915MHz CIRCULAR POLARIZED PATCH ANTENNA

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ABSTRACT

A 915MHz circular polarized patch antenna was designed, built and tested. The antenna dimensions were 160mm X 160mm with 40mm truncations at two opposite corners. The antenna was probe fed at a distance of 150mm from the right edge placed at the horizontal symmetry line. The antenna resonated at the desired frequency with a Return Loss of -15dB, a Gain of +11dB and half power beam width of 43 degrees with respect to the normal plane of incidence. The results closely matched the theoretical and simulated by values within 75%. The 25% difference is attributed to the test environment were reflections in the transmission path were several.

INTRODUCTION

Antennas are all around us, cars, airplanes, satellites, old TV sets, cell phones, radios, laptops to name just a few. Antennas transmit/receive electromagnetic waves over a wide range of frequencies. At either end of a communication link there is some kind of antenna to allow the detection or transmission of information embedded in the signal. A simple patch antenna is shown in figure 1.

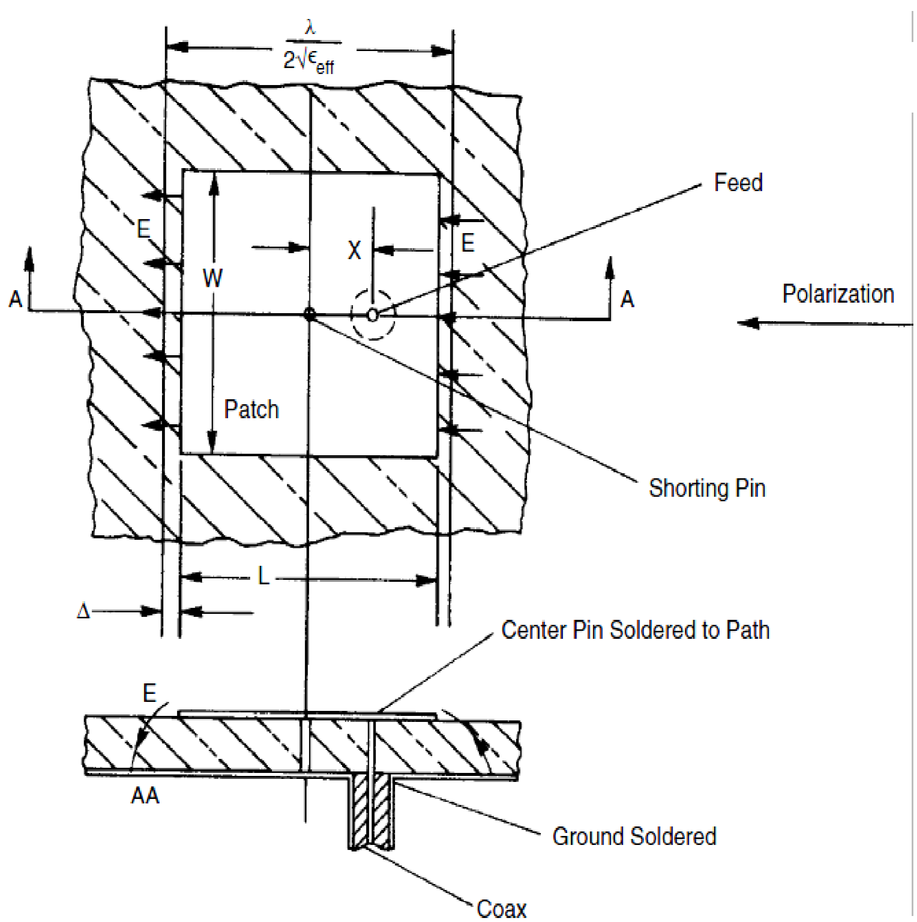


FIGURE 1 Coax-fed microstrip patch antenna.

The dimensions of a patch antenna are obtained using the following equations,

$$Length = L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L$$

Equation 1.

Where f_r is the resonant frequency, ε_r is the dielectric constant of the substrate, μ_o is the relative permeability of free space, ε_o is dielectric permeability constant and ΔL is the extended incremental length.

$$Width = W = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Equation 2.

Where v_o is the free-space velocity of the light and,

$$effective\ dielectric\ contant = \varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}}$$

Equation 3.

In an antenna the width and length are finite and the radiation at the edges undergo fringing as illustrated in figure 2. The fringing field is a function of the ratio of the length of the patch to the height of the substrate and the dielectric constant of the substrate. It influences the resonant frequency of the antenna and must be taken into account.

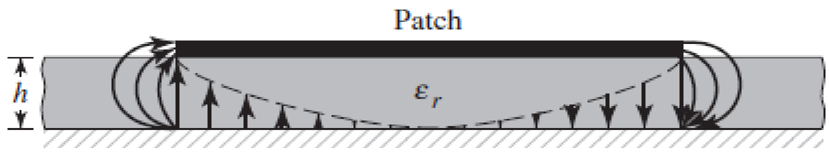


Figure 2 Fringing field effect

Because of the fringing effect the length has to be incremented by ΔL defined in Equation 1. Therefore the incremental length to height ratio can be calculated using the following equation,

$$\frac{\Delta L}{h} = 0.412\frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)}$$

Equation 4

Thus for the actual length of the patch we have,

$$L = \frac{\lambda}{2} - 2\Delta L$$

Equation 5.

This represents a length reduction between 1%- 4%. Therefore the effective length L_e of the patch becomes,

$$L_e = L + 2\Delta L$$

Equation 6.

ANTENNA POLARIZATION

There are several polarization patterns but since circular polarization is required for this project it is the one to be discussed. Circular polarization refers to Electric and Magnetic waves traveling in space at a 90° phase difference from each other as can be seen in figure 4 below,

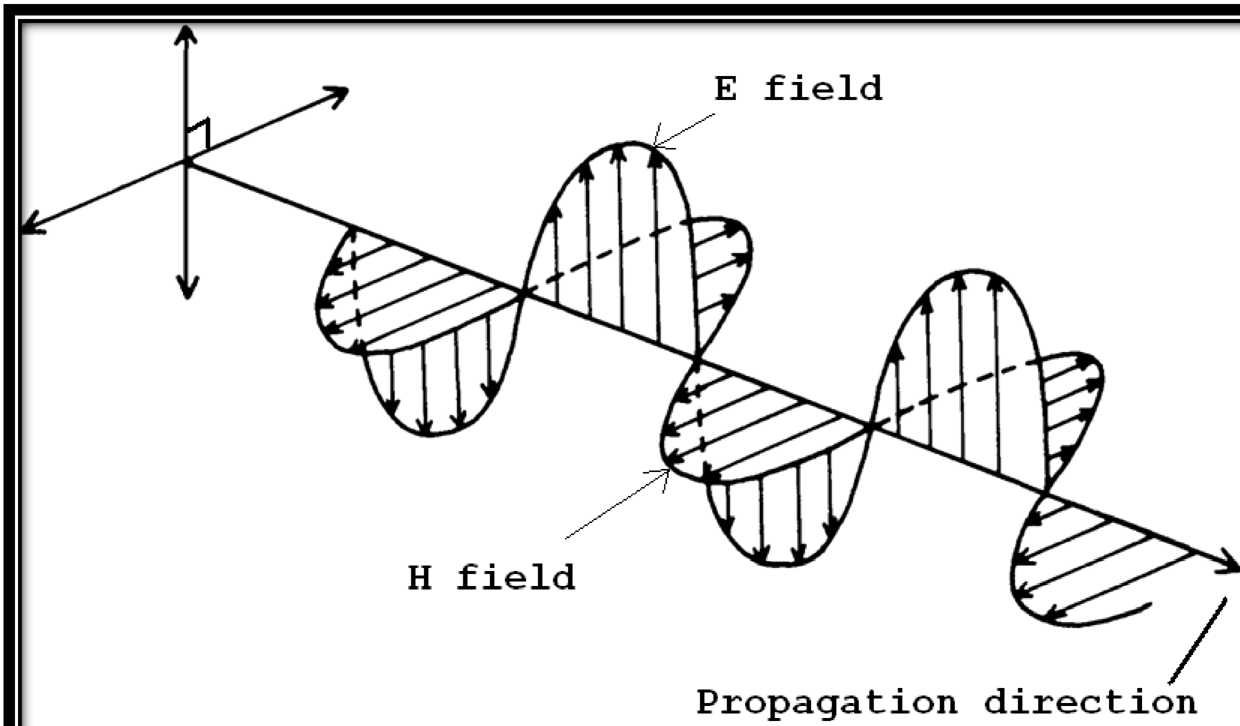


Figure 4. Circular Polarization of EM waves

To achieve circular polarization in a patch antenna the symmetry of the patch has to be modified in one of many ways possible. Some examples on how to achieve this is presented in figure 5.

