Electrical Engineering Department
California Polytechnic State University

Wireless Communications Laboratory
Experiment 7 Report

Lowpass Filter Design and Measurements

Delivered: March 8th 2018

Joe Eckstein
Max Walker

Professor Dean Arakaki

Introduction:

This lab aims design and characterize a 1GHz stepped-impedance low-pass filter using Keysight Technologies' ADS (Advanced Design System) software. In addition, the final filter design will be fabricated on a CNC mill and tested on a network analyzer.

Equipment:

- Anritsu MS4622B Vector Network Analyzer (VNA) (10MHz - 3GHz)
- 2x 2ft semi-rigid Male SubMiniature A (SMA) to Male SMA Cable
- VNA Calibration Kit
- Keysight Advanced Design Suite 2017 (ADS)

Procedure:

1. Design a stepped-impedance low pass filter on ADS with the following specifications:
    a. Cutoff frequency: 1.0GHz
    b. Attenuation: 23.0dB minimum at 1.2GHz
    c. Filter type: Chebyshev
    d. Passband Insertion Loss: 0.5dB maximum
    e. Group delay variation: 5ns maximum across passband
    f. Filter board (PCB): 2" x 4" FR-4 substrate: $\varepsilon_r = 4.4$
    g. Tracewidth limits: 50 mils min and 1600 mils max
2. Submit .gbr files of the final layout along with images of the schematic, frequency response, and board layout with dimensional indicators for fabrication.
3. Solder SMA edge connectors onto the completed PCB.
4. Calibrate the vector network analyzer for 2-port measurements.
5. Record all low pass filter S-parameters and group delay using the network analyzer from 0.1GHz to 2.0GHz capturing data with the hard copy options procedure below.
6. Compare the ADS simulation results to test measurements. Discuss both discrepancies and similarities between the two results.
7. Compare measurements to the operating specifications above.
8. Calculate the board's actual dielectric constant.

<u>VNA Hard Copy Options - Anritsu MS4622B Vector Network Analyzer:</u>

1. Open CaptureVNA on the bench computer.
2. Verify the GPIB address on the computer matches the VNA.
    a. Software, VNA Display Capture 2.45: Interface / GPIB: Address
    b. VNA: Utility / Remote Interface / GPIB Setup: IEEE 488.6: 6
3. Image Capture: Setup / select Bitmap / click on Capture
4. Data Capture: Setup / select Tabular Data / click on Capture
5. To save either data type select File / Save and make sure to manually add the necessary file extension to the filename.

Graphs and Tables:

