ELECENG 4FJ4
Devices and Antennas for Wireless Systems

Project #3: Double Folded Stub Bandpass Filter

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As a future member of the engineering profession, the student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is our own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by **[Wahalathantrige Tisuka Perera, pererw2, 400318373]**

Introduction

For this project, the device I chose was a Double Folded Stub Bandpass Filter. A double folded stub bandpass filter lets signals within a specific range of frequencies pass through while attenuating other signals. As the name suggests, the filter uses folded tuning stubs, which act as resonators that create the desired passbands by allowing specific frequencies and suppressing others outside the specified bandwidth. One advantage is that the folded stubs allow the length of the transmission line to be greater while maintaining a sleek and compact design. Additionally, if constructed properly, the filter is precise in selecting the desired frequencies with minimal loss. A disadvantage of this filter is its limited bandwidth, which makes the filter less reliable if a larger range of frequencies is required to pass through. It has a variety of applications, such as supporting wireless communication systems such as phones and TVs, satellite communication, radar systems [1], and medical equipment such as MRI and ultrasound machines [2]. This report will cover the design specifications, discuss the simulated and measured results, and conclude how the experiment can be improved.

Design Specifications

(i) Frequency Range

- $1\,GHz \leq f \leq 3\,GHz$

For return loss greater than 10dB (Figure 3):

- $1.597\,GHz \leq f \leq 2.3\,GHz$
- Bandwidth: 0.703 GHz

For maximum variation allowance in passband when $|S_{21}| \geq 0.5012$dB (Figure 5):

- $1.377\,GHz \leq f \leq 2.62\,GHz$
- Bandwidth: 1.243 GHz

(ii) S-parameter specifications

Since this is a 2-port network, the S-matrix can be defined as:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

From Figure 6, we can see that the device is reciprocal, and when looking at Figure 7, the S-parameters are $|S_{11}| = |S_{22}| = 0.01479$ and $|S_{12}| = |S_{21}| = 0.9626$. With that in mind, the S-matrix is:

$$S = \begin{bmatrix} 0.01479 & 0.9626 \\ 0.9626 & 0.01479 \end{bmatrix}$$

$$\frac{P_1^{loss}}{P_1^{+}} = 1 - |S_{11}|^2 - |S_{21}|^2 = 1 - |0.01479|^2 - |0.9626|^2 = 7.32\%$$

AWR Initial Design Ouput

(i) Plot of Circuit Layout

The following circuit layout/schematic and simulated plots (Figures 1 to 7) were retrieved from Assignment 6.

