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2 GHz Patch Antenna : Circular Polarized

EE172 – Final Project

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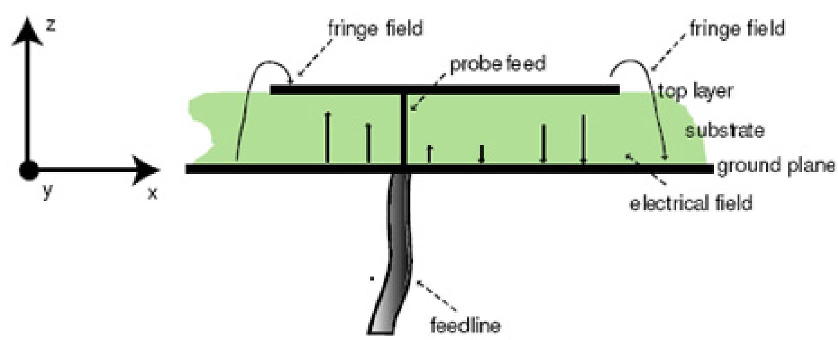
Introduction

For my report, I have chosen to design and build a circularly polarized 2.0GHz Patch Antenna. Due to building cost and convenience some methods were chosen despite the fact it would degrade performance. This report includes a brief description for the theory of how the designed patch antenna operates. This report will also present the design process for the patch antenna, the implementation of the theoretical design to the construction process, and the alterations that were made to the theoretical design which allowed the patch antenna to operate correctly. Data measurements that were taken in a lab with a Network Analyzer are presented to show the performance of the patch antenna. From the data measurements, conclusions and suggestions are formulated and presented at the end of the report.

Theory

The patch antenna operates based upon the effects of a fringing electric field that is generated between the conducting patch and the ground plane. This fringing field will radiate and create a radiation pattern that is determined by multiple design variables. The patch will have a voltage distribution that is low on one side of the x-axis and high on the exact opposite end. This voltage distribution creates an electric field that is generated from the patch to the ground plane on one side while the opposite end of the patch has an electric field that is generated from the ground plane to the patch. This is shown in the figure below.



The length of the patch along the x-axis is how the frequency of the patch is determined. By a rough estimation, the frequency's half-wavelength is the length of the patch. As shown in the picture, the fringing field extends beyond the patch's length which does slightly shift the operating frequency of the patch. To take these effects into consideration, the effective frequency must first be calculated. This is the desired frequency's half-wavelength divided by the effective dielectric constant, as shown below.

$$L_{eff} = \frac{c}{2 \times f_0 \times \epsilon_{r_{eff}}}$$

The fundamental frequency is labeled f_0 while $\epsilon_{r_{eff}}$ is the effective dielectric constant. The effective dielectric constant is defined as:

$$\epsilon_{r_{eff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{\frac{1}{1 + 12\frac{h}{w}}}$$

The variable ‘h’ is the height of the patch, and is defined as the distance between the patch and the ground plane. The variable ‘w’ is the width of the patch and can be considered negligible in its effects on the frequency.

ΔL is the length that the fringing field extends beyond the patch’s length. It is defined as:

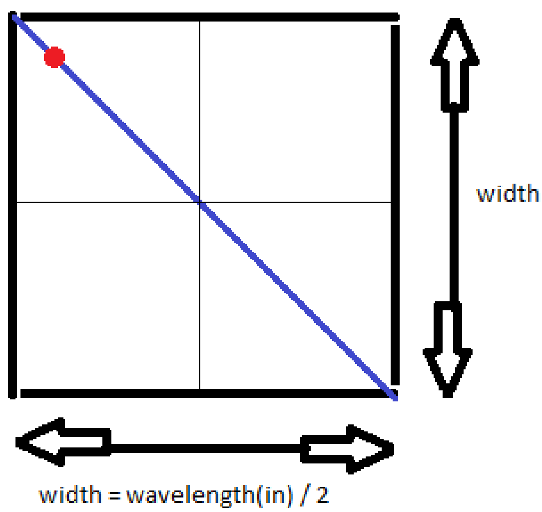
$$\Delta L = 0.412 \times h \times \frac{(\epsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{eff} - 0.258)(\frac{w}{h} + 0.813)}$$

Now using the effective length, and the length due to the fringing field, the overall combined length is found to be :

$$L = L_{eff} - 2\Delta L$$

Using this length as the patch’s actual length will result in the patch’s optimal operating frequency being equal to that of the fundamental frequency, f_0.

There are a variety of ways to make a patch antenna circularly polarized. For this specific case, the antenna was chosen to be circular polarized by feeding the coaxial cable to the patch along the patch’s diagonal axis. Solving mathematically for the location along the diagonal axis that produces the maximal performance is very difficult and dependent upon many variables. Finding the location is easily done experimentally. Below is a figure showing an example of how the patch antenna was fed by the 50Ω coaxial cable to create a circular polarization.