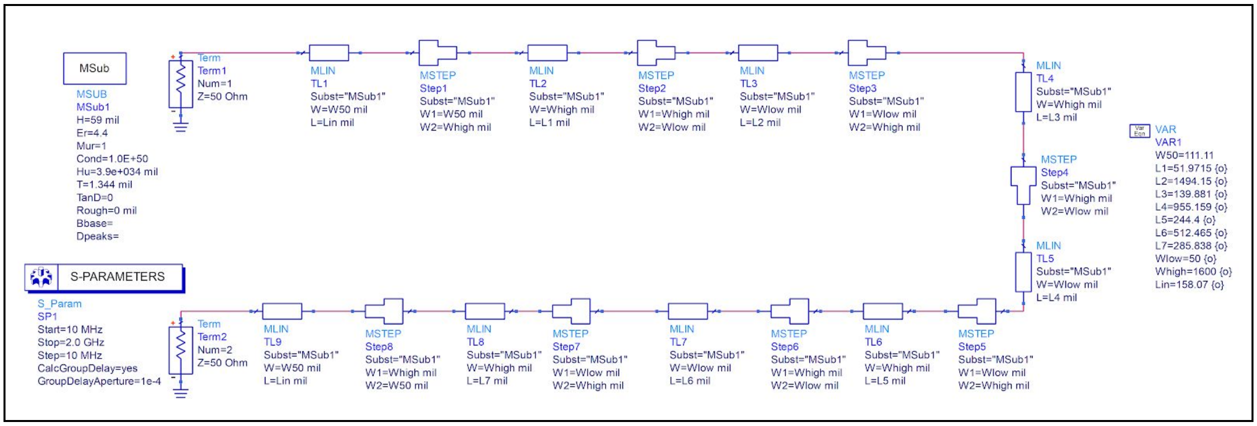

Figure 1: Untested 1GHz LPF Schematic

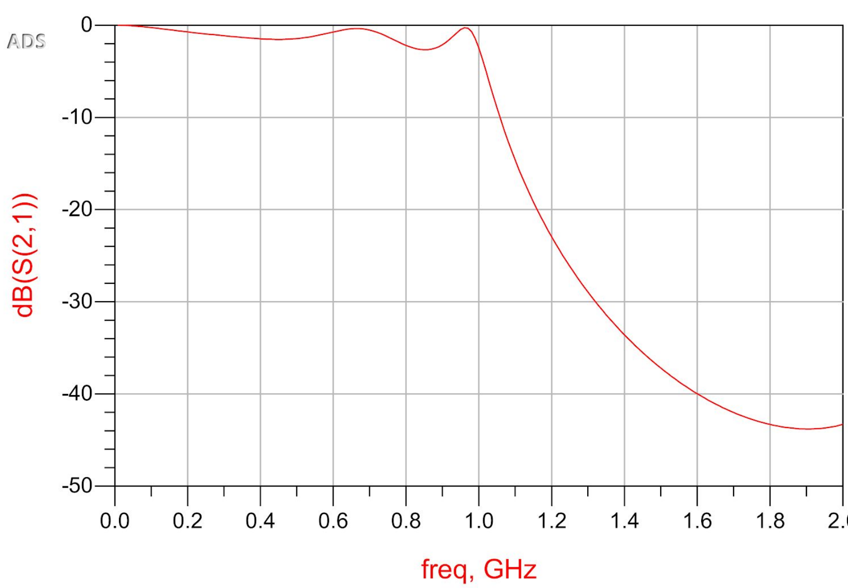

Figure 2: Untested 1GHz LPF Simulated S_{21}

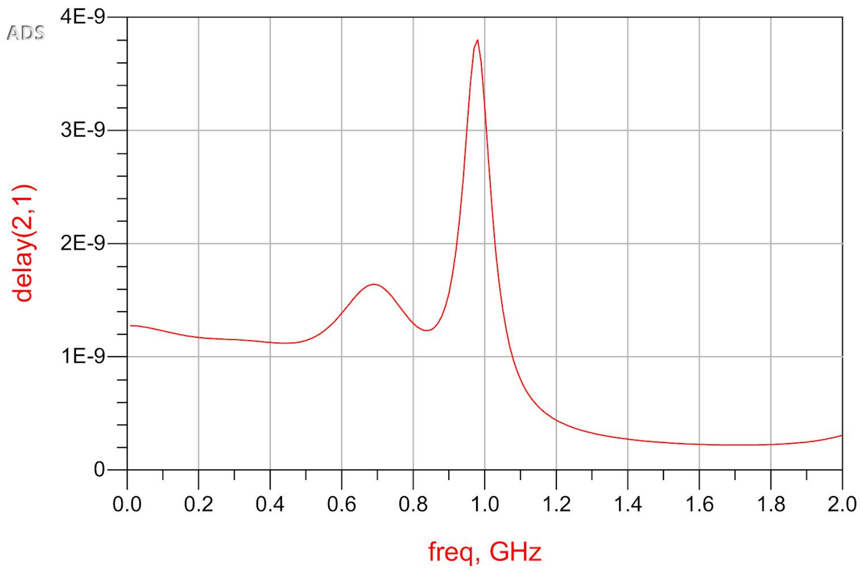