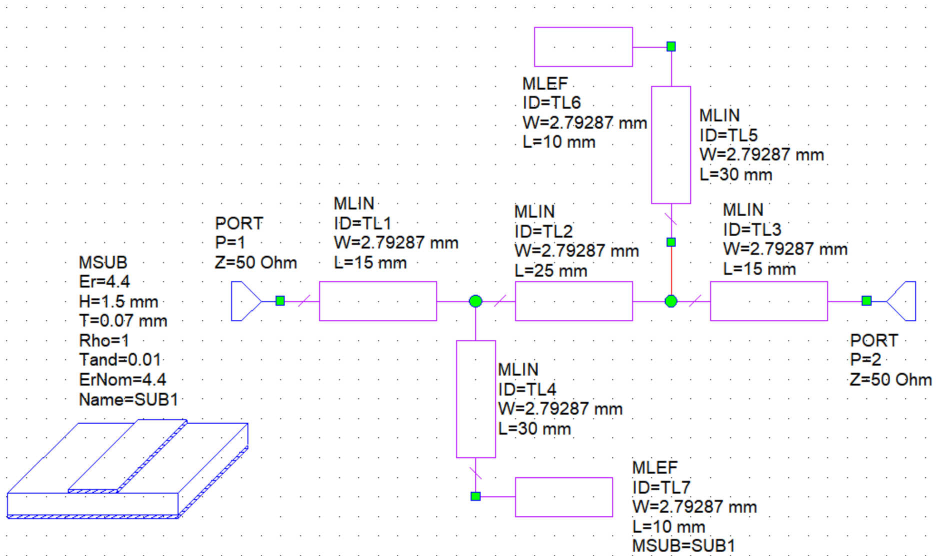

Figure 1: AWR Model of Double Folded Stub Bandpass Filter

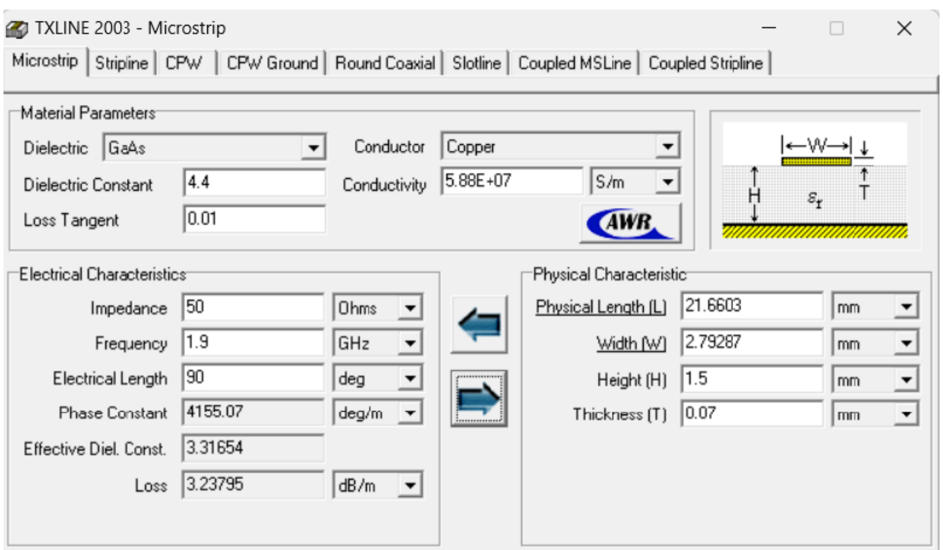

Figure 2: TXLINE Calculating Desired Microstrip Width

(ii) Plots of Simulated S-parameters

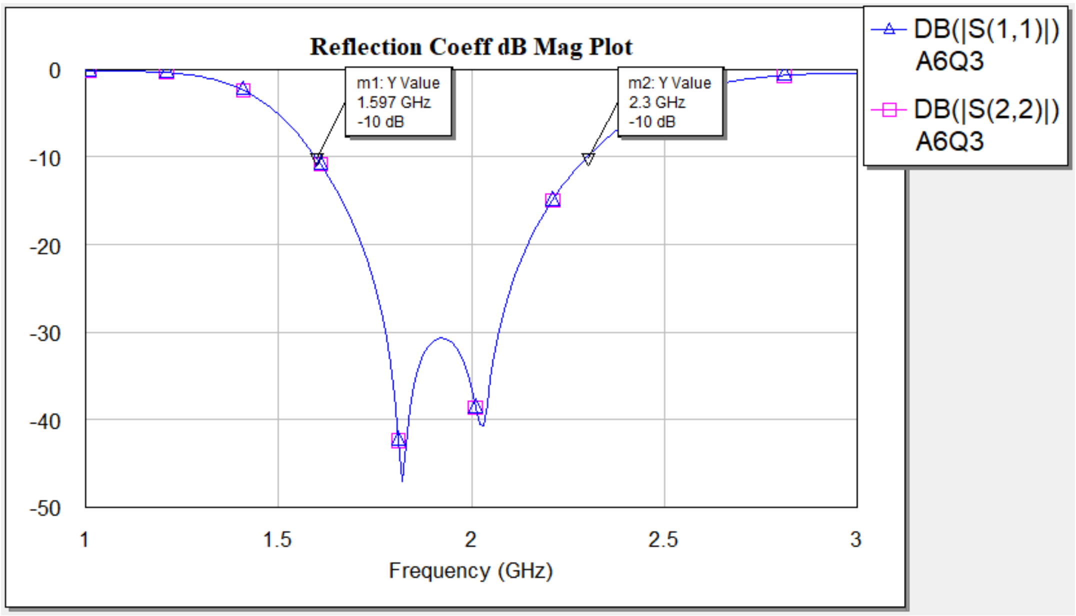

Figure 3: Simulated Reflection Coefficient dB Mag Plot

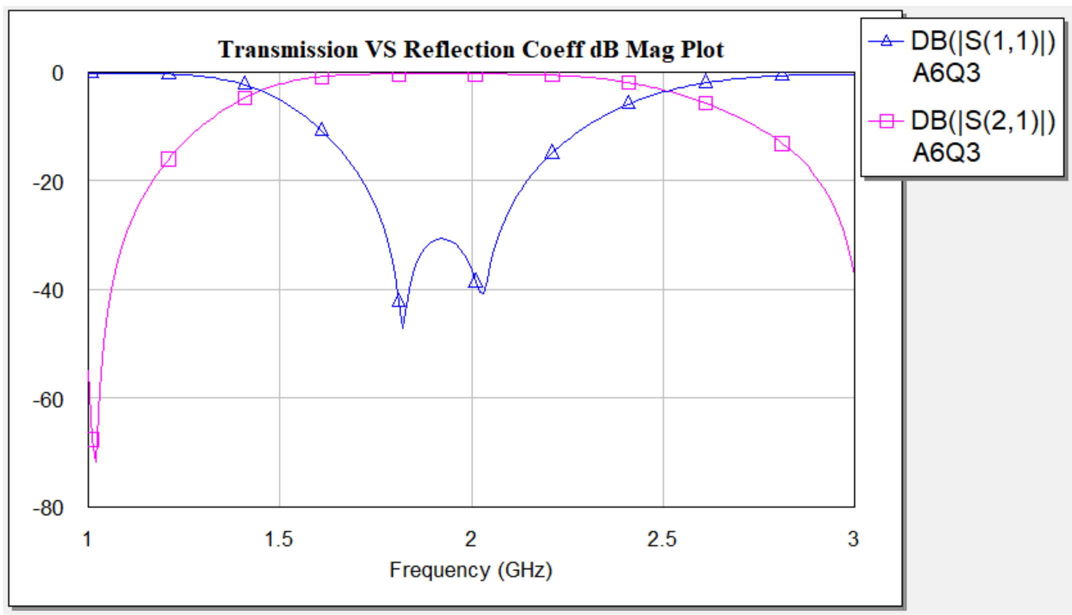

Figure 4: Simulated Transmission vs. Reflection Coefficient dB Mag Plot

