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EEE412 Assignment #2

"I completed this homework assignment independently."

Question #1

For this part, the frequency is set to 5GHz, and the inductor is chosen as 3nH. The corresponding impedance calculation for the 45 degree transmission line is given below.

$$X_L = \omega L = 2\pi * 5GHz * 3nH = 94.24ohm$$

Created circuits is given in Fig. 1.

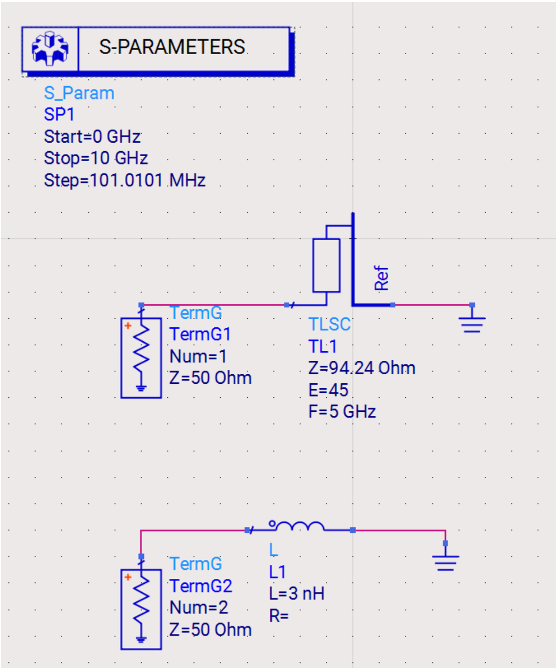


Fig. 1: Inductor approximation circuit

Fig. 2 shows the Z_{11} parameters of both circuits.

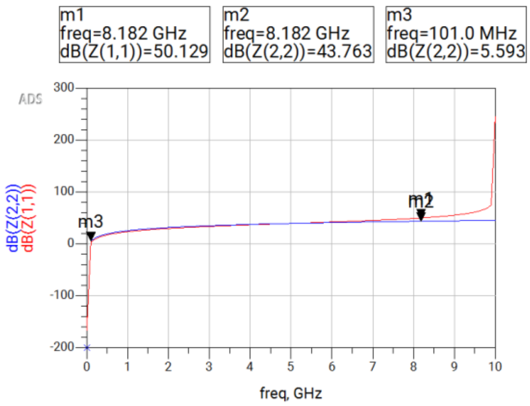


Fig. 2: Z_{11} parameter plots

Using the markers, the 15% error range for Z_{11} parameter, the range starts from 101MHz, and ends at 8.182GHz. The error calculation is given as follows (Markers m1 and m2).

$$\frac{m_1 - m_2}{m_2} = \frac{50.129 - 43.763}{43.763} = 14.54\%$$

ω_0 value is calculated as $31.4*10^9$. So in terms of ω_0, the 15% error range is from 0.0032 ω_0 to 0.26 ω_0.

Question #2

The frequency is again set to 5GHz. Capacitance value is chosen as 1pF. For the 45 degree transmission line, impedance calculation equation is given below.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi * 5GHz * 1pF} = 31.83ohm$$

The created circuit for this part is shown in Fig. 3.

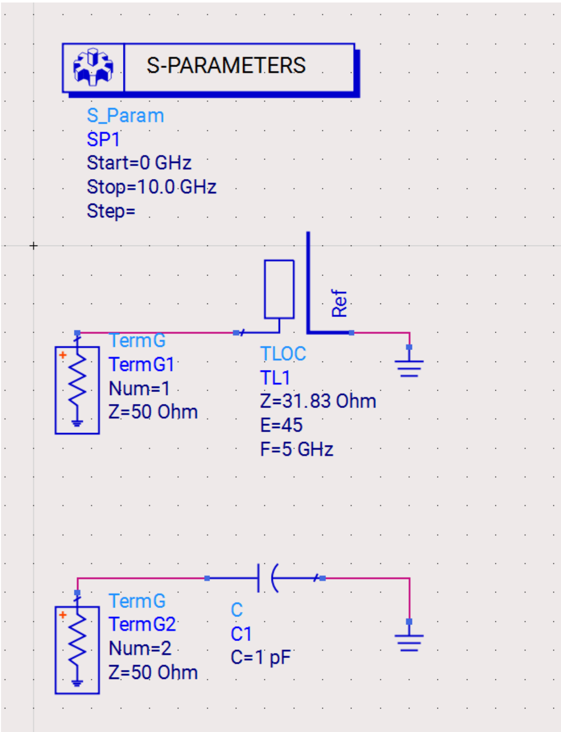


Fig. 3: Capacitor approximation circuits

The Z_{11} parameter plots of the created circuits are given in the figure below.