Figure 3: Untested 1GHz LPF Simulated Group Delay

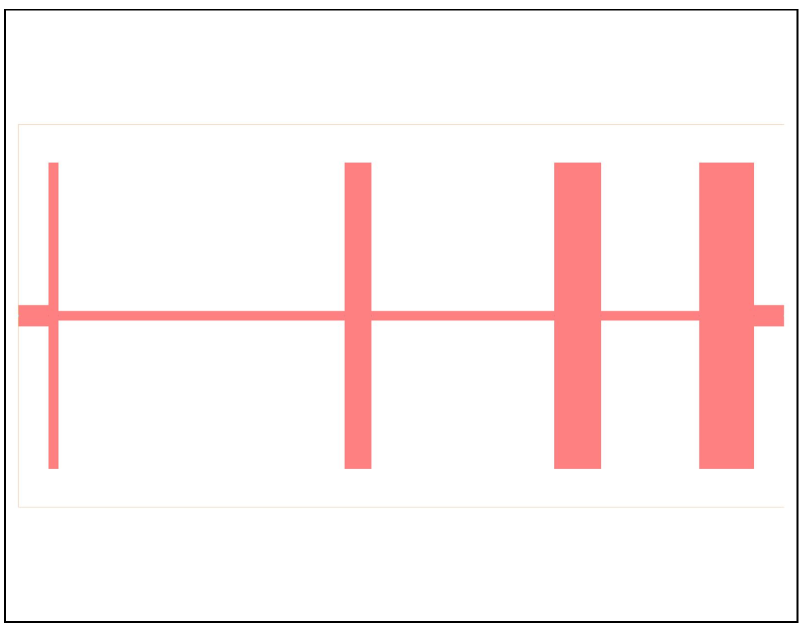

Figure 4: Untested 1GHz LPF Design

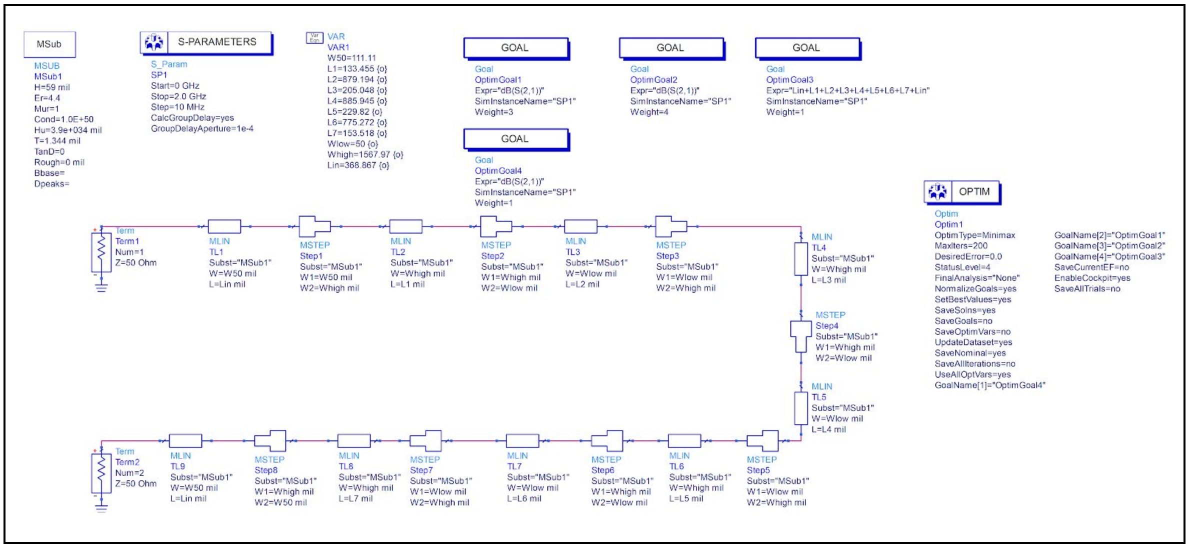

Figure 5: Manufactured 1GHz LPF Schematic

