EE800 - High Speed Interconnects: Assignment 2

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Contents

1 Problem 1: Transmission Model Analysis

1.1 (i) Impulse Response : Analytical analysis

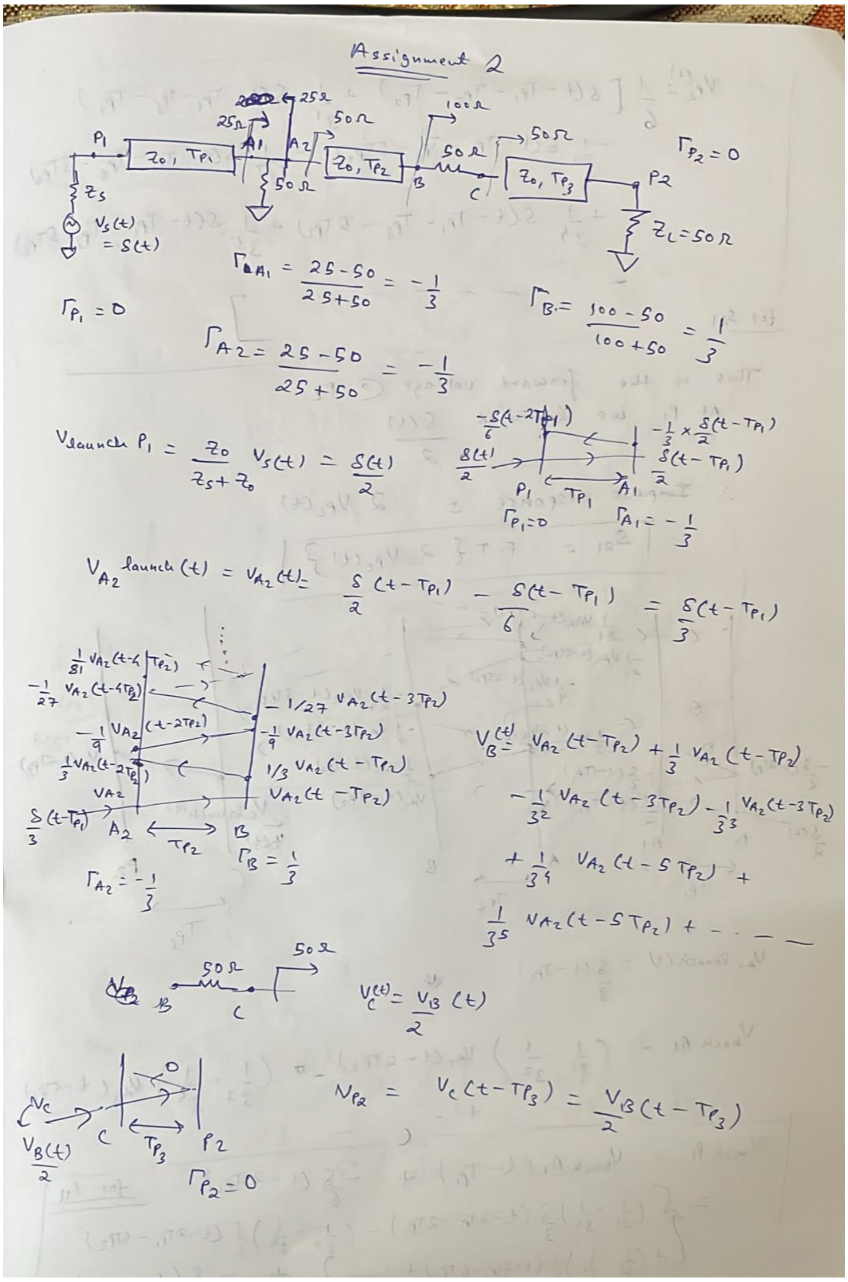
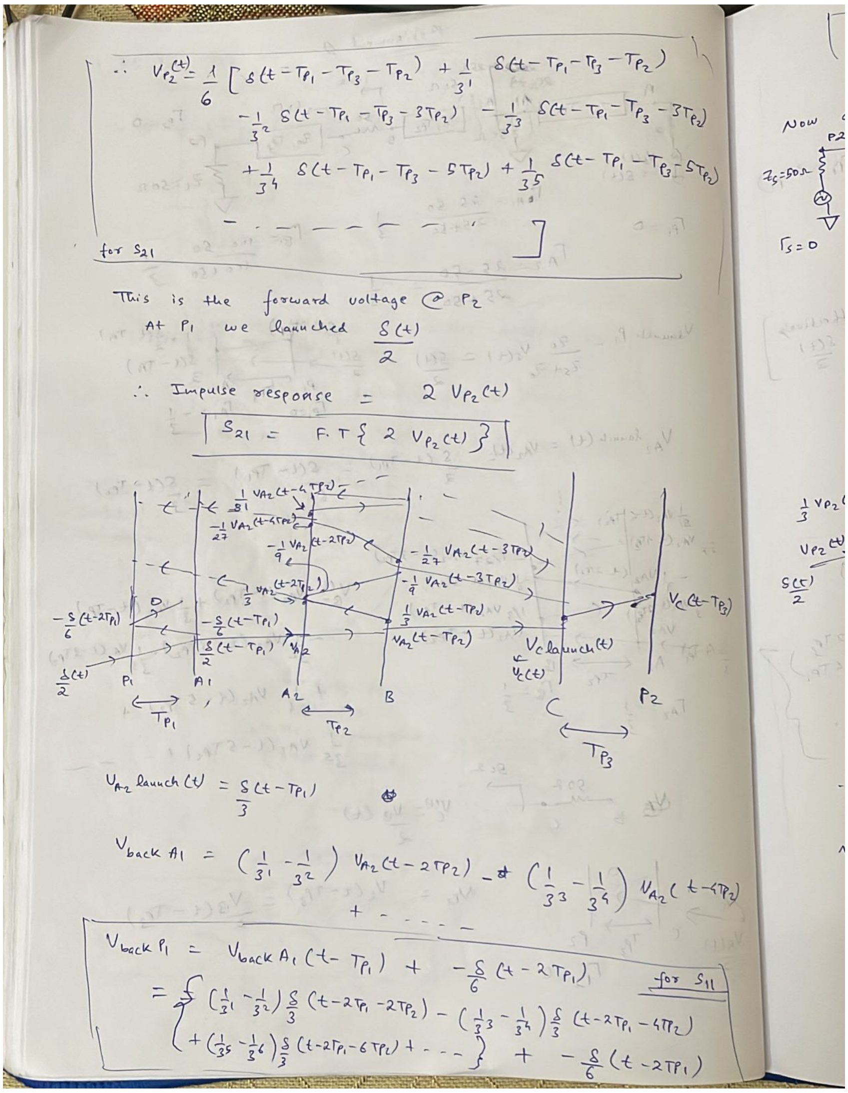


