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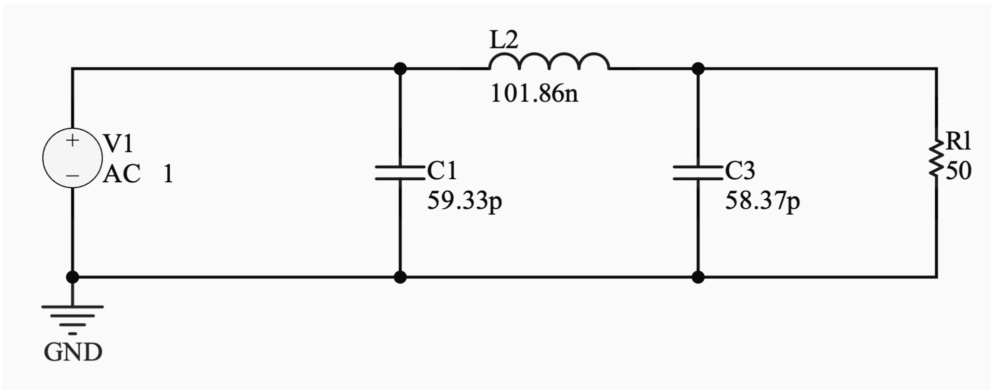
Physics 50 Section 7
Lab Partner: Avery Smith
Module 1 Lab Report
October 3, 2023

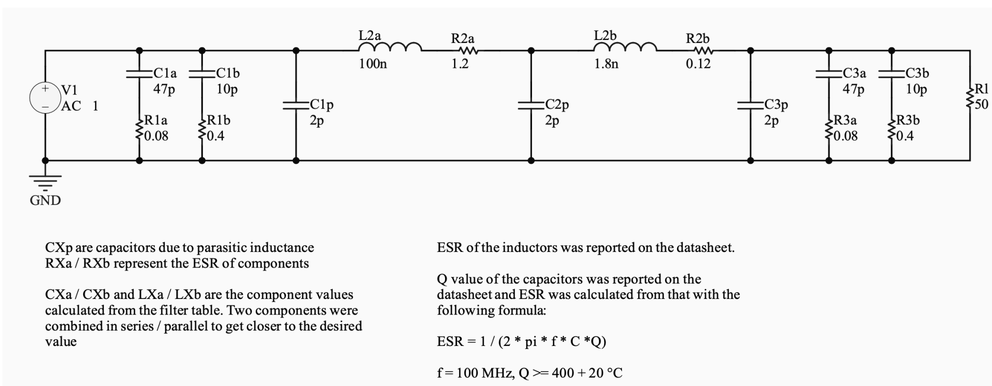
1 Filter Specifications

Parameter	Analytical	Simulated w/ ideal components	Simulated w/ real components	Measured
Filter type	Chebyshev I	NA	NA	NA
Filter order	3	NA	NA	NA
Pass Band Edge (defined as exceeding 1dB ripple)	100 MHz	100 MHz		
Stop Band Start (defined @20dB of rejection)	170 MHz	173.78 MHz		
Insertion Loss	0 dB	0.0206 dB		
In-Band Ripple	0.5	0.5210 dB		