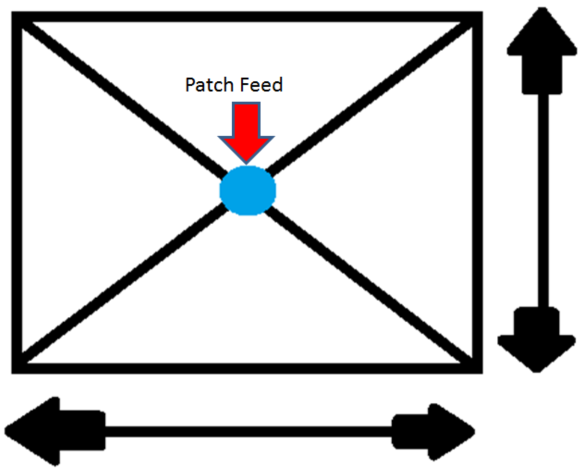
Design Process

First the material was selected, aluminum was chosen for cost purposes, it was cheap and easily accessible to buy. Plastic tubes used for holding Electronic IC's were selected as stands to uniformly hold the patch above the ground plane. Only a few were used so that the dielectric constant could be estimated to be that of air; thereby reducing all previous theoretical calculations described in the theory section to simple half-wavelength equations. The frequency desired was 2.0GHz and therefore the length was estimated to be 3 inches since the wavelength of a 2GHz frequency is 5.9 inches. For symmetry, the width of the patch was also selected to be 3 inches. This would also produce a radiation pattern similar to that of a sphere rather than that of a doughnut pattern which is typical in dipole antenna radiation patterns. A height of 1-inch was selected as the patch's height above the ground plane. A RG58/U cable was selected as the feed transmission line due to its 50Ω impedance.

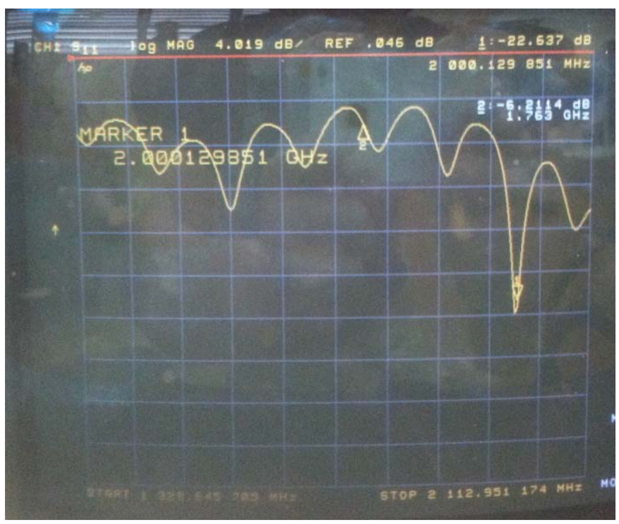
After testing the aluminum patch, I found an area of distance away from the patch's corner, along the diagonal axis to exhibit an expected return loss for a circularly polarized patch. Due to the difficulty of soldering aluminum, my intention was to drill a small hole through the aluminum patch to create a secure contact for the patch and cable feed. This small hole proved to be very degrading to the performance of the patch, and this idea was scrapped.

I then moved on to choosing two different types of material for the patch, brass and copper. I built multiple patch antennas using either brass or copper for the patch. The brass was chosen at a thickness of 0.01 inches, and the copper was chosen at 0.025 inches.
The copper patch was presented in my PowerPoint presentation, but because it was not fully completed and operational at the time this report was written, the copper patch has been excluded from this written report.

The same initial steps were taken. First I tested to see if the fundamental frequency of the patch was operational and the dimensions of the patch proved to be effective. This is how the fundamental frequency was checked.



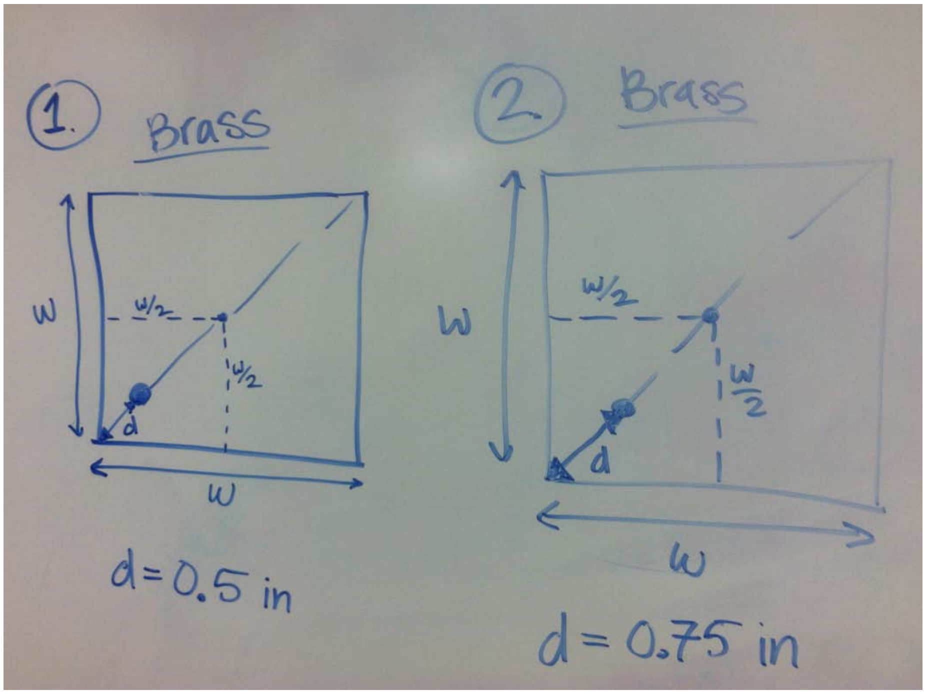
I found that because the ground plane was aluminum and soldering the outer conductor of the 50Ω cable was not an option, that the connection of the ground plane to the outer conductor was highly sensitive. I resorted to sing electrical tape to tape down the outer conductor of the cable feed and using electrical tape to tape the inner conductor of the cable feed to the patch feed location. The dielectric constant of the electrical tape can be ignored since it is minimally thick compared to that of the height. Eventually I was able to test the fundamental frequency for the patch antenna as shown below.