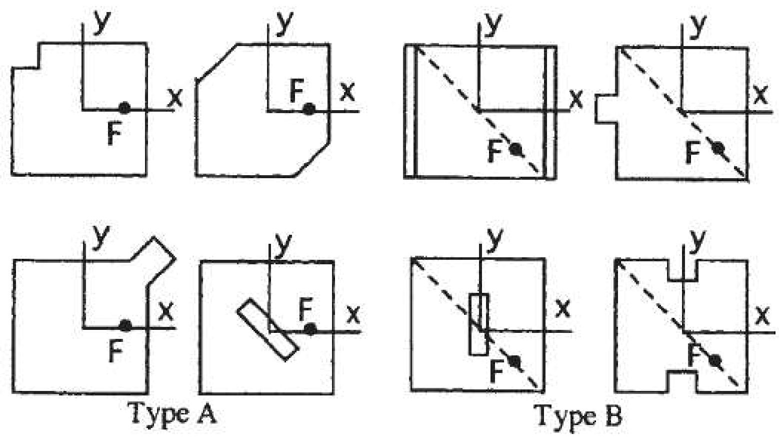


FIGURE 5 Classes of perturbed microstrip patches to generate circular polarization from a single feed. (From R. Garg et al., *Microstrip Patch Handbook*, Fig. 8-15, © 1999 Artech House, Inc.)

The position of the fed, F, is critical to minimize reflection and ensure that the antenna's impedance is matched to the 50Ω coax feed line for maximum power transfer.

RADIATION PATTERN

Patch antennas radiate maximum power in the direction normal to the patch. An example of such pattern is presented in figure 6 below,

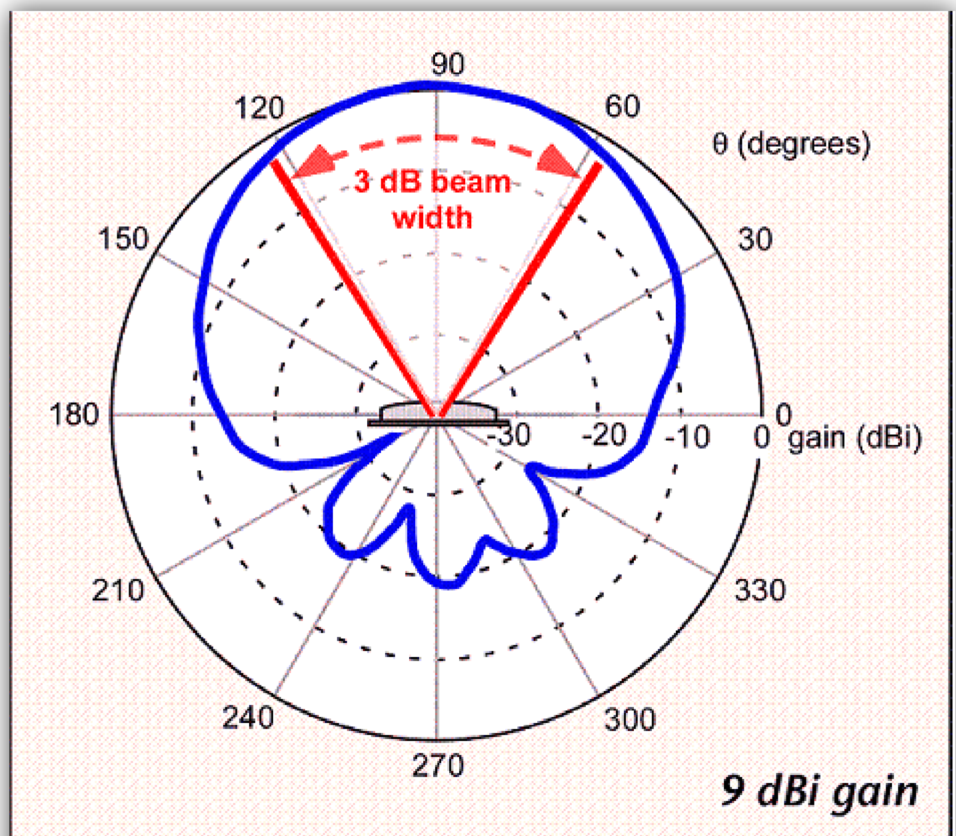


Figure 6. Radiation pattern for patch antenna

From the plot the 3dB beam width represents the point at which the radiated power reduces to half.

ANTENNA GAIN

The gain of the antenna is defined as the amount of power gained or delivered by the antenna. It can be calculated with the following formula,

$$G(\text{antenna}) = G(\text{reference antenna}) - S_{21}(\text{reference antenna}) + S_{21}(\text{antenna})$$

where S_{21} is defined as the transmission coefficient between ports, ie, input and output.

FRONT-TO-BACK RATIO

This is the ratio of the radiated power in front or behind the antenna, which is the difference of the Directivity.

DIRECTIVITY

By definition it is the Gain of a lossless antenna which ignores the effects of conduction losses, dielectric losses, mismatches and cable losses.

PROCEDURE

The dimensions of the half-wavelength patch antenna were determined by the resonant frequency desired and the aid of equations 1 through 6. Based on the results simulations to find the best position of the feed point as to guarantee proper matching, circular polarization and minimum Return loss were run using Microwave Office software from AWR©. Once the best results were obtained a prototype antenna was built using Multipurpose Copper (Alloy 110) Soft Sheet, .027" Thick; 6 x 1.5cm wood lock-stand-offs to guarantee uniform height and one Type-N female connector. The antenna prototype was tested and compared to theoretical and simulated values.

TEST ENVIRONMENT

The antenna was tested at 2 different orientations . Figure 7 shows one of the settings where the measurements took place. The first measurement was performed at a distance of15.4 ft from the transmitting antenna to the Antenna Under Test (ATU) The second position was at 14.25 ft at 30 degrees off from position one.