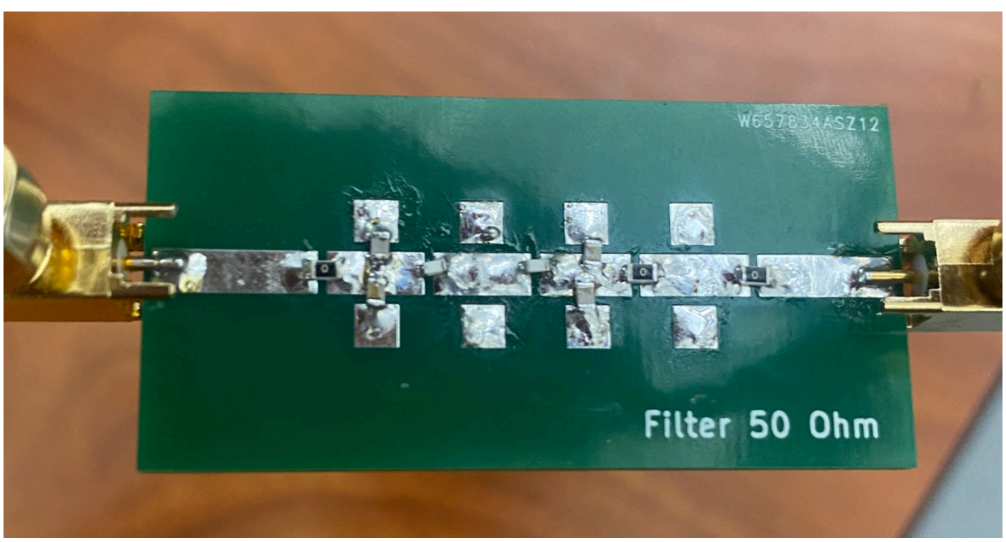
2 Pictures and Schematics



(a) Ideal Components



(b) Real Components



(c) Assembled Design

3 Hand Calculations

We want to design an LC lowpass filter with an f_c of 100 MHz and minimum attenuation of 20 dB at 200 MHz. The allowable passband ripple is 1 dB and the maximum insertion loss is 3 dB. The source and load resistance are equal at 50 ohms.

We can then normalize the attenuation requirements to use attenuation curves:

$$\frac{f}{f_c} = \frac{200 \text{ MHz}}{100 \text{ MHz}} = 2$$

Now we want to select a normalized lowpass filter that offers at least 20 dB of attenuation at a ratio of $f/f_c = 2$.

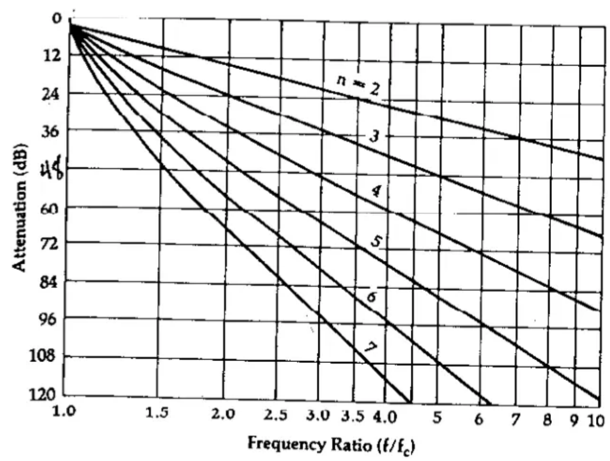


Figure 2: Attenuation characteristics for a Chebyshev filter with 0.5-dB ripple.

From the attenuation plot, we can see that a 3rd order chebyshev filter has greater than the required attenuation at $f/f_c = 2$ Extracting the point at which there is 20 dB of rejection from the transfer function numerically, we get $f_{\text{stop band}} = 170$ MHz.

We have chosen to use the 0.5 dB attenuation table, so the expected in band ripple is 0.5 dB. At the desired stop band, $f = 200$ MHz $\rightarrow f/f_c = 2$, we can see that there is 24 dB of attenuation.

We can predict the attenuation as a function of frequency using

$$A_{\text{dB}} = 10 \log \left[1 + \epsilon^2 C_n^2 \left(\frac{\omega}{\omega_c} \right)' \right]$$

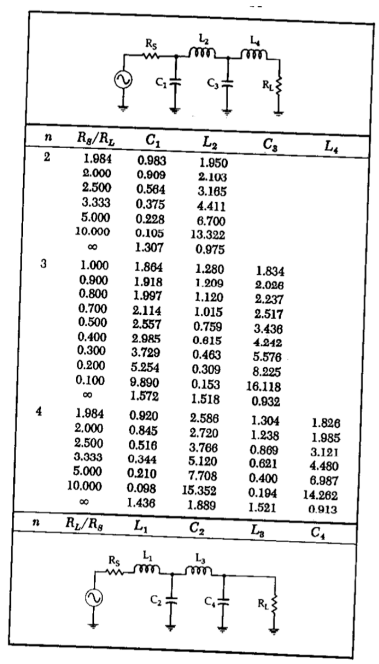
Where:

1. $\epsilon = \sqrt{10^{R_{\text{dB}}/10} - 1} = 0.3493$ ($R_{dB} = 1$ dB is the allowable passband ripple)
2. $\left(\frac{\omega}{\omega_c}\right)' = \left(\frac{\omega}{\omega_c}\right) \cosh B$

