Design, Construction and Testing of Two Omnidirectional Patch Antennas for 2.422 GHz and 1.5754 GHz

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ECE532

Graduate Research Paper

Introduction

The Portland State Aerospace Society is a PSU sponsored club which builds and launches intelligent rockets. Recent versions of the rocket (LV1 and LV2) have complex position sensing systems that communicate to the ground station through IEEE 802.11 wireless communications protocols (WIFI). Another part of the rocket's sensor package is a precision Global Positioning System (GPS). One of the most critical components in both the communications and GPS systems is the antenna. The ideal antenna for a rocket would radiate equally in all directions (including directly along the axis of the rocket), be unaffected by vibration or temperature change, and be easily mounted on the rocket. The continuous-radiator microstrip patch antenna meets nearly all of these requirements.

Design Requirements

The continuous-radiator antenna is essentially a patch antenna which wraps entirely around the rocket. It is fed by several microstrips in a corporate feed network. See Figure 1 for an example of a patch with a corporate feed network. The 802.11 antenna needs to operate at 2.422 GHz with a bandwidth of at least 20 MHz and have an input impedance of 50Ω. The GPS antenna needs to have a center frequency of 1.5754 GHz with a bandwidth of at least 10 MHz. The antennas will be etched onto a sheet of Rogers Corporation RT Duroid 6002 (generously donated by PSU and Rogers Corp.) which has ε_r = 2.94, and thickness h = 1.524 mm. The patch itself will be in the shape of a cylinder with a 5.25-inch diameter (D=133.35 mm). When factoring in the thickness of the Duroid, the diameter is 136.398 mm.

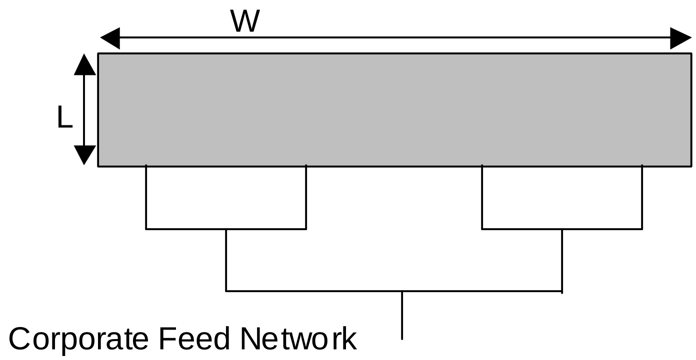

Figure 1: Dimensions for Unrolled Cylindrical Patch Antenna

Antenna Design

At 2.422 GHz, λ_0=123.86mm and λ==$\lambda_0/\sqrt{\varepsilon_r}$=72.24 mm. At 1.5754 GHz, λ_0=190.43mm and λ==$\lambda_0/\sqrt{\varepsilon_r}$= 111.06 mm The width W of the patch will be W=πD = 428.51mm.

According to the *Antenna Engineering Handbook* (third edition by Richard C. Johnson), if we unroll the patch, we will have a rectangle with width W=πD where D is the diameter of the rocket. The length of the patch should be $L=\lambda_0/(2\sqrt{\varepsilon_r})$ or $L=\lambda/2$ = 41.75mm. We need to have more feed lines than wavelengths in W and W/λ=5.93 for 2.244 GHz and W/λ=3.85 for 1.5754 GHz. This means that we need 8 feed lines (N_f) for the WIFI antenna and 4 feed lines for the GPS antenna since we need a power of 2 feed lines for both corporate feed networks. The input impedance at the edge of the patch with no feed line inset for each feed line will be $R_{in} = N_f*60*\lambda_0/W$ = 141.96 Ω for the WIFI and 109.11 Ω for the GPS antenna.

For this antenna, we will be rolling the Duroid into a cylinder so the width of the microstrip traces must be wide enough that they do not break when we roll the substrate. I consulted with Andrew Greenberg of the Portland State Aerospace Society and he advised me that no trace should be less than 0.1 mm. At the thickness and ε_r of Rogers 6002, a trace with 141Ω characteristic impedance would need a trace width of .3183 mm, so we believed that we would have no problem with lines breaking when rolling the antenna.