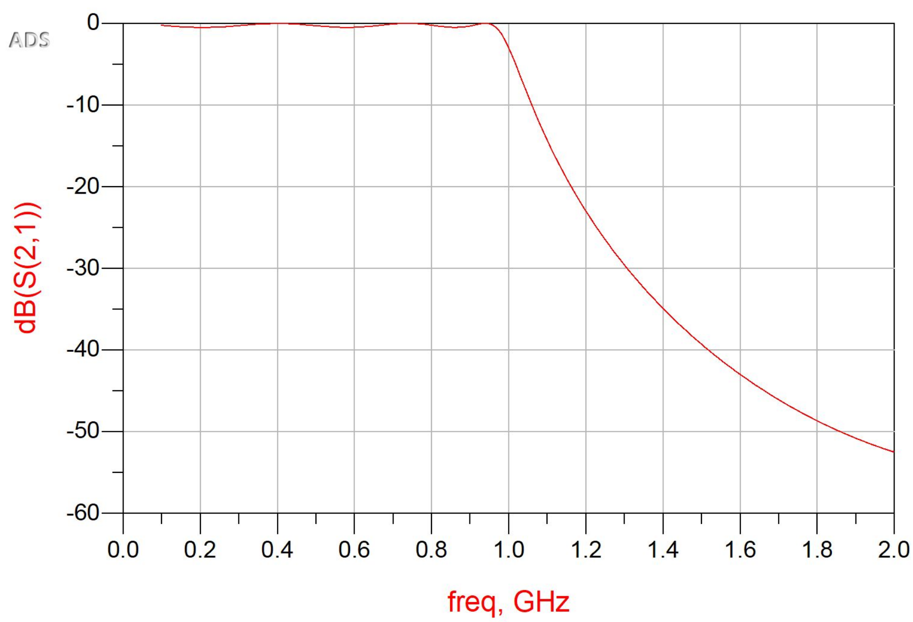

Figure 6: Manufactured 1GHz LPF Simulated S_{21}

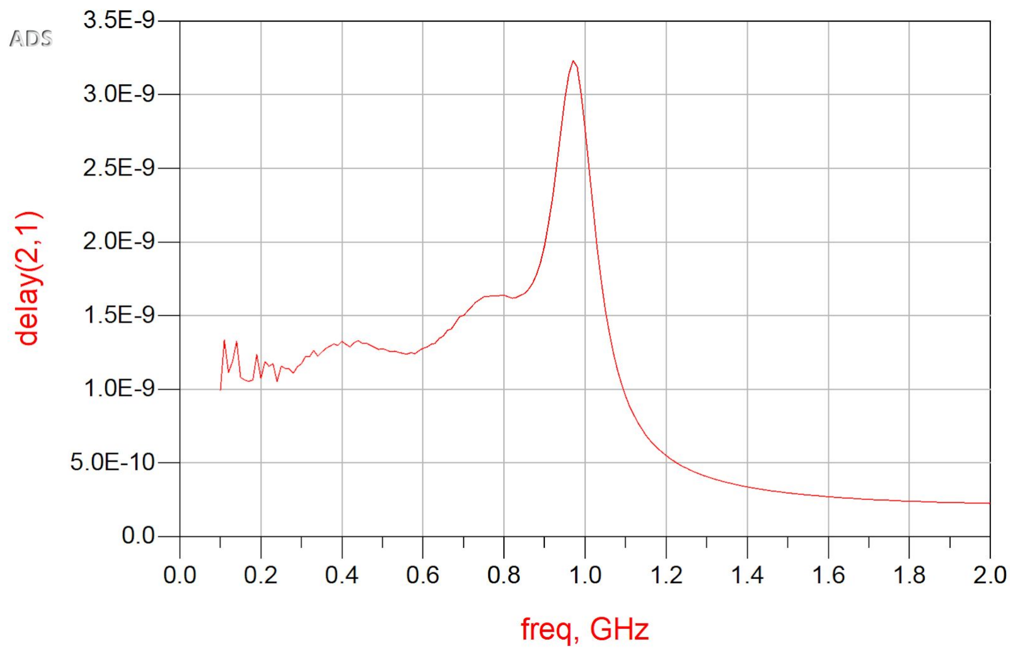

Figure 7: Manufactured 1GHz LPF Simulated Group Delay

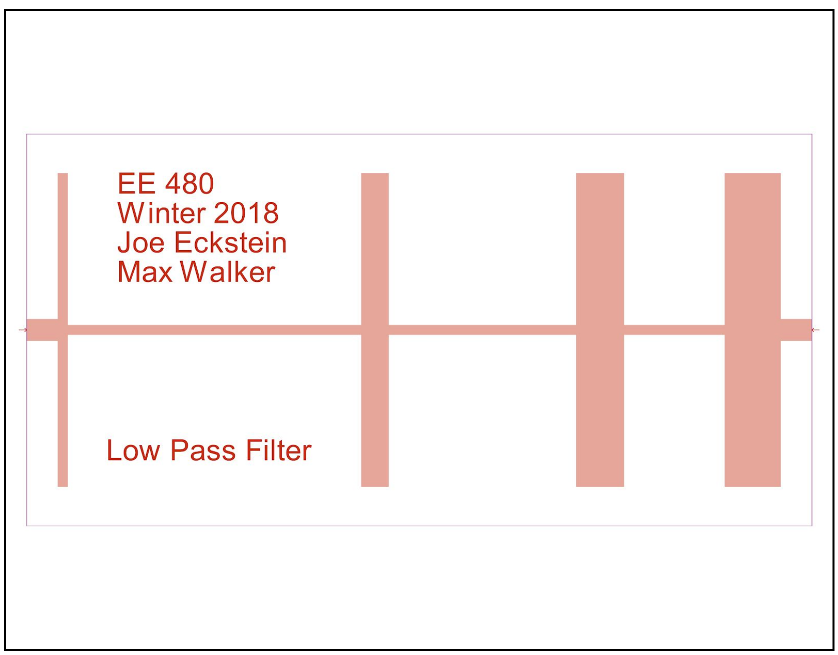

