Goals

The goal of this project was to utilize HFSS to design a one port C-Band Microstrip Patch Antenna. The antenna will have a linear polarization with a substrate material being Rogers 5350B and have a height of 1.524mm. The antenna's input impedance will be 50Ω and will be tested with the use of an anechoic chamber using a reference Vivaldi antenna to measure the realized gain of the patch.

Accomplishments

Following the completion of this lab, we were able to successfully design and validated a microstrip patch antenna for a communication system operating at 3 GHz using Rogers 4350B substrate. The project involved creating the radiating element, simulating its performance with HFSS, and ensuring compatibility with 50-ohm test ports for accurate measurement. The design was fabricated and tested using an anechoic chamber setup utilizing a known reference Vivaldi antenna, with radiation patterns measured on both E-plane and H-plane. The results were compared against simulations, demonstrating strong alignment, and confirming the antenna’s performance objectives.

Discussion

In order to design our patch antenna in HFSS, we broke the design down into two parts. The first part we broke the design into was simply calculating the length and width of the antenna. To do this, we first used the formulas in the uploaded PowerPoint slides to determine the desired length and width for the antenna to operate at 3 GHz. We used the equations $W = \frac{c}{2f_o\sqrt{\frac{\varepsilon_r+1}{2}}}$ to calculate the width. In order to calculate the length, we need an additional three equations ε_{eff}, L_{eff} and ΔL these equations are then used to find L. In order to do this, we must calculate $\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}}$ where *W* is the calculated width and *h* is the given height of the substrate. Next, $L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}}$ and $\Delta L = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$, this gives us the necessary information to compute the length of the patch antenna $L = L_{eff} - 2\Delta L$. Using these equations, a MATLAB script was written to determine both the length and width. These were calculated to be 25.85 mm in length and 32.8 mm in width. The next part of the patch that we needed to design was the feed line and the inset notch. In order to calculate the feed line, we knew that the line needed to have an input impedance of 50 ohms so it could connect to the VNA. Knowing this, we were able to utilize the LineCalc software to get a width of 3.6 mm. To determine the inset of the feed, we used a study on patch antenna theory [1] and set the width to that of the feedline, so we made the inset width 3.6 mm and then we simulated it. Upon looking at the results of that simulation, we noticed that the device could be optimized to maximize gain and the return loss at 3 GHz. After multiple simulations, the optimized width we determined for the inset feed was 3.7 mm on each side of the feed line. After designing and fabricating the antenna, we then had to measure it on the VNA and test it in the anechoic chamber to find the operating frequency and the radiation pattern. Testing the patch antenna on the VNA shown in figure 1 shows that the antenna operates at about 3 GHz, matching the project description. The band of operation is also very narrow, which is expected.

