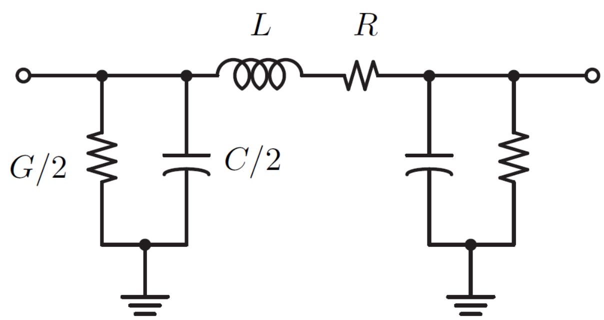
EE 242A Lab 1 Postlab

1. Thru T-Line Model

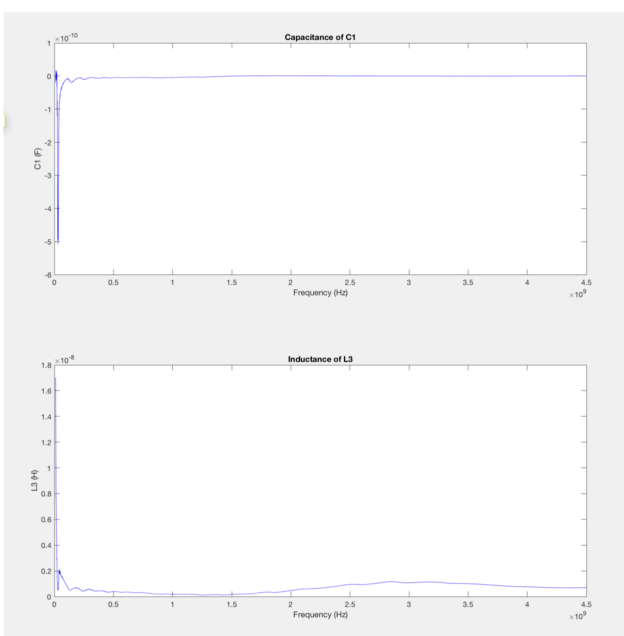
We calculate the values for an equivalent "pi" network for a 0.7mm long section of transmission line. The S-parameters captured from the VNA are converted to Y paramters and a Π circut is formed.

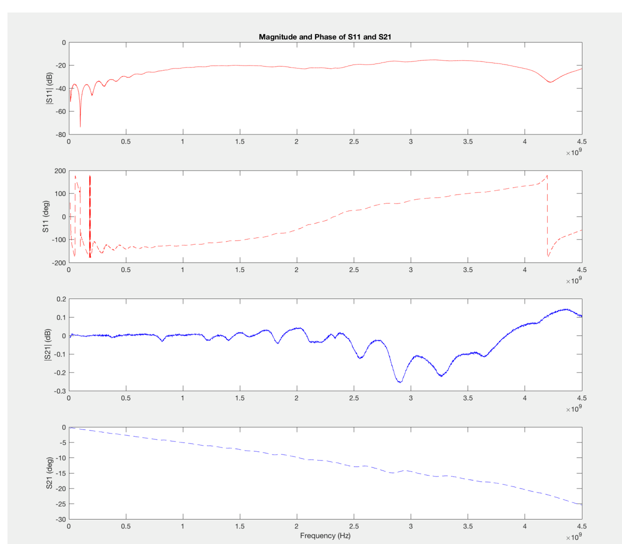


At 600 Mhz, we get these values:

L	34.887 nH
C	-5.0631 pF
R	12.2955 Ω
G	0.0042 $Mhos$

These are the plots generated by the MATLAB script:

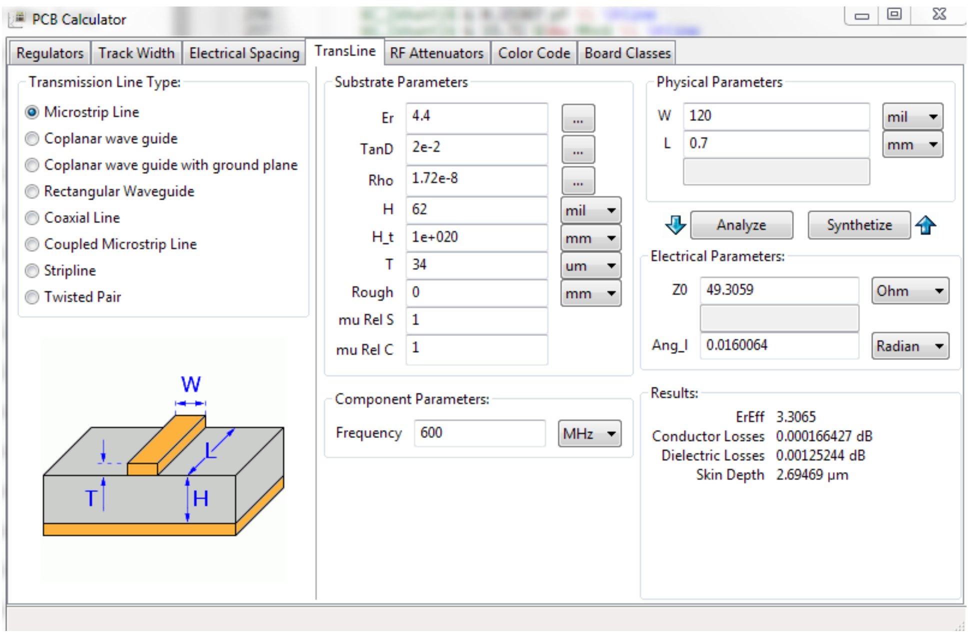




These values don't make sense, but that's OK.

2. Comparison With Theoretical Tline

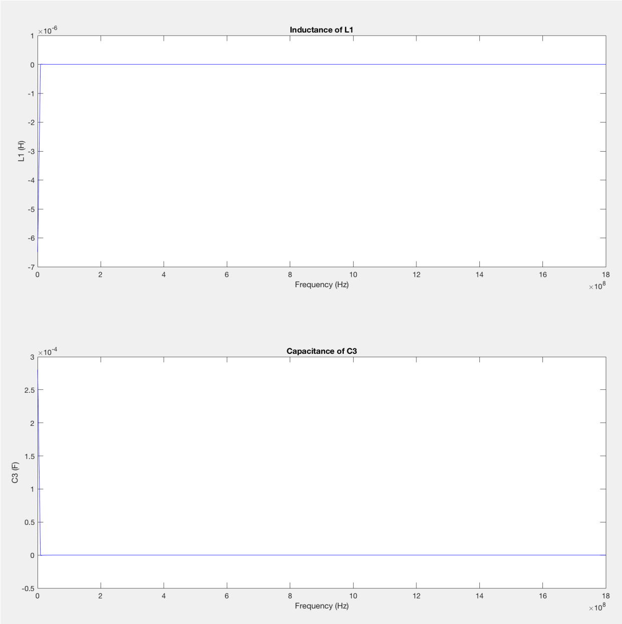
We used the KiCAD PCB calculator by plugging in the geometry of the transmission line and we observe that it matches our measurements.

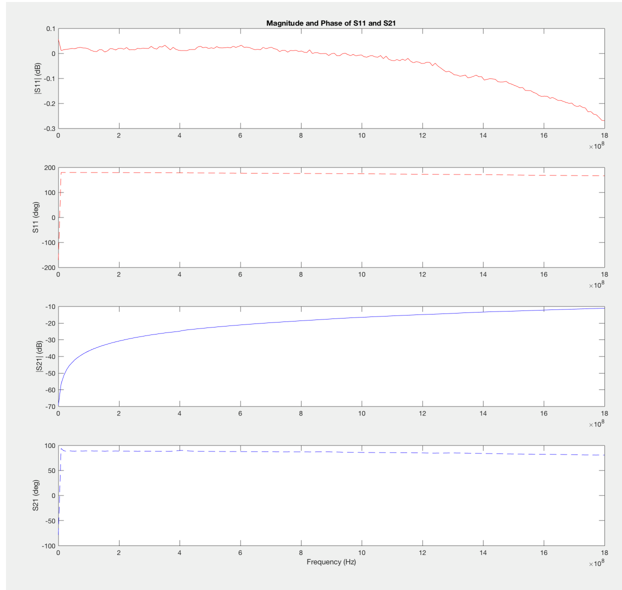


3. Parasitics of Via and 0Ω Shunt

The via and 0Ohm shunt are modeled as T-networks with a shunt leg consisting of an inductor and resistor, and split series legs with a capacitor and resistor.