The corporate feed network operates on the principle that combining two identical feed lines produces a single feed line with half the impedance. Since I will be starting each feed line at the patch at the impedance of the patch edge, I will need to transform that impedance to 100 Ω with a ¼ wave transformer before entering the corporate feed structure. Once at 100 Ω, the top layer of the corporate feed network combines to 50Ω. This 50Ω needs to be converted to 100Ω for the next layer and this can be easily done with another ¼ wave transformer with $Z_0=\sqrt{(R1*R2)}$ where R1 is the input impedance and R2 is the output impedance. In our case, $Z_0=\sqrt{(100*50)} = 70.7\Omega$. To reduce the height of the corporate feed network and to reduce any losses from the feed point to the antenna, I used 50Ω transmission lines as shown in Figure 3. This corresponds to a microstrip trace width of 1.39mm. Figure 2 shows what the overall corporate feed network will look like for the WIFI antenna and the impedances at each of the trace sections.

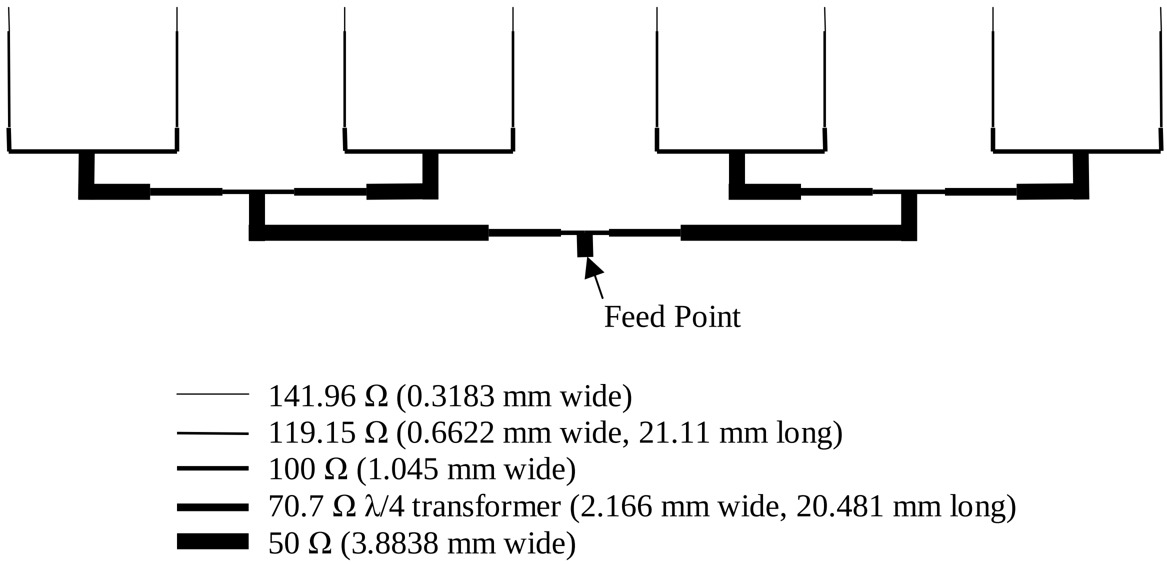

Figure 2: Corporate Feed Network Impedance Diagram

The design of the GPS feed structure is very similar but with a patch edge impedance of 109.11Ω (0.8404 mm wide) and therefore the first ¼ wave transformer needs to be 104.5Ω (0.9394 mm wide and 32.1783 mm long). The 70 Ω transformer length also increases (since the GPS antenna operates at a lower frequency) to 31.458 mm.

I used a program called wrappat from *CAD of Microstrip Antennas for Wireless Applications* by Robert A. Sainati (1996, Artech House Inc.), to calculate the length of the patches. Wrappat uses an iterative process to converge on the correct resonate length for the given frequency and it also gives you the number of feed points and the impedance of each feed point. Wrappat returned a patch length of 53.68 mm for the GPS antenna and a length of 34.24 mm for the WIFI antenna. All calculations of microstrip widths and lengths are given in the attached pages.

Antenna Fabrication

I used Eagle Layout Editor 4.09 to draw both antennas. I laid out the antennas so that we would have the maximum distance between the patches. This meant that the corporate feed structures pointed toward each other on the final design. I left about two centimeters of ground plane overlap for both antennas as well. Andrew Greenberg then used Eagle Layout Editor to generate the appropriate Gerber files to have the etching masks generated for the antennas. Once we had the masks, we took the Duroid and masks to a circuit board manufacturer in the Beaverton area and they etched the board.

