Design of a Microwave Probe Fed Rectangular Micro-strip Patch Antenna

Design Theory

The initial design was done by hand to create a rough model in which to begin simulations. The equations are as listed below and sourced by [1].

$$Width = 1 / (2 \; f_r \; \sqrt{2/(\varepsilon_r + 1)})$$

$$\varepsilon_{eff} = (\varepsilon_r+1)/2 + (\varepsilon_r-1)/2[1+12(h/W)]^{-1/2}$$

$$Length = 0.814 \; h \; (\varepsilon_{eff} + 0.3)(W/h + 0.264) / ((\varepsilon_{eff} - 0.258)(W/h + 0.8))$$

Figure 1 Calculating the dimensions of the patch

The substrate used was foam with an approximate dielectric constant of 1 and the conductor was assumed to be ideal. The center frequency desired was initially 1.76 GHz, which was on the lower capabilities allowed by the Carnegie Mellon Range and 40 MHz above the closest radio astronomy band at 1.72 GHz. Following this, a probe insertion point needed to be calculated for this resonant frequency. Figure 2 shows the equation used to estimate the position acquired from [2].

$$R(x) = R0 \cos^2\left(\frac{\pi x}{L}\right)$$

Figure 2 Calculating the Probe Insertion Point

R(x) is desired to be 50 Ω to match to a coaxial feed. R0 is the edge impedance of the patch antenna. Using Advanced Design Studio (ADS), this was estimated to be 187 Ω. These initial calculations were then used to build a template in ADS and then run through Momentum, a full wave simulator, using a copper conductor with a thickness of 0.5 mm, air as a substrate and an infinite ground plane behind the substrate. Several adjustments were made manually at this point to optimize the dimensions and the final position of the probe was found using a built in optimizer in Momentum.

Simulation Results

The final simulation results are show in Figure 3. The center frequency is 1.75 GHz with a -10 dB bandwidth of 24 MHz. Impedance at the center frequency is 48.35 – 1.5 j Ω, which is acceptably close to 50 Ω.

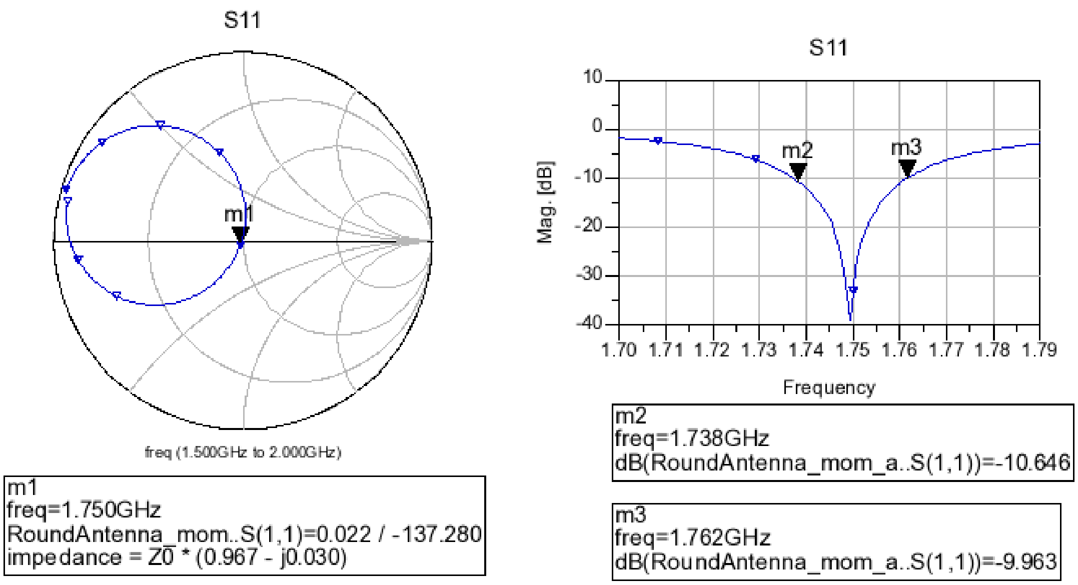

Figure 3 Simulation plots of S11

Figure 4 below shows the layout and dimensions of the patch antenna. The size is 1.04 x 1.605 in^2. However, the ground plane would need to be at least twice the size of the patch to achieve an acceptable gain pattern.