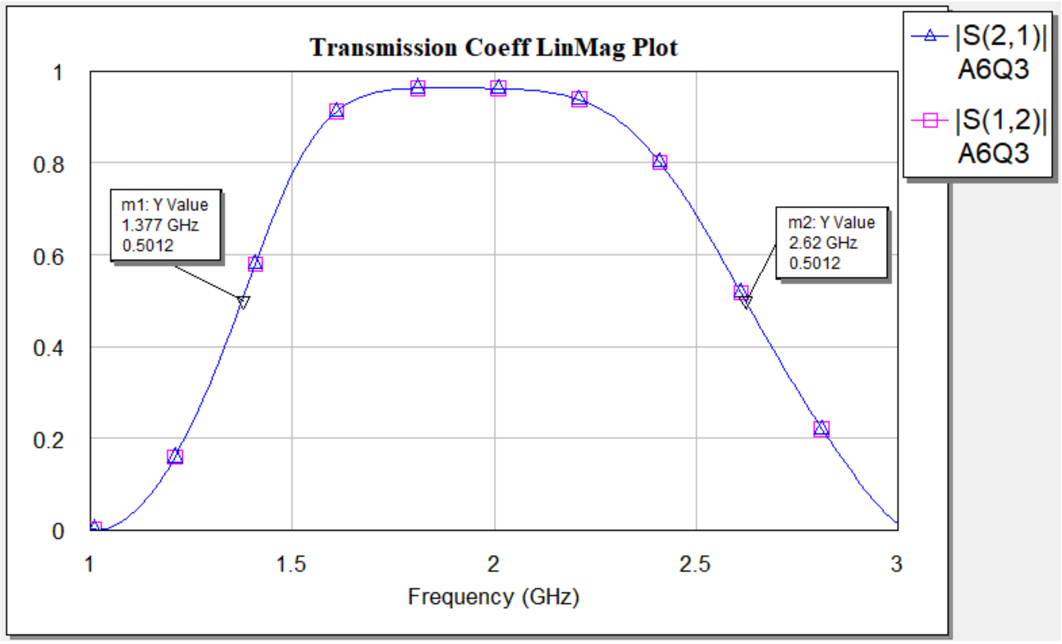

Figure 5: Simulated Transmission Coefficients Linear Mag Plot

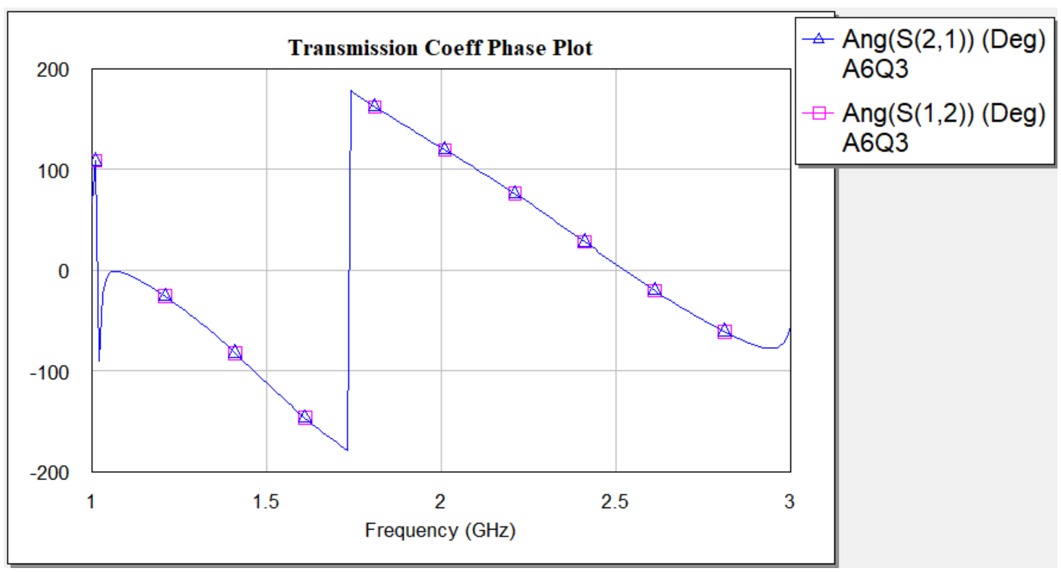

Figure 6: Simulated Transmission Coefficients Phase Plot

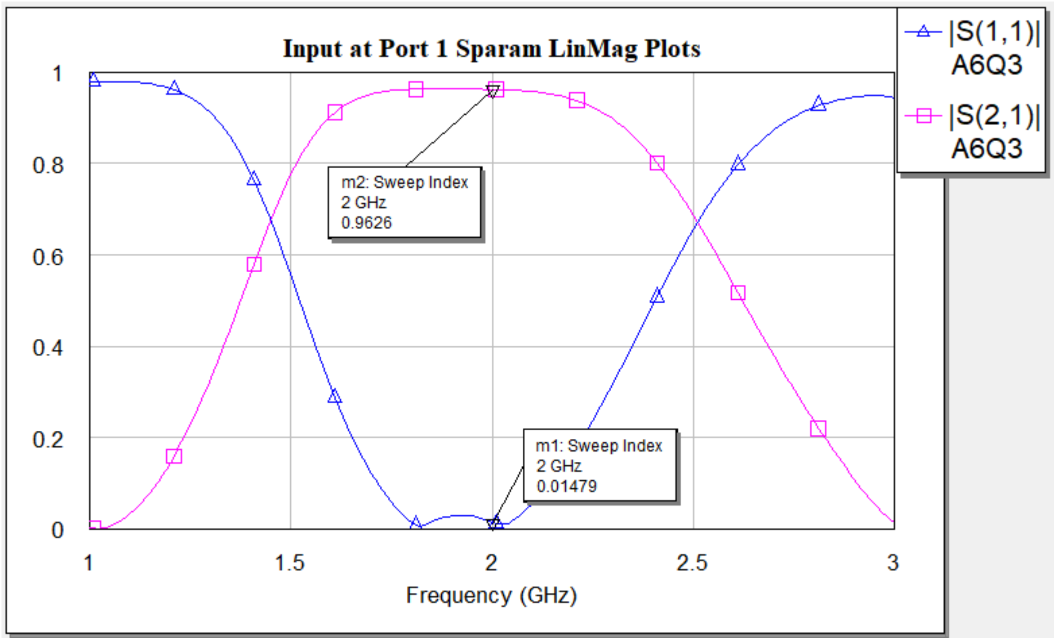

Figure 7: Simulated Input @ Port 1 S-parameter Linear Mag Plots

Final Prototype

(i) Relevant Fabrication Information & Photos of the Final Prototype (Figures 8 to 10)

Required Material
FR4 Substrate Plate (130 mm by 80 mm, Height = 1.5mm, ε_r = 4.4)
Copper Tape (360 mm by 3.175 mm)
Two SMA Port Connectors

Table 1: Material List for the Double Folded Stub Bandpass Filter

Parameters	**Description**	**Values for FR-4 substrate with h = 1.5 mm (ε_r = 4.4) and center frequency of 1.9 GHz**
w	width 50-Ω microstrip line	2.8 mm
l_1	$\approx \lambda_g/2$	25 mm
l_2	$\approx \lambda_g/2$	30 mm
l_3	$\approx \lambda_g/4$	10 mm