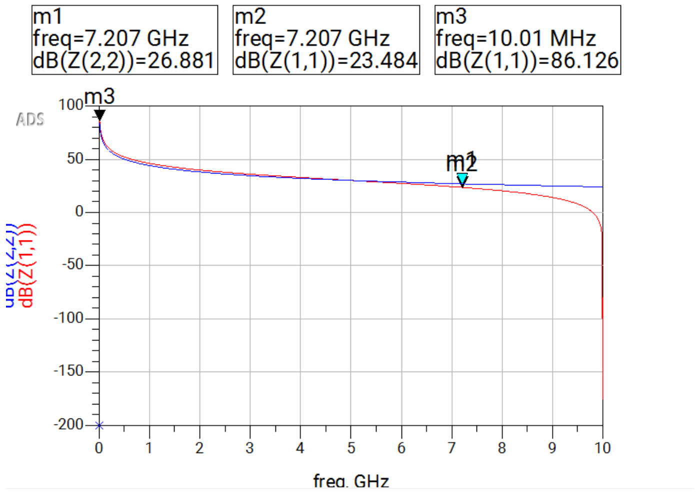


Fig. 4: Z_{11} parameter plots of the capacitor approximation circuits

Using the markers, 15% error range starts from 10.01MHz, and stops at 7.207GHz. The error calculation is given below.

$$\frac{m_1 - m_2}{m_2} = \frac{26.881 - 23.484}{23.484} = 14.46\%$$

ω_0 value is calculated as $31.4*10^9$. So in terms of ω_0, the 15% error range is from 0.00032 ω_0 to 0.23 ω_0.

Question #3

For this part, Kuroda's first identity is analysed. Figure below shows the identity.

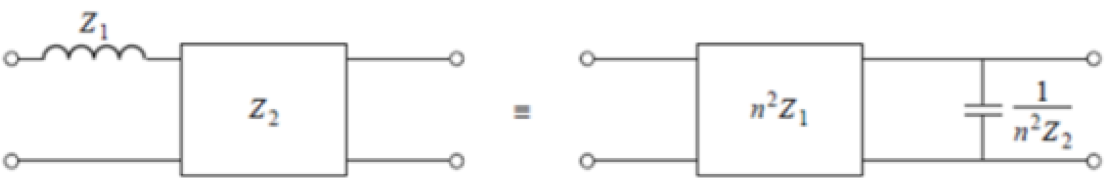


Fig. 5: Kuroda's first identity

The circuits in the figure below are created to analyse the Kuroda's first identity.

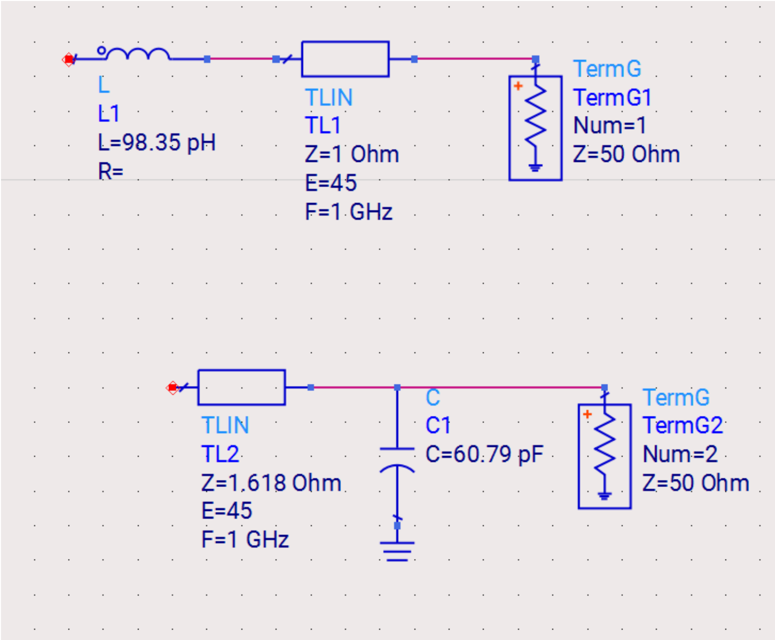


Fig. 6: Circuits for Kuroda's first identity check

For simplicity, Z_1 value is chosen as 0.618 and Z_2 value is chosen as 1. The corresponding inductor value is derivation can be seen below. The frequency is chosen as 1GHz.

$$X_L = \omega L = 0.618$$

$$0.618 = 2\pi f * L$$

$$L = 98.35pH$$

After, n^2 value is calculated from the Z_1 and Z_2 values, which turned out to be 2.618. The new impedance values are given below.

$$n^2 = 2.618$$

$$n^2 Z_1 = 1.618$$

$$X_c = \frac{1}{n^2 Z_2} = \frac{1}{2.618}$$

$$X_c = \frac{1}{\omega C} \rightarrow C = 60.79pF$$

The imaginary parts of Z_{11}'s are plotted. Fig. 7 belongs to the first circuit and Fig. 8 belongs to the second circuit, respectively.

