week 11 Lab Report

Part 2: Simulating Termination Strategies for Differential Pair with Siemens HyperLynx

Hyounjun Chang

Objective of Lab: Explore effects of different termination strategies (Differential only, Single-Ended, None) on eye diagram of signals, and compare the results with T-termination from Part 1.

Summary of Experiment: Same differential driver schematic was created from Part 1 (with 0.2ns skew), but with different termination strategies (96.7 ohm differential only, 50 ohm single-ended only, none). All three terminations lead to worse results than T-termination due to reflections, although some are better than others. Maximum speed of differential only termination was estimated based upon the eye diagram of the signal.

The same driver schematic with 50-ohm transmission line with 0.2ns skew was created with differential termination only. Only 96.7 ohm resistor was added between the load (1 megaohm), unlike T-termination.

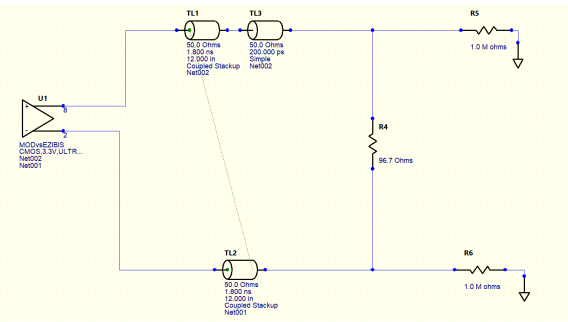

Figure 1: 96.7 Ohm differential termination schematic. Note that despite being 50 ohms on t-line, differential impedance is slightly lower at 96.7 ohms.

The resulting eye diagram has an impact on both the driver and receiver. The differential driver has an eye height of 5.47V compared to 5.95V with T-termination. Differential receivers have a much higher drop from 5.13V to 4.38V. Eye width of the signal is still above 900ps, with the exception of single-ended receivers at 792ps. This is due to the fact that the differential receiver only cares about the voltage difference. This drop is due to common signal impedance mismatch. There is also an overshoot on the receiver end of the signal.

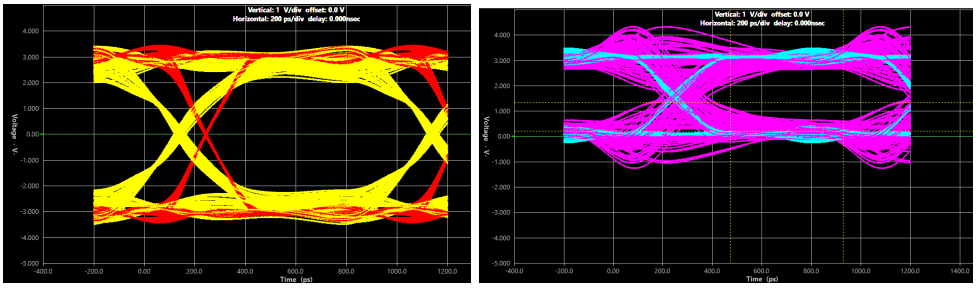

Figure 2: Eye Diagrams of differential signal (Left, Red: Driver, Yellow: Receiver) and single-ended signal (Right, Light Blue: Driver, Pink: Receiver) with differential termination

96.7Ohm Differential, 0.2ns Skew, 1Gbps	Eye Height (V)	Eye Width (ps)
Driver (single)	2.49	949
Receiver (single)	2.00	792
Differential Driver	5.47	979
Differential Receiver	4.38	941

Figure 3: Table for Eye Diagram for 0.2ns delay with Differential Termination

The same schematic was terminated with 50 ohms on both ends of termination for single-ended termination. 1 megaohm resistor was placed between 2 transmission lines for differential voltage measurement. This schematic only matches the common impedance.

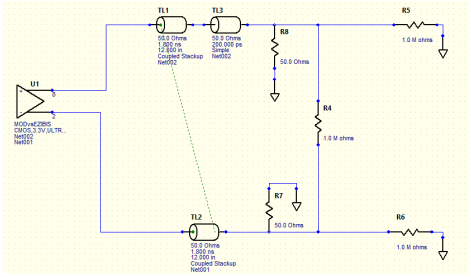

Figure 4: 50 Ohm Single-Ended termination schematic

The resulting diagram is much messier than with differential termination. The eye is visible from the driver end, but the eye height is much lower (5.13V vs 3.92V), and eye width much shorter (985ps vs 758ps). The eye does not exist on the receiving end, as differential impedance is not matched. This leads to a wide range of differential voltages between 15V and -15V from a 3.3V CMOS driver, which will cause problems. The eye height and width measurement from simulation are irrelevant, as no eye exists. Do note that the scale of the eye diagram is different for each image below

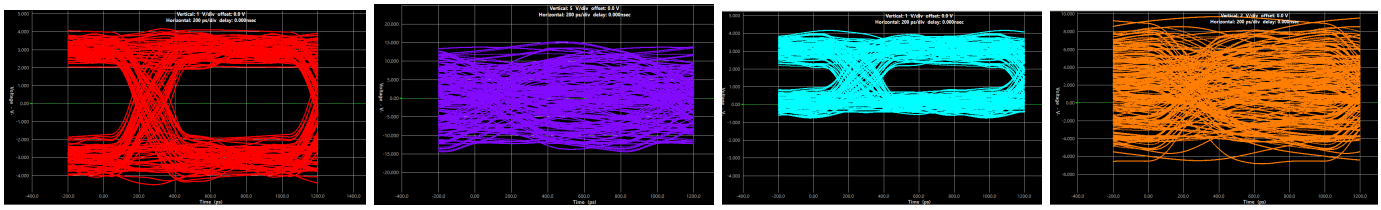

Figure 5: Differential Signal on Driver (far-left) and Receiver (middle-left), Single-Ended Signal on Driver (middle-right) and Receiver (far-right)