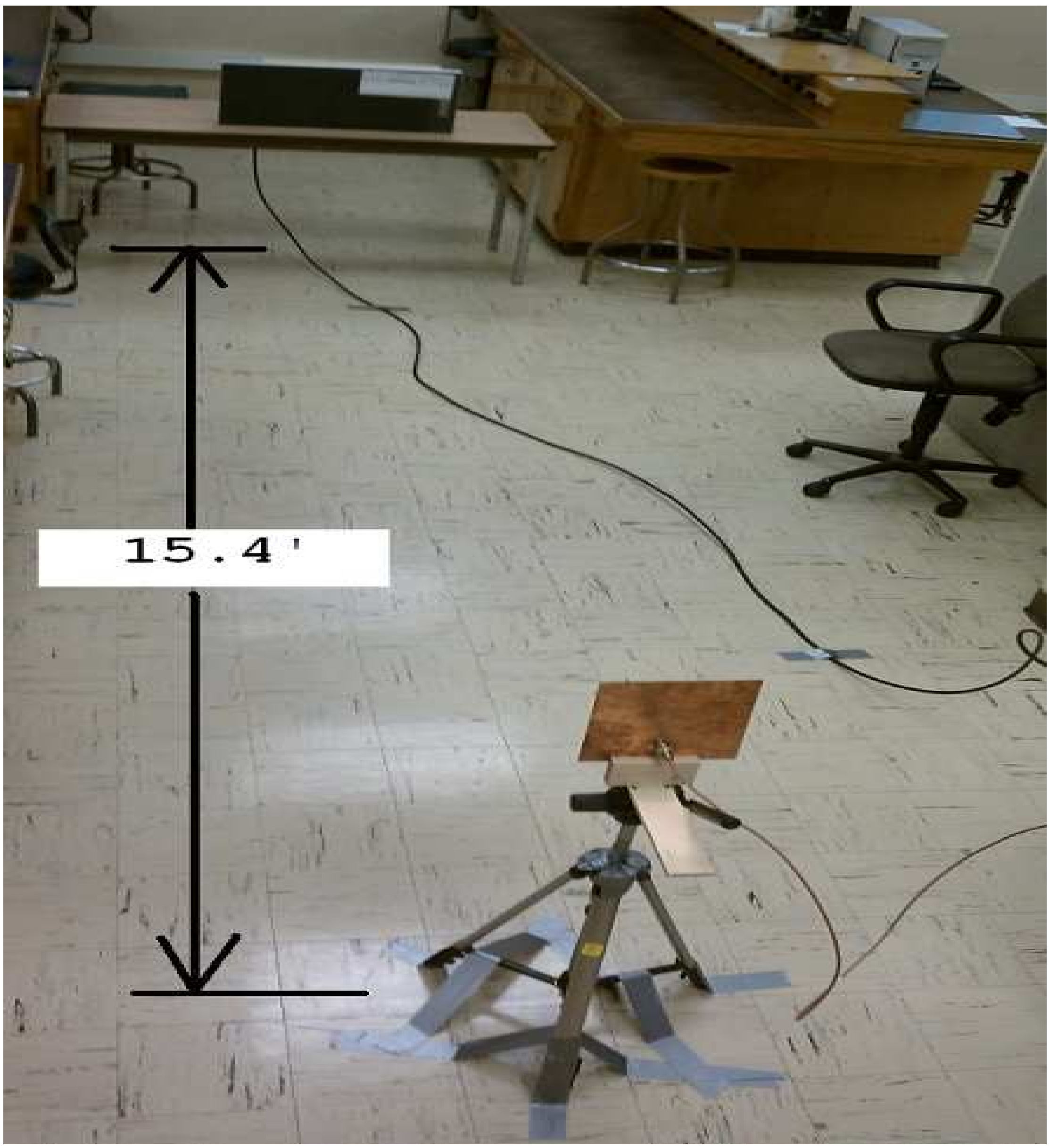
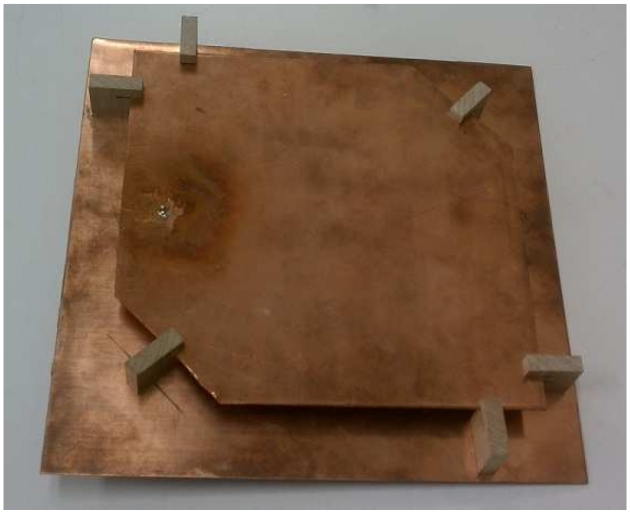


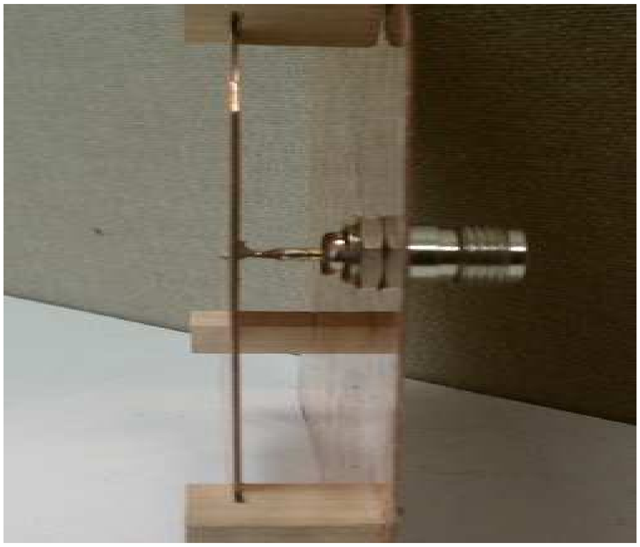
Figure 7. Test set up environment

RESULTS

The original dimensions of the patch antenna were: L= 164mm, W=164mm and H=20mm. The final dimensions of the patch antenna as a result of the simulations were, L= 160mm, W=160mm and H=15mm. The probe feed was place at1.5 cm from patch's right edge at ~8cm from top/bottom.



Antenna front view



Antenna Side view

The RL (S11) value simulated was -21.989dB as shown in figure 8.