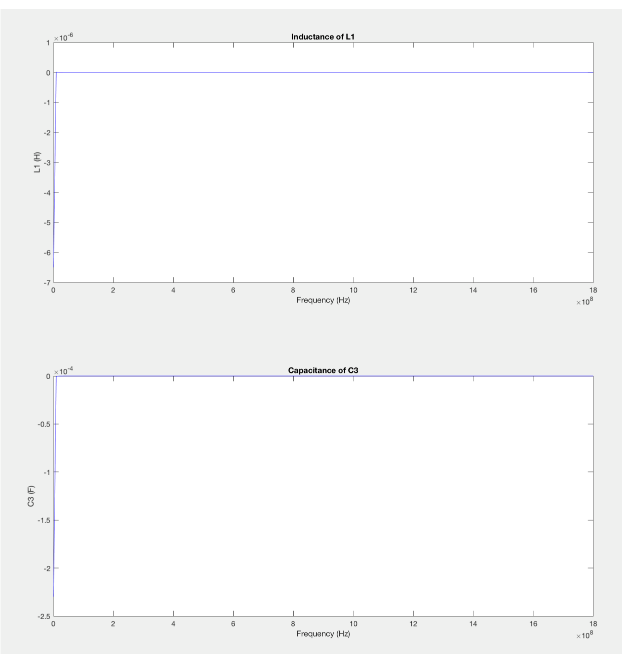
At 600 Mhz, we get these values for the via:

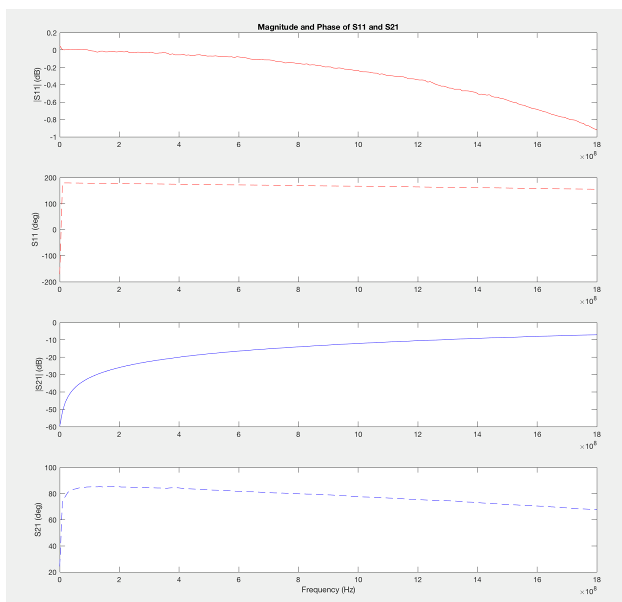




L_{shunt}	0.58 nH
C_{series}	215 pF
R_{shunt}	0.0037 Ω
R_{series}	-0.1927 Ω

For the 0Ω shunt resistor:

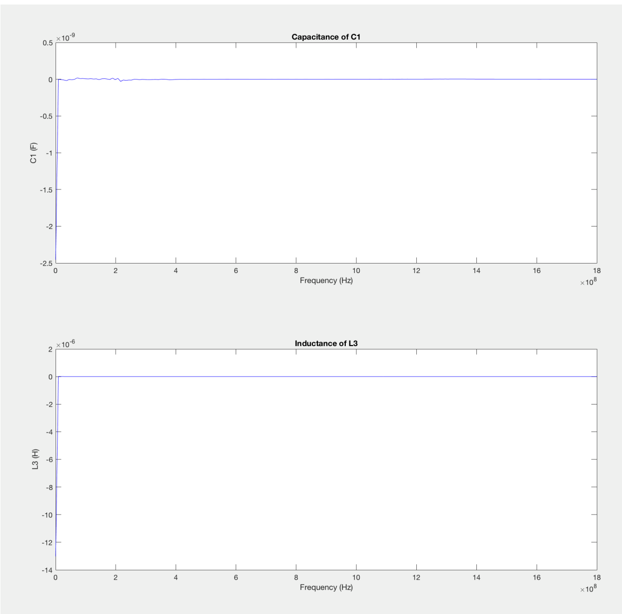


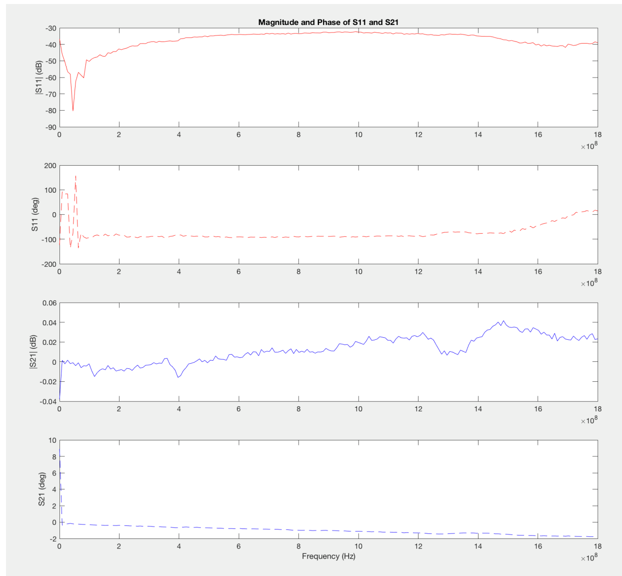


L_{shunt}	1.009 nH
C_{series}	39 pF
R_{shunt}	0.0772 Ω
R_{series}	-0.1294 Ω

4. Parasitics of 0Ω in Series

We use the Π model.

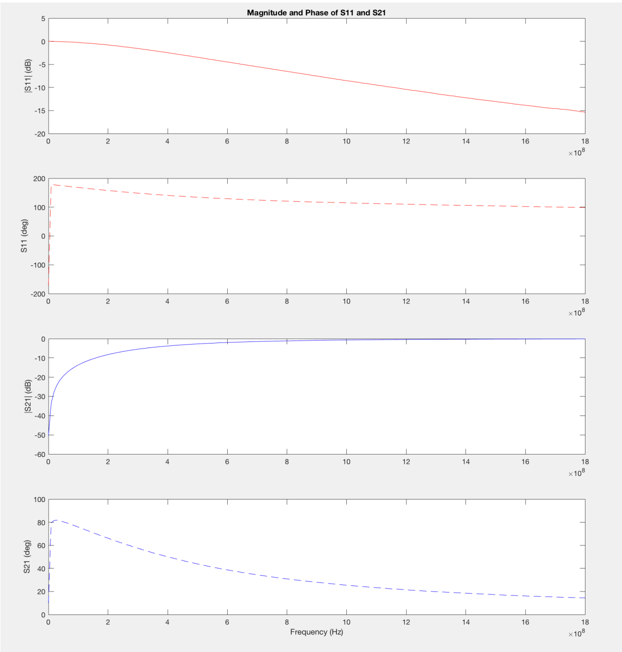




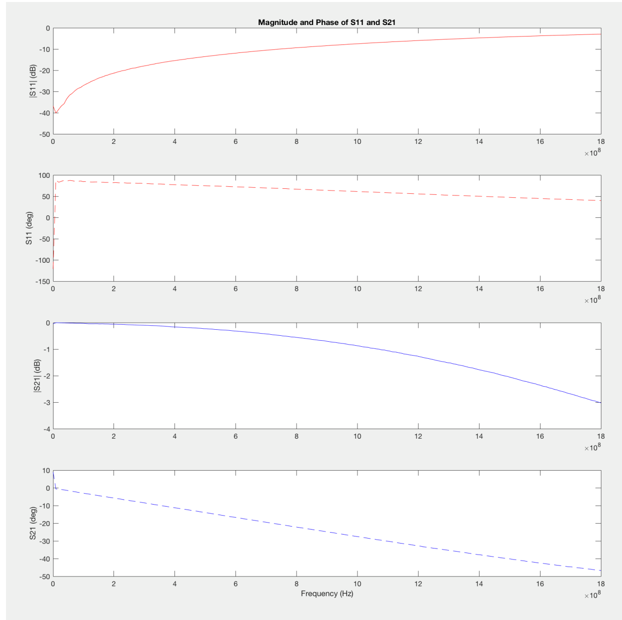
L_{series}	-9.7877 pH
C_{shunt}	-0.662 pF
R_{series}	0.0772 Ω
G_{shunt}	0.0017 Mho