Table 2: Parameter List for the Double Folded Stub Bandpass Filter

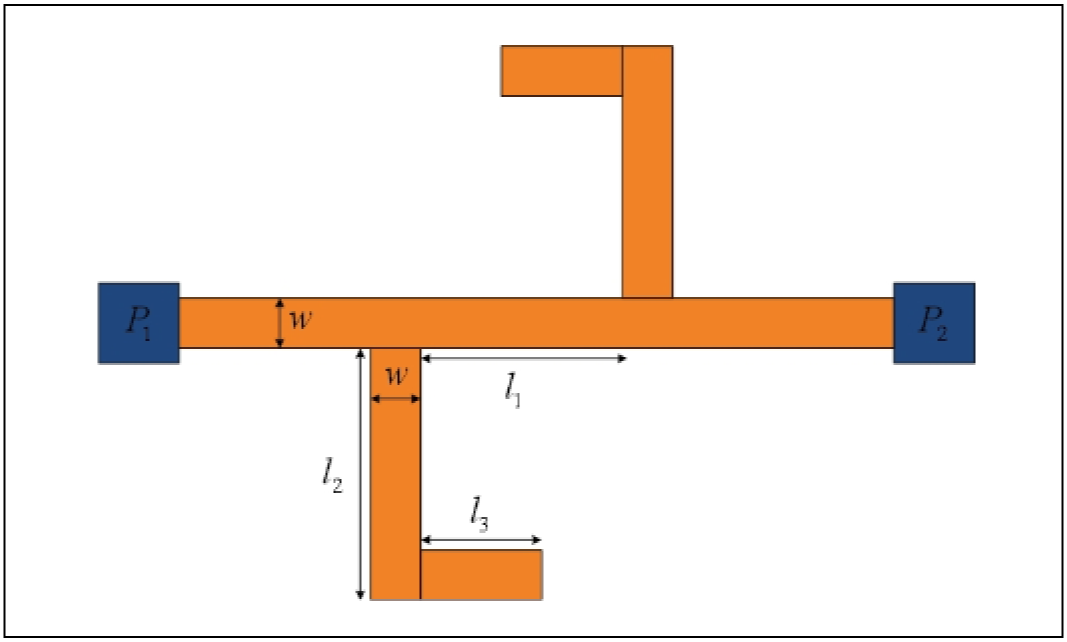

Figure 8: Schematic of Double Folded Stub Bandpass Filter

Figure 9: Top of My Double Folded Stub Bandpass Filter Prototype

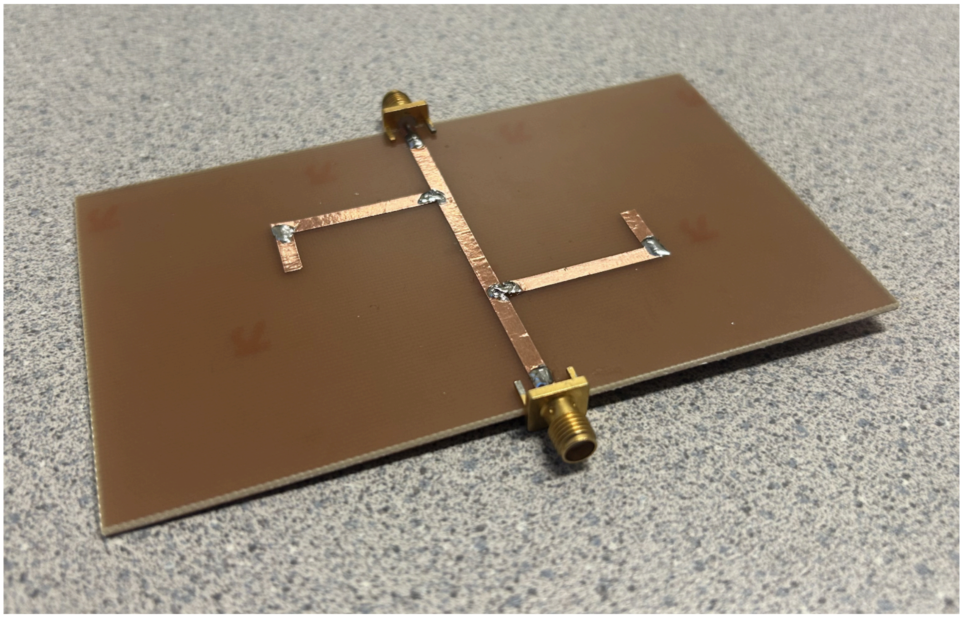

Figure 10: Another Angle of Double Folded Stub Bandpass Filter Prototype

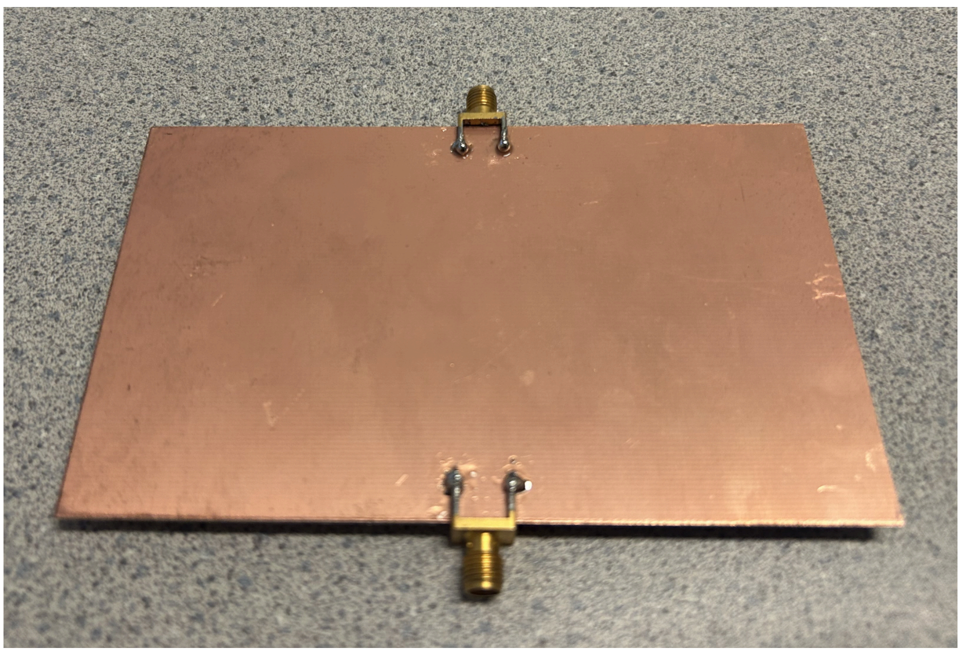

Figure 11: Bottom of My Double Folded Stub Bandpass Filter Prototype

The prototype was constructed using the materials and following the measurements provided in the tables above. The major difference between the prototype and the simulation was the width of the copper tape, which will be discussed in the conclusion section of this report. For better electrical connections between the copper tape, I soldered where each strip meets and where the prongs of the ports met the strip and the plate, using the equipment courtesy of the IEEE McMaster Student Branch. Then I measured the S-parameter plots of the prototype using the VNA from our lab room, ITB-155.