As the board was being etched, I was informed that the etching actually removes more metal than the mask covers. This is called over-etching and with the thickness of metal on our piece of Duroid, the process would over-etch by about .001” on each side. Had I known about this, I could have increased the sizes of my traces.

Once the board was etched, we gave the board to Tom, a Xerox employee to roll the board into a cylinder. Next, Andrew and Tim soldered SMA connectors to the inside of the board at the feed point for each antenna.

Antenna Testing

The first test I performed on the antennas was a simple S11 test on a network vector analyzer. Dr. Brano was kind enough to let us use the one in his lab and his grad students gave us a great deal of help.

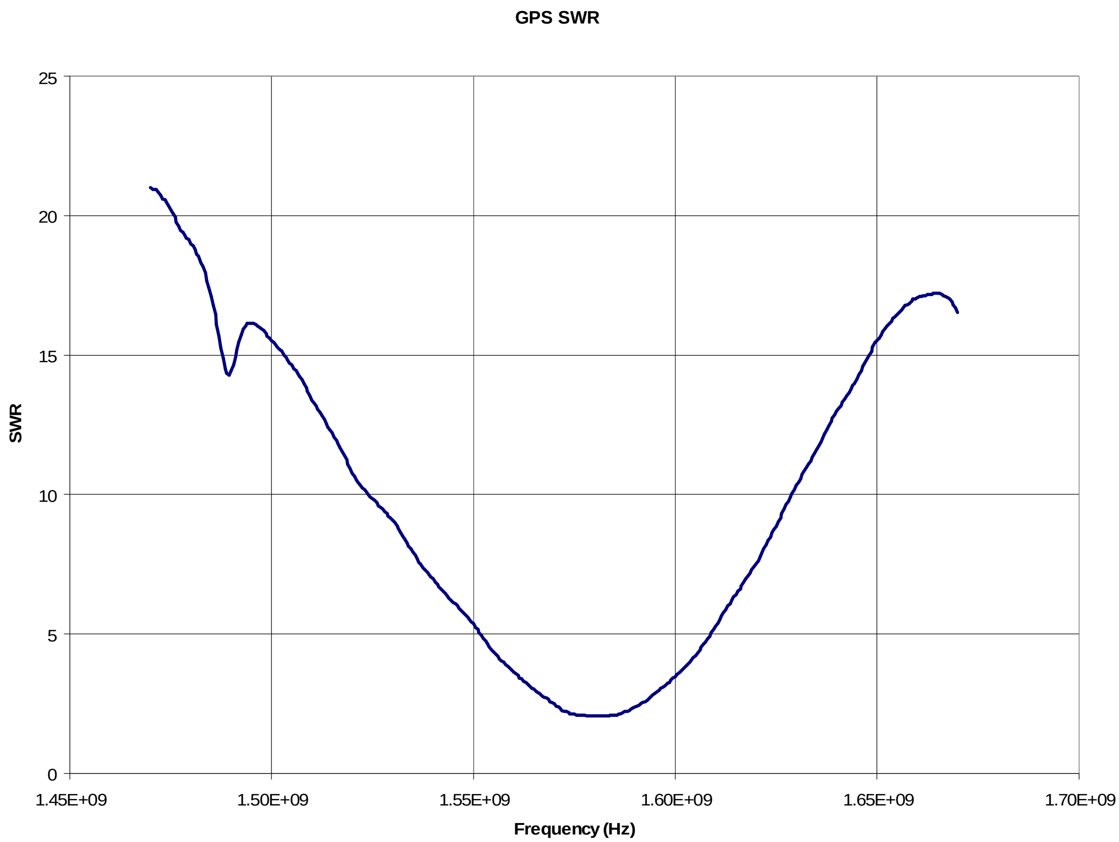

Figure 3: GPS Antenna SWR

We can see in Figure 3 that the SWR for the GPS antenna dips quite nicely to about 3 at around 1.575 GHz. On closer inspection as in Figure 4, we see that the resonate frequency is actually closer to 1.58 GHz.