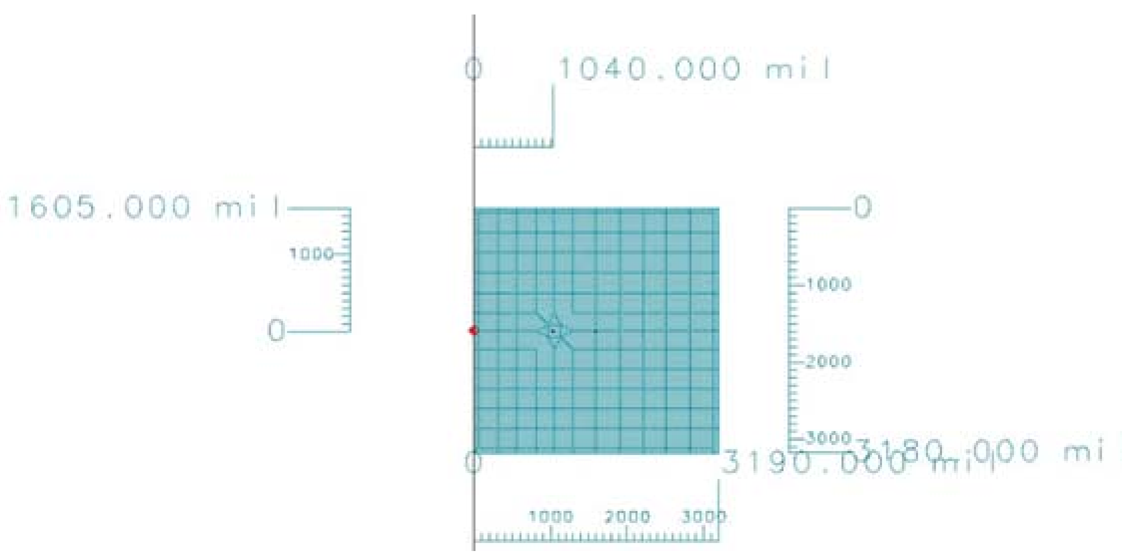

Figure 4 Layout and Dimensions of the Antenna

Measurements and Analysis

The antenna was constructed using copper tape as a conductor, foam as a substrate and an aluminum sheet as the ground plane. Figure 5 shows the constructed antenna.

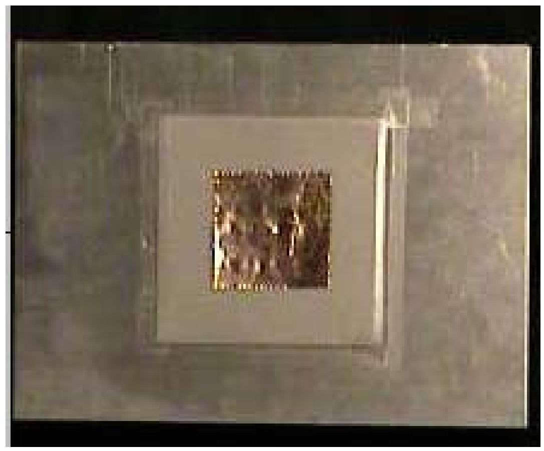

Figure 5 Patch Antenna

A simple measurement using a network analyzer showed the center frequency at 1.775 GHz with a -20 dB bandwidth of 58 MHz. With these positive results, the antenna was sent to the Carnegie Mellon range for gain pattern measurements. A frequency sweep at the range showed a center frequency of 1.85 GHz, a full 100 MHz higher than simulation results. The -10dB bandwidth was measured at 24 MHz.