Figure 1: Derivation of impulse response (1)



$$\therefore V_{P_2}(t) = \frac{1}{6}\Big[\delta(t - T_{P_1} - T_{P_3} - T_{P_2}) + \frac{1}{3^1}\delta(t - T_{P_1} - T_{P_3} - T_{P_2})$$
$$- \frac{1}{3^2}\delta(t - T_{P_1} - T_{P_3} - 3T_{P_2}) - \frac{1}{3^3}\delta(t - T_{P_1} - T_{P_3} - 3T_{P_2})$$
$$+ \frac{1}{3^4}\delta(t - T_{P_1} - T_{P_3} - 5T_{P_2}) + \frac{1}{3^5}\delta(t - T_{P_1} - T_{P_3} - 5T_{P_2})$$
$$- \cdots \Big]$$

for S_{21}

This is the forward voltage @ P_2

At P_1 we launched $\frac{\delta(t)}{2}$

$\therefore$ Impulse response $= 2\,V_{P_2}(t)$

$$\boxed{S_{21} = \text{F.T}\{2\,V_{P_2}(t)\}}$$

$$V_{A_2\,\text{launch}}(t) = \frac{\delta}{3}(t - T_{P_1})$$

$$V_{\text{back}\,A_1} = \left(\frac{1}{3^1} - \frac{1}{3^2}\right)V_{A_2}(t - 2T_{P_2}) - \left(\frac{1}{3^3} - \frac{1}{3^4}\right)V_{A_2}(t - 4T_{P_2}) + \cdots$$

$$V_{\text{back}\,P_1} = V_{\text{back}\,A_1}(t - T_{P_1}) + -\frac{\delta}{6}(t - 2T_{P_1})$$

for S_{11}

$$= \Big\{\left(\frac{1}{3^1} - \frac{1}{3^2}\right)\frac{\delta}{3}(t - 2T_{P_1} - 2T_{P_2}) - \left(\frac{1}{3^3} - \frac{1}{3^4}\right)\frac{\delta}{3}(t - 2T_{P_1} - 4T_{P_2})$$
$$+ \left(\frac{1}{3^5} - \frac{1}{3^6}\right)\frac{\delta}{3}(t - 2T_{P_1} - 6T_{P_2}) + \cdots\Big\} + -\frac{\delta}{6}(t - 2T_{P_1})$$

Figure 2: Derivation of impulse response (2)