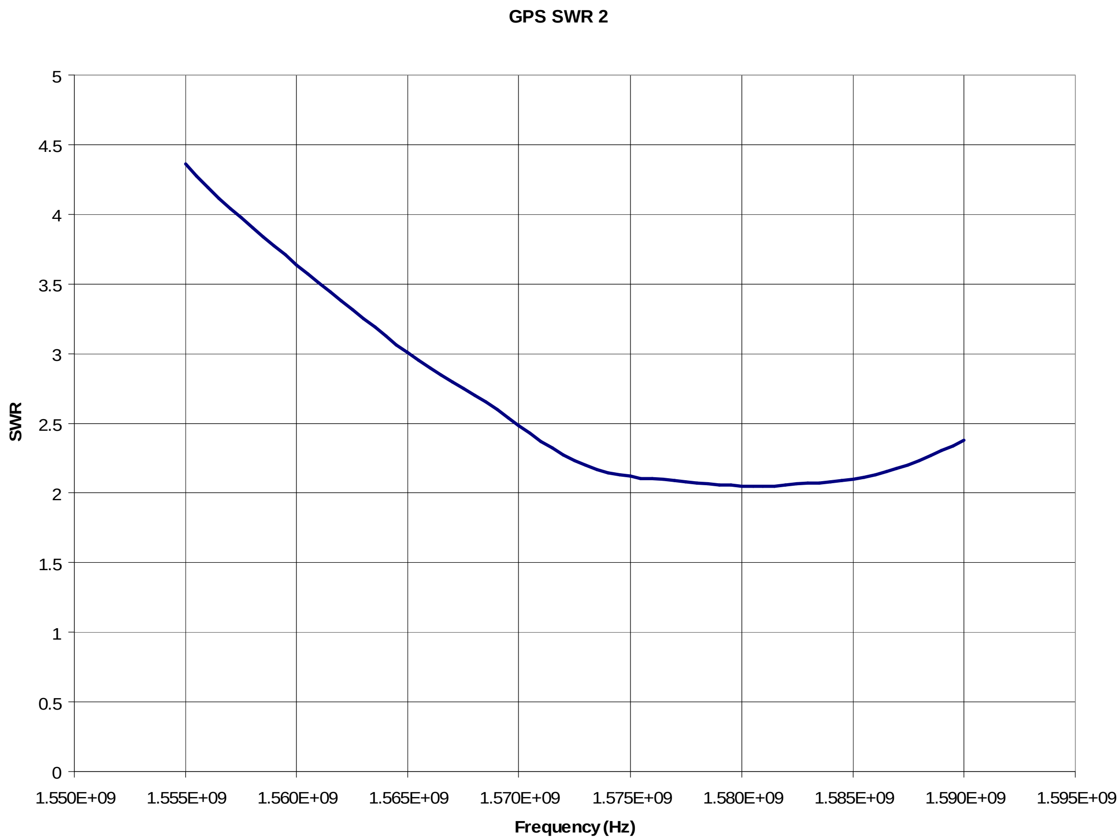

Figure 4: GPS SWR Near Target Frequency

I believe that the antenna is resonating at a higher frequency because the patch was over-etched, making the patch shorter. We believe that the resonant frequency may be reduced by applying a coat of non-conductive paint to the antenna. The minimum SWR is just over 2, indicating that about half of the energy entering the antenna is actually being radiated. Ideally we would want an SWR of 1 but I think that changes in the microstrip widths (and therefore impedances) due to over-etching are causing the elevated SWR.

Next we tested the WIFI antenna and found that the SWR was around 7. Upon close inspection of the corporate feed structure, it was discovered that there were several tears in the copper. All of the tears occurred at changes of microstrip width and all of the tears were parallel to the axis of roll. Out of desperation, we decided to try to solder the tears together, even though doing so would change the conductor thickness, conductor conductivity, and probably conductor width as well. Upon retesting, we found that the WIFI antenna's SWR dipped as low as two very near our desired frequency as in Figures 5 and 6.