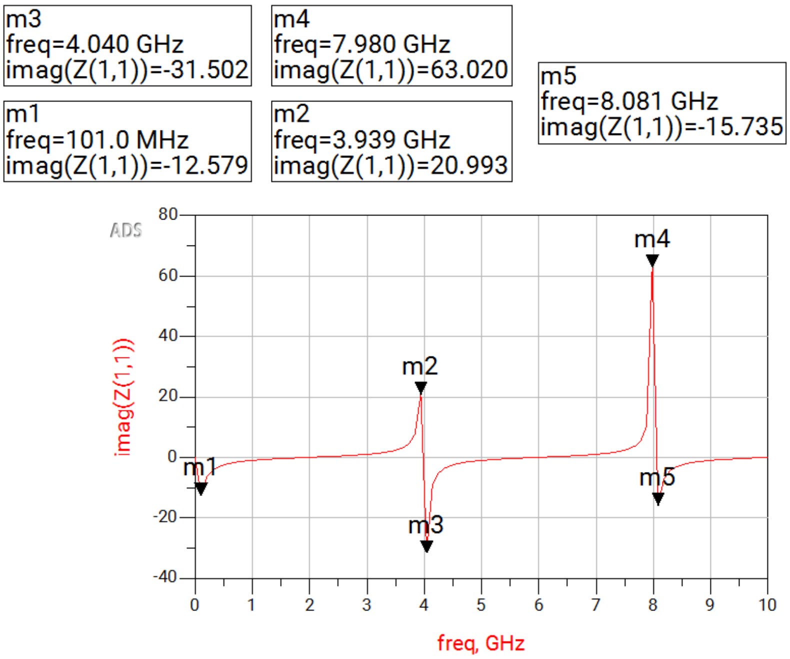


Fig. 7: Z11 imaginary plot of the first circuit

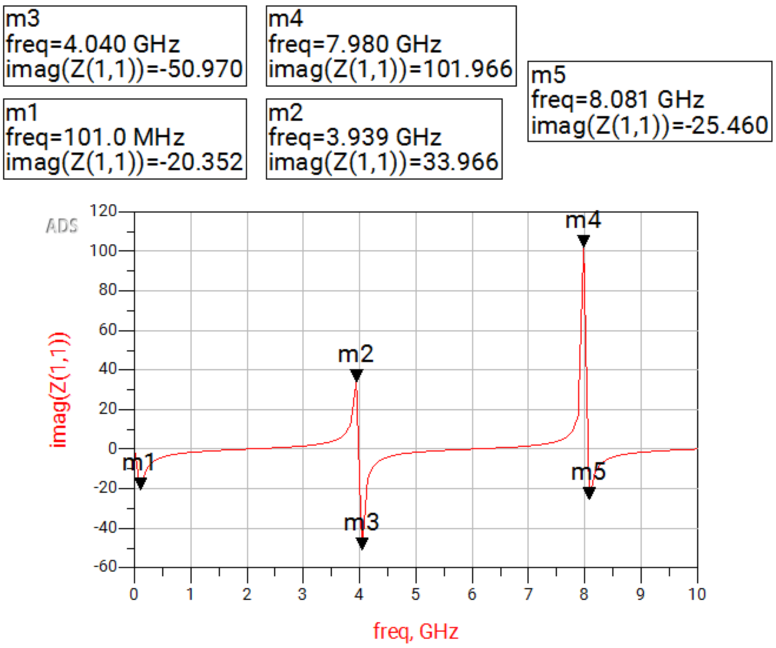


Fig. 8: Z11 imaginary plot of the second circuit

As seen from the above two plots, the shapes are identical, only the peak points change. None of the peak points rely inside the 15% error range. Therefore between the peak points, 15% error percentage is satisfied.

Question #4

a) For the low-pass filter design, center frequency (f_0) is chosen as 5GHz. According to the Chebyshev 0.2dB ripple prototype filter, the g values are given below for a third order circuit.

$$g_1 = g_3 = 1.228$$

$$g_2 = 1.153$$

Using the LCL topology, the values for inductors and the capacitor are calculated regarding the below formulas.

$$L_1 = L_3 = \frac{z_0 g_1}{\omega} = 1.95nH$$

$$C_2 = \frac{g_2}{z_0 \omega} = 0.734pF$$

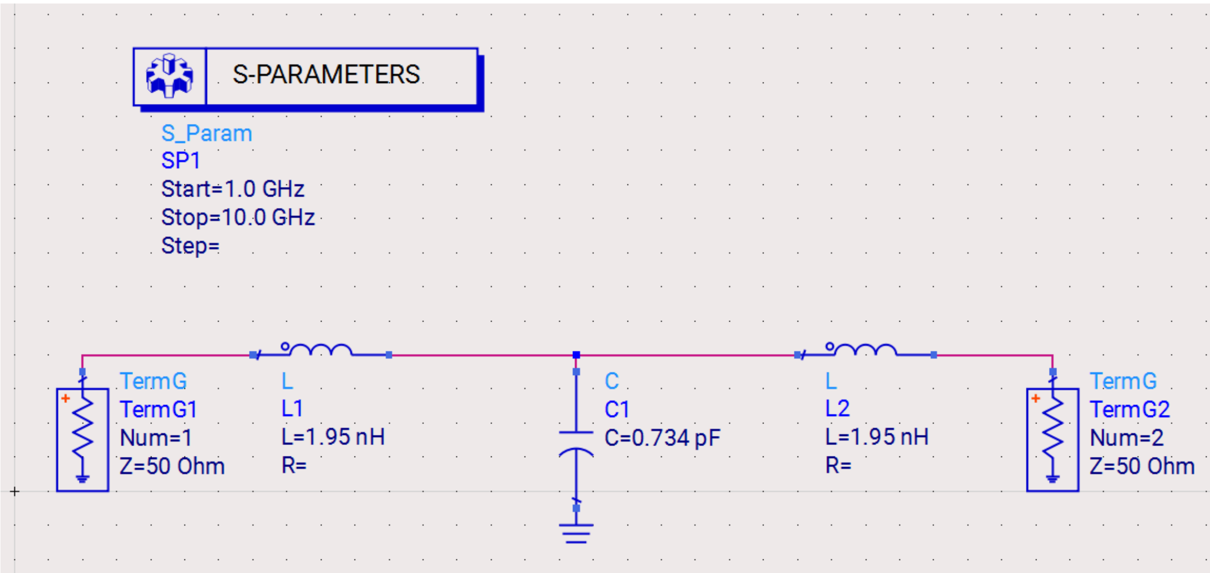


Fig. 9: Designed third-order 0.2dB ripple low-pass filter with LCL topology

The corresponding S_{11} and S_{21} graphs can be seen in the figure below.