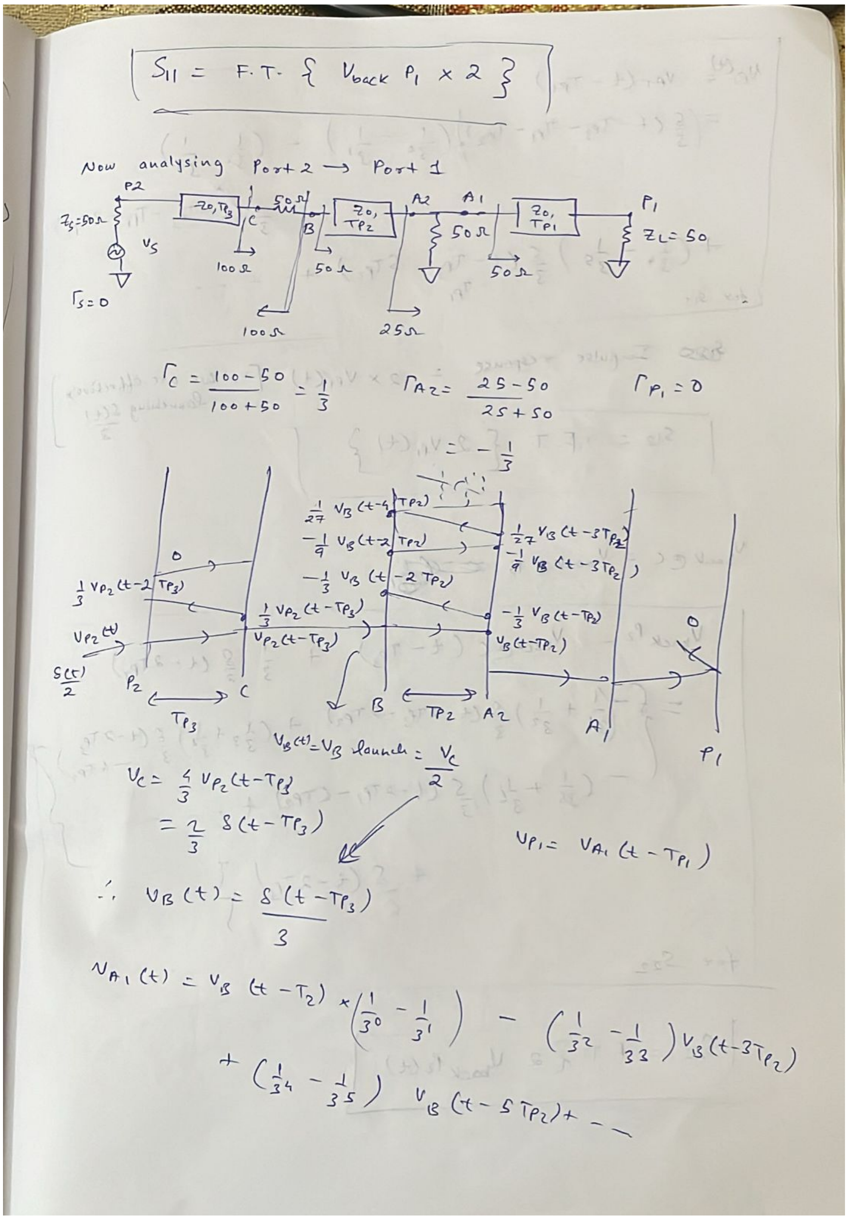
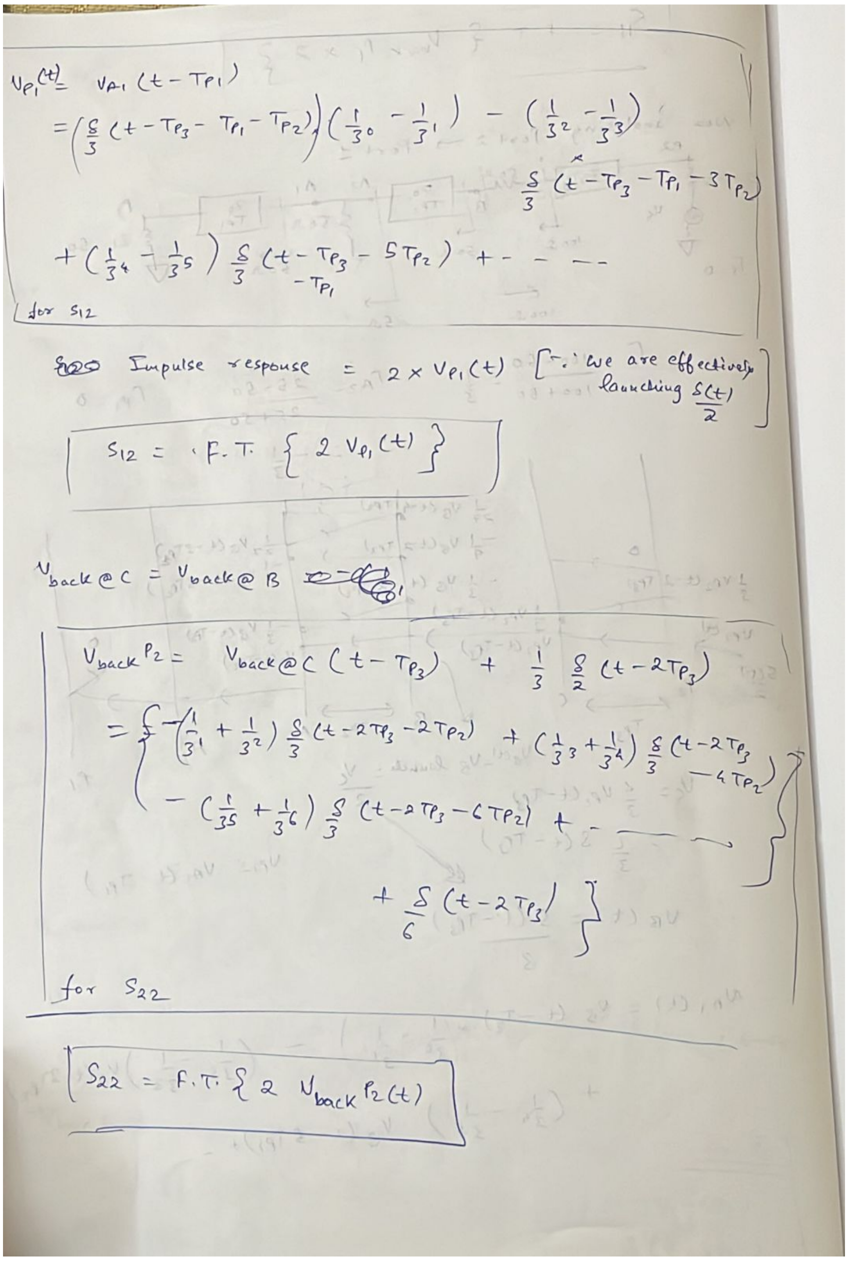