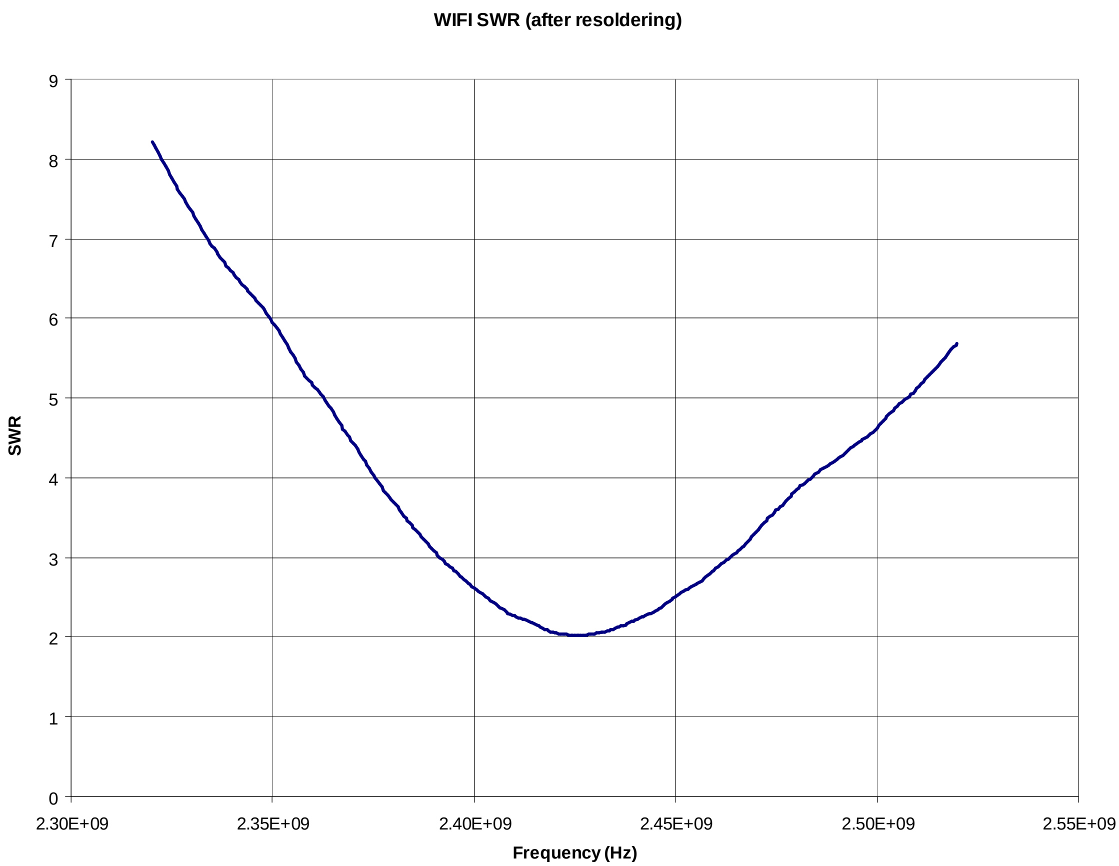

Figure 5: WIFI SWR (Wide View)