5. Inductor in Shunt/Series Models

We used a 8.7 nH 0603 chip wirewound inductor.



Inductor in Shunt



Inductor in Series

Inductor in shunt (T model)

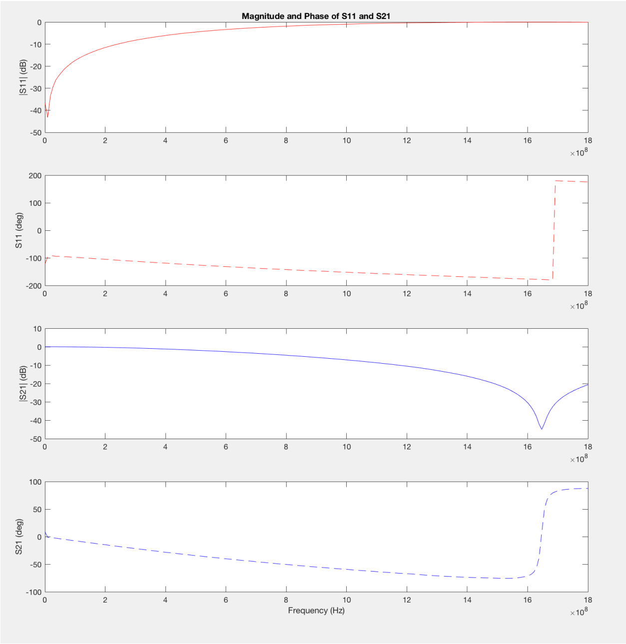
L_{shunt}	8.69 nH
C_{series}	0.192 nF
R_{shunt}	0.5433 Ω
R_{series}	-0.2070 Ω

Inductor in series (pi model)

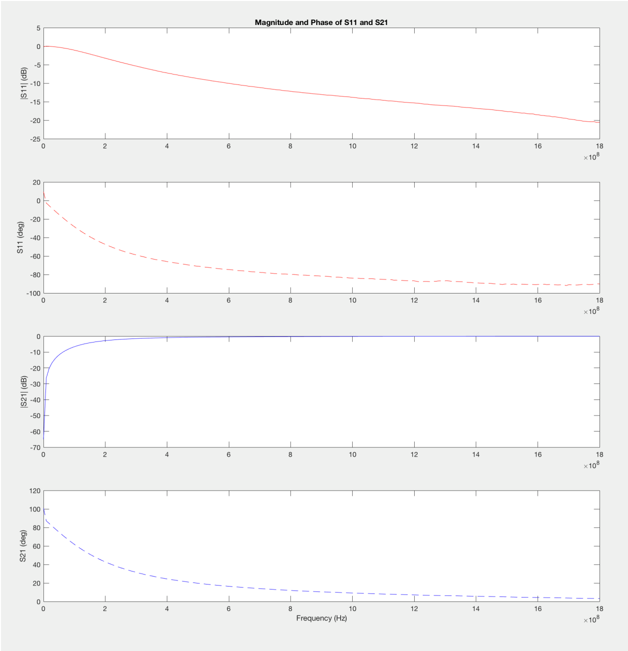
L_{series}	7.44 nH
C_{shunt}	0.109 pF
R_{series}	0.5443 Ω
G_{shunt}	-5.25 μMho

5. Capacitor in Shunt/Series Models

We used a 8 pF 0603 chip capacitor.



Capacitor in Shunt



Capacitor in Series

Cap Shunt (T model)

L_{shunt}	184 pH
C_{series}	7.31 nF
R_{shunt}	0.2091 Ω
R_{series}	-0.1162 Ω

Cap Series (Pi model)

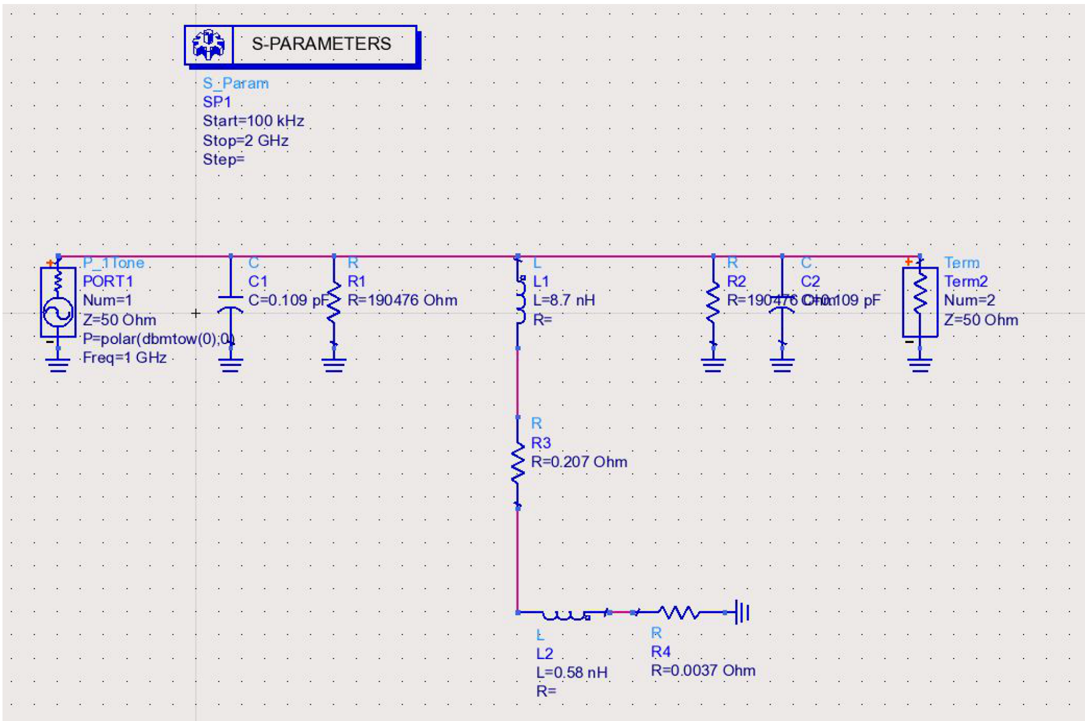
L_{series}	-8.264 nH
C_{shunt}	0.15367 pF
G_{shunt}	15.72 μMho
R_{series}	0.2091 Ω

6. Isolating the Package Parasitics

We think the extrinsic paramters of C_{shunt} (representing the pad to ground parasitic capacitance), G_{shunt} (representing the pad to ground dielectric leakage), C_{series} (representing the capacitance from pad to pad). For the via, there is a L_{shunt} and R_{shunt} to ground.