3. $B = \frac{1}{n}\cosh^{-1}\left(\frac{1}{\epsilon}\right)$

4. $C_3(x) = 4x^3 - 3x$

The following table can be used to calculate component values for $n = 3$ and $R_S/R_L = 1$ as follows:



n	R_S/R_L	C_1	L_2	C_3	L_4
2	1.984	0.983	1.950		
	2.000	0.909	2.103		
	2.500	0.564	3.165		
	3.333	0.375	4.411		
	5.000	0.228	6.700		
	10.000	0.105	13.322		
	∞	1.307	0.975		
3	1.000	1.864	1.280	1.834	
	0.900	1.918	1.209	2.026	
	0.800	1.997	1.120	2.237	
	0.700	2.114	1.015	2.517	
	0.500	2.557	0.759	3.436	
	0.400	2.985	0.615	4.242	
	0.300	3.729	0.463	5.576	
	0.200	5.254	0.309	8.225	
	0.100	9.890	0.153	16.118	
	∞	1.572	1.518	0.932	
4	1.984	0.920	2.586	1.304	1.826
	2.000	0.845	2.720	1.238	1.985
	2.500	0.516	3.766	0.869	3.121
	3.333	0.344	5.120	0.621	4.480
	5.000	0.210	7.708	0.400	6.987
	10.000	0.098	15.352	0.194	14.262
	∞	1.436	1.889	1.521	0.913
n	R_L/R_S	L_1	C_2	L_3	C_4

Figure 3: Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple.

Plugging in we get:

$$C_1 = \frac{1.864}{2\pi(100 \times 10^6)50} = 59.33 \text{ pF}$$
$$L_2 = \frac{(1.280)(50)}{2\pi(100 \times 10^6)} = 101.86 \text{ nH}$$
$$C_3 = \frac{1.834}{2\pi(100 \times 10^6)50} = 58.37 \text{ pF}$$

Because we are making a lowpass filter, we can use the provided schematic as is. We have chosen to use the **top** schematic in 3.

Calculation showing power delivered to a 50 Ohm if your filter were driven by a 1 Vpp, 0 VDC offset, 50 MHz sine wave from a voltage source w/ 50 Ohm output impedance.

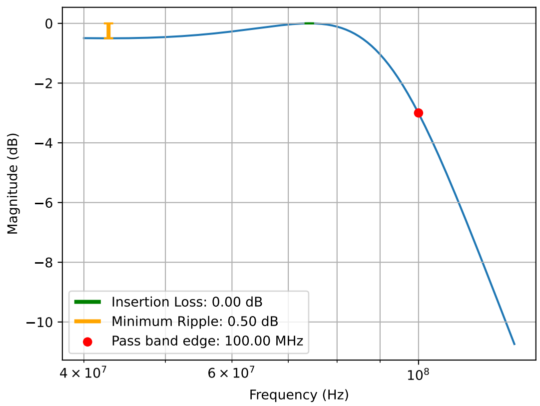
The input wave has a power of

$$P = \left(\frac{1\ V}{2\sqrt{2}}\right)^2 \frac{1}{50\Omega} = 2.5 \text{ mW} \approx 4 \text{ dBm}$$

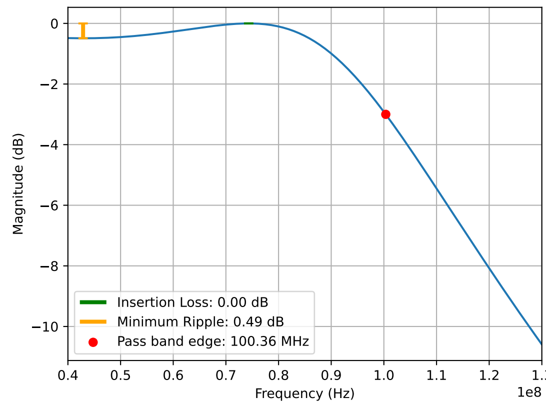
50 MHz is a low enough frequency that we can assume the only loss is due to insertion loss (see page 8 for insertion loss measurement). Then the total power delivered into the load is:

$$4 \text{ dBm} - \text{Insertion Loss} = 4 \text{ dBm} - 0.84 \text{ dBm} = 3.16 \text{ dBm} \approx 2 \text{ mW}$$