Figure 3: Derivation of impulse response (3)



$$v_{P_1}(t) = v_{A_1}(t - T_{P_1})$$

$$= \left(\frac{\delta}{3}(t - T_{P_3} - T_{P_1} - T_{P_2})\right)\left(\frac{1}{3^0} - \frac{1}{3^1}\right) - \left(\frac{1}{3^2} - \frac{1}{3^3}\right)\frac{\delta}{3}(t - T_{P_3} - T_{P_1} - 3T_{P_2})$$

$$+ \left(\frac{1}{3^4} - \frac{1}{3^5}\right)\frac{\delta}{3}(t - T_{P_3} - 5T_{P_2} - T_{P_1}) + - - - -$$

for S_{12}

Impulse response $= 2 \times v_{P_1}(t)$ [$\because$ we are effectively launching $\frac{\delta(t)}{2}$]

$$\boxed{S_{12} = F.T.\left\{2\, v_{P_1}(t)\right\}}$$

$$V_{back@C} = V_{back@B}$$

$$V_{back}{}^{P_2} = V_{back@C}(t - T_{P_3}) + \frac{1}{3}\,\frac{\delta}{2}(t - 2T_{P_3})$$

$$= \left\{ -\left(\frac{1}{3^1} + \frac{1}{3^2}\right)\frac{\delta}{3}(t - 2T_{P_3} - 2T_{P_2}) + \left(\frac{1}{3^3} + \frac{1}{3^4}\right)\frac{\delta}{3}(t - 2T_{P_3} - 4T_{P_2}) - \left(\frac{1}{3^5} + \frac{1}{3^6}\right)\frac{\delta}{3}(t - 2T_{P_3} - 6T_{P_2}) + - - - \right.$$

$$\left. + \frac{\delta}{6}(t - 2T_{P_3}) \right\}$$

for S_{22}

$$\boxed{S_{22} = F.T.\left\{2\, V_{back}{}^{P_2}(t)\right\}}$$

Figure 4: Derivation of impulse response (4)

1.2 (ii) Simulation Results-Python

The following plots are obtained using python based on the derivation of the impulse responses for S11 , S12 , S21 and S22 . Here is the link for the code used to get these results: https://colab.research.google.com/drive/1-O1bRPFgsVD49GxcF0zkI1U9ELxYejft?usp=sharing.