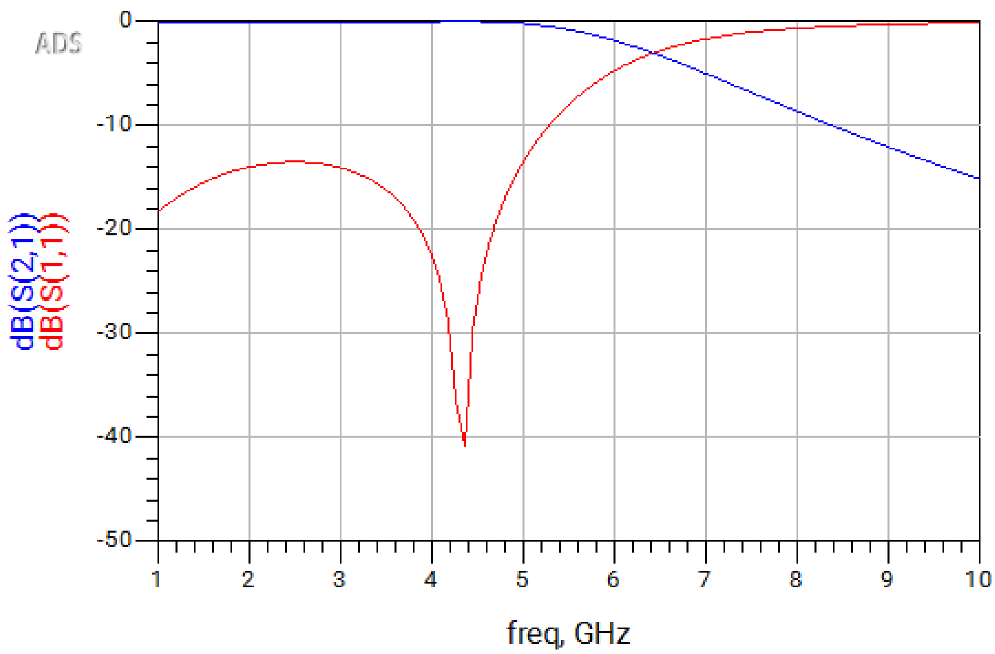


Fig. 10: S_{11} and S_{21} graphs of the designed low-pass filter

b) In this step, inductors and capacitors are replaced with series and shunt stubs respectively. Using the below formulas, impedance of the transmission lines are calculated with respect to 50ohm termination resistances at 5GHz.

$$X_L = \omega L = 61.26 ohm$$

$$X_c = \frac{1}{\omega C} = 43.36 ohm$$

The circuit built with the transmission lines are shown in the figure below.

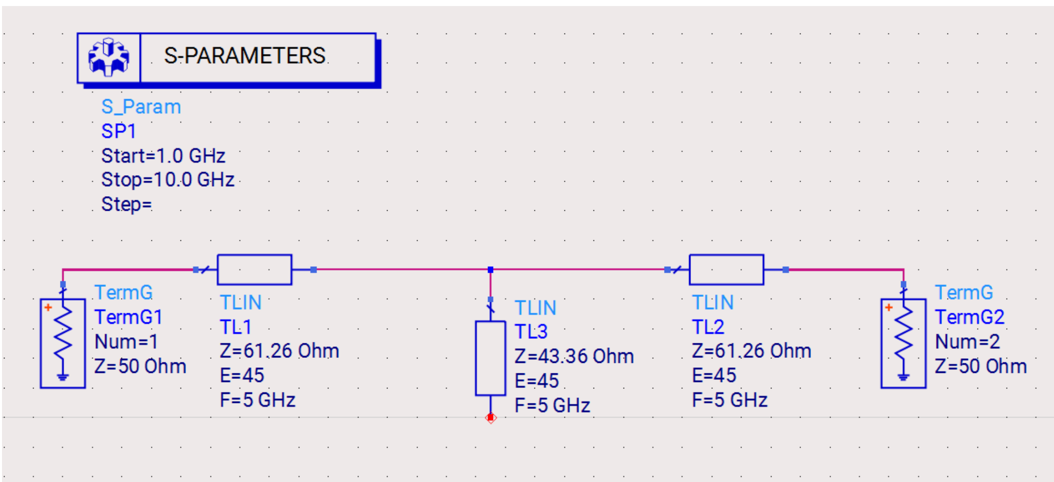


Fig. 11: Low-pass filter with transmission lines

The S_{11} and S_{21} plots of this circuit is shon in Fig. 12.

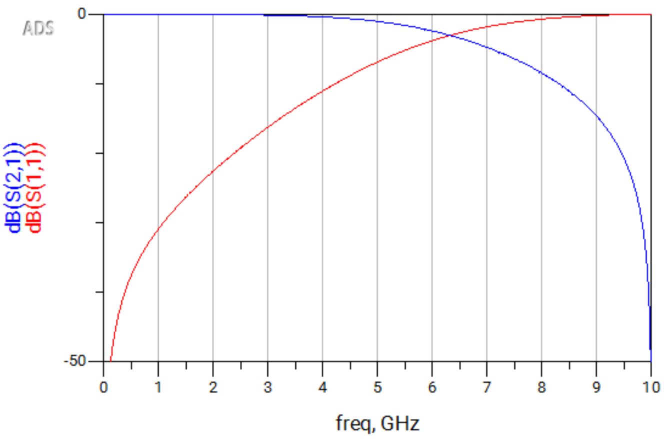


Fig. 12: S_{11} and S_{21} plots of the low-pass filter with transmission lines

c) In this part, $\lambda_0/8$ transmission lines of impedance z_0 are added to both ends of the circuit. Then using the Kuroda's identity to transform series stubs to shunt stubs. The calculation steps are given below.

