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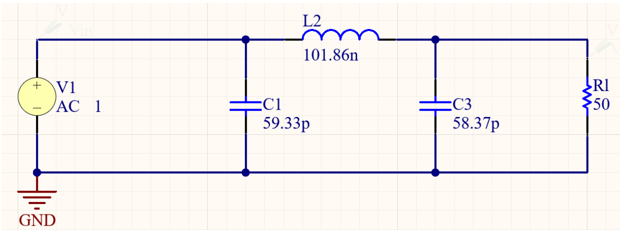
Physics 50 Section 7
Lab Partner: Avery Smith
Module 1 Lab Report
October 3, 2023

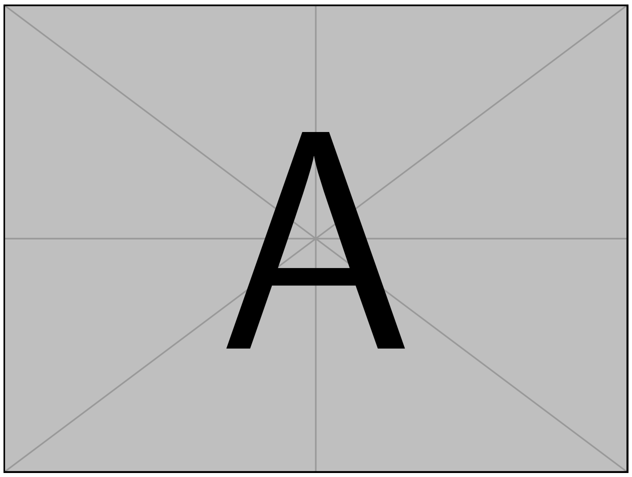
# 1 Filter Specifications

| 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 | | |

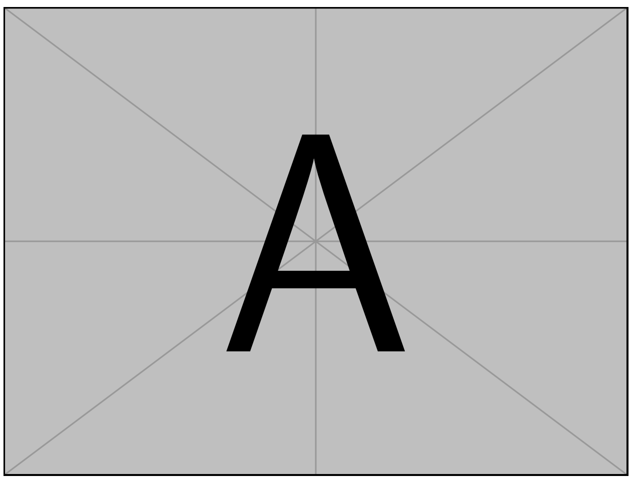
## 2 Pictures and Schematics




(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 $f/f_c = 2$. From the attenuation plot, we can see that a 3rd order chebyshev filter

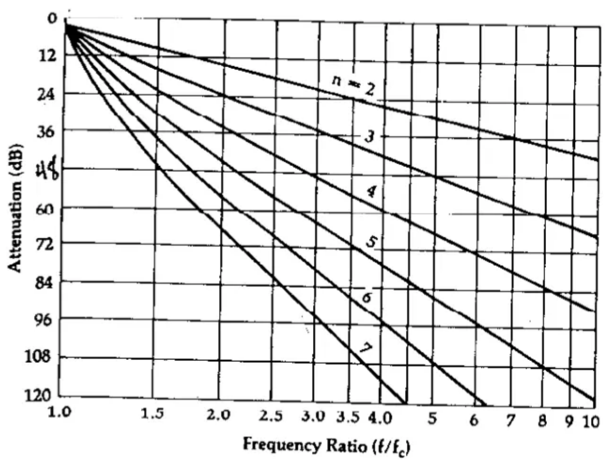


Figure 2: Attenuation characteristics for a Chebyshev filter with 0.5-dB ripple.

has greater than the required attenuation at $f/f_c = 2$ and that the attenuation is equal to 20 dB at $f/f_c \approx 1.7 \implies f_{\text{stop band}} = 170$ MHz