Figure 8: Manufactured 1GHz LPF Design

Figure 9: Measured 1GHz LPF S_{21}

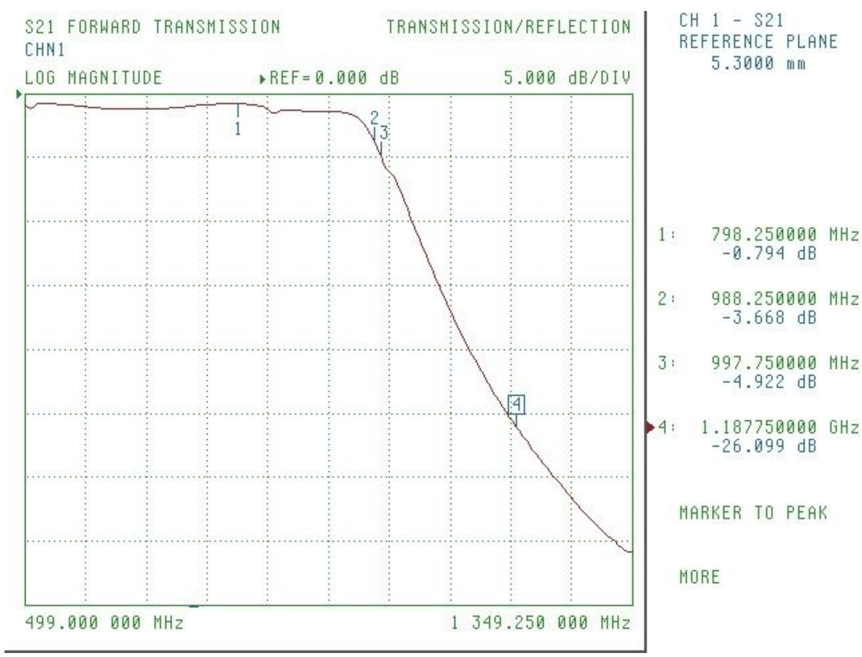

Figure 10: Measured 1GHz LPF S_{21} Cutoff

Figure 11: Measured 1GHz LPF Group Delay

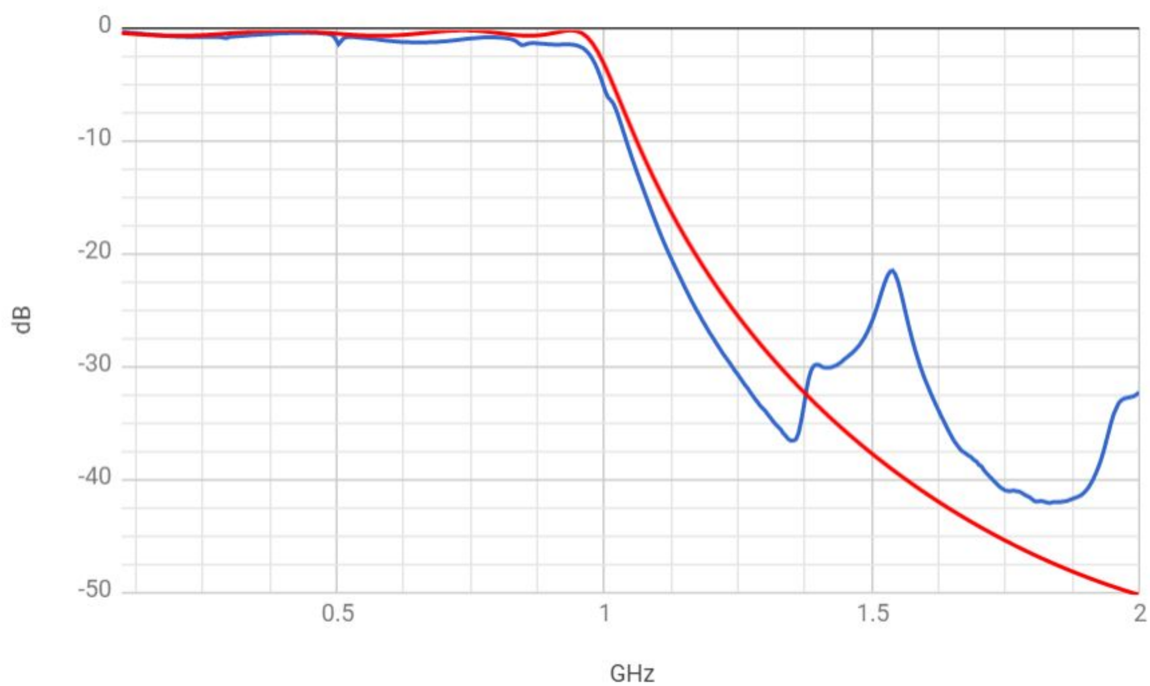