Once the fundamental frequency was confirmed I moved on to testing the circularly polarized patch feed location.

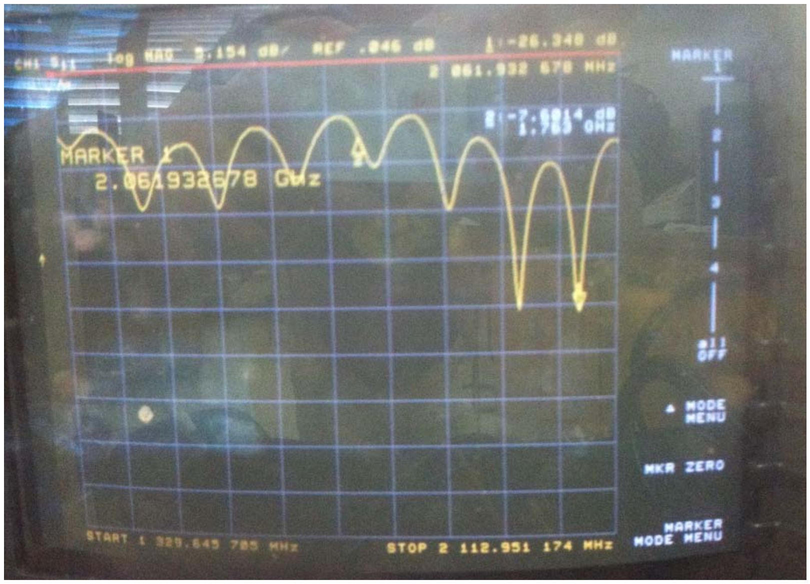
This location can be found by measuring the Return Loss of the antenna. It is important to note the Return Loss in comparison to that of the noise floor. A large difference is very important and will allow for optimal performance. The introduction of a circularly polarized field will also exhibit a different Return Loss pattern than that of the linearly polarized fundamental frequency's Return Loss.

First I began by building two different patch antennas with different feed locations along the diagonal axis as shown below.

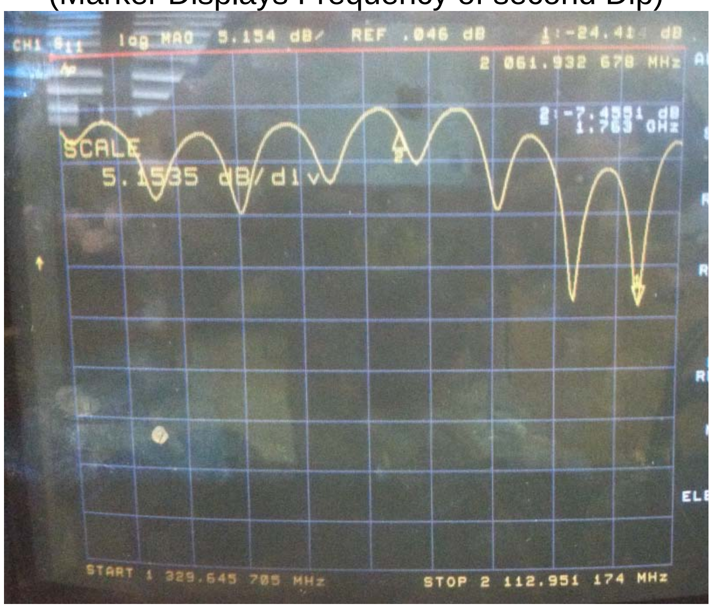


The length 'd' was defined as the length from the patch's corner. First I tested the Return Loss for that of the 0.5 inch d-length. The Return Loss pattern was found to exhibit a pattern that I did not desire. The pattern is shown below.

Next I moved on to the 0.75 inch d-length and tested the Return Loss. I found the pattern to be more to my liking, and choose to continue on with this location. The Return Loss for this location is shown below with a frequency indicator and a DB/Scale indicator.