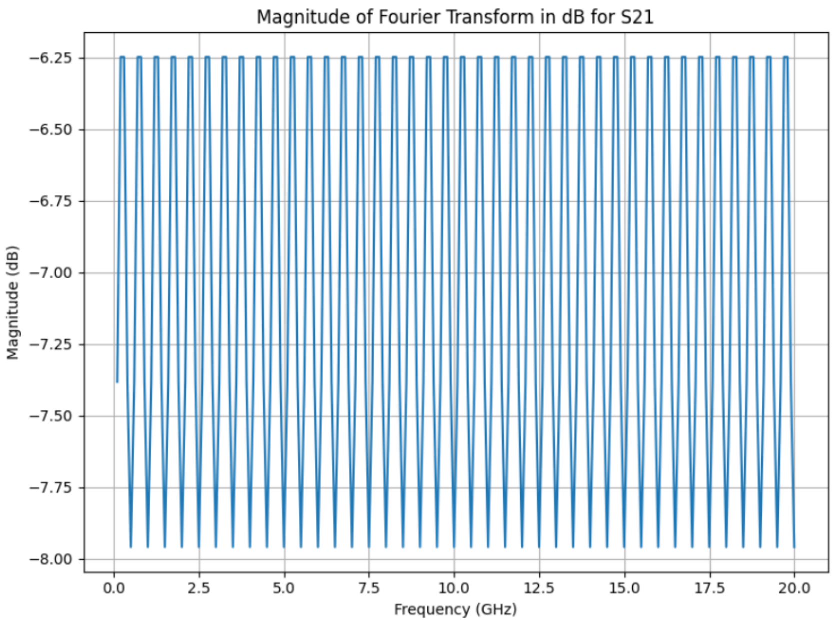


Figure 5: S21

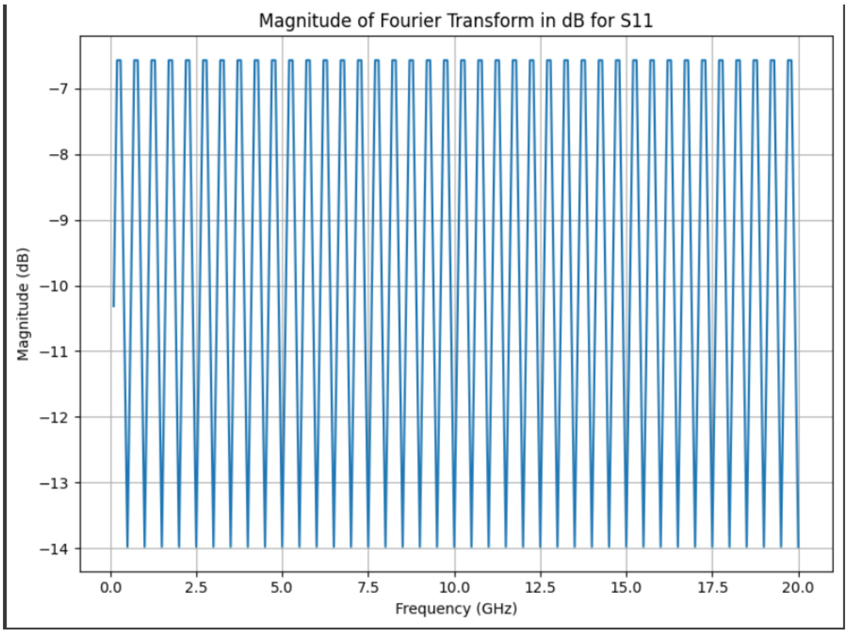


Figure 6: S11

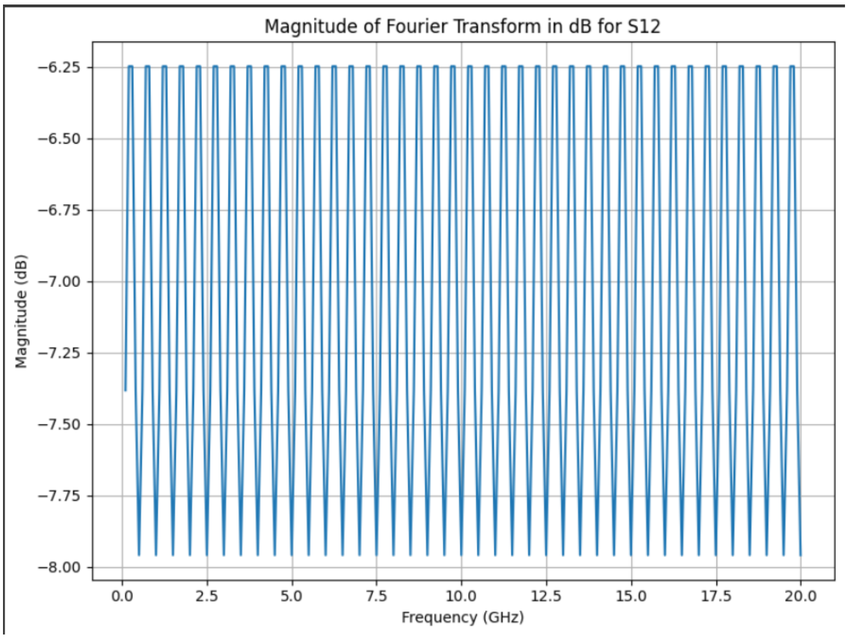


Figure 7: S12

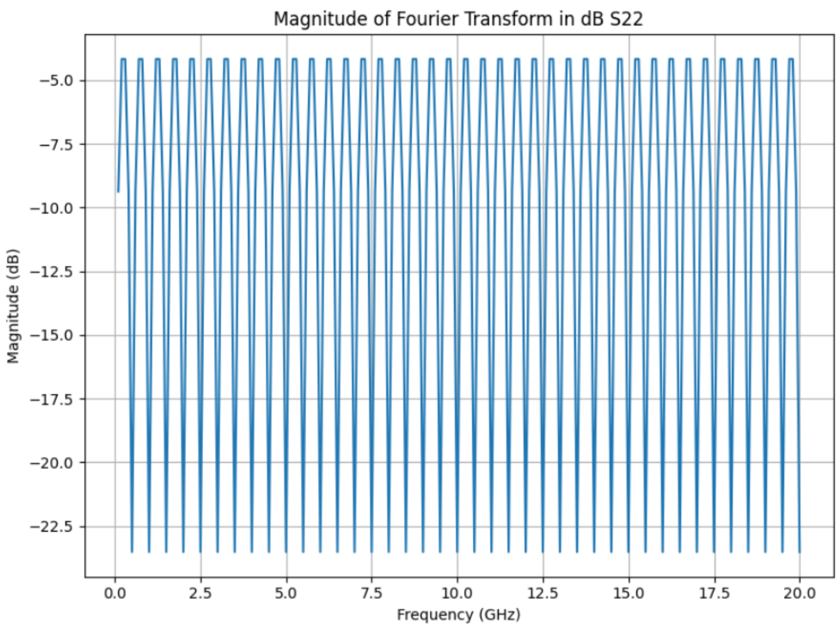


Figure 8: S22

1.3 (iii) Simulation Results-Cadence

The L and C values chosen for each of the transmission line : $L = 2.5mH, C = 1\mu F$ And the propogation velocity :

$$v_p = \frac{1}{\sqrt{LC}} = 20000m/s$$

Then lengths of these transmission lines are then calculated based on this propagation velocity as (length of line $= v_pTp$): $14\mu m, 20\mu m$ and $6\mu m$. The simulation was carried out by sweeping frequency over the range of 100MHz to 40GHz with a step size of 100MHz and the magnitude plots (in dB) were plotted as shown in figure 10 .

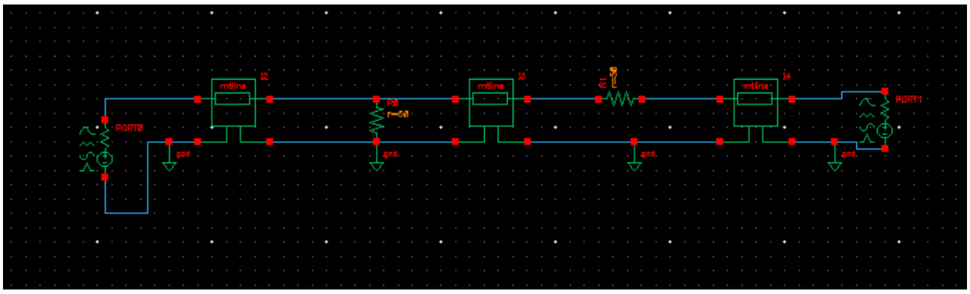


Figure 9: Schematic for given Transmission Line model

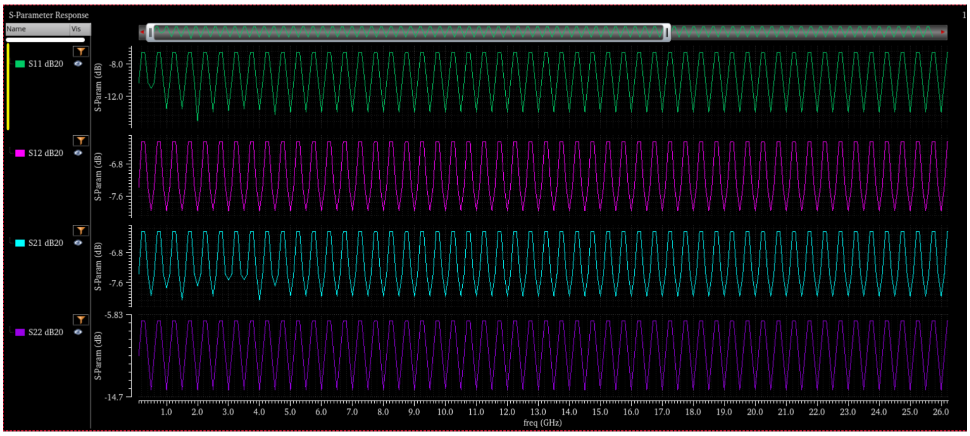


Figure 10: Simulation Results for S parameters (cadence)

The results obtained in cadence are very close to those obtained using python and analytical analysis of the transmission model .