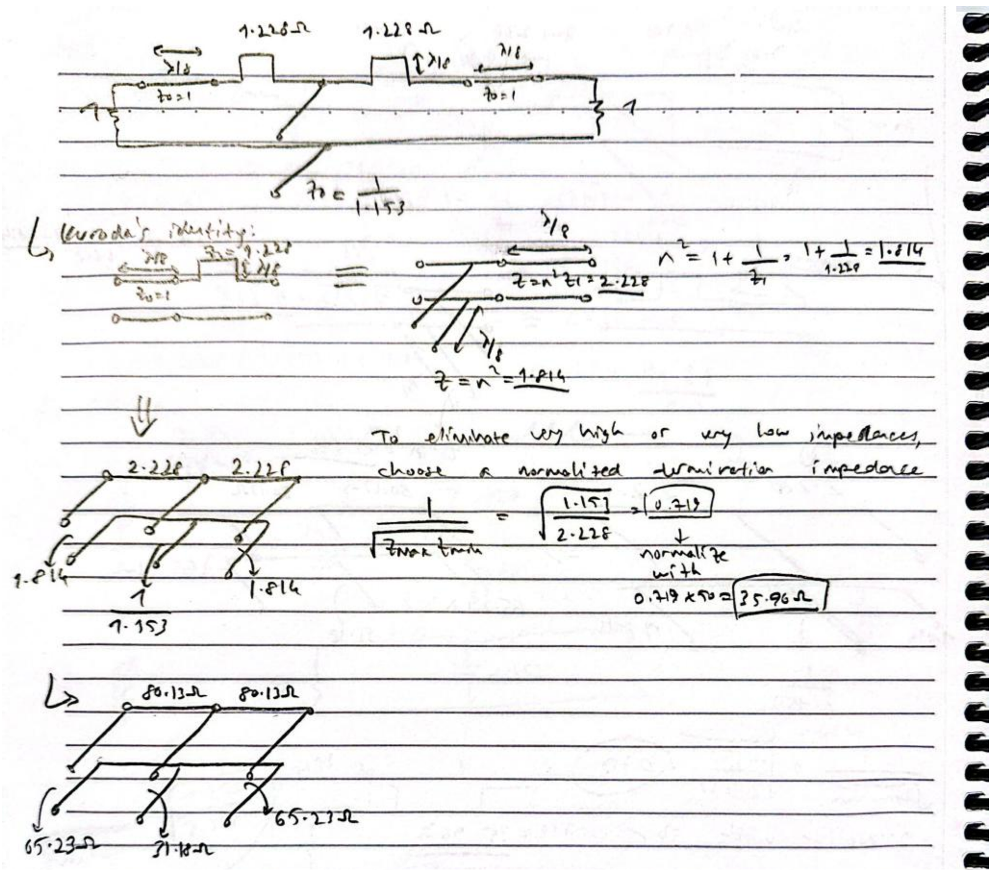


Fig. 13: Calculation steps of part c)

The S_{11} and S_{21} plots are given in the figure below.

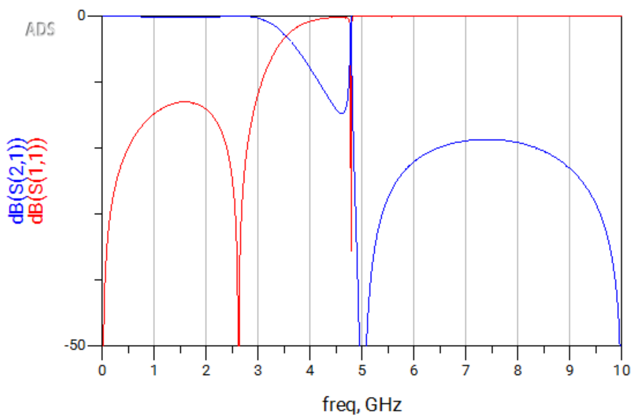


Fig. 14: S_{11} and S_{21} plots for part c)

d) Finally, $\lambda_0/4$ transmission lines are added as impedance inverters at both sides of the low-pass filter. Because of the $\lambda_0/4$ length, the degree of them is changed to 90. The calculation of these two stubs are given below.

$$Z = \sqrt{50 * 35.96} = 42.4ohm$$

The corresponding final schematic of the low-pass filter is shown in Fig. 15.

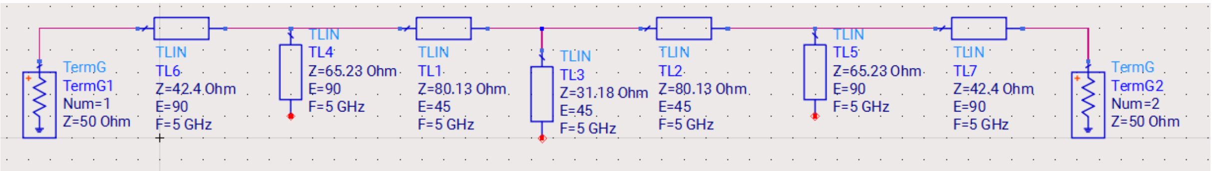


Fig. 15: Final schematic of the low-pass filter

After adding $\lambda_0/4$ transmission lines, S_{11} response got more rounded (not sharper) edges.