Figure 12: Manufactured 1GHz LPF Simulated (Red) and Measured (Blue) S_{21}

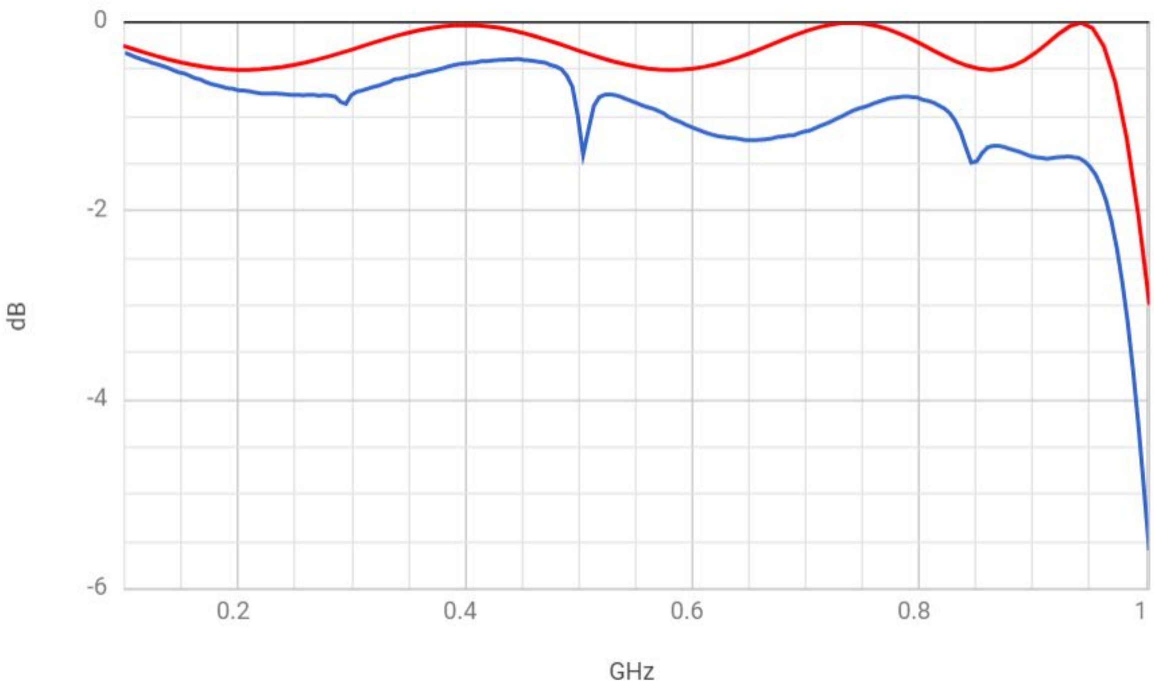

Figure 13: Passband of Manufactured 1GHz LPF Simulated (Red) and Measured (Blue) S_{21}