1.4 (iv) Step Response

The step response is obtained by convolving the unit step with the impulse response (S21) . Here we are performing convolution of unit step with series of impulses . The same response is observed via lattice diagram .

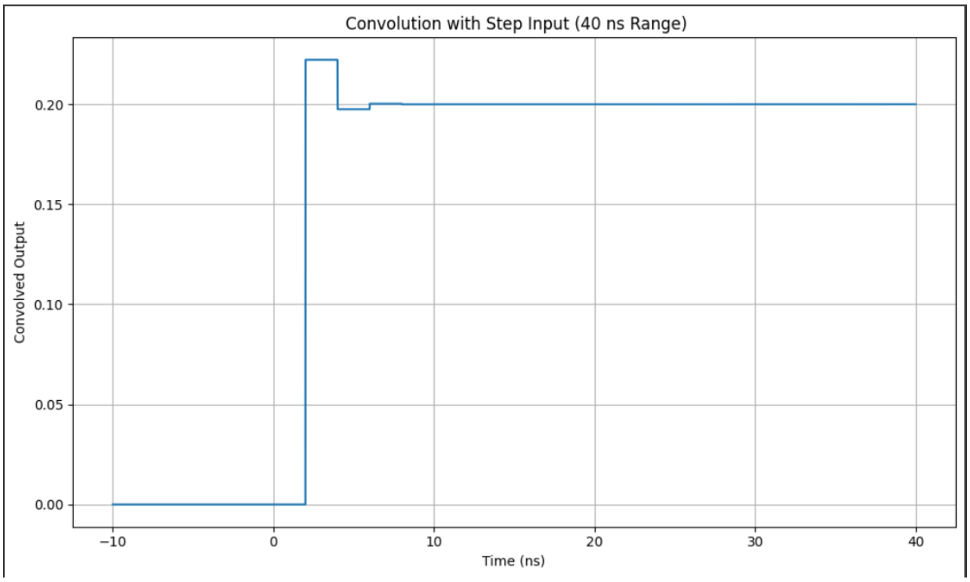


Figure 11: Step response (python)

Similarly simulation was carried out in cadence by applying a pulse of duration 1s (much greater than simulation time of 40ns) at port 1 and very low rise-fall times of 1fs .The output was observed at port as shown in figure 12 . The ports were replaced by voltage source and resistors as shown in figure 13 .

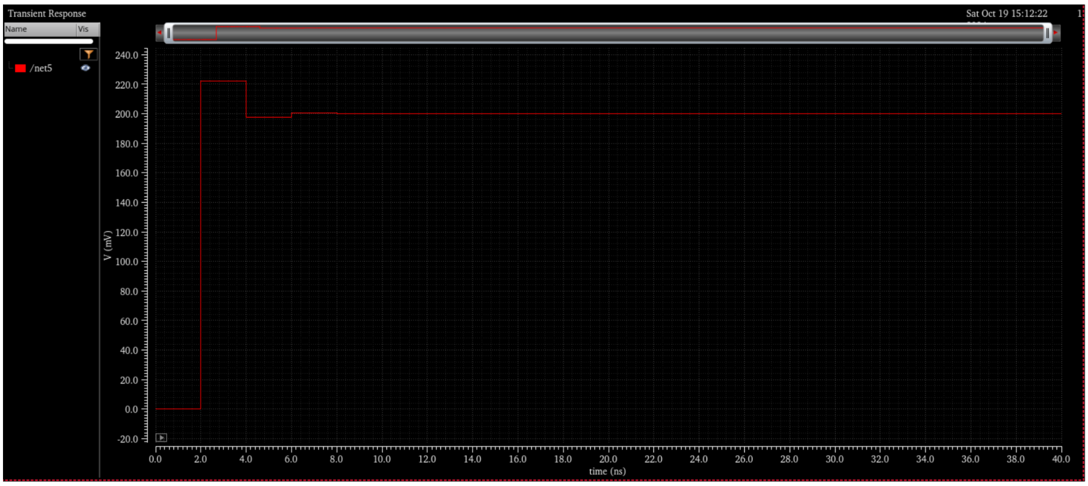


Figure 12: Step response (cadence)

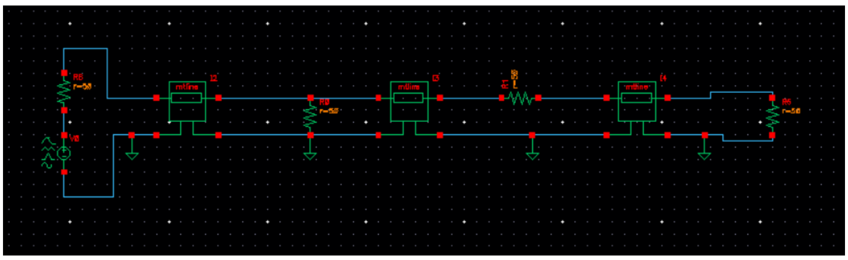


Figure 13: Schematic used for step response

2 Problem 2: Multi-line Stripline Channel Design

In this question, we want to create a multiline stripline channel to support high frequency data transfer. The length is fixed, the number of lines is chosen and we vary the pitch and width of the lines to keep the return losses small. Then, we perform an eye-analysis to have a statistical eye opening of 40mV for 68% UI at 1e-15 BER. The load and source port impedances are 50Ω, and a parasitic capacitance of 200fF at each port.