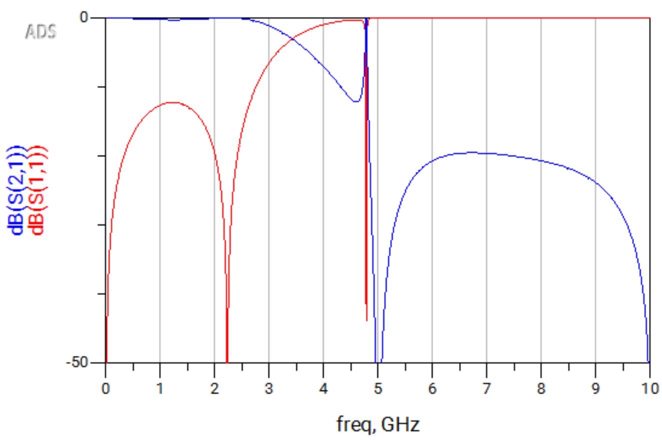


Fig. 16: S_{11} and S_{21} plots for part d)

Question #5

For designing a bandpass filter, the center frequency (f_0) is chosen as 700MHz. The bandwith is chosen as 5% of that value, which is 35MHz. First, CLC topology is used to create a LPF. Figure 17 shows that circuit. The calculations are given below the figure.

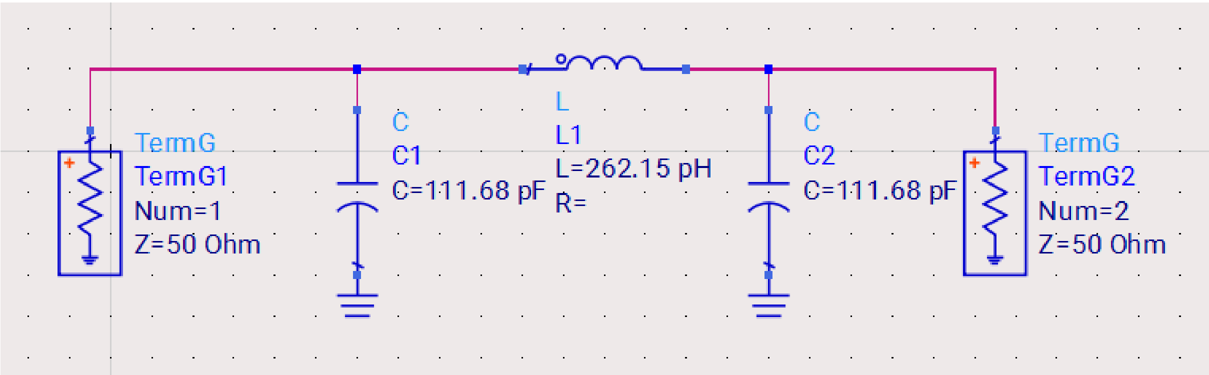


Fig. 17: Created Low-pass filter

$$g_1 = g_3 = 1.228$$

$$g_2 = 1.153$$

$$g_4 = 1$$

$$C_1 = C_3 = \frac{g_1}{\Delta w z_0} = \frac{1.228}{2\pi * 35MHz * 50} = 111.68pF$$

$$L_2 = \frac{z_0 g_1}{\Delta w} = \frac{50 * 1.153}{2\pi * 35MHz} = 262.15pH$$

Then, the resonating C and L values are added to obtain a bandpass filter.

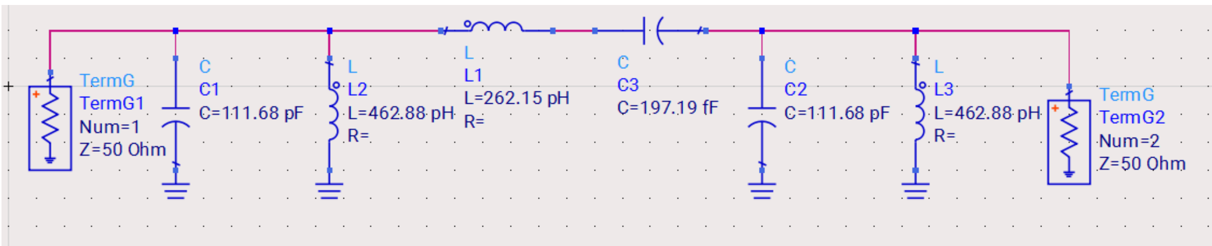


Fig. 18: Created bandpass filter

The calculations for the shunt inductors and series C that are resonating at f_0 are given below.

$$L_1 = L_3 = \frac{1}{{w_0}^2 C_1} = 462.88pH$$

$$C_2 = \frac{1}{{w_0}^2 L_2} = 197.19fF$$

The corresponding S_{11} and S_{21} graph is given below.