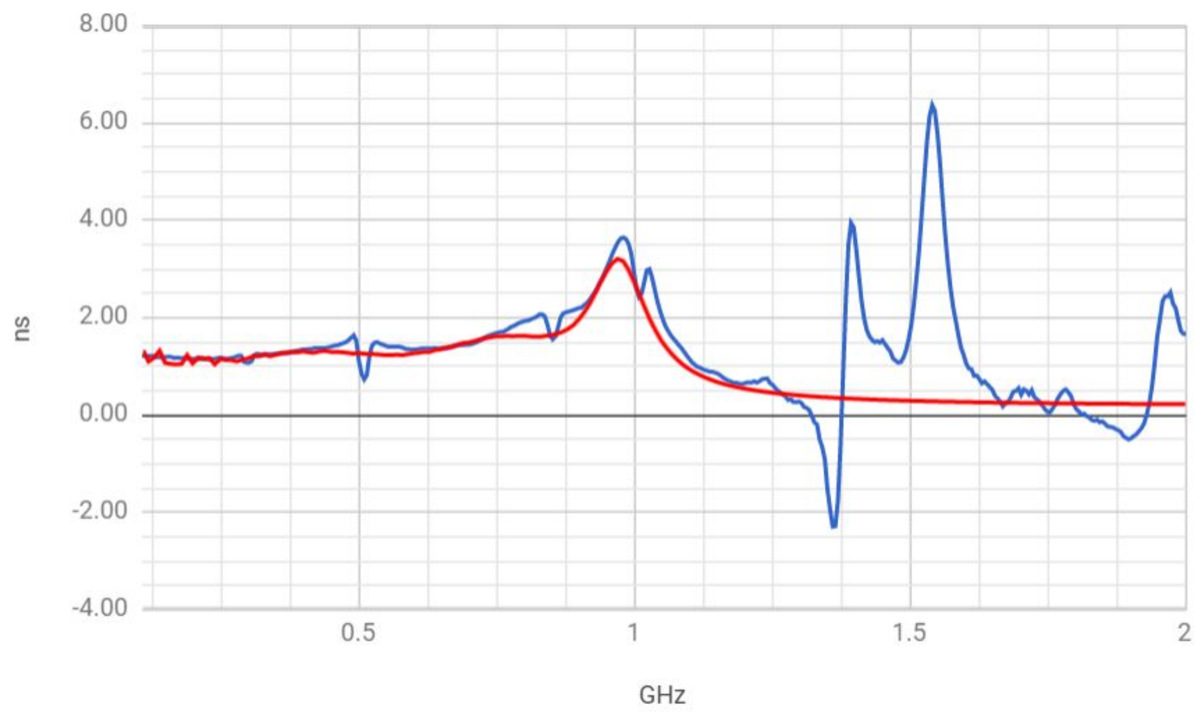

Figure 14: Manufactured 1GHz LPF Simulated (Red) and Measured (Blue) Group Delay

Discussion:

As seen in Figure 12 and 13, both the simulated and measured gain were very similar in the passband as expected. The measured gain had a greater passband insertion loss of about 0.7dB. This was probably due to the difficulty of securing the SMA connector to the filter. Some FR4 had to be removed before the SMA connector could fit on the board, making the dielectric around the connector non-uniform, changing the impedance of the grounds of the connector. The passband ripple was also greater than 0.5dB. As seen in Figure 13, the measured gain had the same general form as the simulated results, however is became more attenuated as the frequency increased. This is because attenuation increases with frequency. Both the simulated and measured cutoff frequencies were within 12MHz of eachother.

The rolloff for both the simulated and measured gain were similar up to 1.4GHz. The cause of this spike is unknown. However, the increase in the measured gain shown in Figure 12 did not provide a gain of over -23dB, maintaining a minimum 23dB loss after 1.2GHz. The rolloff of the measured gain was also greater than the simulated gain. This is also probably due to the increasing attenuation seen in the passband.

The group delay was within 5ns across the passband of both the measured and simulated filters as shown in Figure 14. Again, at 1.4GHz the group delay between the measured and simulated filters change dramatically due to some unknown cause.

The actual dielectric constant for the board was calculated to be $3.99 \times 10^{-11} F m^{-1}$. The dielectric constant used in the ADS simulation was $3.90 \times 10^{-11} F m^{-1}$. This difference could account for the 12MHz difference in the cutoff frequency.

Conclusion:

A 1GHz LPF was developed in ADS and successfully simulated a passband ripple of less than 0.5dB, and achieved a 23dB loss at 1.2GHz. The measured results did not have a passband ripple of less than 0.5dB, however the minimum 23dB loss at 1.2GHz was satisfied. There was one anomaly in the measured data starting at 1.4GHz, however the passband through 1.4GHz acted as expected.

References:

1. Pozar, David, M. *Microwave and RF Wireless Systems.* John Wiley & Sons, 2001. Print.
2. California Polytechnic San Luis Obispo Electrical Engineering Department. “Wireless Communications Laboratory.” California Polytechnic State University, 2018. Print.
3. Anritsu, *MS4622B Network Analyzer Operating Manual,* 2007.