To start, we have arbitrarily chosen the number of lines to be 5. The transmitting ends are given by Ports 1, 2, 3, 4 and 5. The corresponding receiving ends are Ports 11, 12, 13, 14 and 15. S-parameter analysis is done from 0 to 20 GHz as our maximum bit rate is limited to 40Gbps.

2.1 Return Losses

Return losses have to be maintained below -15dB at all necessary frequencies. Figure 14 shows the return losses for Ports 1 to 5. Similarly, 15 shows the return losses for Ports 11 to 15. It can be seen that all return losses are maintained below -15dB, especially for Ports 1 to 5.

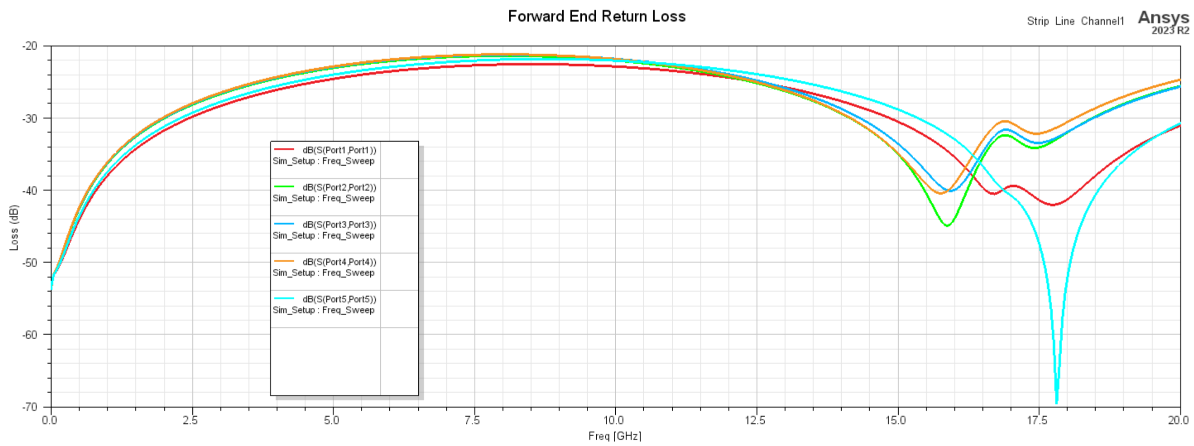


Figure 14: Return Losses from Transmitting end

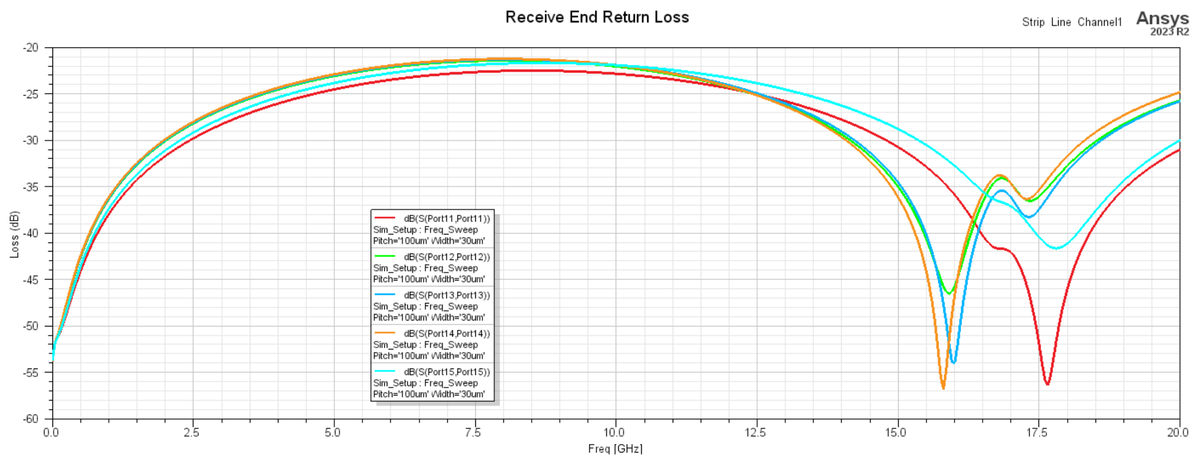


Figure 15: Return Losses from Receiving end

2.2 Cross-Talk

We want to see the response of transmission in one line on other lines. This is called crosstalk. Figure 16 shows the s-parameter graph of sending from Port 3 on Ports 11, 12, 14 and 15, which are on the far side of the input port. Similarly, figure 17 shows the effect on Ports 1, 2, 4 and 5, which are on the near end of the input.