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

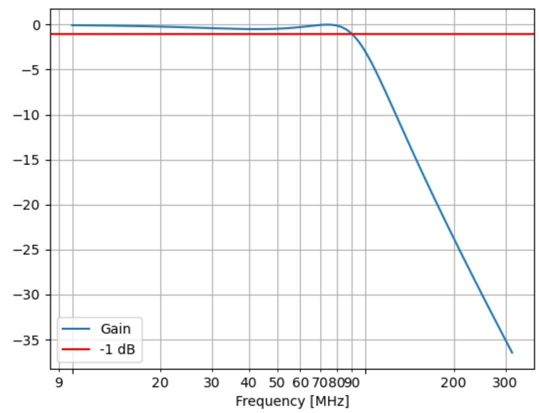
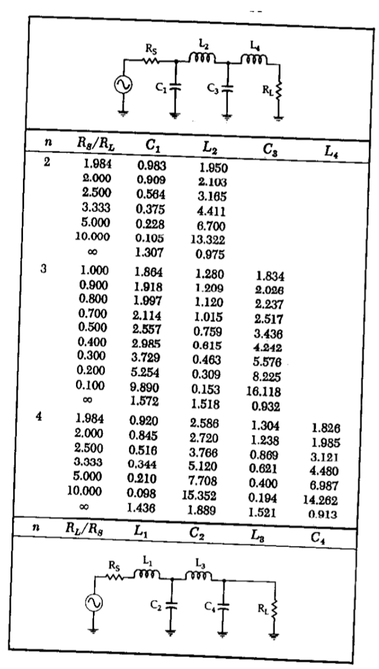



Figure 3: Attenuation characteristics for a Chebyshev filter with 0.5-dB ripple.

Plotting this in python (code link) we get: Extracting the pass band ripple from the graph we get 0.5 dB, as predicted from the filter table in figure 4 The same table can also 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 4: Chebyshev Low-Pass Prototype Element Values for 0.5-dB Ripple.

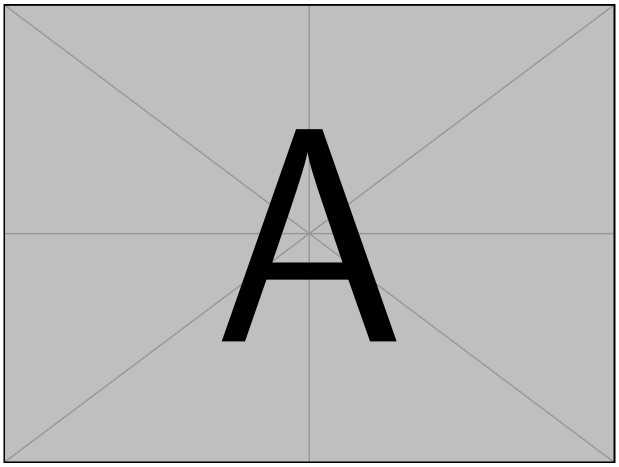
$$C_1 = \frac{1.864}{2\pi(100 \times 10^6)50} = 59.33 \text{ pF}$$

$$L_2 = \frac{(1.280)(50)}{2\pi(100 \times 10^6)} = 101.86 \text{ nH}$$

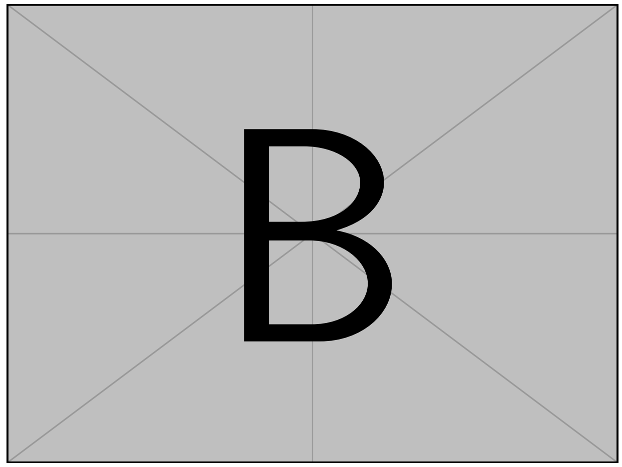
$$C_3 = \frac{1.834}{2\pi(100 \times 10^6)50} = 58.37 \text{ pF}$$

Because we are making a lowpass filter, we can use the provided schematic as is. We have chosen to use the **top** schematic in 4.