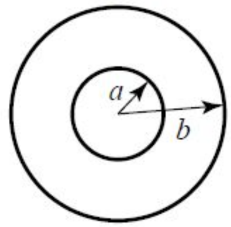
(Marker Displays Frequency of second Dip)



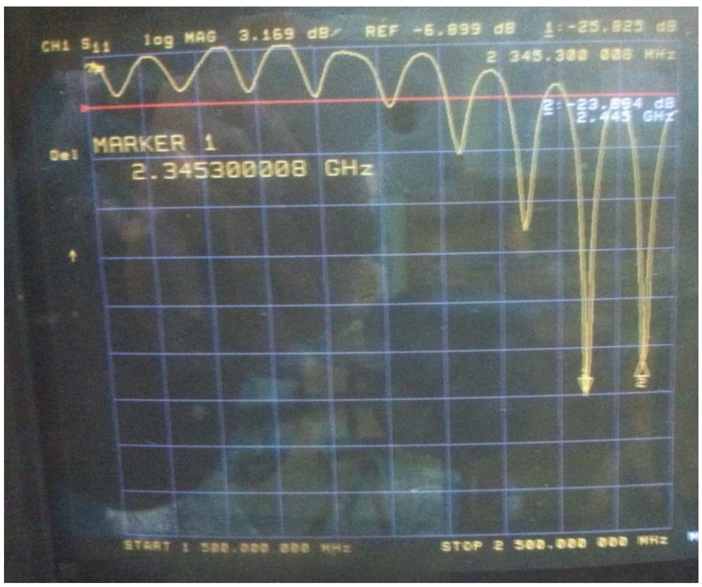
(DB/Division indicator)

The second dip in the Return Loss is to be expected since the Electric Field radiating is circularly polarized.

Now that the location for the circularly polarized patch feed had been found, I went to solder the feed cable to the patch to create a more secure connection. In doing so, I found a tremendous source of error. By peeling back the outer conductor to make contact with the ground plane, I was changing the impedance of the cable line. As described in the Telegrapher's Equations the impedance of the cable line is defined by:

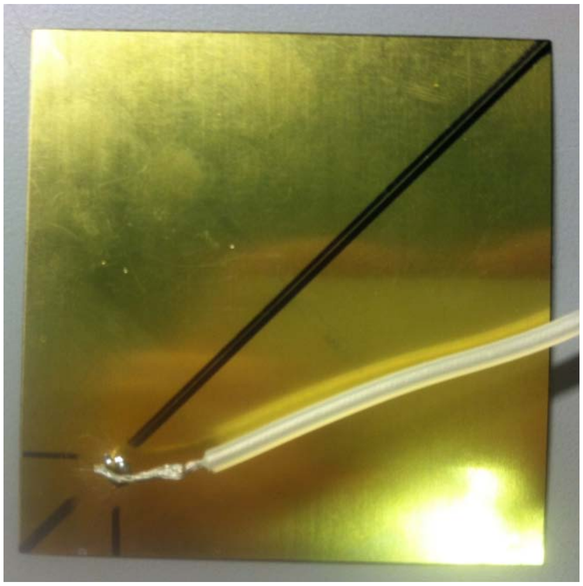
	COAX
	
R	$\frac{R_s}{2\pi}\left(\frac{1}{a}+\frac{1}{b}\right)$

The effects of peeling the outer conductor away from the inner conductor introduced a significant frequency shift in the operating frequency as shown.

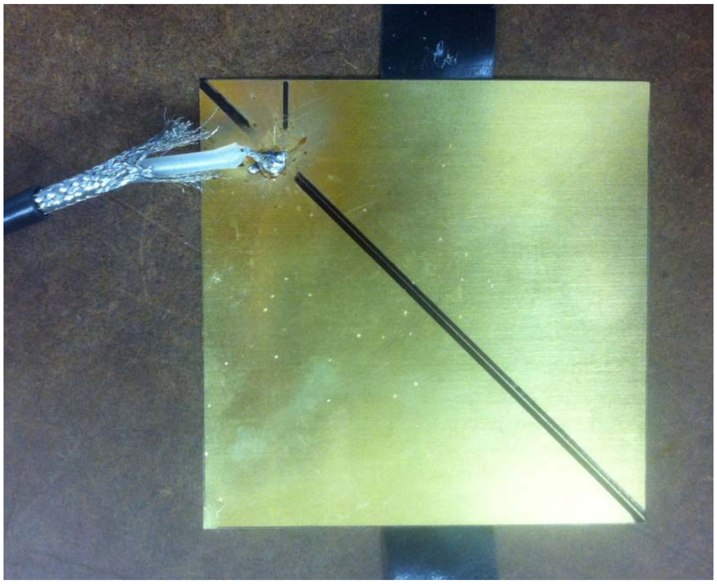


Since the shift in the frequency was so large, 345MHz, I went back to the drawing board.