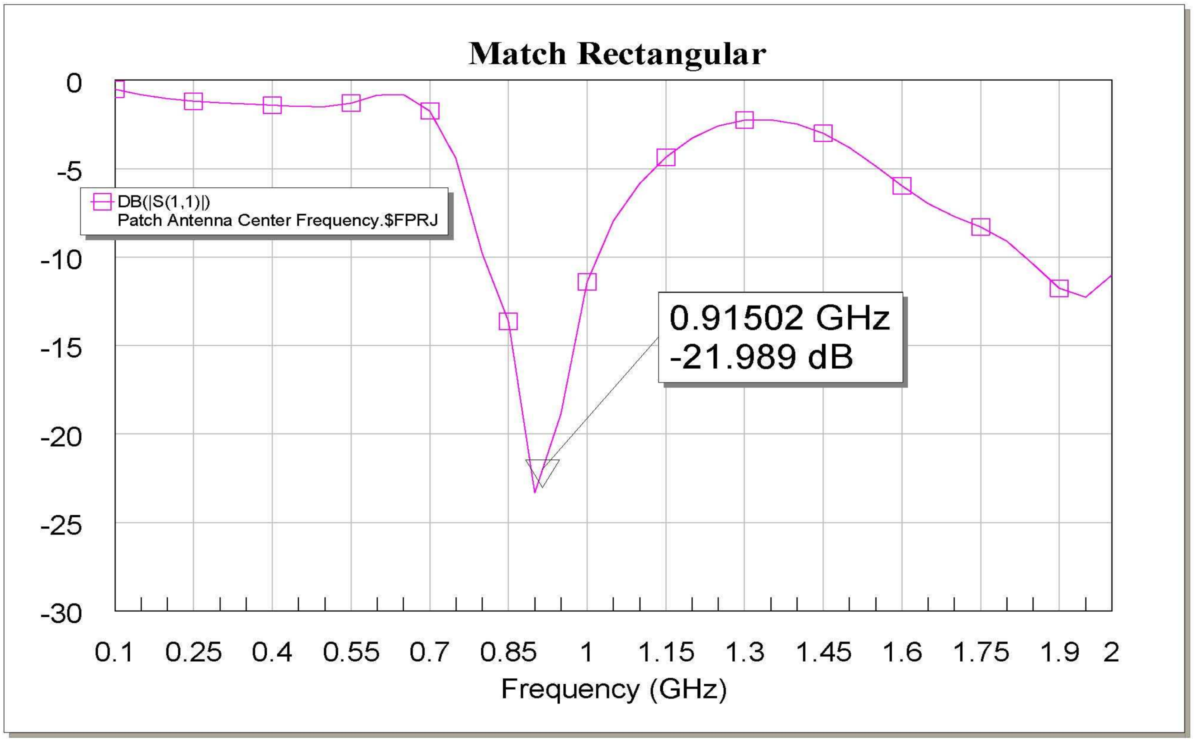


Figure 8. Simulated RL (S11) results

The measured RL value was -15.4dB shown in figure 9.

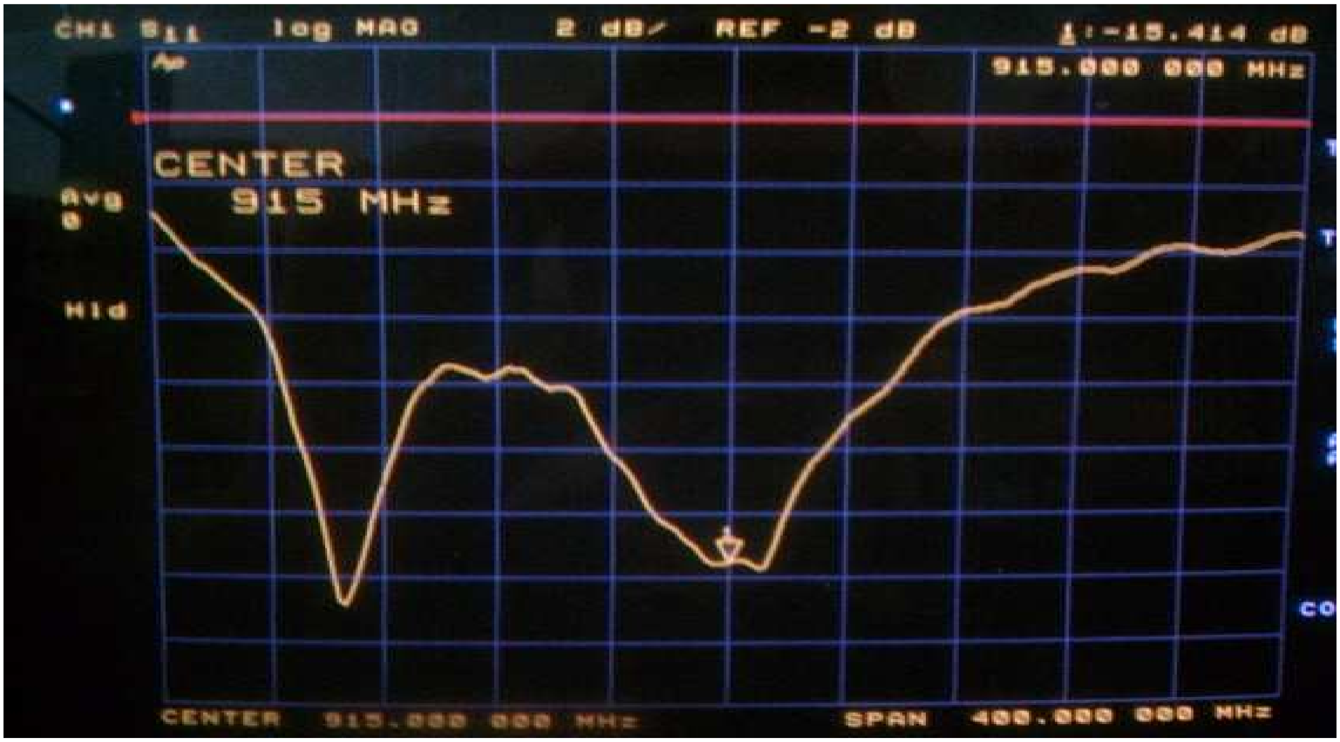
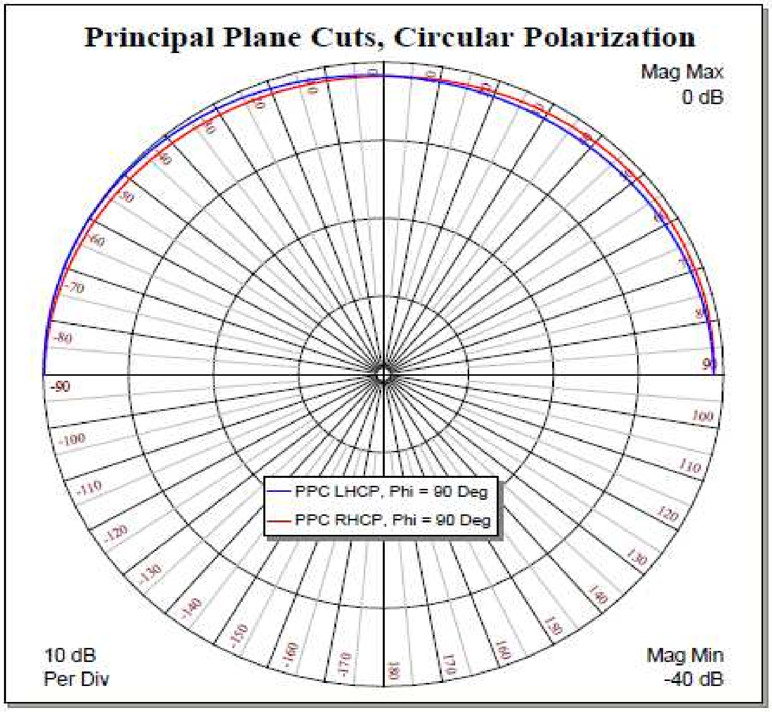
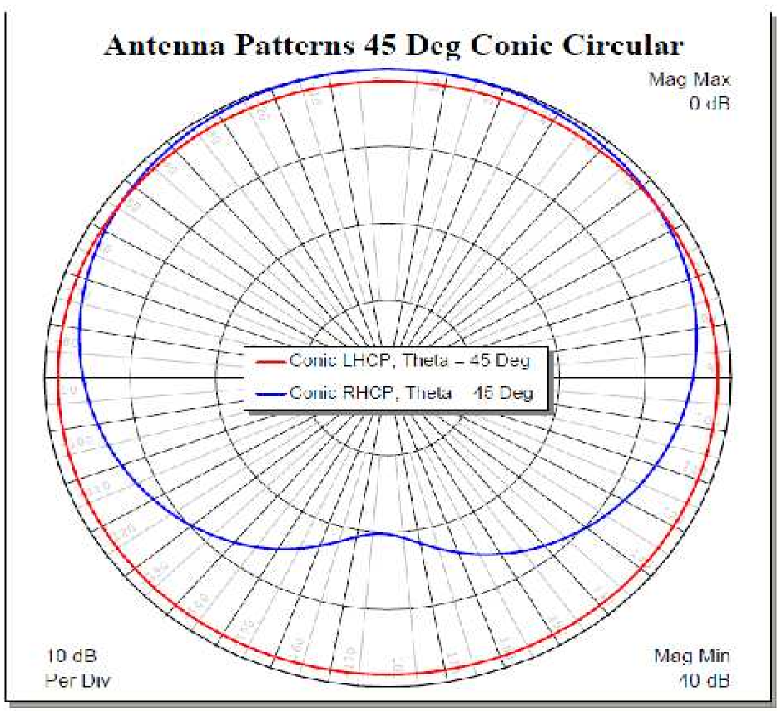


Figure 9. Measured RL (S11).

