

# ECEN 5224: Week 15 Lab Report

## Part 1: High Speed Serial Link Simulation with Matlab SerDes Designer Hyounjun Chang

**Objective of Lab:** Explore effects of lossy interconnects on signal integrity on the RX, and mitigating its effects with Feed-Forward Equalizer (FFE) Filter.

**Summary of Experiment:** A lossy line was simulated on Matlab SerDes Designer using default settings, and S-Parameter file of real-life interconnects (provided by instructor). Effects of lossy lines were simulated by analyzing waveforms of impulse response, PRBS signal, and eye diagram on Matlab. FFE filter was used to equalize and open up the eye diagram for lossy models and real-life interconnects with measured S-Parameters. Maximum data-rate was analyzed for real-life high-speed serial links.

To simulate insertion loss of 10dB at 5GHz Nyquist frequency (10Gbps), the default loss model for SerDes Designer was used in Matlab. A 1V pure differential signal was given with 10ps rise-time with -10dB insertion loss at 5GHz (10 Gbps) for the transmission line. Using no filters results in signals below. There is no signal integrity issue currently.

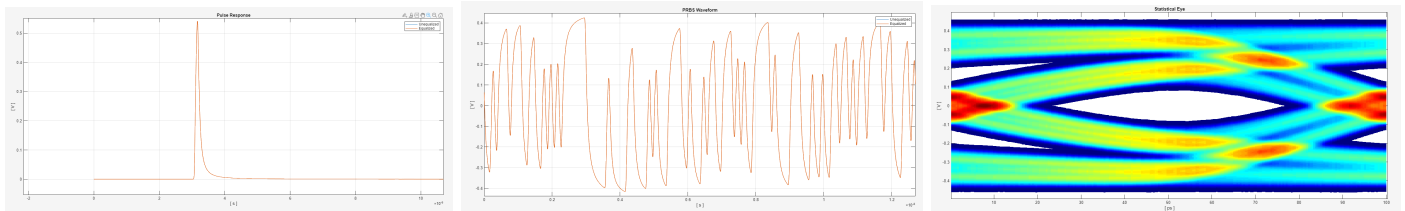


Figure 1: Impulse Response (Bottom-Left), PRBS signal (Bottom-Middle), and Eye Diagram (Bottom-Right) for Lossy Line with -10dB insertion Loss@ 5GHz

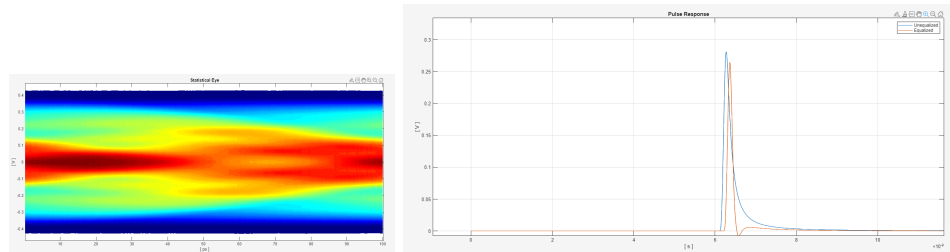


Figure 2: Eye Diagram for -20dB loss @ 5GHz (Bottom-Left), Impulse Response (Bottom-Right, Blue: no filter, Orange: FFE filter)

Increasing the insertion loss to -20dB loses the eye as higher frequencies are attenuated even more. An equalizing filter is needed to reopen the eye. Feed-Forward Equalizer (FFE) Filter was added on TX-end to make this happen. Filter of Tap weight  $[0, 1, -0.4, -0.1, 0]$ , which shifts the signal by UI was used in the FFE filter. This equalizes the signal, and reopens the eye by reducing ISI (also seen from Impulse Response). The eye diagram is open again for the 10Gbps PRBS signal.

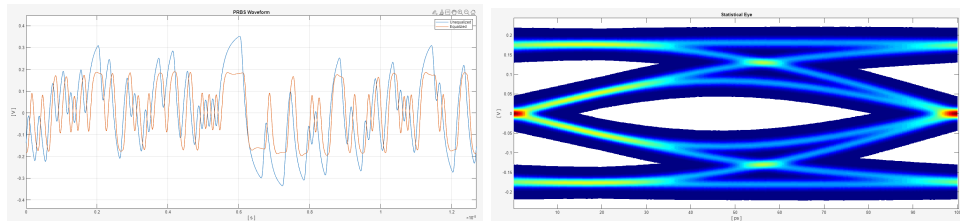


Figure 3: PRBS signal (Left, Blue: no filter, Orange: FFE filter), Eye Diagram with FFE filter (Right) for -20dB loss @ 5GHz

S-Parameter files of two 15-inch differential interconnect (with and without stub) was provided by the instructor (Prof. Bogatin), with the goal of estimating the highest data achievable. Similar to the previous model, a customized FFE with tap weights were used to maximize performance.