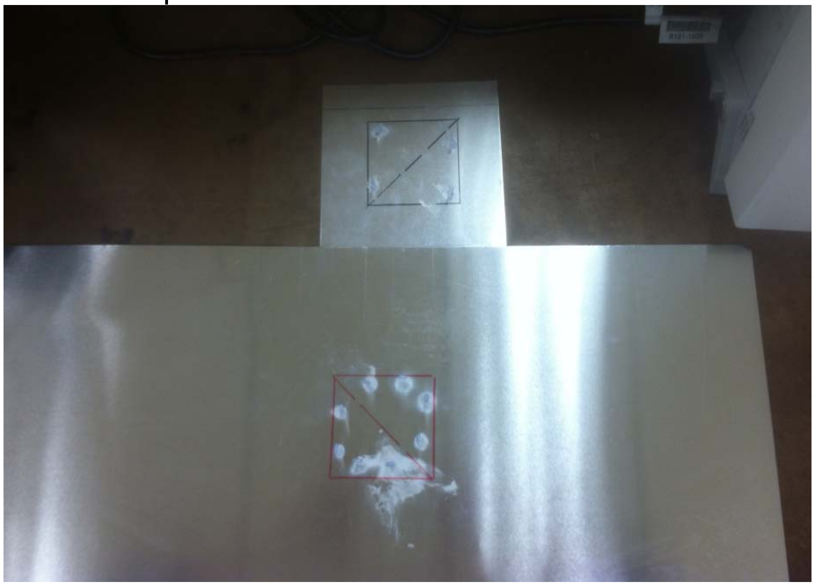
The soldering location is shown in the picture below.



Due to the height of the patch above the ground plane, and the fact the cable feed has to be slightly stripped from the outer conductor, the cable feed will radiate and create an electric field. The greater the patch's height is in distance above ground plane will allow the cable's radiating electric field to become more profound in the patch's error sources. For this reason I decreased the height of the patch to 0.5 inches above the ground plane. I also desoldered the cable feed and re-soldered it to the bottom of the patch in the same location with a minimal length of the inner cable's conductor exposed as possible. The patch was re-assembled and measured. This is a picture of the corrected soldering job and a lesser exposed cable feed.