The simulated circular polarization plot is shown below,



The simulated radiation pattern is shown below



The radiation pattern was measured twice at distinct locations. The antenna was rotated 360° along the z-axis. The values obtained were ave raged and a 2-D plot was generated and shown in figure 11 given a measured 3dB of about 86°

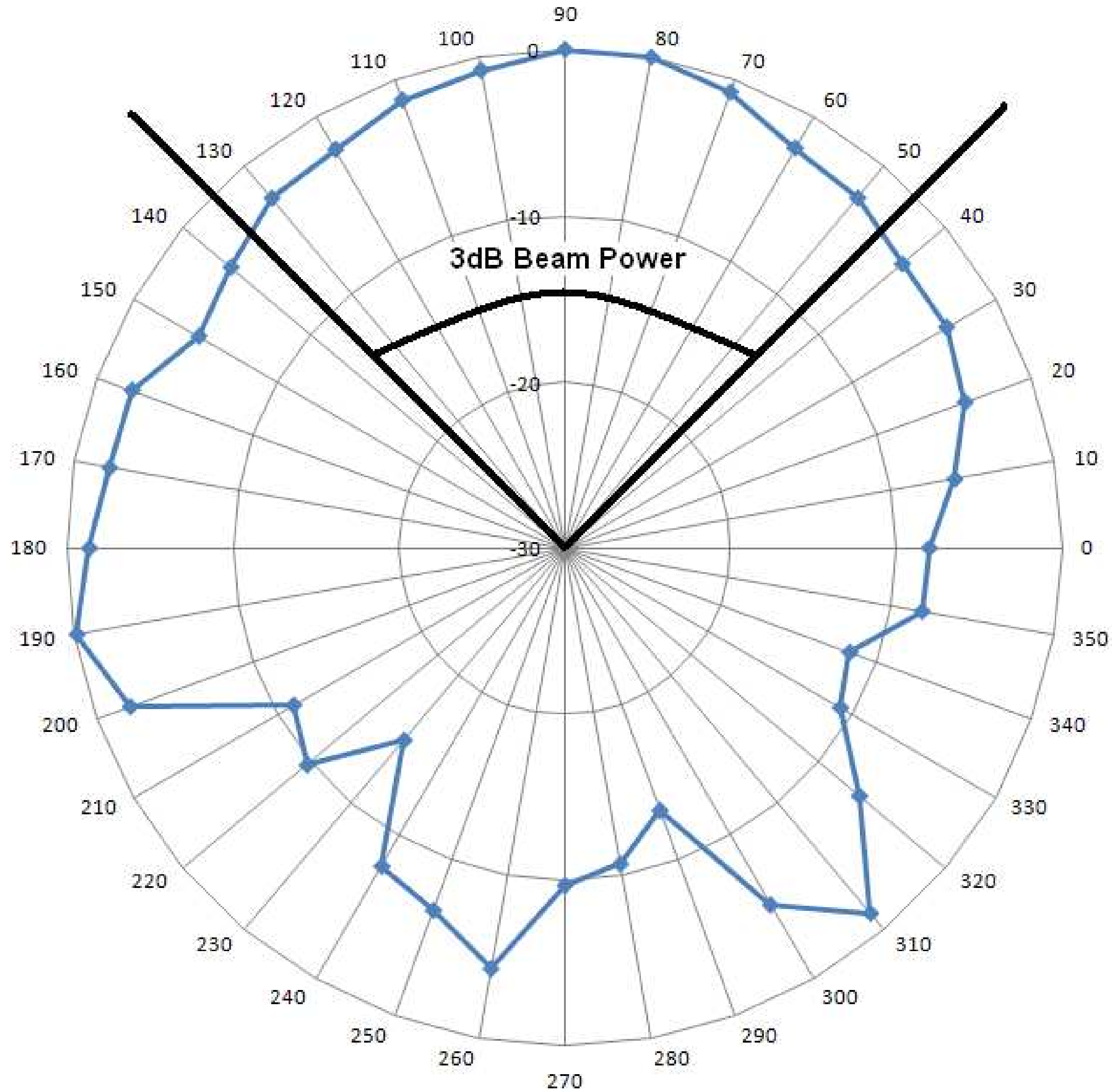


Figure 11. 2-D plot of the 360° measured radiation pattern

The radiation pattern was also measured at elevation angles from 0° to 180° Figure 12 below shows an averaged 2-D plot of the results,