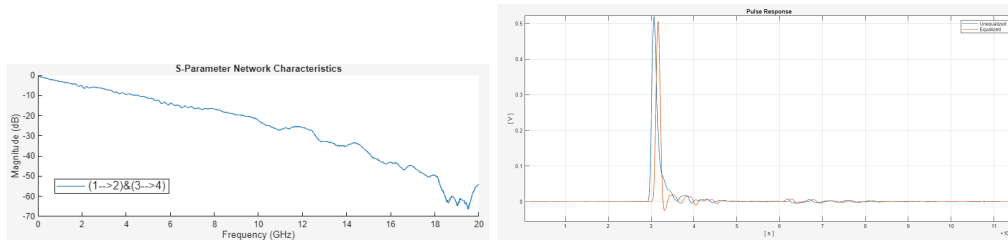


Figure 4: S-Parameter for K1\_stub\_no\_15inch\_FR408\_bottom-routed-1.s4p (Left), Impulse Response (Right, Blue: no filter, Orange: with FFE filter)

Without the presence of a stub, dropoff in the insertion loss is uniform up to ~18Gbps. Because the transmission line is long, the slope of descent is significant, however.

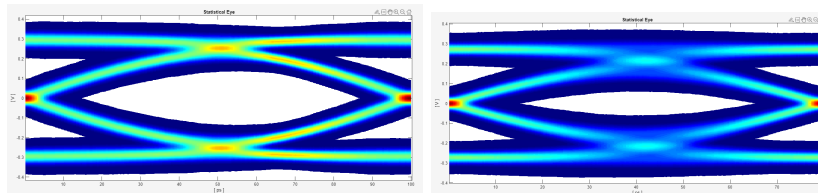


Figure 5: Eye Diagram for 10Gbps PRBS signal (Left), 12.5Gbps PRBS signal (Right)

Finding the target eye width is  $0.4UI$  (w/o random jitter) will give an estimate for maximum bit-rate allowed, as  $0.3UI$  is reserved for random jitter. Using the tap weight of  $[0 \ 1 \ -0.3 \ -0.05 \ 0.02]$  gives us a faster impulse response time albeit at longer.  $80ps$  UI ( $12.5Gbps$ ) gives us  $\sim 50ps$  eye width, which is slightly under  $0.4$  UI. **The estimated maximum bit-rate is  $\sim 12.5Gbps$  for the 15 inch interconnect without a stub.** This gives us a Nyquist frequency of  $\sim 6GHz$ , which is much lower than the resonant frequency.

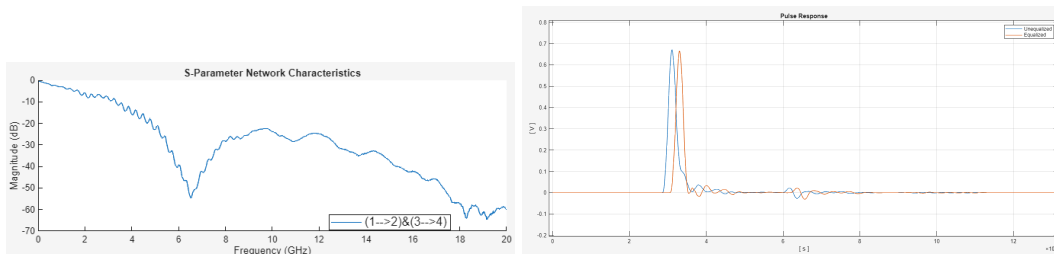


Figure 6: S-Parameter for K2\_stub\_yes\_15inch\_FR408\_stub-2.s4p (Left), Impulse Response (Right, Blue: no filter, Orange: with FFE filter)

The same procedure was followed for a 15-inch transmission line with a stub. The insertion loss drops off dramatically around  $6GHz$  due to  $\frac{1}{4}$  wavelength resonant frequency. Due to this feature, maximum bitrate will be lower than the transmission line without a stub. Using the tap weight of  $[0 \ 1 \ -0.17 \ -0.02 \ 0]$  gives us an impulse response with less ISI and faster response. At  $7.14Gbps$ ,  $\sim 0.4UI$  is consumed by deterministic jitter. **The estimated maximum bit-rate is  $\sim 7.2GHz$  for the 15 inch interconnect with a stub.** This gives us a Nyquist frequency of  $\sim 3.6$  GHz, which is still lower than the stub resonant frequency from S-Parameter.

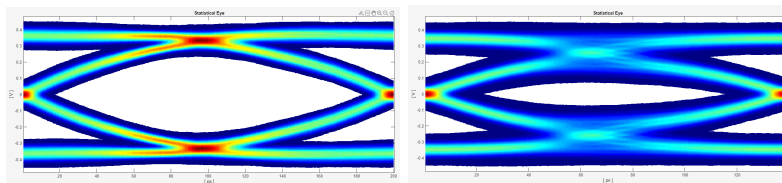


Figure 7: Eye Diagram for 5Gbps PRBS signal (Left), 7.14Gbps PRBS signal (Right)

**Conclusion for Lab:** Lossy lines create signal problems due to different attenuation at different frequencies. This causes problems for high-speed serial links, and equalization is necessary for some transmission lines. Feed-Forward Equalizer (FFE) filter is one solution which can be added to TX to modify the analog signal. This allows us to open the eye of the PRBS signal even at significant insertion losses such as  $-20dB$ , allowing us to maximize bitrate of the signal. However, design of the filter taps require knowledge of the S-Parameters (or loss profile), and the weights need to be adjusted for the specific transmission line. Real-life stubs create a resonant frequency which significantly reduces the maximum signal which can be transmitted, measured by the eye diagram resulting in a width of  $0.4UI$ , and should be avoided if possible.