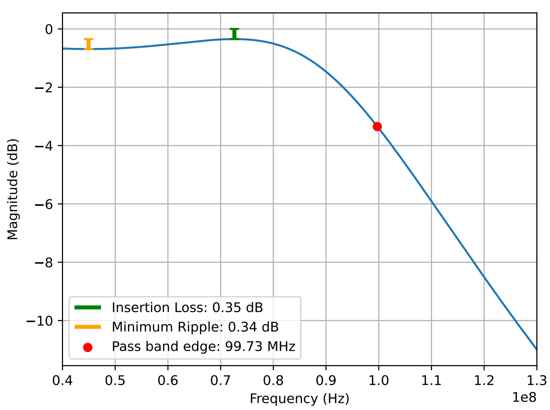
4 Magnitude of S21 in Pass band



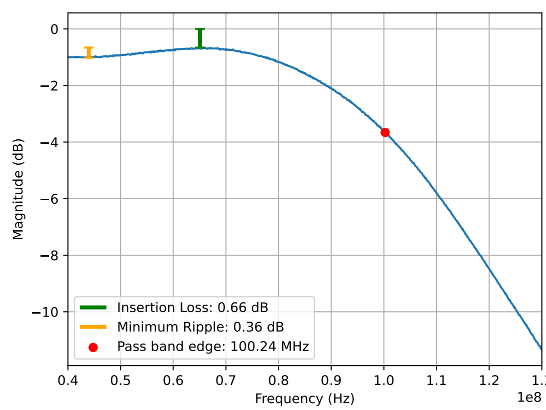
(a) Analytical Design



(b) Simulated design with ideal components



(c) Simulated Design with real components



(d) Assembled Design

5 Phase of S21 in Pass band

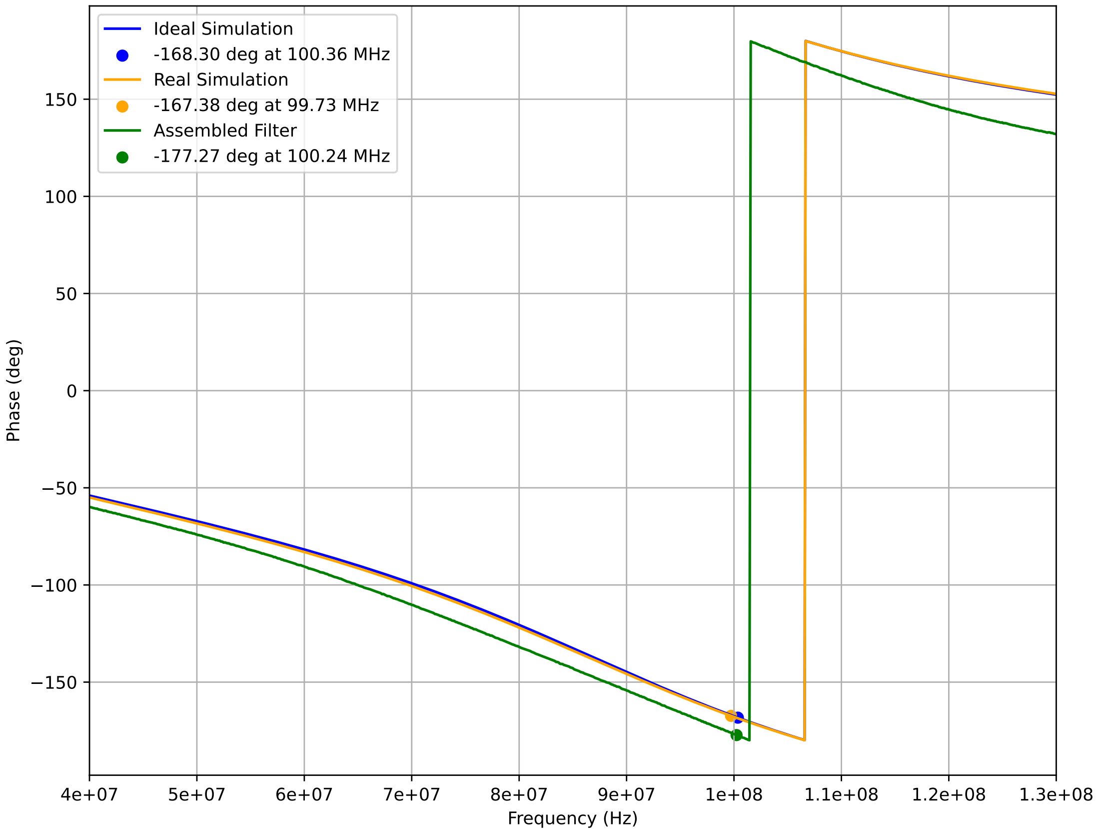
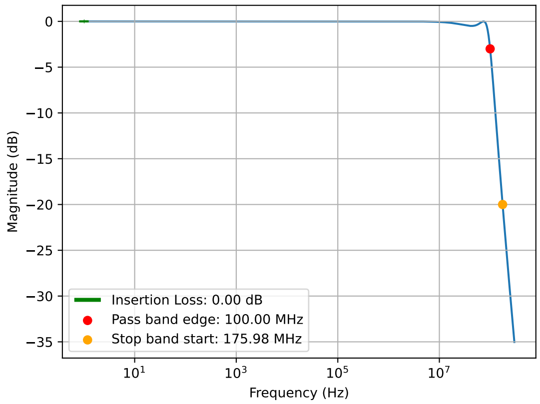
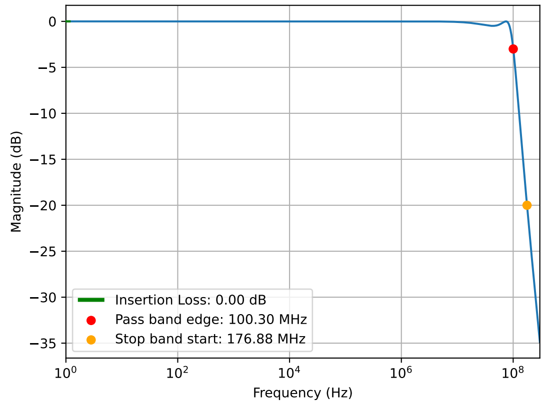