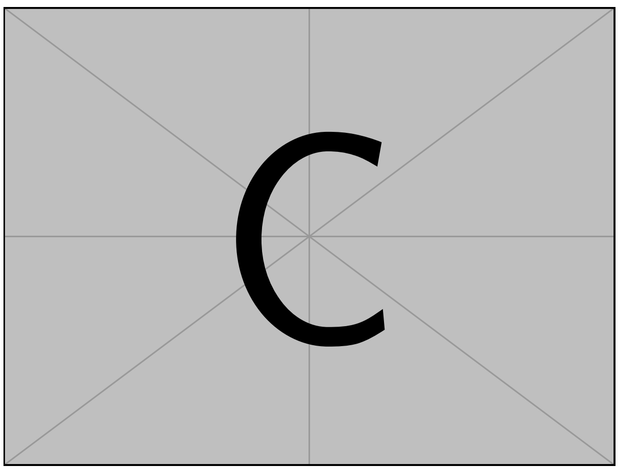
# 4 Magnitude of S21 in Pass band



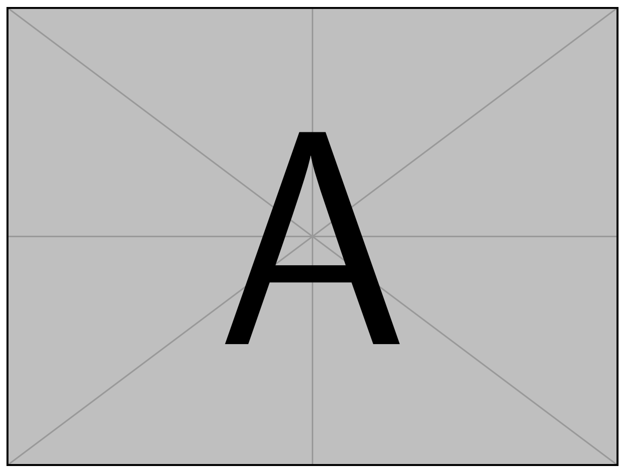

(a) Analytical Design




(b) Simulated design with ideal components




(c) Simulated Design with real components




(d) Assembled Design