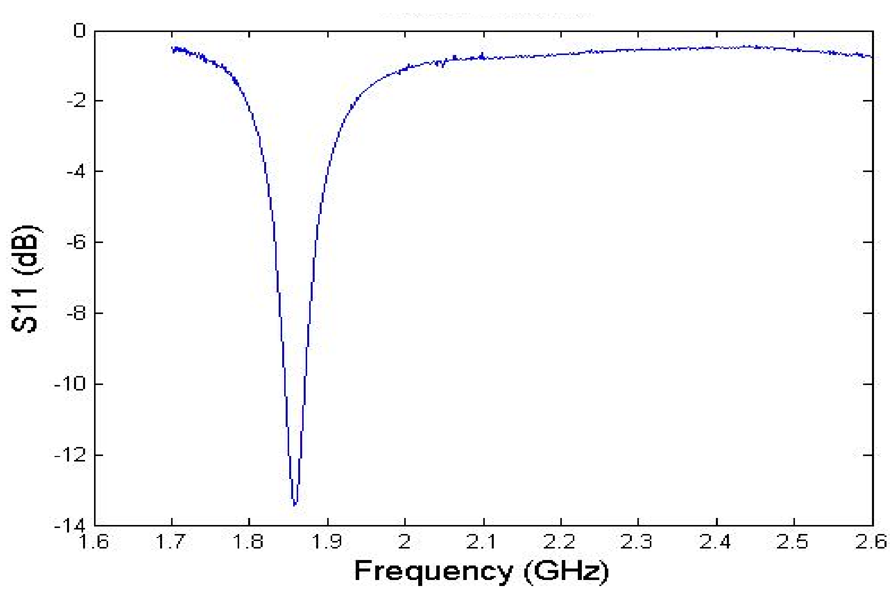

Figure 6 Range S11 Measurements

Figure 7 shows the gain pattern of the antenna with a peak gain of 9.5 dB at 0 degrees and 0 dB at 60 degrees. This pattern is heavily dependent on the ground plane being relatively large to the antenna. Having a 125 degree input range with this patch antenna would suffice for a GPS system since satellites near the horizon would not provide accurate data. It is more prevalent to achieve a clear link with the satellites directly overhead.

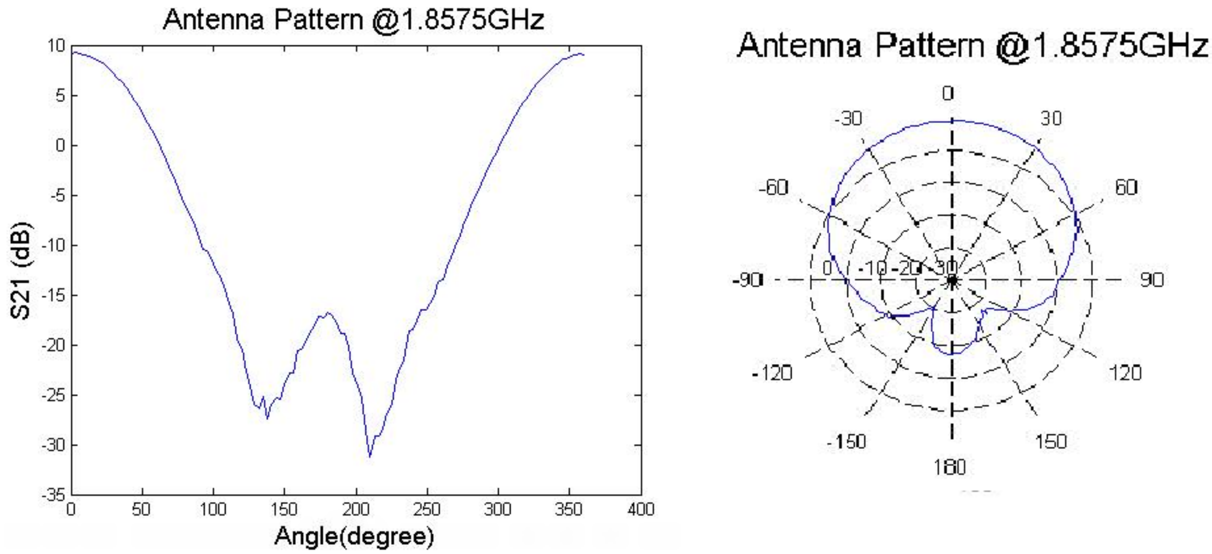

Figure 7 Antenna Pattern at 1.8575 GHz.

Conclusions

The final measurements of the patch antenna had a center frequency of 100 MHz higher than the simulation. This was unexpected as initial bench tests with a network analyzer showed only a 25 MHz shift. This could have been caused by inconsistent calibration of equipment or the way the antenna was mounted for the measurements. Of particular concern was the way the antenna mounted at the CMU range. However, the end result was not catastrophic, the new operating frequency does not violate any radio astronomy band, nor did it affect the link budget equations by much. The extra propagation loss was compensated by the built in margin in the receiver noise figure estimations.

References

[1] "Rectangular Microstrip Patch using Coaxial Probe Feed" Prof. Dan Stancil, http://www.propagation.gatech.edu/ECE6390/protected/RectPatch_Line_RevJune27_08_Exp2.pdf

[2] "Design of Rectangular Microstrip Patch Antennas for the 2.4 GHz Band" Dr. Max Ammnan

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