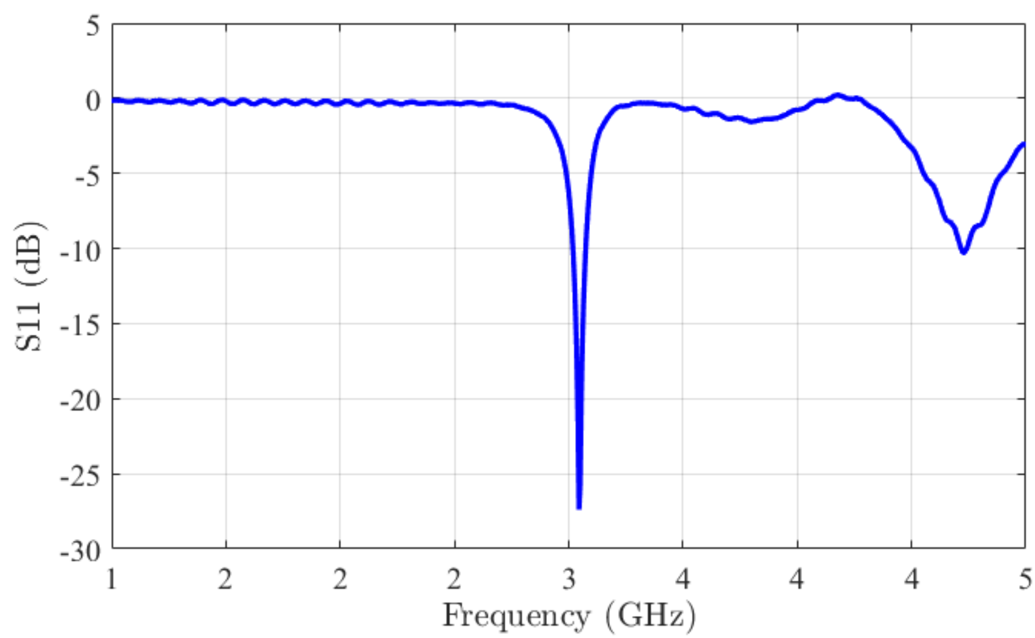

Figure 1: S11 plot of patch antenna.

Patch antenna

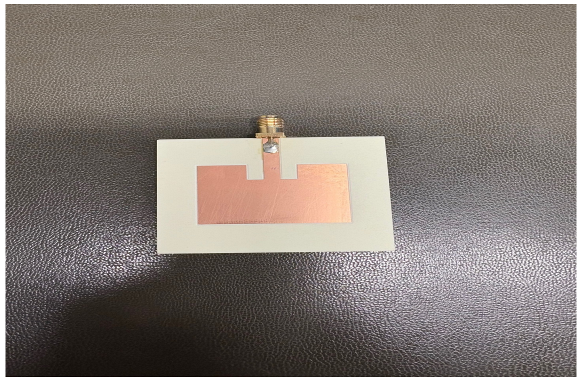

Figure 2: Fabricated patch antenna

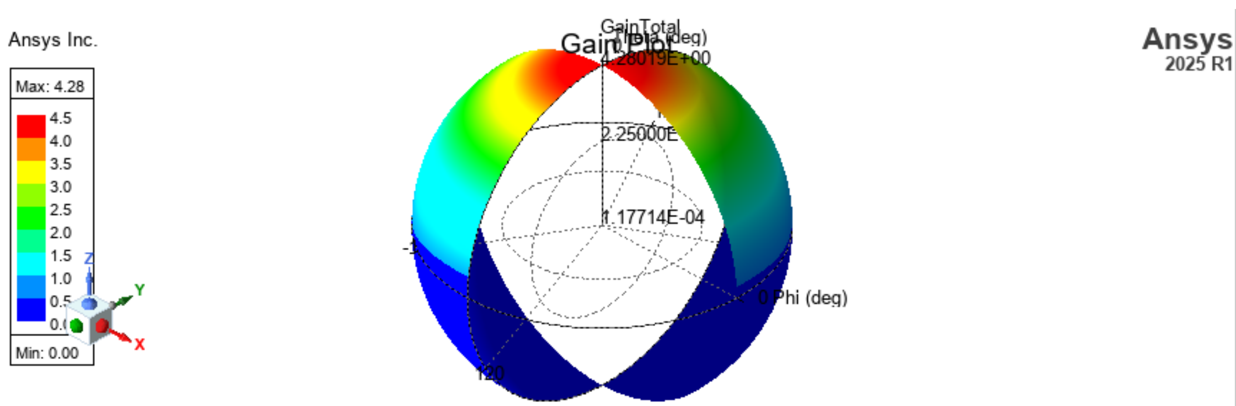

Figure 3: Radiation pattern of simulated Patch antenna

Figure 2 above shows the fabricated patch antenna, and figure 3 shows the simulated radiation pattern. From the figure above, we see a very large lobe above the antenna with a very symmetrical spherical shape. This matches our theoretical understanding of how patch antennas are meant to work. We also see the simulated gain value to be 4.28 dB. Since the measured patch gain is –37.9 dB and the reference Vivaldi gain is –33dB, the difference added to the Vivaldi gain of 9.16 provided a power gain of 4.26 dB, which is extremely similar to the simulated design. This result was unexpected; however, it could be attributed to the fabrication of the device being extremely accurate, in addition to the measurement conditions also being very ideal.