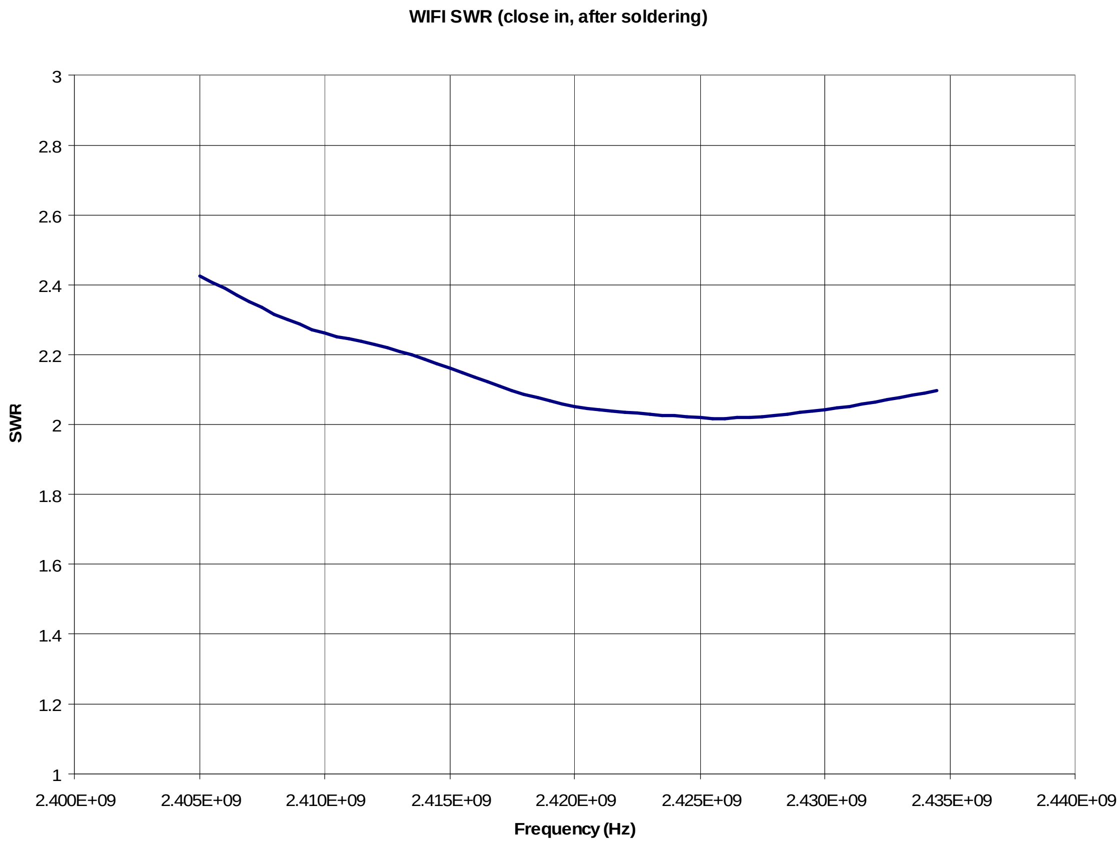

Figure 6: WIFI SWR (Narrow View)

As you can see in Figure 6, the resonant frequency for this antenna was just above 2.425 GHz.

Andrew Greenberg contacted out contact at Xerox and they agreed to let us use their anechoic chamber to test the antennas radiation patterns. Their chamber is semi-anechoic (the floor is a ground plane rather than RF absorbent) as you can see in Figure 7.

Figure 7: The Anechoic Chamber at Xerox.

In Figure 7, you can see our patch antenna to the far left, me in the center, and the Xerox's receiving antenna to the right. We used a combination log periodic and bowtie antenna to receive our transmitted signal. This antenna was designed by the engineers at Xerox and had an extremely wide bandwidth (From less than 1 MHz to 3 GHz).