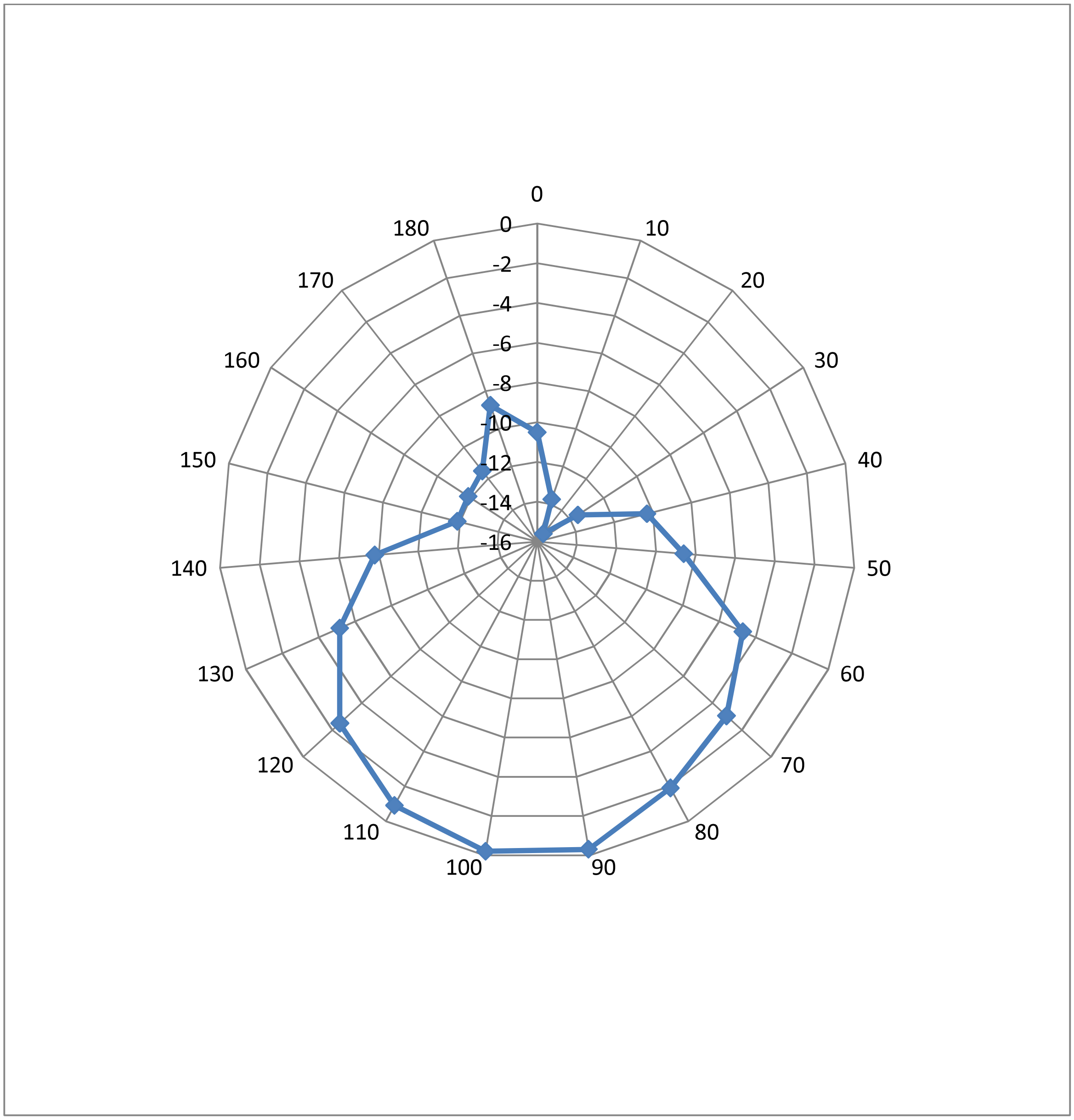


Figure 12. 2-D plot of the radiation measurements from 0- 180°

ADDITIONAL SIMULATIONS

During the matching process using MWO software there were several probe fed positions that resulted in different values of S11 (RL) at 915MHz and a few other resonant frequencies. Graphs of probe position VS RL and frequency peaks are shown below. The starting point was a patch of dimensions 160mmX140mm and the feed was moved along the main diagonal from right to left in increments of 2.5mmx2.5cm which is roughly the diameter of 18awg wire. Figure 13 shows Peak frequencies as a function of probe feed. At various points peaks were minimums or maximums.

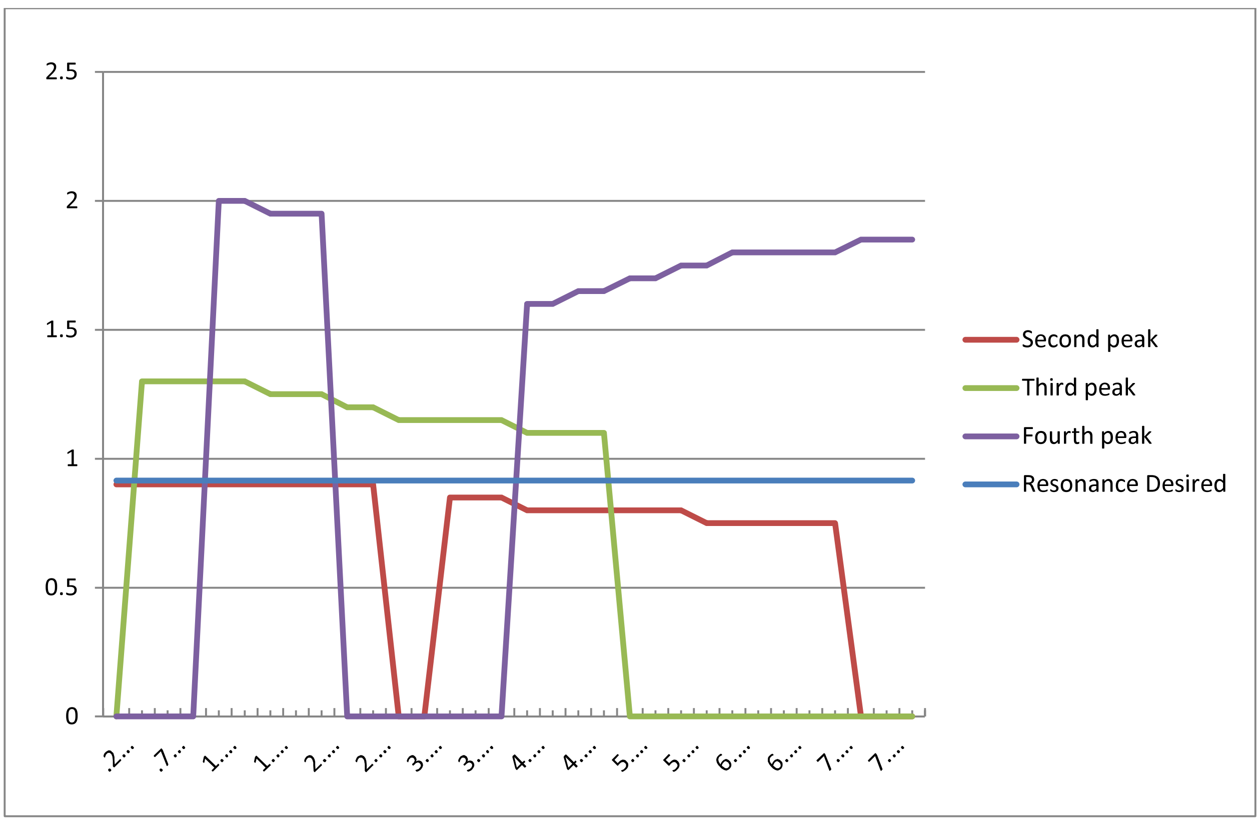


Figure 13. Frequency peaks observed as probe was moved down the main diagonal

As can be seen in figure 14 the return loss decreased to almost none towards the center of the patch. The lower portion of the graph was similar to the top portion due to the symmetry of the patch.

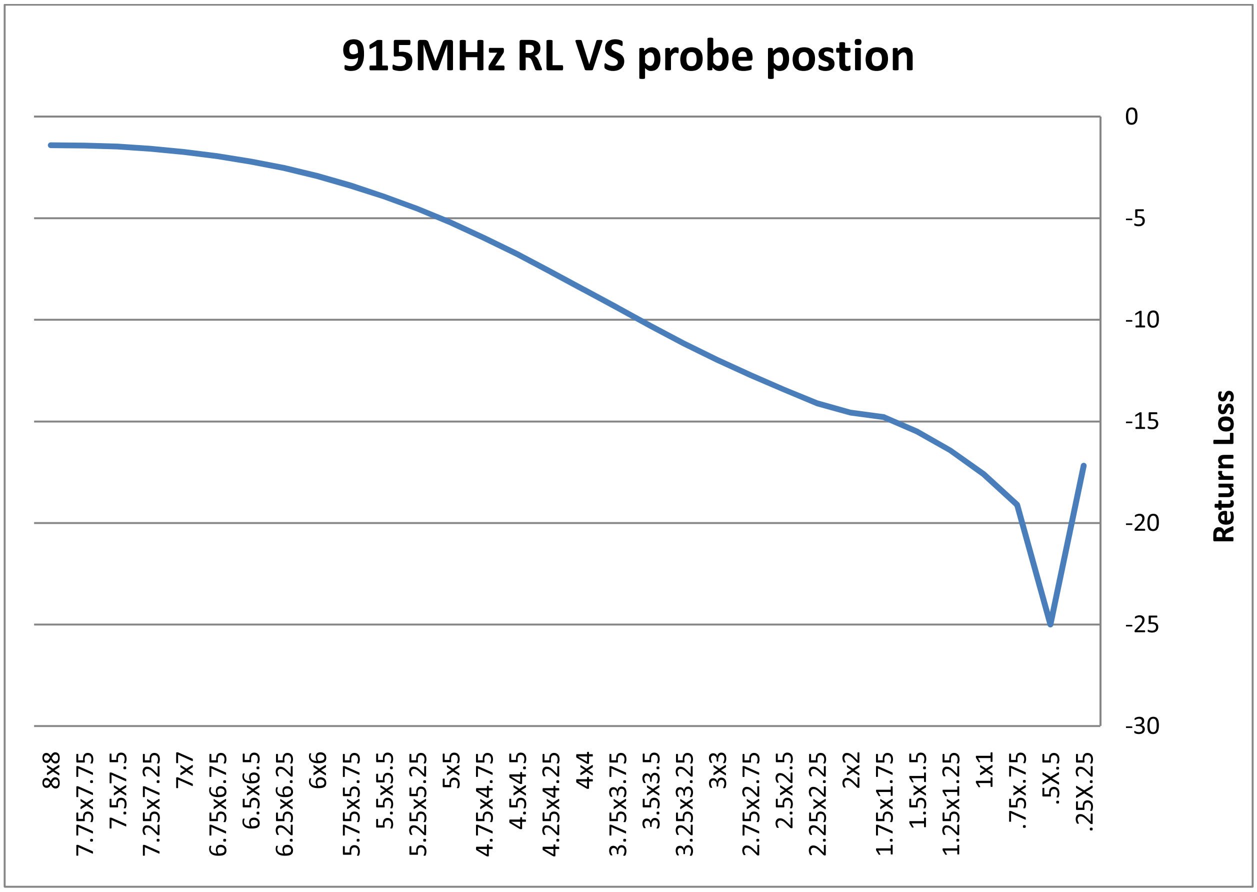


Figure 14. Return loss at 915MHz.