# 5 Phase of S21 in Pass band

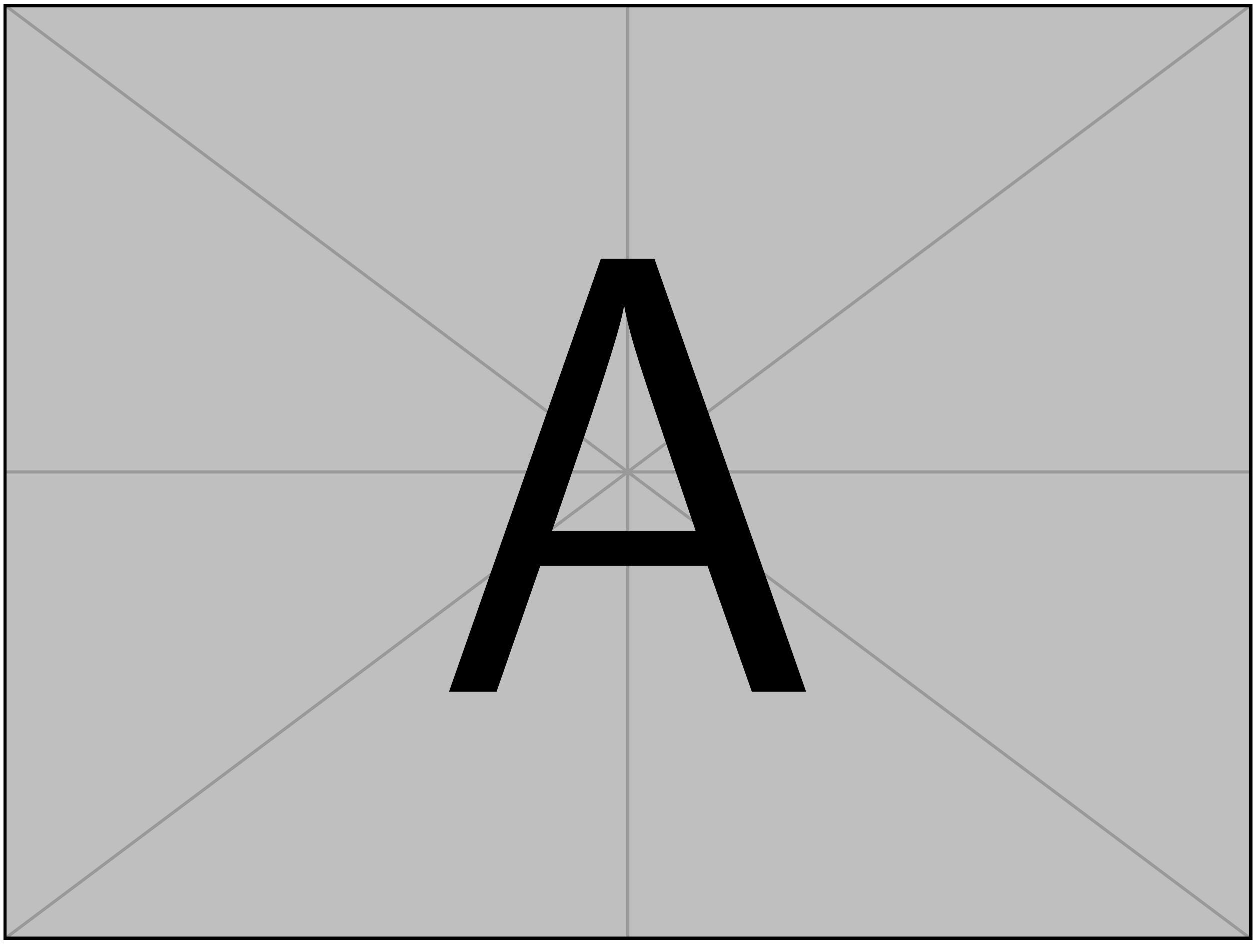
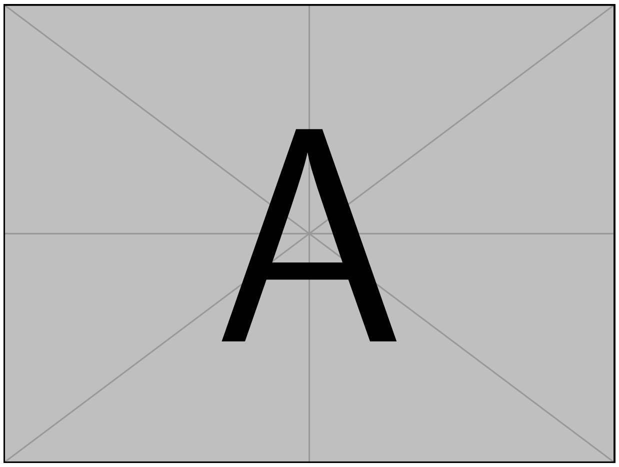
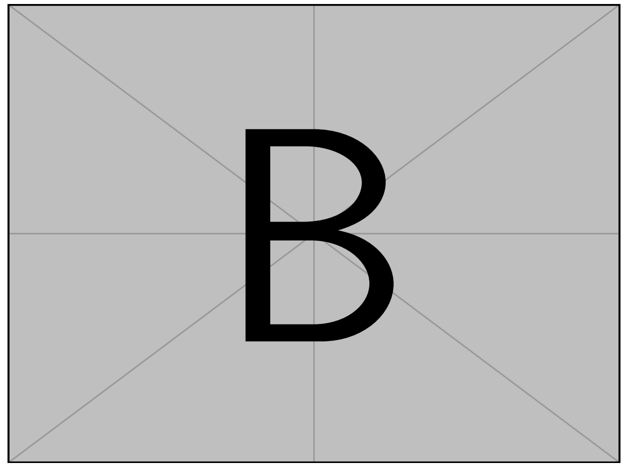


Figure 6: Phase of S21 in Pass band for ideal simulation, real simulation, and assembled design