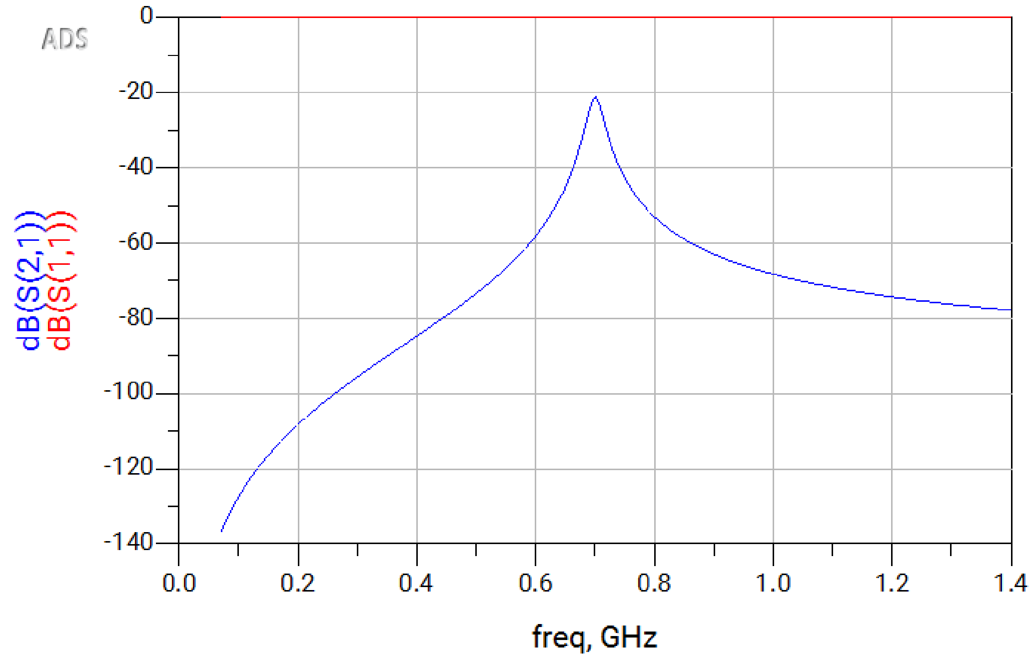


Fig. 19: Bandpass filter S parameter graph

As expected, it has a peak around 700MHz.

The next step is adding inverters to convert series branches to shunt. Figure 20 shows the new schematic of the bandpass filter with inverters.

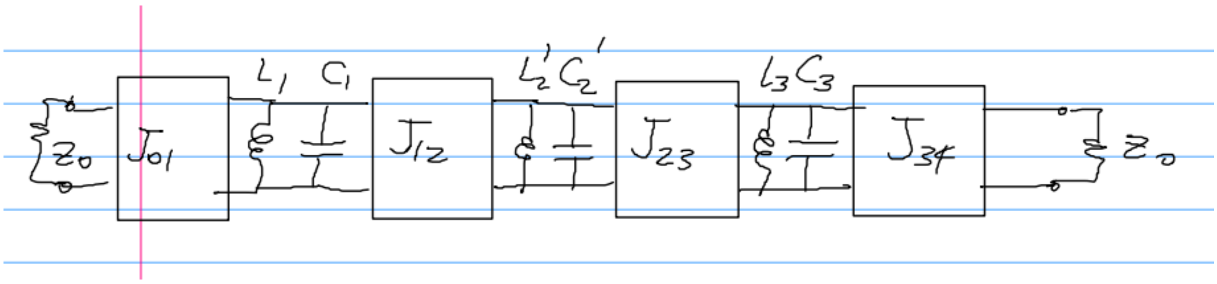


Fig. 20: Bandpass filter with inverters added

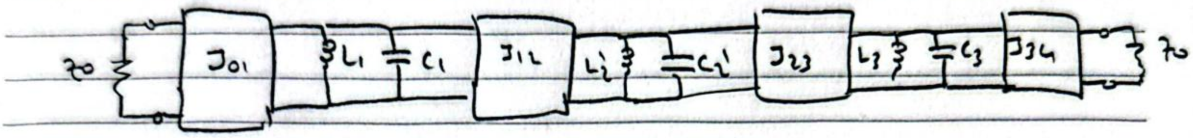
The derivation of the unknowns are given in the figure below.

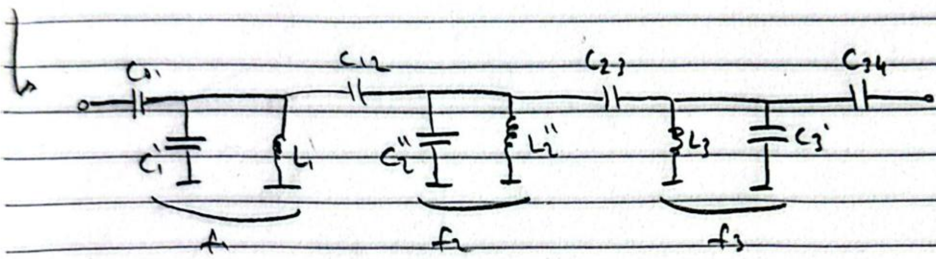
$\Delta = 5\%$ as chosen $\quad g_1 = g_3 = 1.228 \quad g_2 = 1.151 \quad g_4 = 1$

$$J_{01} = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{4g_1}} = 3.57\times10^{-3} = J_{34}$$

$$J_{12} = \frac{1}{Z_0}\frac{\pi\Delta}{4\sqrt{g_1 g_2}} = 6.6\times10^{-4} = J_{23}$$

$$L_2' = \frac{C_2}{J_{12}^2} = 15.47\ \text{pH} \qquad C_2' = L_2 J_{12}^2 = 3.34\ \text{pF}$$