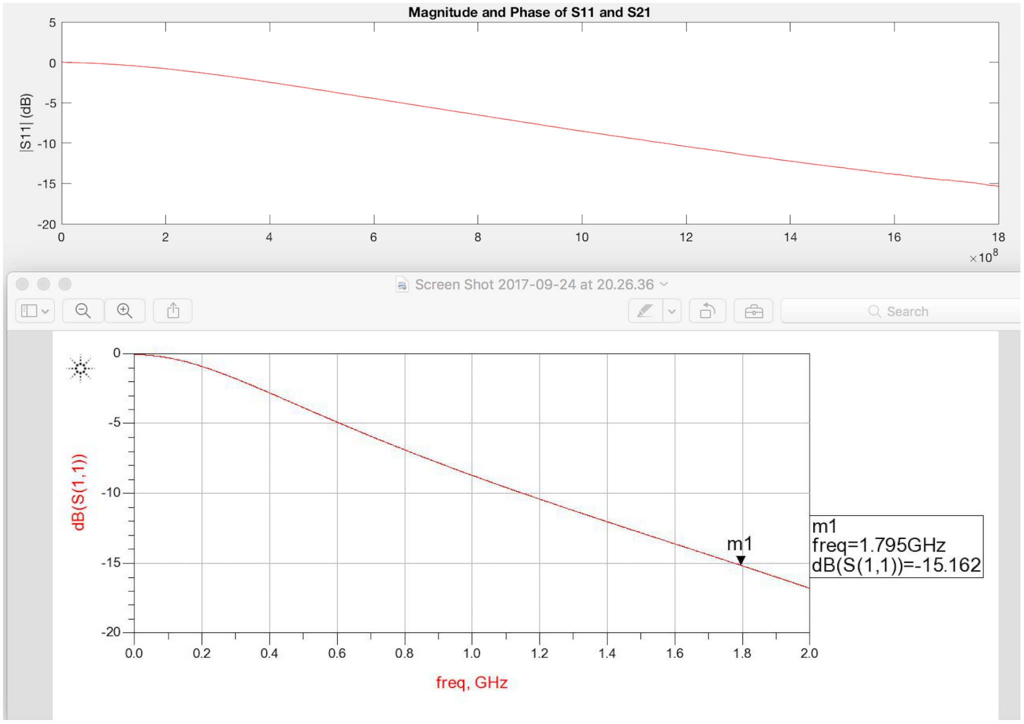
$C_{shunt,pp}$	0.109 pF	Calculated from series inductor
$G_{shunt,pp}$	5.25 μMho	Calculated from series inductor
$C_{series,pad-pad}$	1.17 μF	Calculated from open (we know it's wrong)
$L_{shunt,via}$	0.58 nH	Calculated from via
$R_{shunt,via}$	0.0037 Ω	Calculated from via

We construct a T model of a shunt inductor using the above values for the via and pad models. Here is the schematic in ADS:



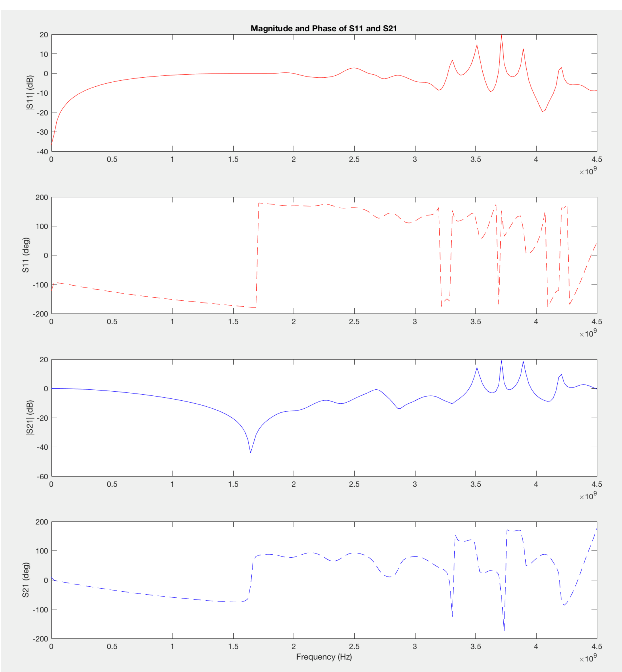
T-Model of Shunt Inductor in ADS

We compare the S_{11}, of the ADS model to the measured S_{11} of the shunt inductor, and they match well.

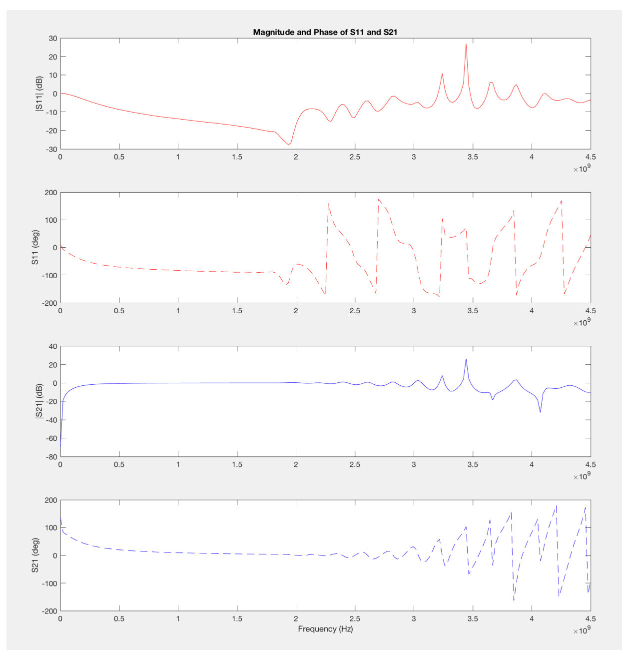


Shunt Inductor Model vs Measured Data

7. Capacitor at High Frequency



Capacitor in Shunt



Capacitor in Series

Based on s-parameter data, we trust the model up to 1.6GHz.

9. Time Spent

We spent over 5 hours each beyond the allocated lab time to finish this lab.

EE 242A Lab 2 Prelab

1. LC Low Pass Filter

   (a) We used the design tool included in ADS, DesignGuide, to design a 5-component Chebyshev filter, with 100 MHz corner frequency, 1dB passband ripple, and 40dB rolloff at 200 MHz.

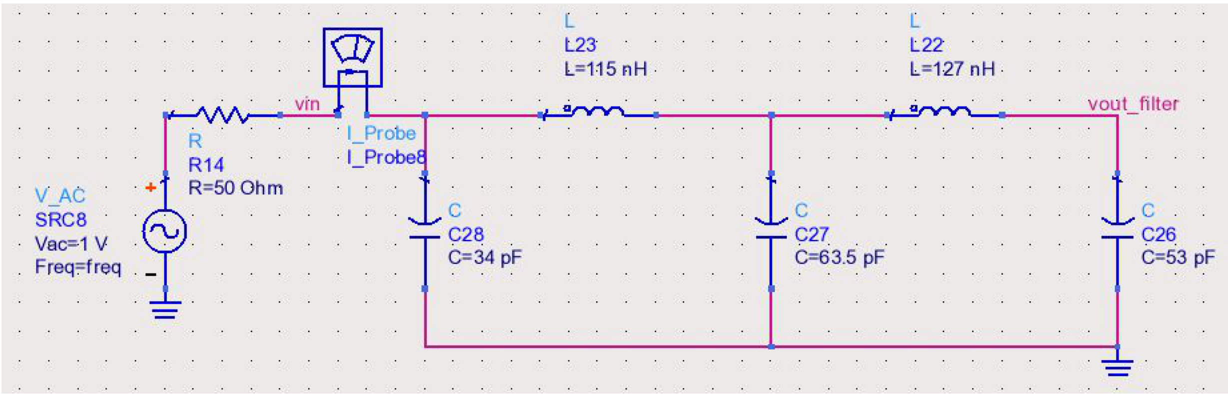


Figure: LC low pass filter

We devised the following component values:

$$C_1 = 34 \text{ pF}$$

$$L_1 = 115 \text{ nH}$$

$$C_2 = 63.5 \text{ pF}$$

$$L_2 = 127 \text{ nH}$$

$$C_3 = 53 \text{ pF}$$

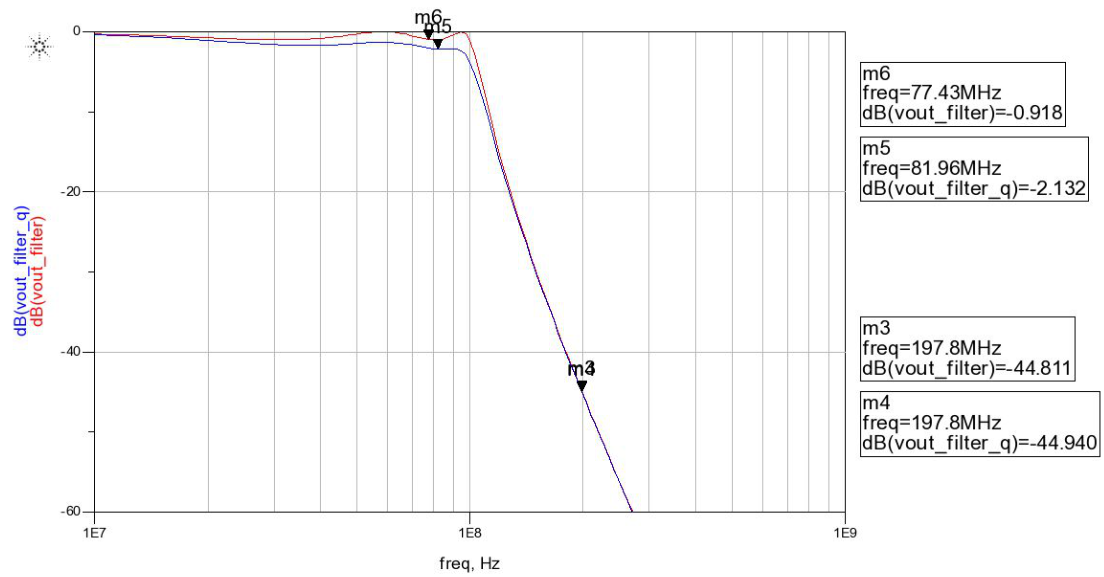


Figure: Magnitude plots of low pass filter

(b) Above, we plot the magnitude of both the ideal filter (in red) and the filter with Q factors (in blue). We see the bandwidth (3dB frequency) to be at 100 MHz. We see the 200 MHz rejection to be better than 40 dB. The in band ripple for the ideal filter stays within 1 dB. We will discuss the filter with Q factor in part (d).

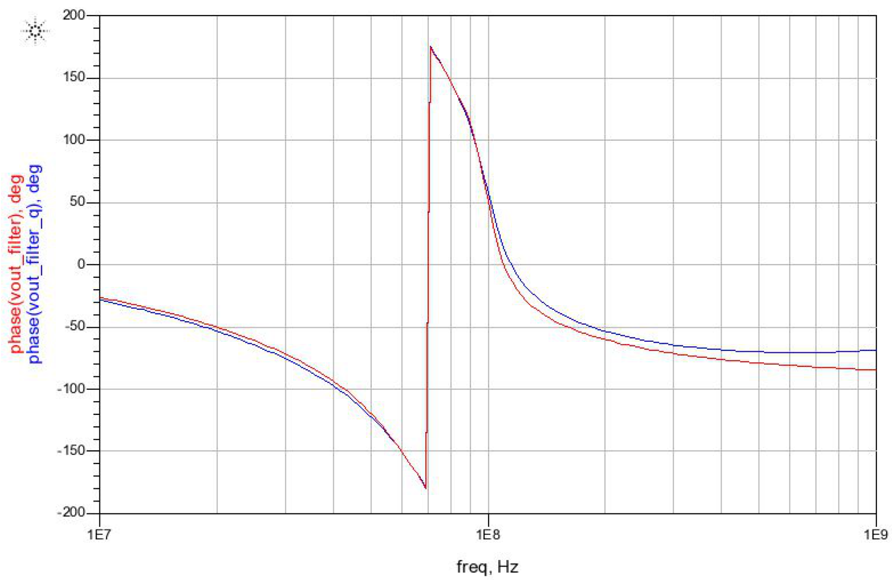


Figure: Phase plots of low pass filter

Above, we plot the phase of both the ideal filter (in red) and the filter with Q factors (in blue). We note the 2π phase shift, as expected in a 2nd order LC filter.

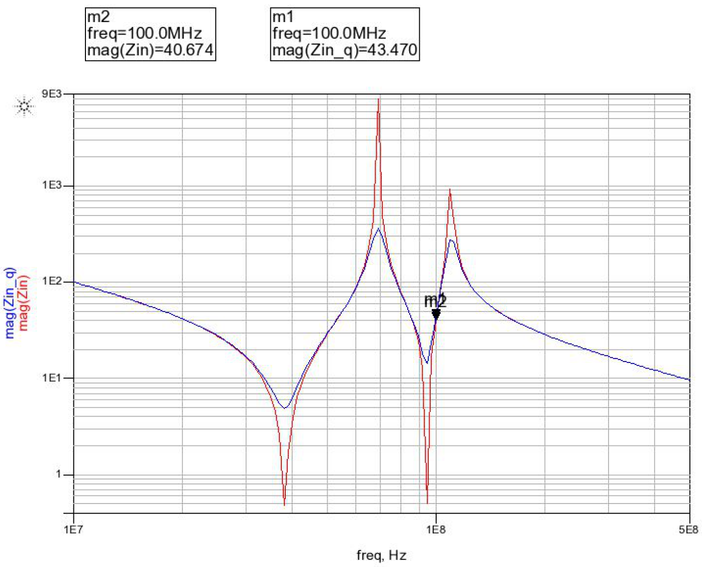


Figure: Impedance plots of low pass filter

Above, we plot the impedance of both the ideal filter (in red) and the filter with Q factors (in blue), looking in after the source resistance. We find that the impedance at the corner frequency is slightly off from the intended 50 Ω matching impedance. We also see 4 impedance spikes, with each pair corresponding to one of the LC resonance peaks. We will discuss the filter with Q factor in part (d).

(c) Monte Carlo simulation omitted

(d) We re-simulate the response with inductors with effective $Q = 20$ and capacitors with effective $Q = 100$.

For the L's:

$$Q = 20 = \frac{\omega L}{R} = \frac{2\pi \cdot 100\text{ MHz} \cdot 115\text{ nH}}{R} \implies R = 3.6\ \Omega$$
$$Q = 20 = \frac{\omega L}{R} = \frac{2\pi \cdot 100\text{ MHz} \cdot 127\text{ nH}}{R} \implies R = 3.9\ \Omega$$

For the C's:

$$Q = 100 = \frac{1}{\omega C R} = \frac{1}{2\pi \cdot 100\text{ MHz} \cdot 34\text{ pF} \cdot R} \implies R = 0.5\ \Omega$$
$$Q = 100 = \frac{1}{\omega C R} = \frac{1}{2\pi \cdot 100\text{ MHz} \cdot 63.5\text{ pF} \cdot R} \implies R = 0.25\ \Omega$$
$$Q = 100 = \frac{1}{\omega C R} = \frac{1}{2\pi \cdot 100\text{ MHz} \cdot 53\text{ pF} \cdot R} \implies R = 0.2\ \Omega$$