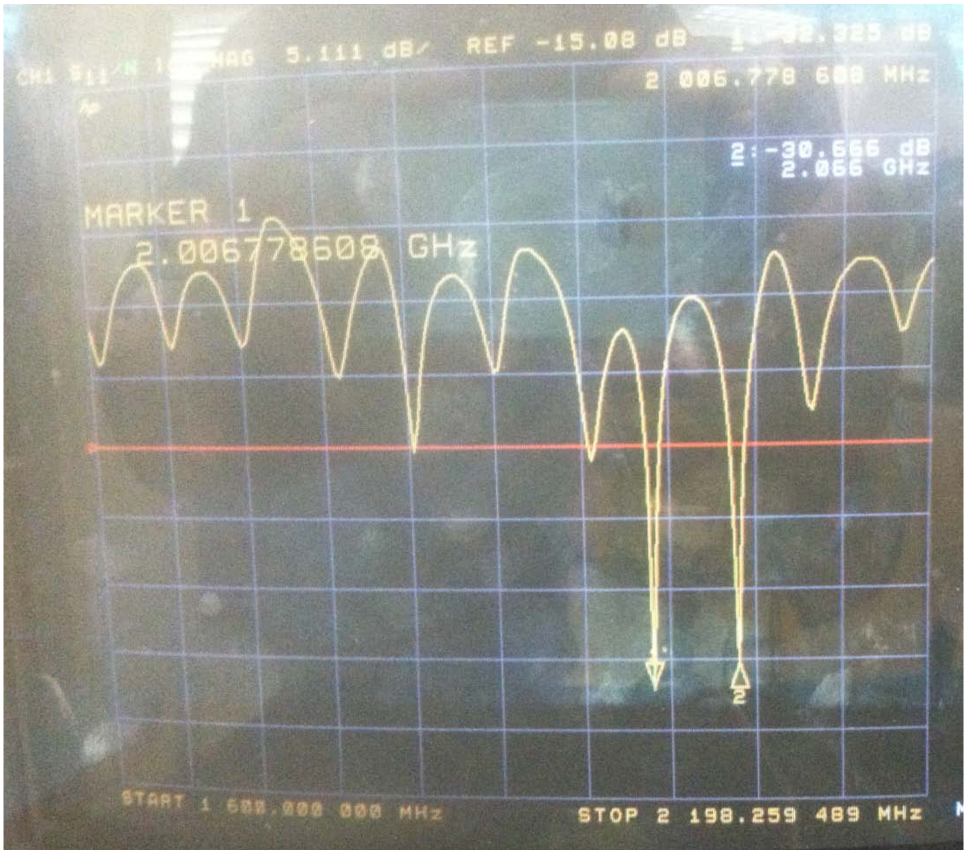


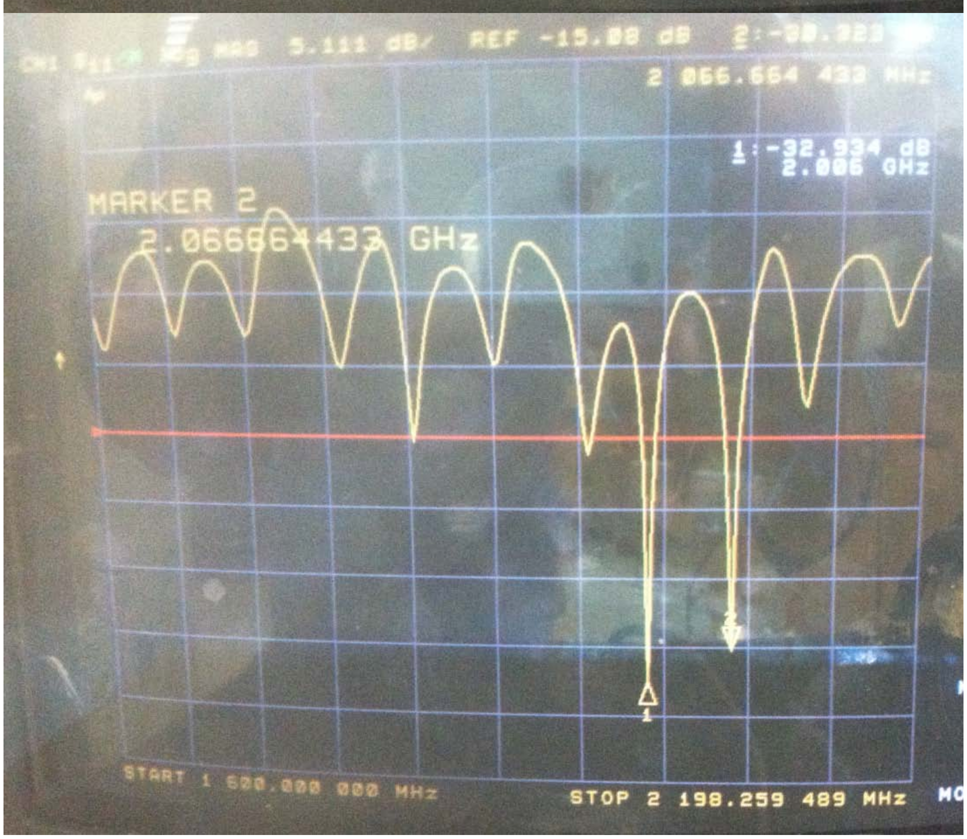
The size of my original ground plane was a 4"x4" aluminum sheet. For maximal operation, the ground plane size should be relatively infinite from the patch's perspective for optimal results. 1 inch larger in width and length was most likely contributing to some sort of error as well. For this reason, the ground plane size was increased as shown in the photo below.



Next the test environment was setup as shown.

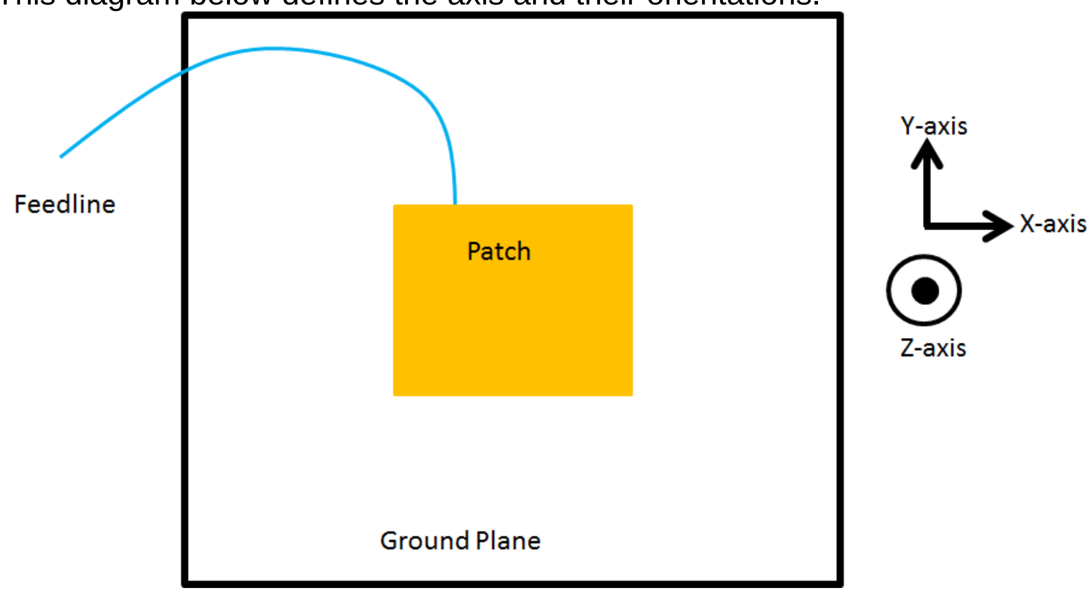
The Return Loss for the new patch antenna was measured and the results are shown below.


5.111 dB/
REF -15.08 dB
2 006.778 608 MHz
2:-30.666 dB
2.066 GHz
MARKER 1
2.006778608 GHz
START 1 600.000 000 MHz
STOP 2 198.259 489 MHz


5.111 dB/
REF -15.08 dB
2 066.664 433 MHz
1:-32.934 dB
2.006 GHz
MARKER 2
2.066664433 GHz
START 1 600.000 000 MHz
STOP 2 198.259 489 MHz

The DB per division on the display is 5DB/div and as shown, both Return Loss spikes are very close to the 2GHz frequency as designed. This is as expected, therefore I moved on to measuring the S21, Insertion Loss, parameter to test the amount the antenna is circularly polarized. Measurements were made considering two planes, the x-z plane and the y-z plane. Measurements for the S21, Insertion Loss, were made by using a simple dipole antenna that was 3 inches long and made from a copper wire. Each measurement was taken 18 inches away from the center of the patch. The 18 inches was always measured from the center of the patch to the center point on the dipole antenna. Since the frequency of the antenna corresponds to 2GHz, the wavelength is 5.9 inches. Measurements should be taken as Far-Field measurements which were estimated to be approximately 3 wavelengths away in my test environment. Although it is not ideal, it was still able to measure the Insertion Loss of the antenna.