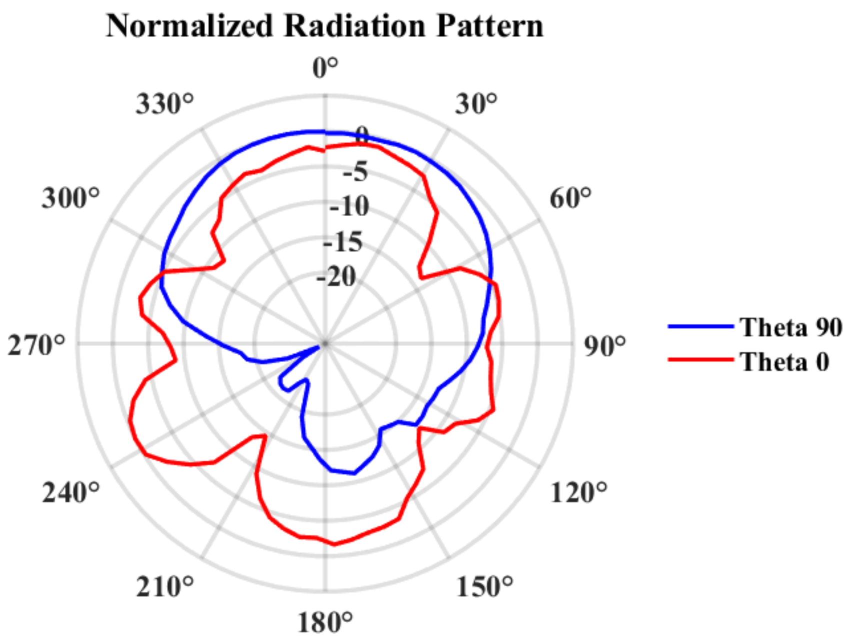

Figure 4: E-plane and H-plane of patch antenna (along theta)

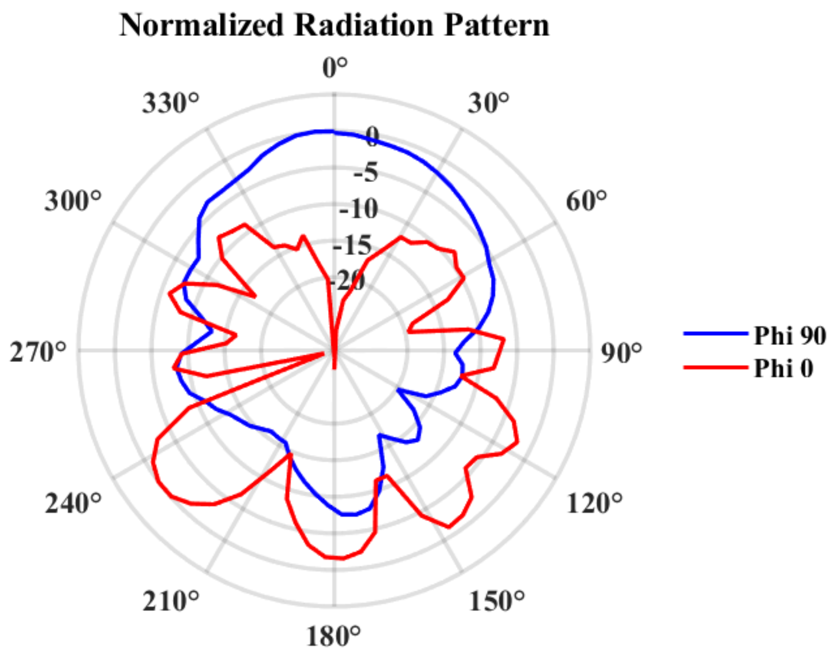

Figure 5: E-plane and H-plane of patch antenna (along phi).