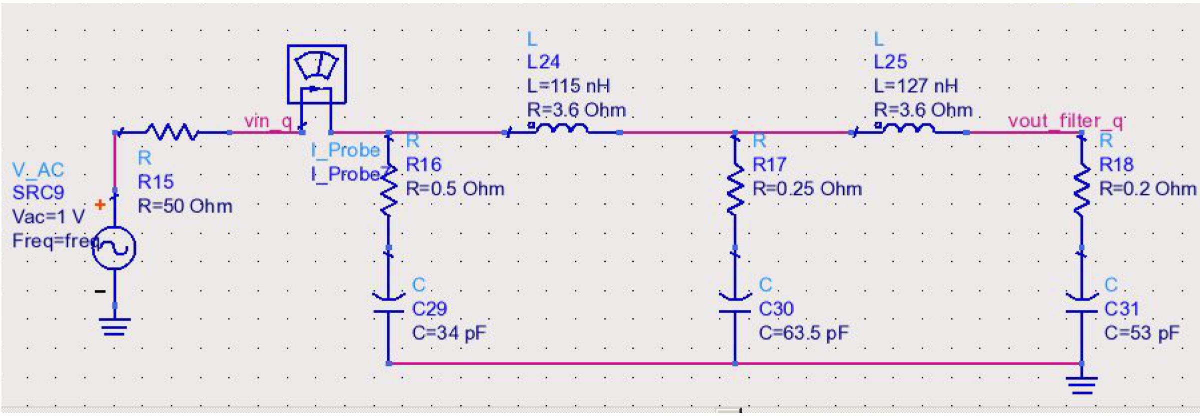


Figure: LC low pass filter with Q values

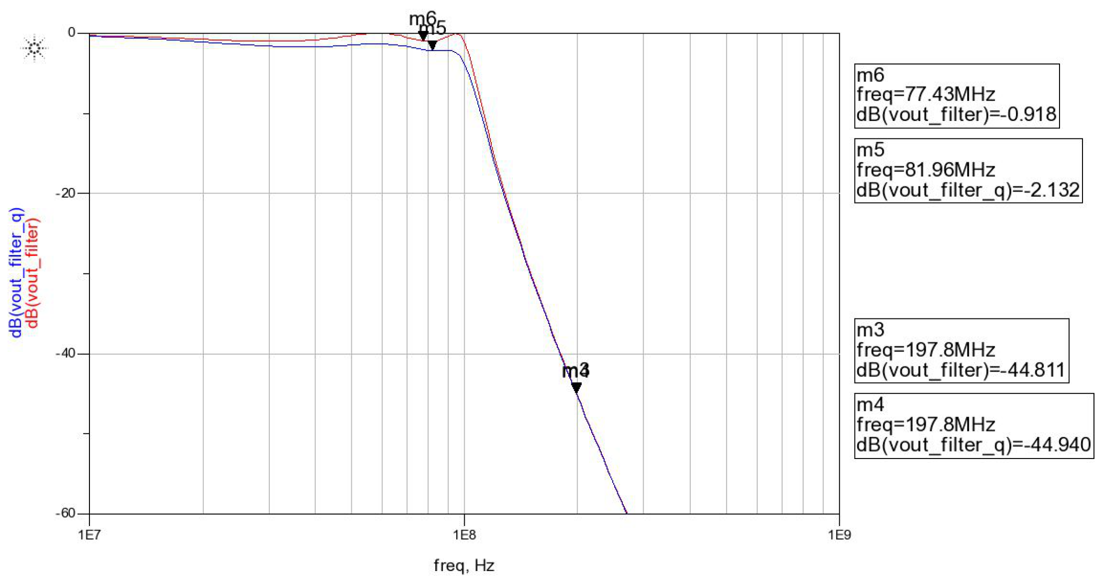


Figure: Magnitude plots of low pass filter

We repeat the above magnitude plot for convenience. We see that the passband ripple is worsened, increasing to 2 dB. We see the response at the corner frequency is attenuated, not the clean value from the ideal circuit. The 3db frequency thus is now just short of 100 MHz. The attenuation at 200 MHz does not change significantly.

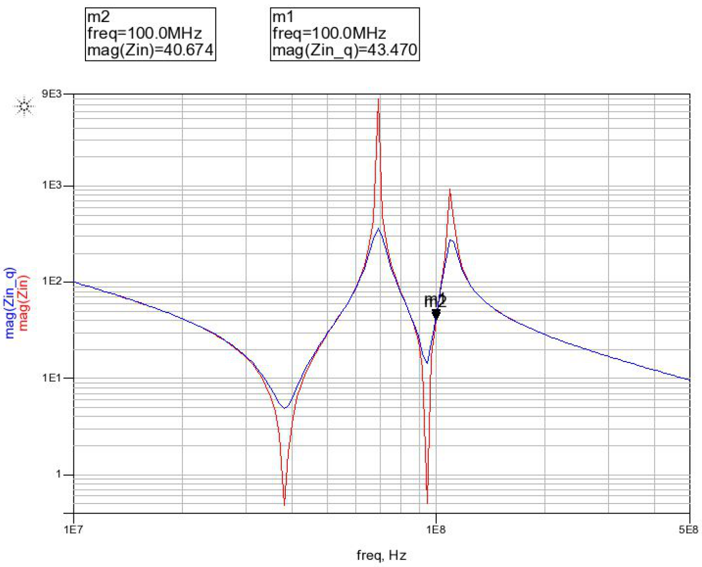


Figure: Impedance plots of low pass filter

We repeat the above impedance plot for convenience. The sharpness of the resonance peaks are significantly subdued. In between peaks, the impedances values have not changed significantly.

2. LC Band Pass Filter

   (a)

$$\omega_1 = 630 \text{ MHz}, \ \omega_2 = 780 \text{ MHz} \implies \omega_c = \sqrt{630 \cdot 780} = 700.1 \text{ MHz}$$

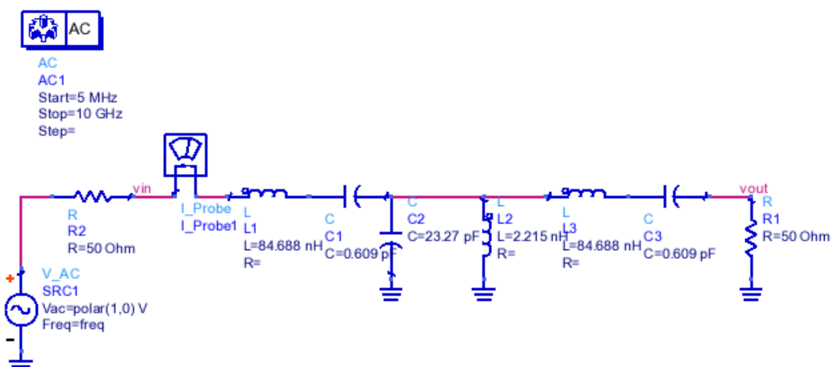
Using an online design tool[1] and doing a T network LC filter, the series components for the bandpass filter are:

$$L = 84.688 \text{ nH}$$
$$C = 0.609 \text{ pF}$$

The shunt components are:

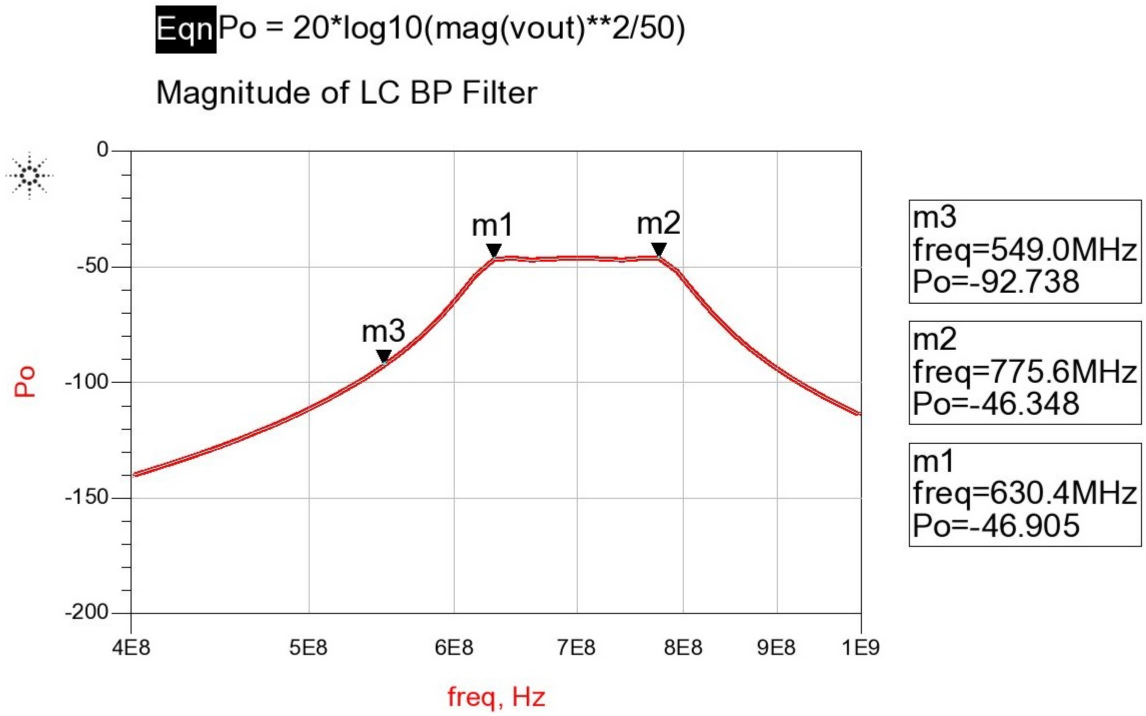
$$L = 2.215 \text{ nH}$$
$$C = 23.27 \text{ pF}$$

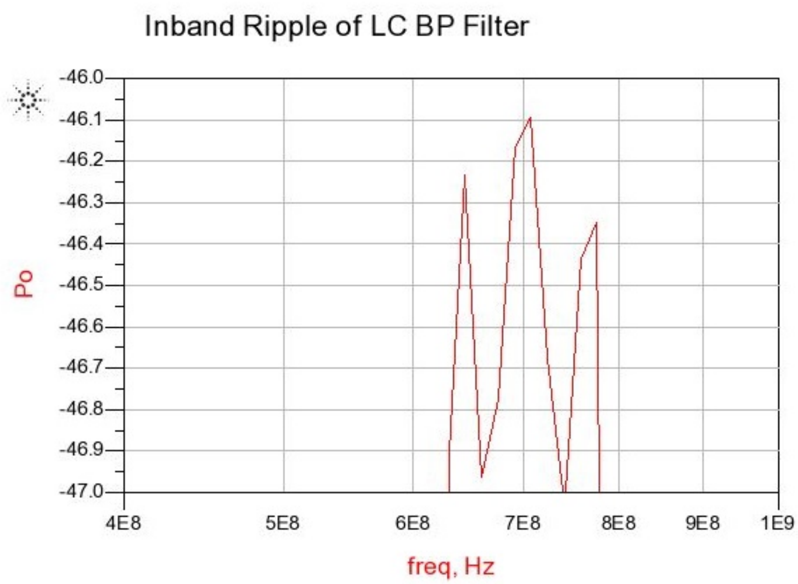
We used 2 LC series pairs and 1 LC shunt pair.

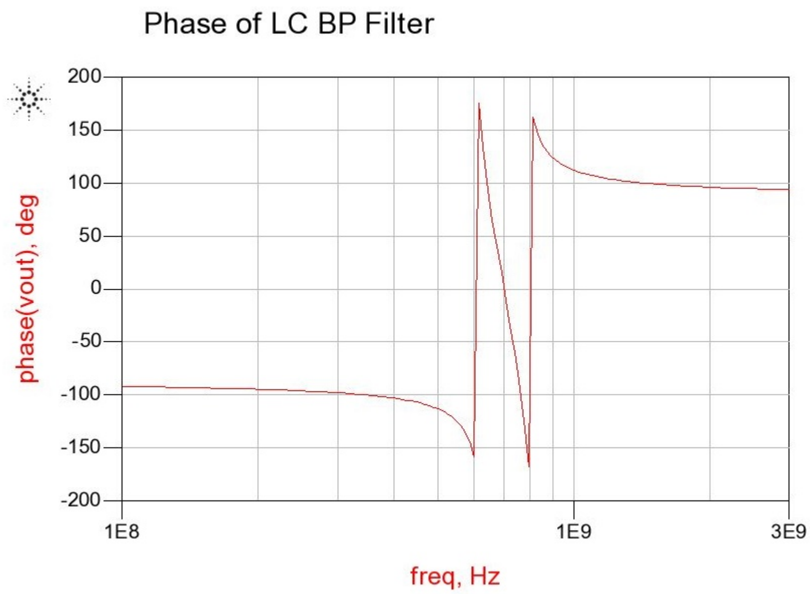


   (b) Simulated plots:

[1] https://www.electronicproducts.com/Bandpass_Filter_Design_Calculator.aspx


Eqn Po = 20*log10(mag(vout)**2/50)
Magnitude of LC BP Filter
m1
m2
m3
m3
freq=549.0MHz
Po=-92.738
m2
freq=775.6MHz
Po=-46.348
m1
freq=630.4MHz
Po=-46.905
Po
freq, Hz
0
-50
-100
-150
-200
4E8
5E8
6E8
7E8
8E8
9E8
1E9


Inband Ripple of LC BP Filter
Po
freq, Hz
-46.0
-46.1
-46.2
-46.3
-46.4
-46.5
-46.6
-46.7
-46.8
-46.9
-47.0
4E8
5E8
6E8
7E8
8E8
9E8
1E9



The bandwidth is approximately 145 MHz. The stopband rejection is $-46-(-92.7) = 46.7$ dB. The max inband ripple is roughly 0.9 dB.

(c) Monte Carlo simulation omitted

(d) For the L's:

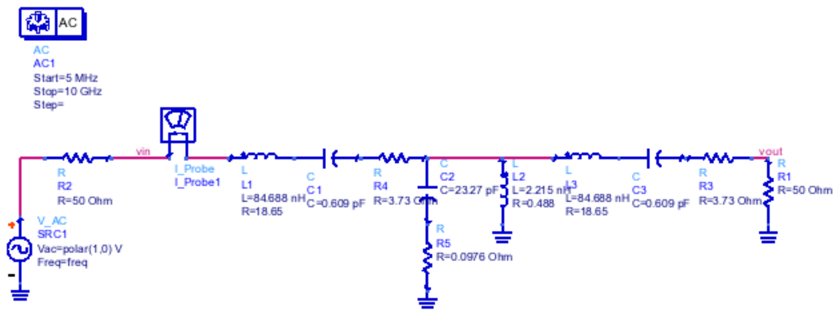
$$Q = 20 = \frac{\omega L}{R} = \frac{2\pi \cdot 700.1 \text{ MHz} \cdot 84.688 \text{ nH}}{R} \implies R = 18.65\ \Omega$$