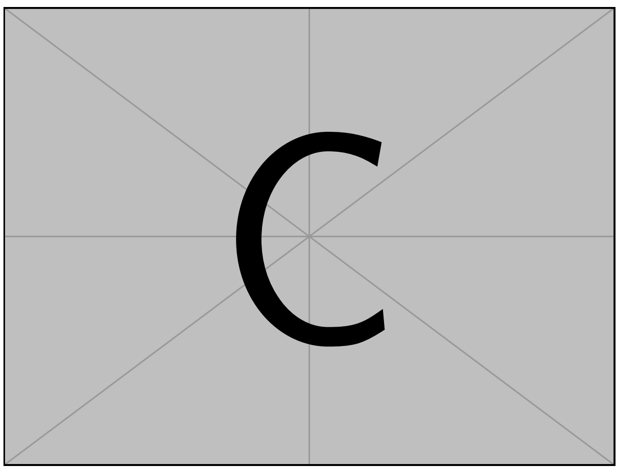
# 6 Magnitude of S21 from DC to Stop band



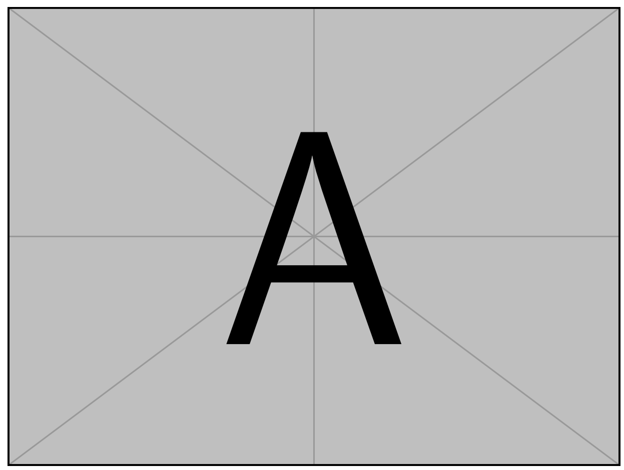

(a) Analytical Design




(b) Simulated design with ideal components

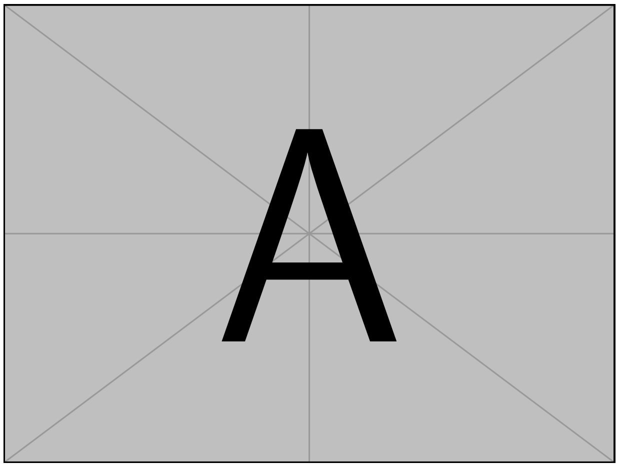



(c) Simulated Design with real components

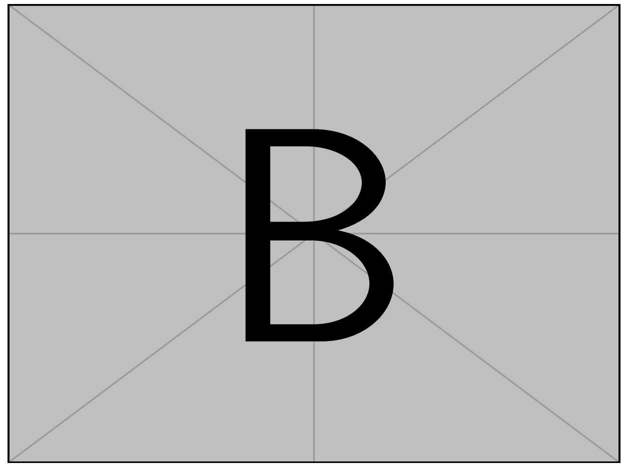



(d) Assembled Design

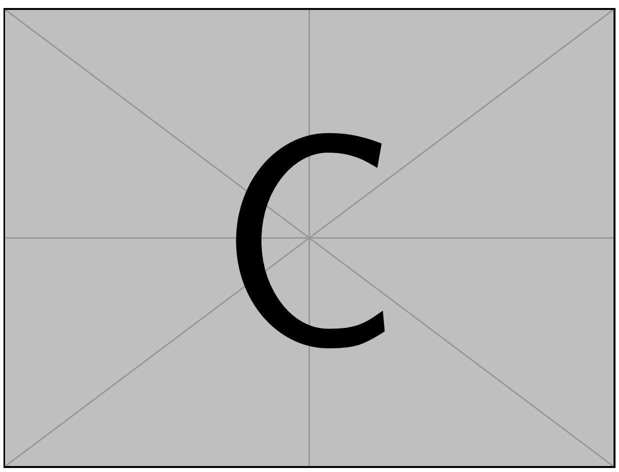