The second peak resonance as a function of probe feed is shown below. The turning points are due to the peak changing 50MHz as can be seen in Figure 13 above. The range for this peak was from 750MHz to 900MHz. At 750MHz from 6x6 to 7.25x7.25; 800MHz from 4.25x4.25 to 5.75x5.75; 850MHz from 3.5x3.5 to 4x4; and 900MHz from .25x.25 to 2.75x2.75. All others RL= 0. As shown in figure 15.

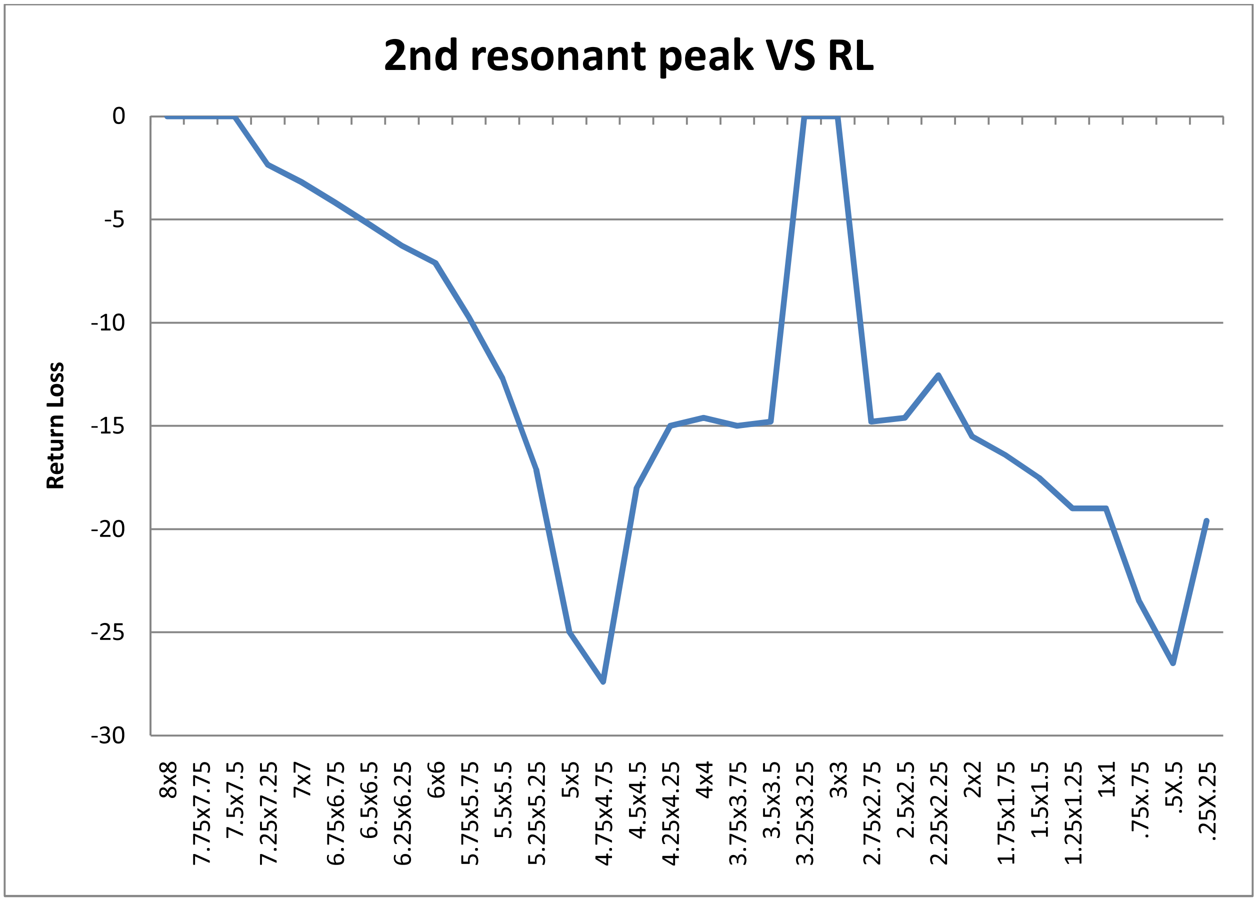


Figure 15. RL values for the range 750MHz to 900MHz.

The third peaks happened from 1.1GHz to 1.3GHz. Figure 16 shows the changes the return loss values undergo as the probe was moved. 1.1GHz peaks happened from 4.25x4.25 to about 5x5; 1.15GHz from 3x3 to 4x4; 1.2GHz from 2.5X2.5 to 2.75x2.75; 1.25GHz from 1.75x1.75 to 2.25x2.25; 1.3GHz from .25x.25 to 1.5x1.5, else no resonant frequencies in this range appeared.