Figure 5: Phase of S21 in Pass band for ideal simulation, real simulation, and assembled design

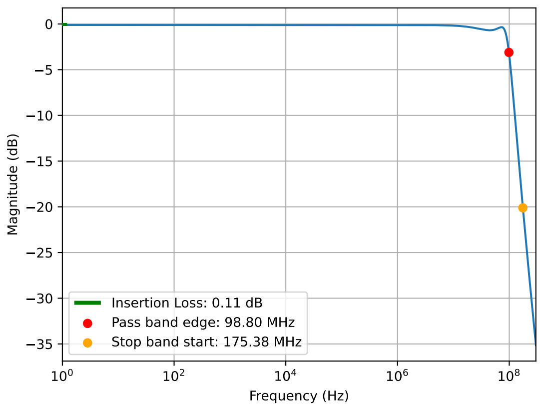
6 Magnitude of S21 from DC to Stop band



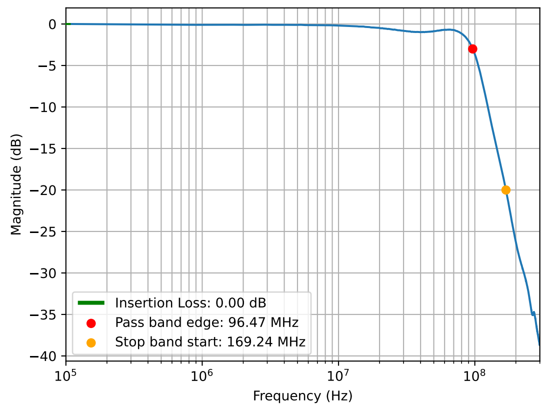
(a) Analytical Design



(b) Simulated design with ideal components

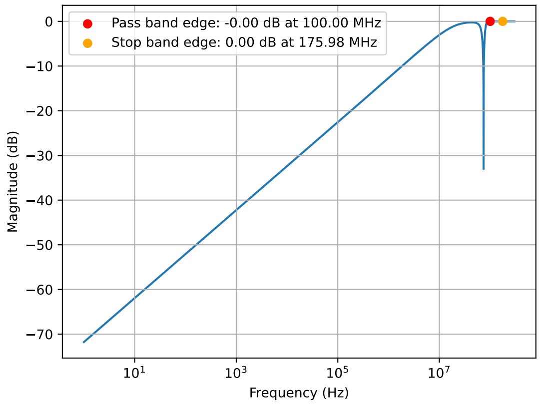


(c) Simulated Design with real components

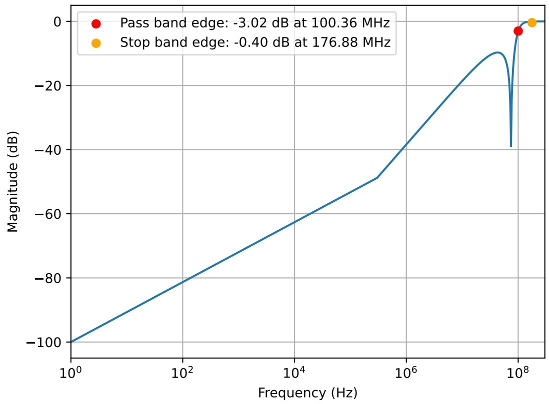


(d) Assembled Design

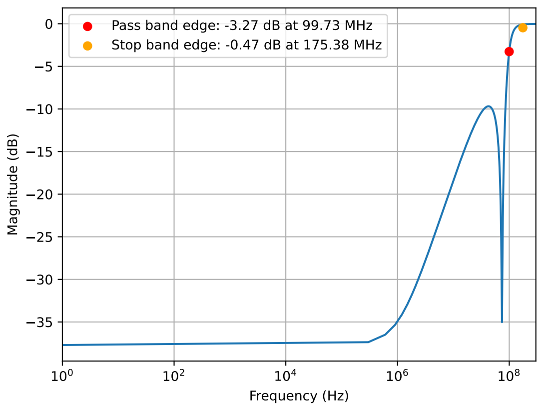
7 Magnitude of S11 from DC to Stop band



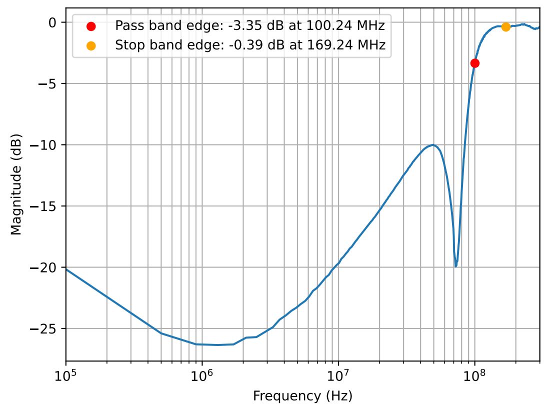
(a) Analytical Design