This diagram below defines the axis and their orientations.



Since the Return Loss showed two different spikes, I measured the Insertion Loss at both frequencies of the spikes. Marker 1 indicated a frequency of 2.007GHz while the second marker indicated a frequency of 2.07GHz. At each point of measurement, two orientations of the dipole antenna were tested; the first was a 0-degree orientation of the antenna and the second orientation was 90-degrees shifted. In the presented data from 0 degrees to 180 degrees always started at the +x/y axis in both the X-Z and Y-Z plane. The +x-direction corresponds to the arrow in the diagram above. Same is true for the +y-direction.

For the X-Z plane measurement, the 0-degree orientation was when the dipole antenna pointed towards the +y-axis direction and was parallel to the y-axis. The 90-degree orientation for the X-Z plane was with the dipole antenna parallel to the x-axis and pointed towards the patch antenna.

For the Y-Z plane measurement, the 0-degree orientation was with the dipole antenna pointed towards the +x-axis direction and was parallel to the x-axis. The 90-degree orientation for the Y-Z plane was with the dipole antenna parallel to the y-axis and pointed towards the patch antenna. This corresponded to a 90-degree change in direction for the dipole antenna.

Here is the full set of date for the X-Z plane.

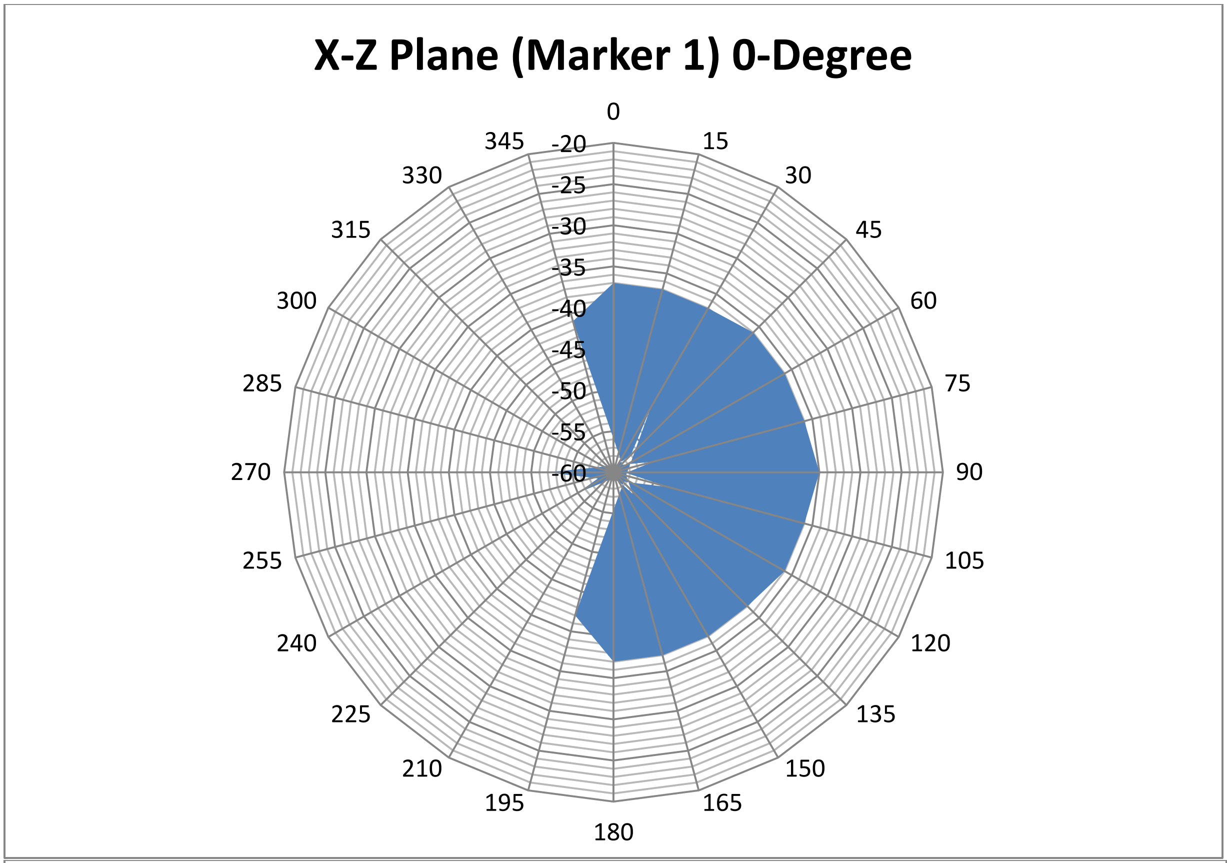
X-Z Plane (0-Degree Measurement)			X-Z Plane (90 degree measurement)		
DEGREES	Marker 1 (Db) 2.007 GHz	Marker 2 (Db's) 2.07 GHz	Degree	Marker 1 (Db) 2.007 GHz)	Marker 2 (Db) 2.07 GHz
0	-37	-40	0	-36	-37
15	-37	-40	15	-36	-37
30	-37	-38	30	-36	-39
45	-36	-38	45	-36	-38
60	-36	-37	60	-36	-37
75	-36	-36	75	-35	-36
90	-35	-36	90	-36	-35
105	-36	-37	105	-37	-36
120	-36	-37	120	-37	-37
135	-37	-38	135	-38	-36
150	-37	-39	150	-37	-38
165	-37	-40	165	-37	-41
180	-37	-40	180	-40	-41
195	-42		195		
210	-69		210		
225	-63		225		
240	-55		240		
255	-65		255		
270	-52		270		
285	-67		285		
300	-58		300		
315	-67		315		
330	-67		330		
345	-41		345		