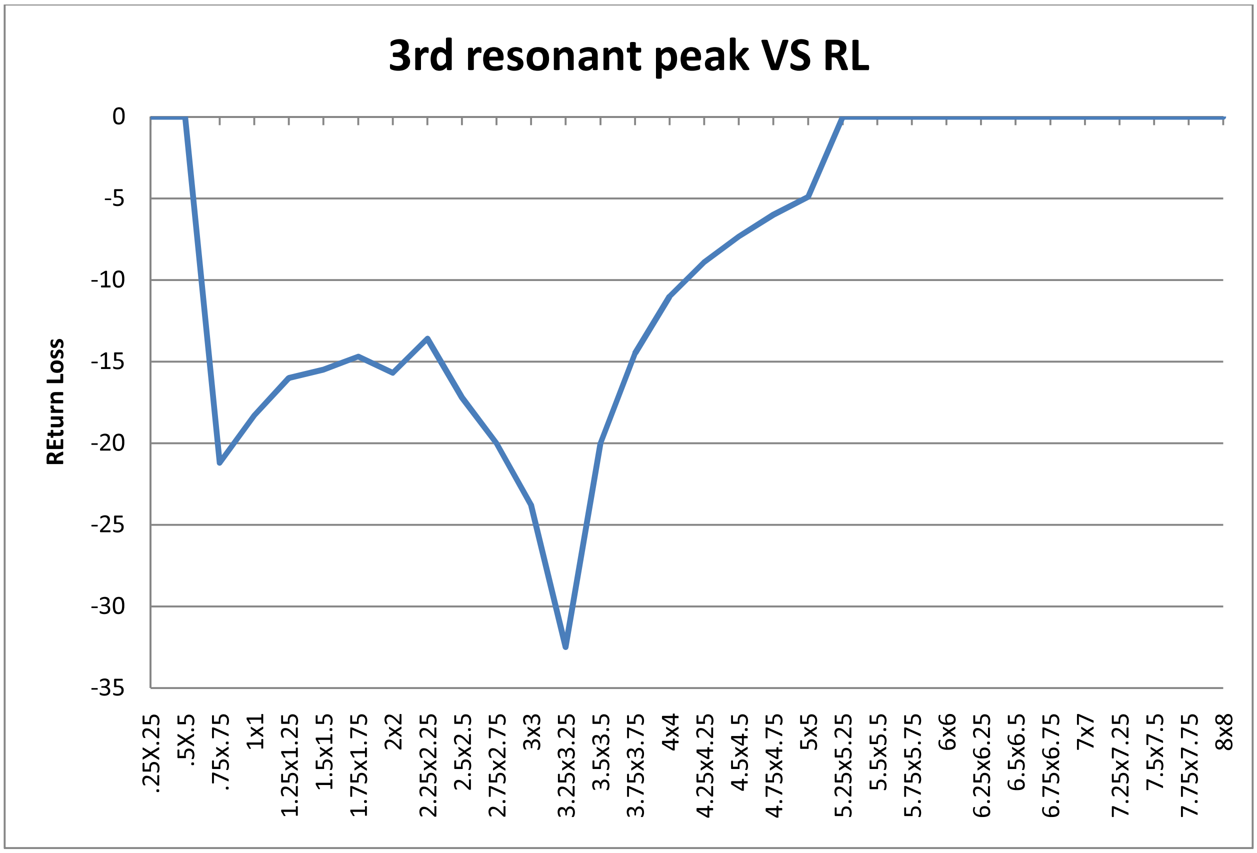


Figure 16. Return loss values from the range 1.1GHz to 1.3GHz

The last peak range happened from 1.6GHz to 2GHz. The values were broader for these ranges can be seen in figure 17.

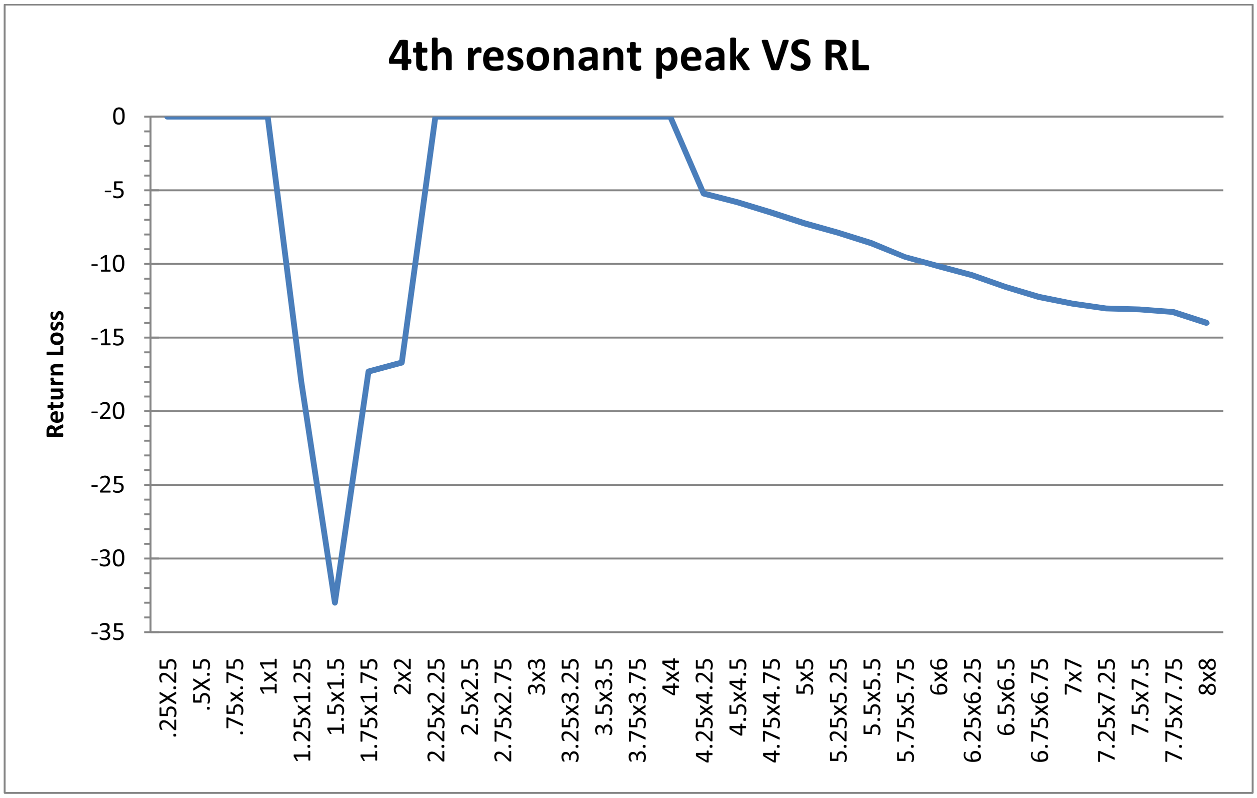


Figure 17. Return loss values from the range 1.6GHz to 2GHz

ANALYSIS OF RESULTS

At first the measurements obtained were not as close to the simulated or theoretical values, in part due to non-ideal conditions encountered during testing. Nevertheless, the design met the goals of at least -15dB Return loss, resonant frequency of 915MHz and the ability to receive/transmit circular polarized EM waves. The measurements obtained deviate about 25% from theory due to reflections from the doors, metal white boards and other objects placed randomly within the path of transmission, imperfections in the metal cuts and in the materials used to fabricate the antenna. The measured 360° radiation plot was not a s well defined at the theoretical values predicts for reasons explain above. The results obtained while matching the antenna using MWO software and that were a part of the project are worth mentioning. Starting with the probe from the top left corner of the patch and moved down the diagonal line to the bottom right corner of the patch showed a trend of symmetrical results past the center of the patch. Several frequencies resonated when the probe was place at different locations but were pretty close to its counterpart. When the probe was moved from the top right corner down to the lower left corner similar results occurred. In the simulations of the patch were $L \neq W$ the resonant frequencies did not change much nor did the RL obtained for $L=W$ but the bandwidth at which the peaks occurred were narrower. In theory, the length determines the resonant frequencies so changing W had little impact in the RL obtained as a function of the probe position. The width W along with the height determines the bandwidth of the patch, so there was no surprise that the RL did not change much as the width was decreased to about 100mm once a proper 50Ω match was obtained. The truncations made to the antenna in order to achieve circular polarization were performed once a proper 50Ω match was obtained. As the patch was trimmed the plane cut resolved to close to 0dBm for the range -90° to +90°.

In the end the simulations and measured results agree with theoretical values presented herein.

CONCLUSION

I made several mistakes during the course of this project. The original idea was to use Styrofoam whose dielectric constant ε_r =1.1 is close to that or the air ε_r =1.0 but the sheet of copper chosen was 27mils and heavy. I couldn't find any glue or similar to attach the patch and the ground plate together. Instead I used wood studs held by 4-40 screws that, although very small could have affected the behavior of the antenna. The N-Type connector came loose during the measurement process. I measured the RL before measurements to be -17dB but at the end of the measurements it was -12dB. I retightened the connector and re-measured RL ending in -15.14dB. The radiation pattern measurements were partially redone. When I noticed the values did not change more than a couple hundreds of dB I concluded the connector came loose while removing the test cable.

This project can be improved by reducing the size of the patch by trying different types of substrates since the higher the ε_r the smaller the dimensions of the antenna. Improve RL and bandwidth. Perform test in open space to minimize reflections. Finally compare different metal thickness and chose the best one that better suits this purpose.