50Ohm Single-Ended, 0.2ns Skew, 1Gbps	Eye Height (V)	Eye Width (ps)
Driver (single)	1.37	716
Receiver (single)	0.335	121
Differential Driver	3.92	758
Differential Receiver	0.71	123

Figure 6: Table for Eye Diagram for 0.2ns delay with Single-Ended Termination

Single-ended termination resistors were removed to remove termination. Only 1 megaohm load resistor was added, alongside 0.2ns skew. This results in the same eye diagram result as the single-ended termination only, with the eye not distinguishable on the receiver end. Matching the differential impedance is the most crucial to having a good eye diagram.

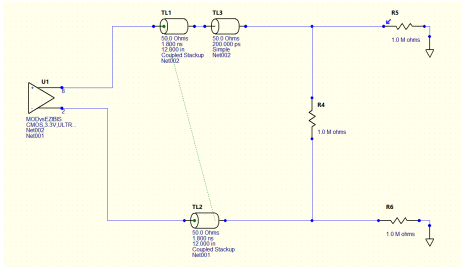

Figure 7: No termination schematic

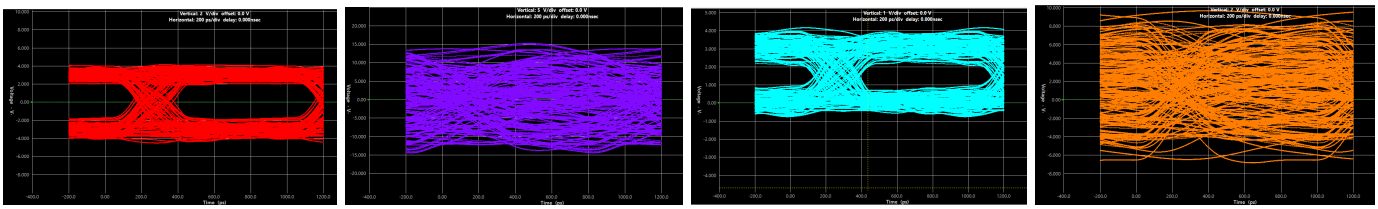

Figure 8: Differential Signal on Driver (far-left) and Receiver (middle-left), Single-Ended Signal on Driver (middle-right) and Receiver (far-right)

No Termination, 0.2ns Skew, 1Gbps	Eye Height (V)	Eye Width (ps)
Driver (single)	1.37	716
Receiver (single)	0.335	121
Differential Driver	3.92	758
Differential Receiver	0.71	123

Figure 9: Table for Eye Diagram for 0.2ns delay without Termination

Eye diagram simulation was done with different data rates (1Gbps, 2Gbps, 3Gbps) on the differential receiver end. Schematic with differential termination only was used as instructed. As the data rate of the signal increases, eye height decreases. At 1Gbps, there is 4.49V eye height, but only 0.69V at 3Gbps. Eye height is still distinguishable at 2Gbps (2.77V), so the **estimated max data rate is between 2Gbps and 3Gbps**.

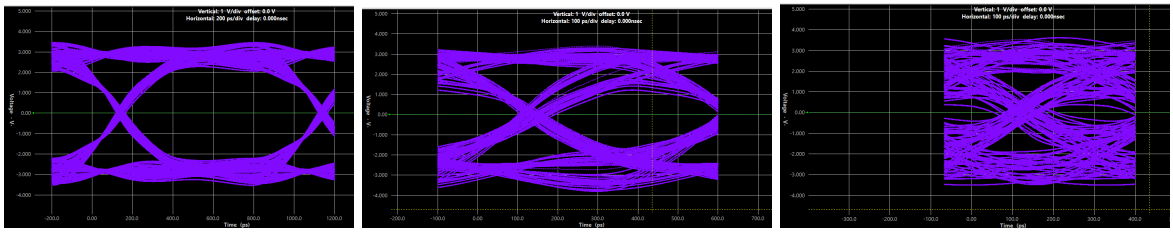

Figure 10: Differential Termination at 1Gbps (left), 2Gbps (middle), and 3Gbps (right)

Differential Termination, 0.2ns Skew, Differential Receiver	Eye Height (V)	Eye Width (ps)
1Gbps (1ns UI)	4.49	941
2Gbps (500ps UI)	2.77	401
3Gbps (333ps UI)	0.69	177

Figure 11: Differential Termination at 1Gbps (left), 2Gbps (middle), and 3Gbps (right)

Conclusion for Lab: Termination strategy significantly affects eye diagram on the receiver end. T-termination is the best termination, as it matches both differential and common impedances. Differential termination still generates enough eye height at lower bit-rates. Single-ended and no termination results in lack of eye in the diagram. This implies that differential impedance matching is more important in the receiver end to minimize reflections. If possible, T-termination should be used in all cases for maximum signal integrity.