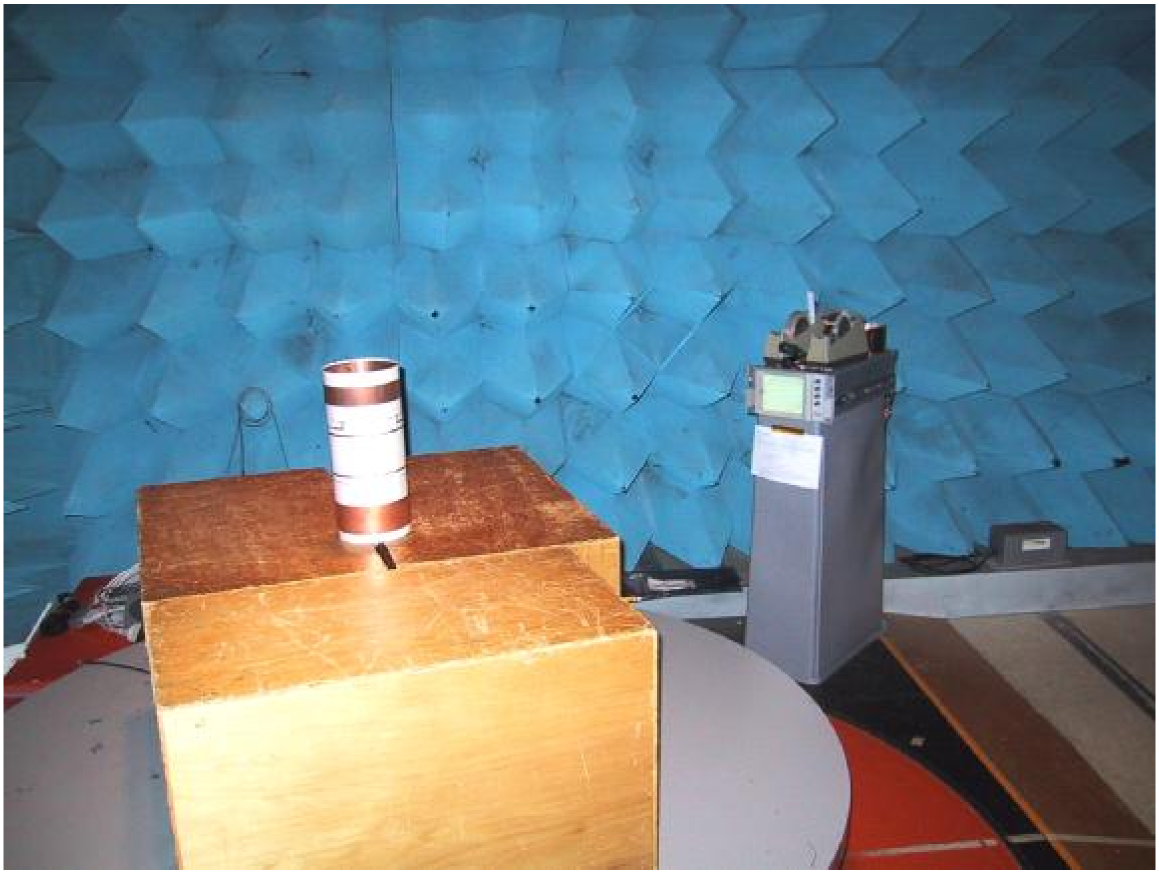

Figure 8: Antenna Setup

Figure 8 shows the turntable that we used to rotate the antenna. This turntable had a resolution of about 1 degree and could rotate up to 1000 pounds. We placed the antenna on the wooden boxes and centered the antenna above the table’s pivot point. The antenna is being fed from below with the cable being fed through the boxes.

We had a fair amount of difficulty receiving any signal from the antenna. Our biggest problem was that the chamber and cabling were not optimized for 2.5 GHz and so we had a great deal of system loss just trying to feed the antenna. We used a spectrum analyzer with a tracking generator to both send stimulus to and to receive from the antenna.

We decided to make 3 revolutions for each of the antennas, one with the antenna vertical (an azimuth sweep) and two with the antenna on its side (elevation sweep) one side sweep at azimuth = 0 degrees and one at azimuth at 90 degrees. Unfortunately, we had left a 60 dB attenuator in the receive path which attenuated our signal beyond our ability to distinguish it from the noise floor. We tested the WIFI with the attenuator in place and the GPS antenna with the attenuator in place before we realized that the numbers we were getting were just noise. We finally found the attenuator and removed it and retested the GPS antenna but we didn't have time to retest the WIFI antenna. Figure 9 shows the azimuth data for the GPS antenna.