# 7 Magnitude of S11 from DC to Stop band



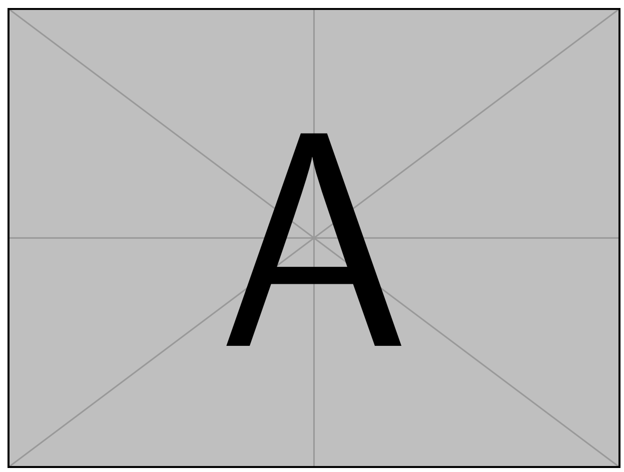

(a) Analytical Design




(b) Simulated design with ideal components




(c) Simulated Design with real components

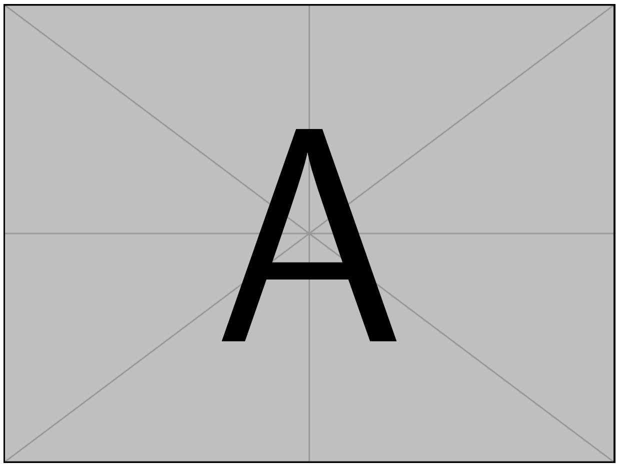



(d) Assembled Design

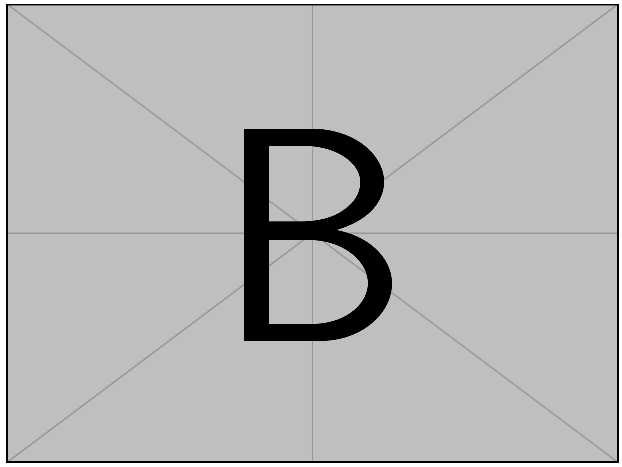
# 8 Smith Charts for S11 and S21 from DC to Stop band