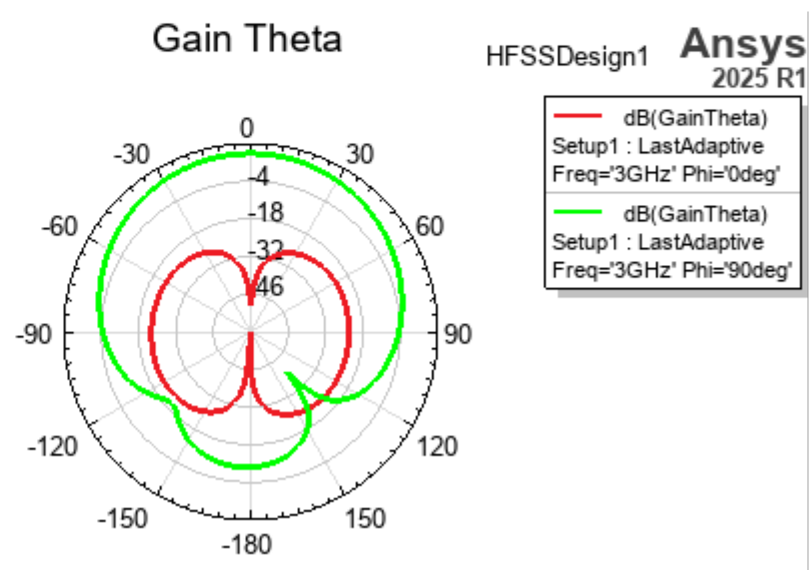

Figure 6: Simulated radiation pattern for patch antenna (along theta).

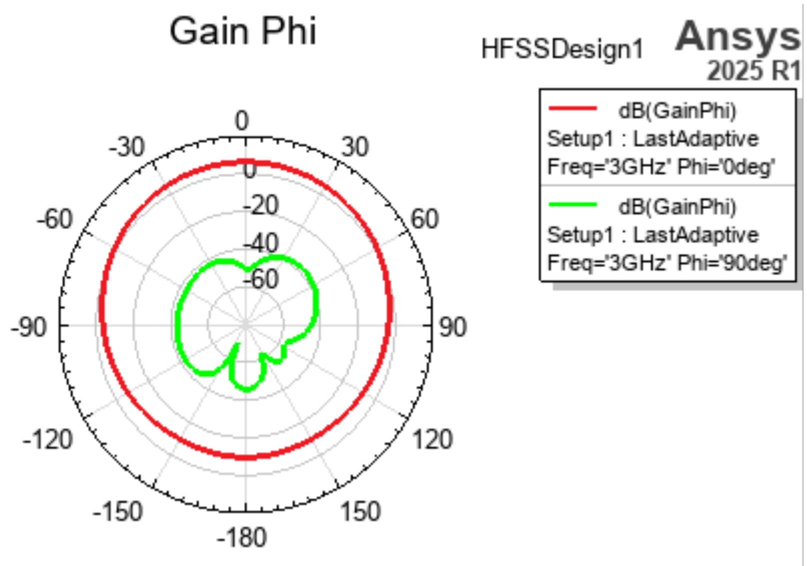

Figure 7: Simulated radiation pattern for patch antenna (along theta).

Figures 4 and 5 above show the measured radiation pattern. Figure 5 shows the pattern perpendicular to the patch, and figure 4 shows the pattern parallel to the patch. Figure 5 also appears as less directional and shows more significant side lobes (around 30°, 330°, 230°, 150°, 180˚, etc.), with some reaching up to about -10 dB below the main beam. When observing figure 4 we see that the pattern is highly directional with a relatively clean main beam around 20˚. The determined HPBW is approximately 100˚ from 310˚ to 50˚ (figure 4). When comparing the simulated plots from figures 6 to 7 to the ones measured in figures 4 and figure 5, the simulated plots show lobes that are more uniform and symmetrical. The lobes observed in figures 4 and 5 can be attributed to the feedline which also affects the fields, or the ground plane not being large enough and also the fact that the simulations were run in an ultra-ideal environment, which is not possible to recreate in real life.

In conclusion, the designed antenna met the criteria and provided gain values very similar to the simulations and performed better than initial expectations as we anticipated a larger deviation from our HFSS simulation.

Citations

[1] Mbinack, C., Tonye, E., & Bajon, D. (2014). Microstrip-line theory and experimental study for the characterization of the inset-fed rectangular microstrip-patch antenna impedance. *Microwave and Optical Technology Letters*, *57*(2), 514–518. https://doi.org/10.1002/mop.28877