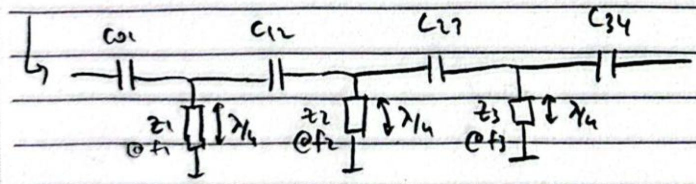


$$C_{01} = \frac{J_{01}}{w_0\sqrt{1-(Z_0 J_{01})^2}} = 824.93\ \text{fF} = C_{34} \qquad C_{12} = \frac{J_{12}}{w_0} = 150.06\ \text{fF} = C_{23}$$

$C_1' = C_1 - C_{01} = 111.52\ \text{pF}$

$C_3' = C_3 - C_{34} = 110.65\ \text{pF}$

$C_2'' = C_2' - C_{12} - C_{23} = 3.039\ \text{pF}$



$$Z_1 = \frac{1}{8f_1C_1'} = 1.6 \qquad Z_2 = \frac{1}{8f_2C_2''} = 1.772 \qquad Z_3 = \frac{1}{8f_3C_3'} = 1.604$$

$$f_1 = \frac{1}{2\pi\sqrt{C_1'L_1}} = 700.502\ \text{MHz} \qquad f_2 = \frac{1}{2\pi\sqrt{C_2''L_2'}} = 2.32\times10^{10}$$

$$f_3 = \frac{1}{2\pi\sqrt{L_3C_3'}} = 702.616\ \text{MHz}$$

Fig. 21: Derivations for the inverters

Fig. 22 shows the bandpass filter with series capacitors added.

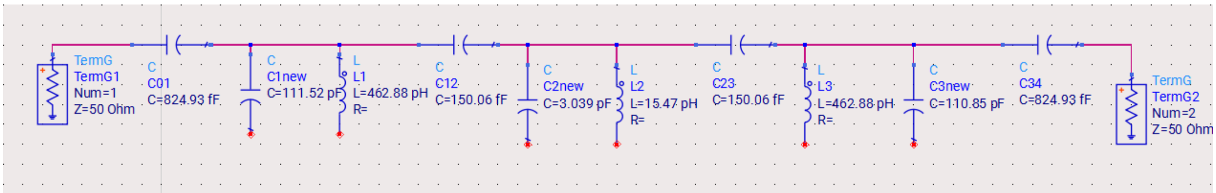


Fig. 22: Bandpass filter with series C added

As the final step, the LC resonaters are replaced with the transmission lines. Figure 23 shows the circuit.

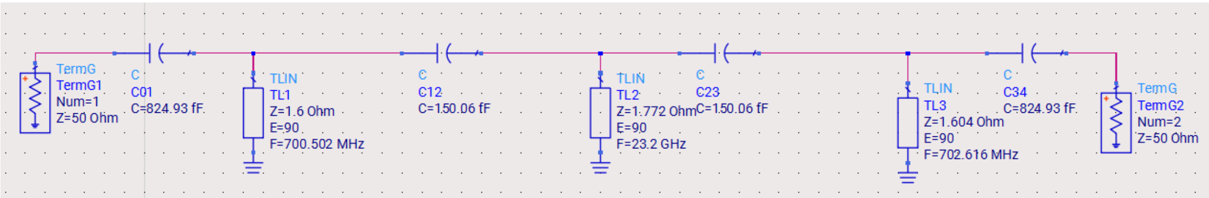


Fig. 23Final schematic of the bandpass filter

The corresponding S_{11} and S_{21} plot is given in the figure below.

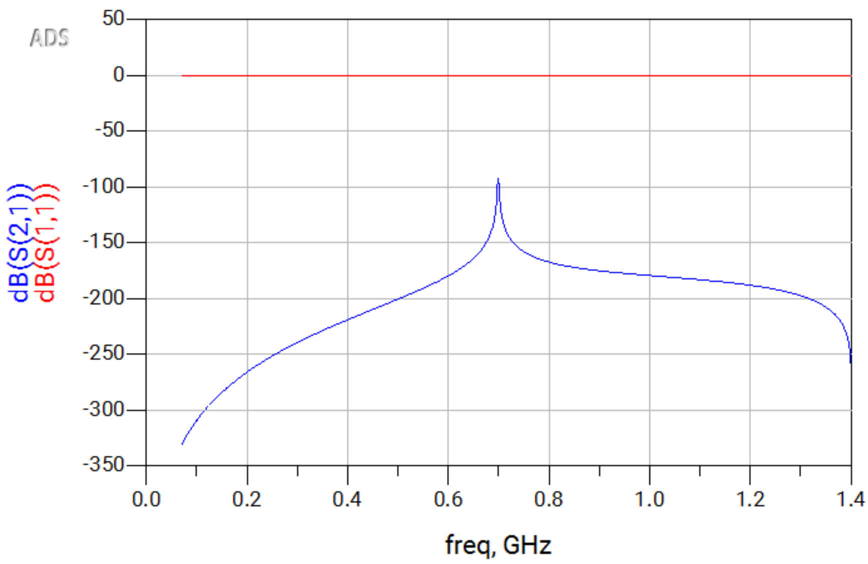


Fig. 24: S_{11} and S_{21} plot for the final bandpass schematic

As expected, the center frequency of the circuit is at 700MHz, which is the value initially chosen. Also, the graph resembles to the one in Fig. 19. The specifications are satisfied.