S11

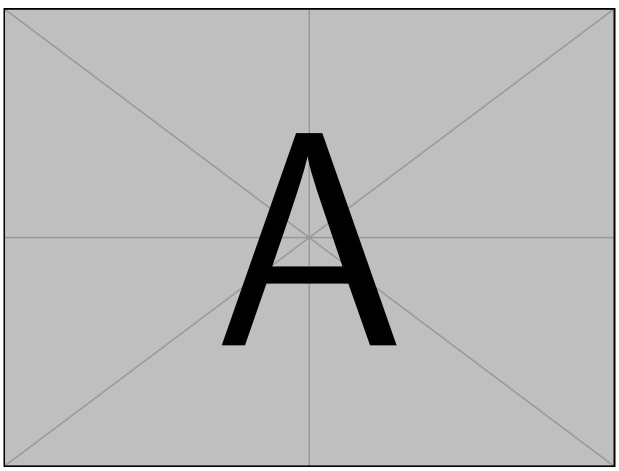
S21



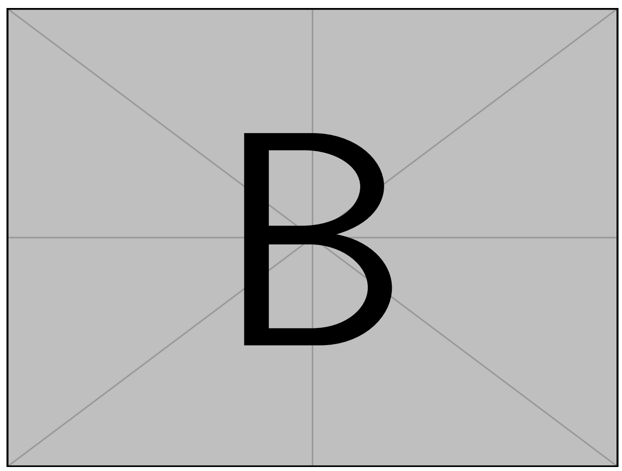

(a) Ideal Simulation S11



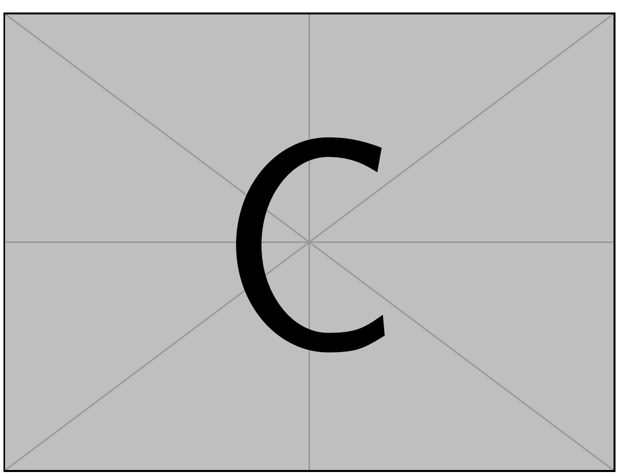

(b) Ideal Simulation S21



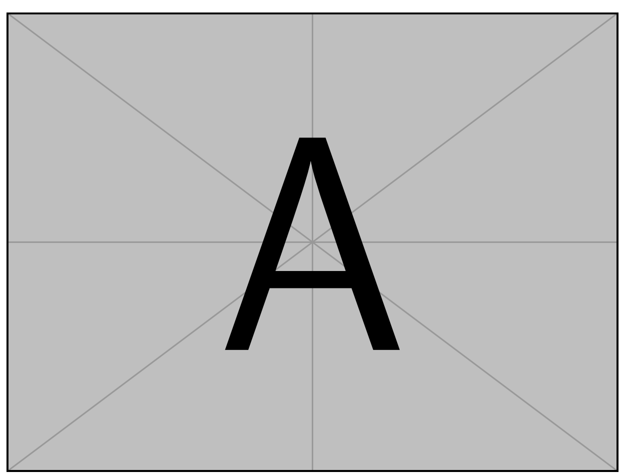

(c) Real Simulation S11




(d) Real Simulation S21




(e) Assembled Design S11




(f) Assembled Design S21

# 9 Discussions

# 10 Takeaways