(b) Simulated design with ideal components



(c) Simulated Design with real components

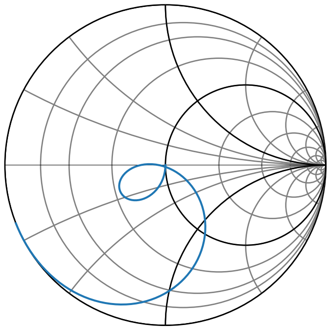


(d) Assembled Design

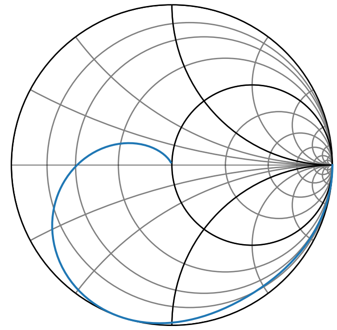
8 Smith Charts for S11 and S21 from DC to Stop band

S11

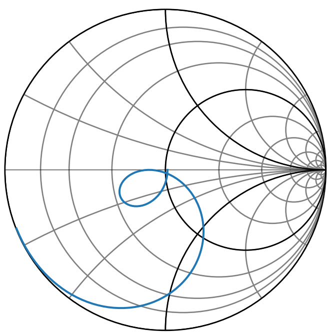
S21



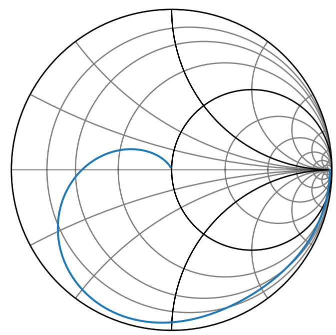
(a) Ideal Simulation S11



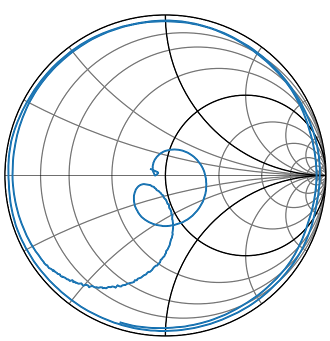
(b) Ideal Simulation S21



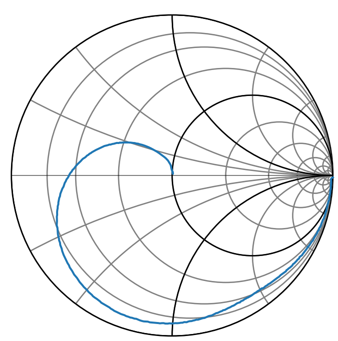
(c) Real Simulation S11



(d) Real Simulation S21



(e) Assembled Design S11



(f) Assembled Design S21

9 Discussions

10 Takeaways