(ii) Plots of Measured S-parameters

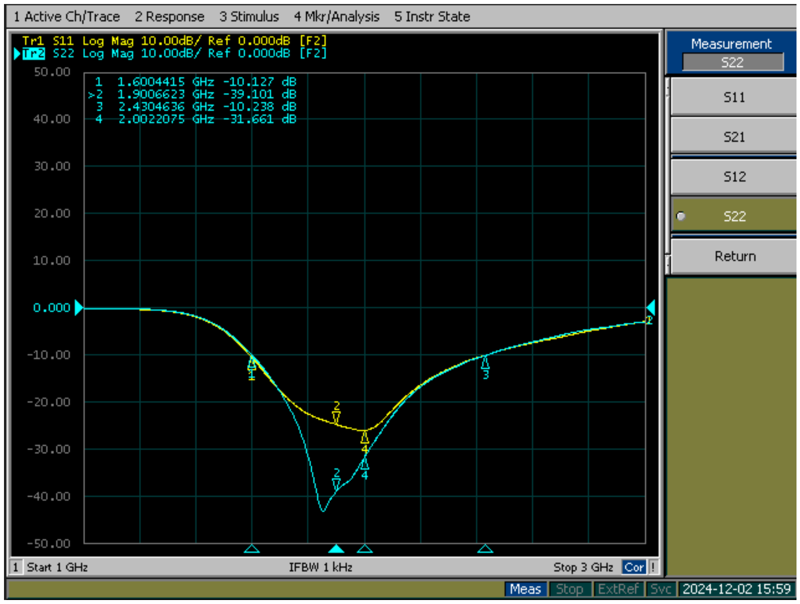

Figure 12: Measured Reflection Coefficient dB Mag Plot

When comparing the simulated and measured reflection coefficient plots (Figures 3 & 12, respectively), the bandwidth is roughly 0.830 GHz between 1.600 GHz ≤ f ≤ 2.430 GHz, for a return loss greater than 10dB. Compared to the simulated results, the measured bandwidth is greater by 0.127 GHz. This discrepancy is likely due to parasitic elements and human error.

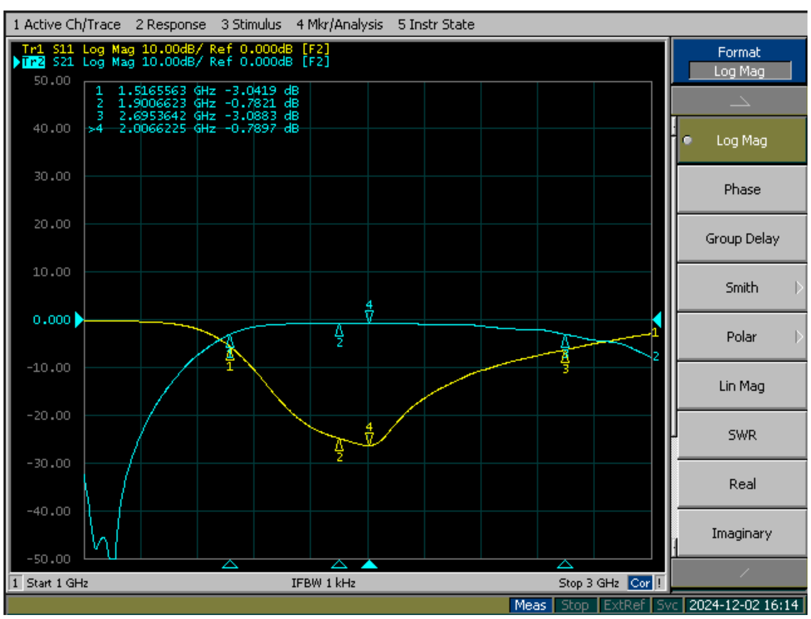

Figure 13: Measured Transmission vs. Reflection Coefficient dB Mag Plot

When comparing the simulated and measured transmission vs. reflection coefficient plots (Figures 4 & 13, respectively), markers were placed to match close to the bandwidth of the simulated plot ($10log_{10}\left|S_{21}\right| \geq -3dB$). These results are similar to those of the simulated ones, with discrepancies occurring likely due to parasitic elements and human error.