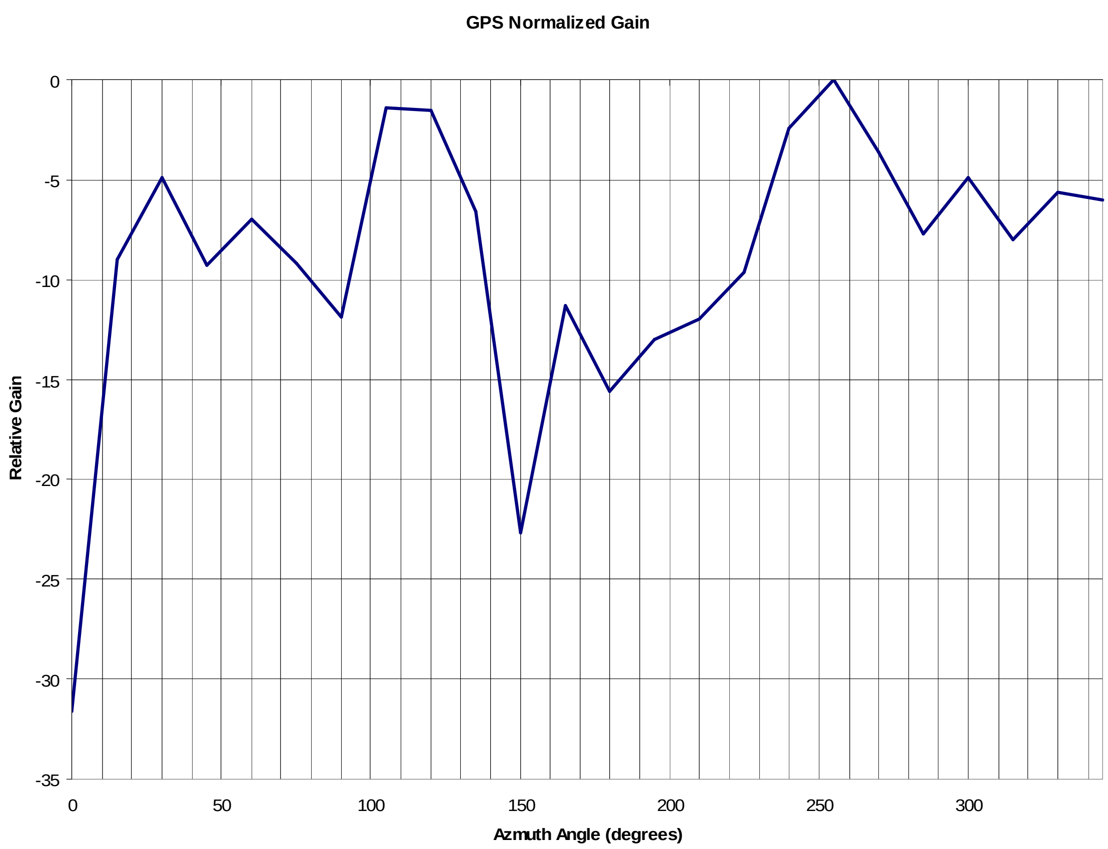

Figure 9: Normalized Azimuth Gain for GPS Antenna

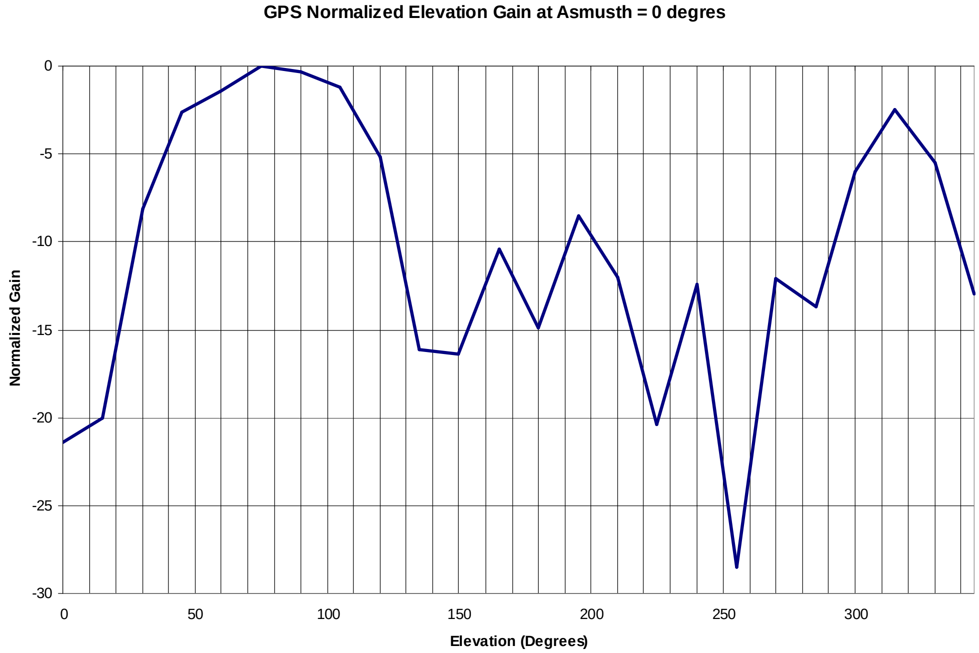

Figure 10: Normalized Elevation Gain of GPS Antenna at Azimuth = 0 Degrees

As you can see from the data, it is difficult to see any kind of pattern. One of the problems with the data is that we only took a reading every 15 degrees and there was a considerable amount of variability in the data between the 15 degree marks. We noticed that the in the elevation data, the reading could swing as much as 10 dB between 15 degree marks, especially when the axis of the antenna was pointed more towards the receiving antenna.

Conclusions

Designing and constructing these antennas gave me valuable experience with practical patch antenna design and measurement considerations. When we have more time we will be returning to Xerox to do a more detailed antenna pattern measurement with a resolution closer to 1 or 2 degrees. I believe that these two antennas will work fine for the rocket.