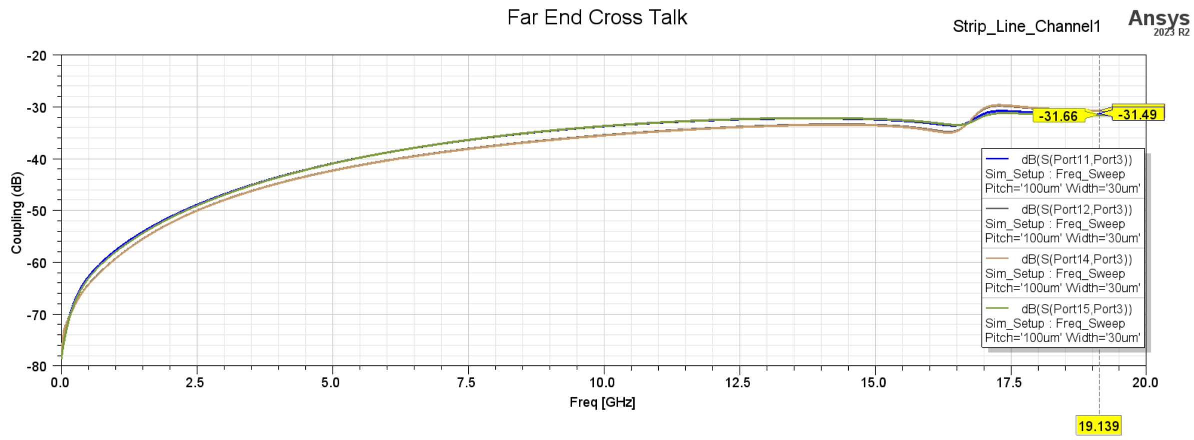


Figure 16: FEXT from Port 3

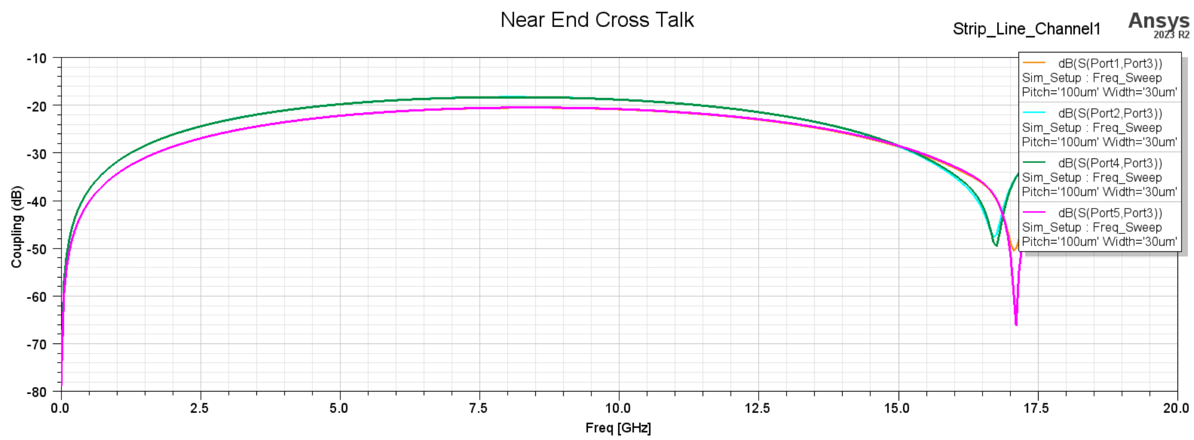


Figure 17: NEXT from Port 3

2.3 Statistical Eye Diagram

Figure 18 shows the eye diagram obtained for center line (Line 3) of the stripline channel setup at 30 Gbps. The mean voltage is 375 mV and we want a 40mV eye opening for 68% of UI at 1e-15 BER. The markers on the plot show the approximate locations where we have an eye opening of atleast 40mV.

By looking at the UI coordinates of the markers, we see that the time interval it is open for our sensitivity and BER is $0.8696 - 0.1692 = 0.7004$UI or 70% of UI. We thus have satisfied our requirement as the signal in the centermost line is the most affected by interference.

Note that the markers are placed conservatively and thus the eye opening is slightly more than calculated.

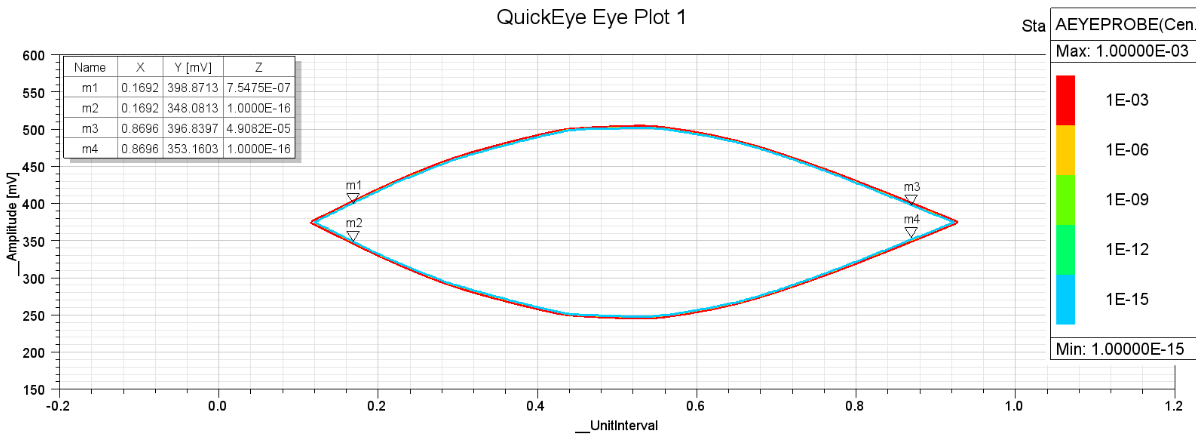


Figure 18: Eye Diagram of Line 3 at 30 Gbps line speed

2.4 Parameter Report

- Width = 30μm, Pitch = 100μm, Length = 5mm
- Number of lines = 5
- Total Die edge = 430μm
- Bit-rate per Line = 30 Gbps
- Total Bit-rate = 150 Gbps