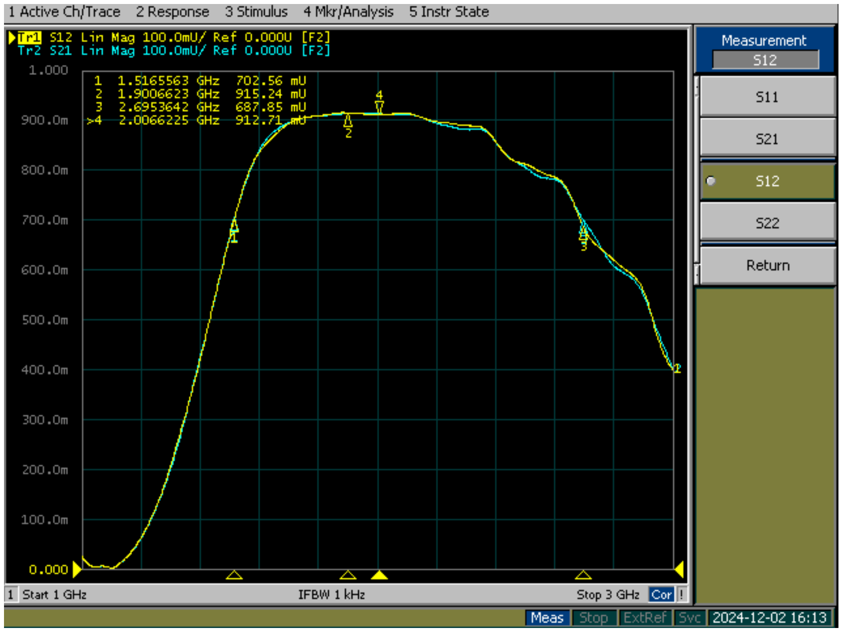

Figure 14: Measured Transmission Coefficients Linear Mag Plot

When comparing the simulated and measured transmission coefficient linear plots (Figures 5 & 14, respectively), the bandwidth is approximately 1.178 GHz between 1.517 GHz $\leq f \leq$ 2.695 GHz. The measured bandwidth is roughly 0.065 GHz greater. This discrepancy is likely due to parasitic elements and human error.

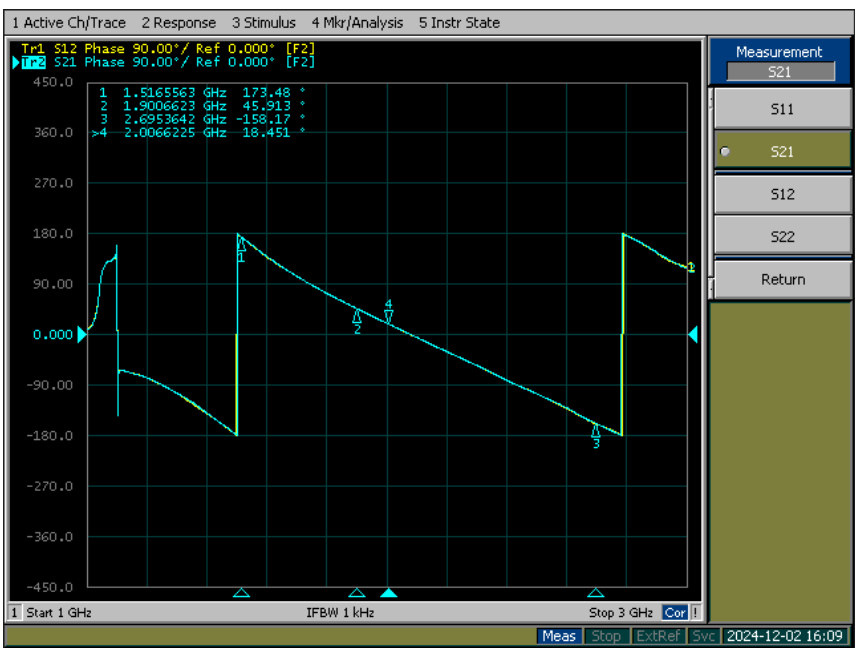

Figure 15: Measured Transmission Coefficients Phase Plot

When comparing the simulated and measured transmission coefficient phase plots (Figures 6 & 15, respectively), the device is shown to be reciprocal since $|S_{21}| = |S_{12}|$. This is further confirmed in the measured plot, proving that the prototype constructed is a viable double folded stub bandpass filter.