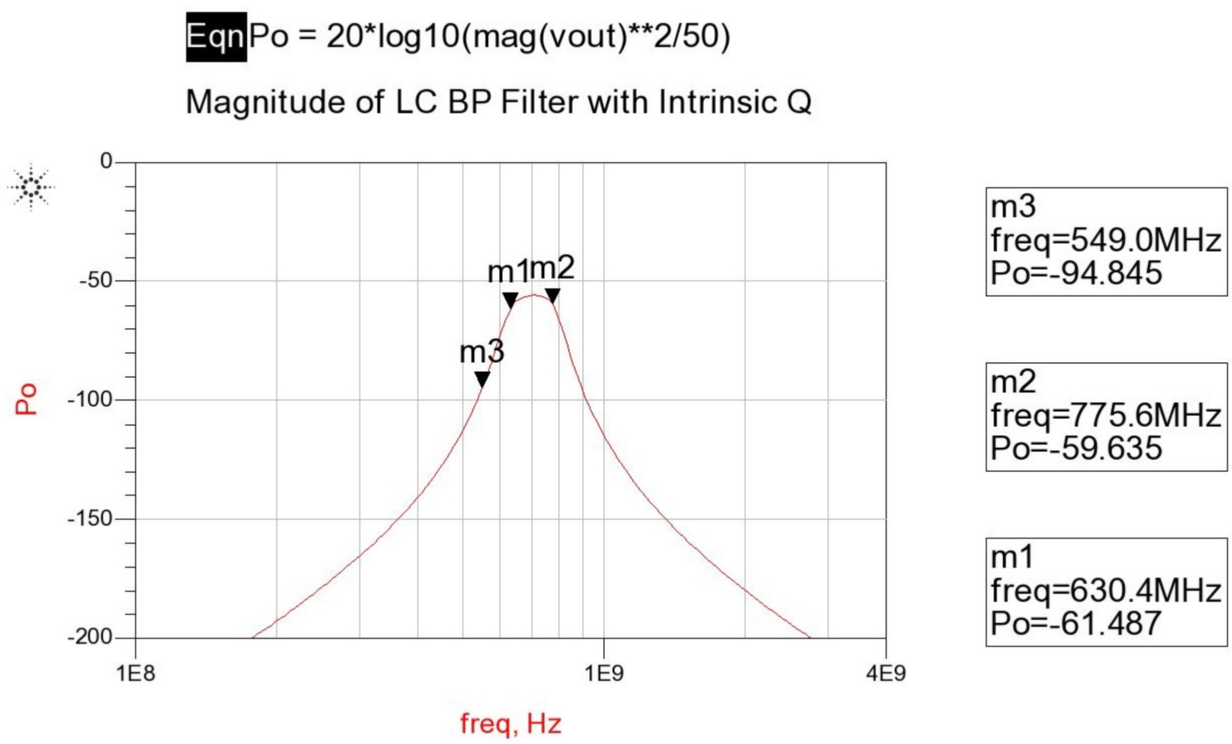
$$Q = 20 = \frac{\omega L}{R} = \frac{2\pi \cdot 700.1 \text{ MHz} \cdot 2.215 \text{ nH}}{R} \implies R = 0.488\ \Omega$$

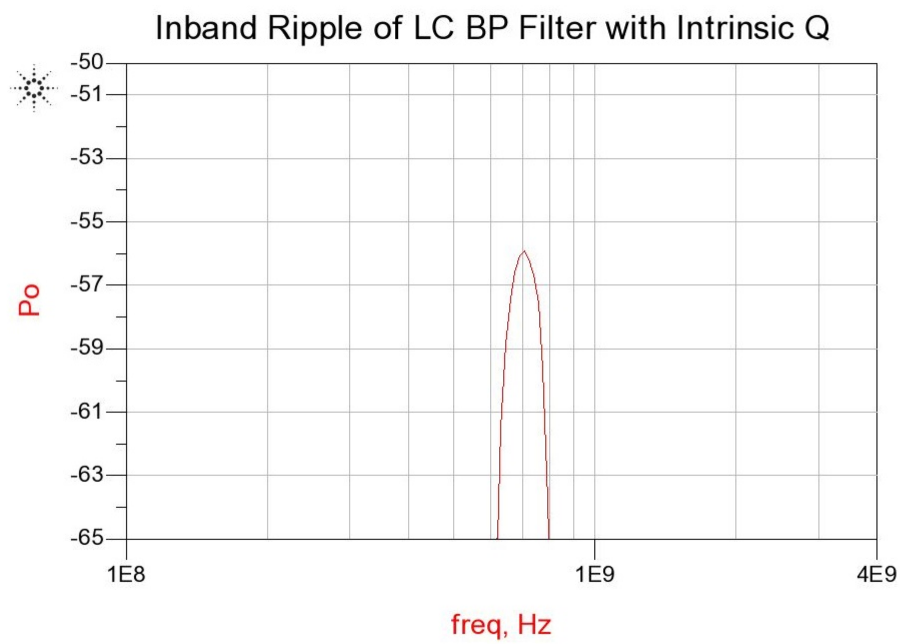
For the C's:

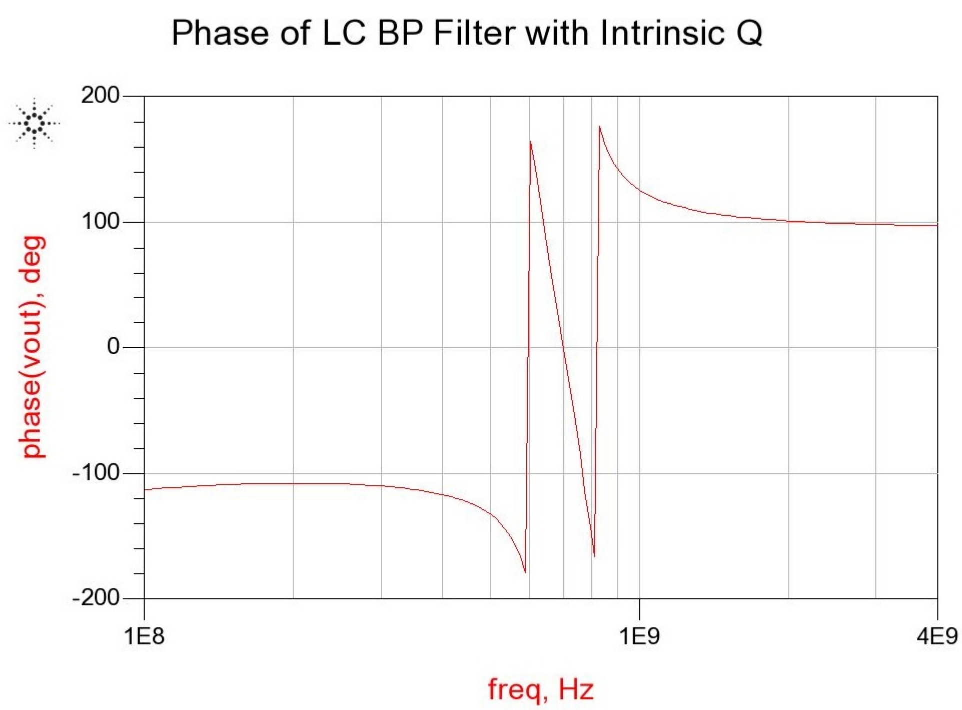
$$Q = 100 = \frac{1}{\omega CR} = \frac{1}{2\pi \cdot 700.1 \text{ MHz} \cdot 0.609 \text{ pF} \cdot R} \implies R = 3.73\ \Omega$$

$$Q = 100 = \frac{1}{\omega CR} = \frac{1}{2\pi \cdot 700.1 \text{ MHz} \cdot 23.27 \text{ pF} \cdot R} \implies R = 0.0976\ \Omega$$


AC
AC1
Start=5 MHz
Stop=10 GHz
Step=
R2
R=50 Ohm
V_AC
SRC1
Vac=polar(1,0) V
Freq=freq
vin
I_Probe1
L1
L=84.688 nH
R=18.65
C1
C=0.609 pF
R4
R=3.73 Ohm
C2
C=23.27 pF
R5
R=0.0976 Ohm
L2
L=2.215 nH
R=0.488
L3
L=84.688 nH
R=18.65
C3
C=0.609 pF
R3
R=3.73 Ohm
vout
R1
R=50 Ohm


Eqn Po = 20*log10(mag(vout)**2/50)
Magnitude of LC BP Filter with Intrinsic Q
Po
freq, Hz
m1
m2
m3
m3 freq=549.0MHz Po=-94.845
m2 freq=775.6MHz Po=-59.635
m1 freq=630.4MHz Po=-61.487





Adding in the Q of the components decreased our effective bandwidth (narrowing the band) as well as introducing more loss in the circuit. The phase did not change much due to adding the effective series resistances.