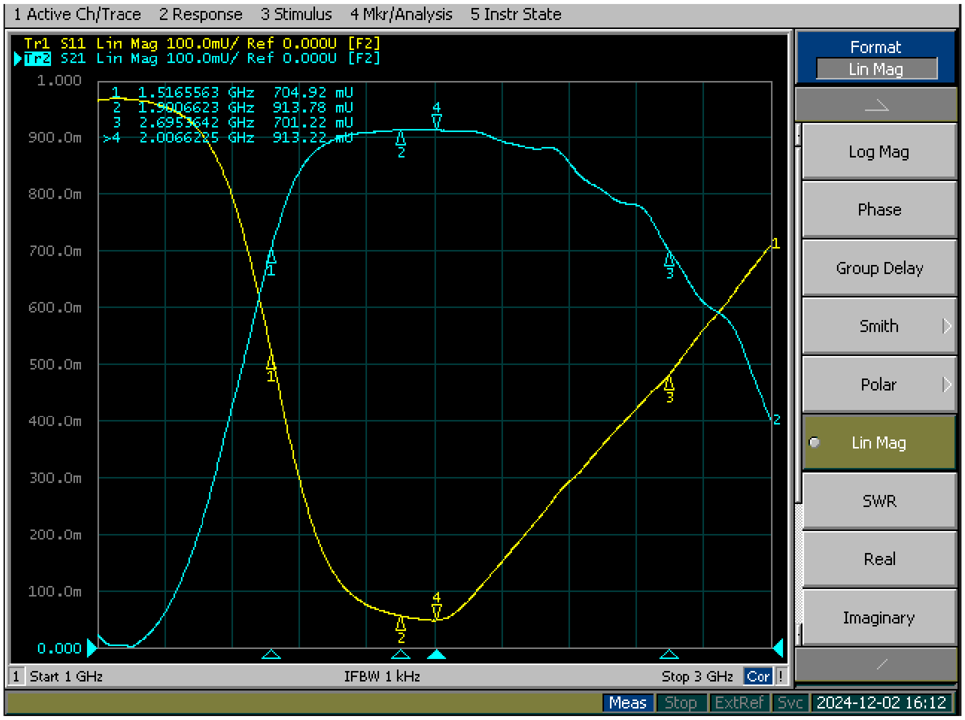

Figure 16: Measured Input at Port 1 S-parameter Linear Mag Plots

When comparing the simulated and measured reflection coefficient plots (Figures 7 & 16) respectively), at a center frequency of 1.9 GHz, the measured S-parameter coefficients are approximately $|S_{11}| = 0.05$ $|S_{21}| = 0.914$. Since we know the device is reciprocal, the S-matrix can be defined as:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} 0.05 & 0.914 \\ 0.914 & 0.05 \end{bmatrix}$$

The power dissipation can be calculated as:

$$\frac{P_1^{loss}}{P_1^{+}} = 1 - |S_{11}|^2 - |S_{21}|^2 = 1 - |0.05|^2 - |0.914|^2 = 16.21\%$$

Therefore at the resonance frequency, about 83.79% of the transmission coefficient passed through the filter. This is to be expected since the device isn't capable of receiving 100% power in the real world, due to its internal components absorbing power from the signal. The measured power loss is also 8.89% greater than the simulated power loss. This slight increase was expected, likely due to parasitic elements and human error. I will discuss the "human error" in the next section.

Conclusions and Comments

To summarize the points I made above, the final prototype I made is suitable and functions as a double folded stub bandpass filter when comparing the results to the simulations. The device allowed the transmission coefficients to pass through while blocking the reflection coefficients. The results also helped confirm the reciprocality of the prototype.

Although my measured results are relatively similar to those of the simulated results, there is still room for improvement. If I were to revisit this project, I would focus more on the accuracy of parameters and better soldering connections. My initial issue with the prototype was the width of the copper tape itself. In the simulations, its width was approximately 2.8mm, as well as in the instructions for the project. However, when measuring before applying it to the copper plate, the width of the copper tape was a little over 3mm. While that doesn't seem like a lot and could be disregarded, I'm sure it was a factor in some slight inaccuracies in my measured plots. Next time, I would cut the width of the copper tape down to 2.8mm, or just use 2.8mm tape if it was available. Also when I applied the strips onto the plate, I could've focused more on applying the strips more accurately, as there is a slight asymmetry between both stubs. Another area for improvement was the soldering. In Figures 9 & 10, the connections between the tape and ports are shown. Figure 11 shows the soldered connections between the copper plate and the prongs of the ports. These connections could've been better as there was a slight gap between the plate and the prongs of the ports. This was likely another one of the reasons why the measured results weren't closer to those of the simulated results.

While I do believe there is room to improve, I also think the final prototype and measured results were a success, in helping me gain a better understanding of how double folded stub bandpass filters function and how I can apply them in scenarios outside the lab.

References

[1] P. Peintaisong, Y. Rojprasitporn, R. Lerdwanittip and A. Namsang, "Dual-band Bandpass Filter with Folded Couple Lines and Pentagon Stubs," 2024 International Technical Conference on Circuits/Systems, Computers, and Communications (ITC-CSCC), Okinawa, Japan, 2024, pp. 1-4, doi: 10.1109/ITC-CSCC62988.2024.10628196 (accessed Dec 11, 2024)

[2] N. Claus, K. Y. Kapusuz, J. Verhaevert, and H. Rogier, “Compact and Hybrid Dual-Band Bandpass Filter Using Folded Multimode Resonators and Second-Mode Suppression,” MDPI, https://www.mdpi.com/2079-9292/13/10/1921 (accessed Dec. 13, 2024).