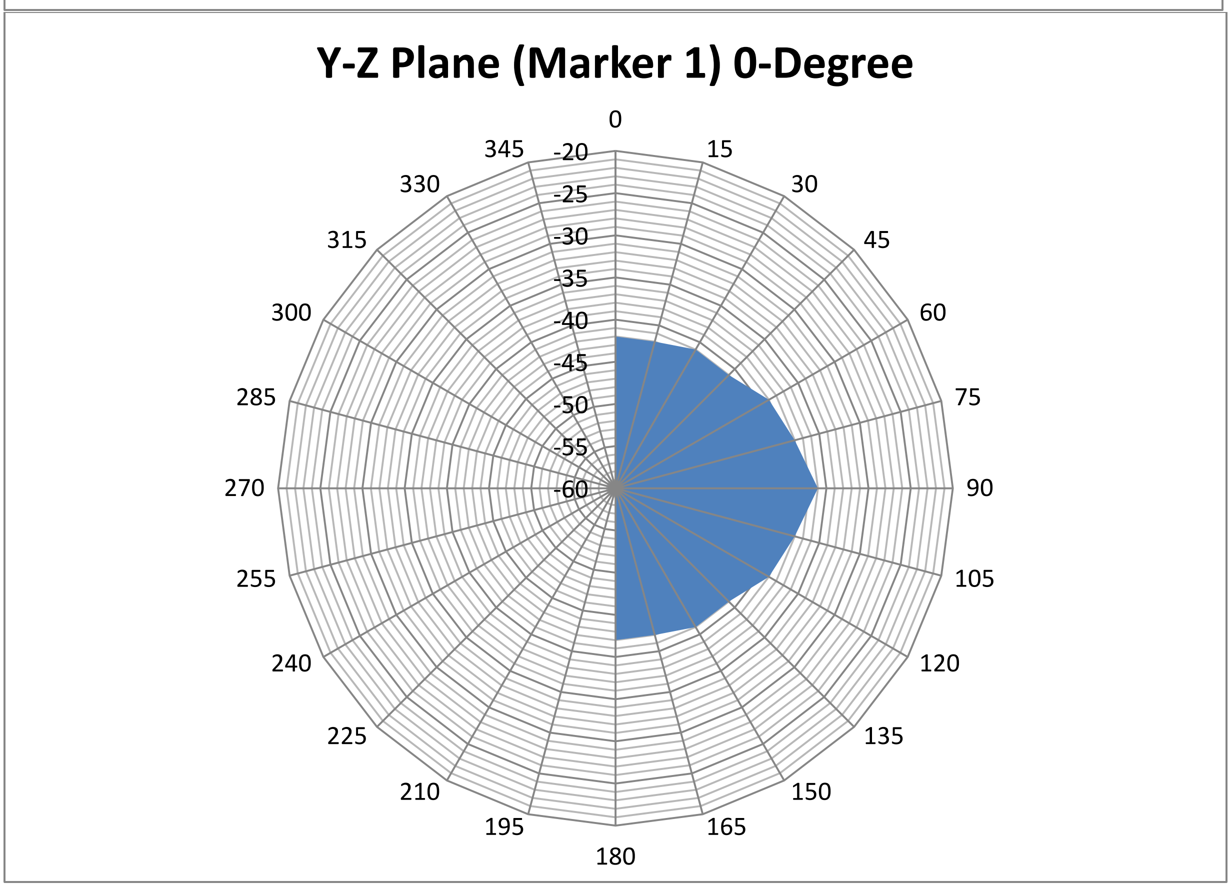
Here is the full set of data for the Y-Z Plane.

Y-Z Plane (0-Degree measurement)			Y-Z Plane (90 Degree measurement)		
DEGREES	Marker 1 (Db) 2.007 GHz	Marker 2 (Db) 2.07 GHz	Degree	Marker 1 (Db) 2.007 GHz	Marker 2 (Db) 2.07 GHz
0	-42	-40	0	-43	-44
15	-42	-39	15	-43	-44
30	-41	-39	30	-42	-44
45	-41	-39	45	-41	-43
60	-39	-37	60	-41	-42
75	-38	-36	75	-41	-41
90	-36	-35	90	-38	-39
105	-38	-37	105	-40	-40
120	-39	-39	120	-41	-41
135	-41	-40	135	-42	-42
150	-41	-40	150	-42	-43
165	-42	-40	165	-42	-44
180	-42	-41	180	-43	-44

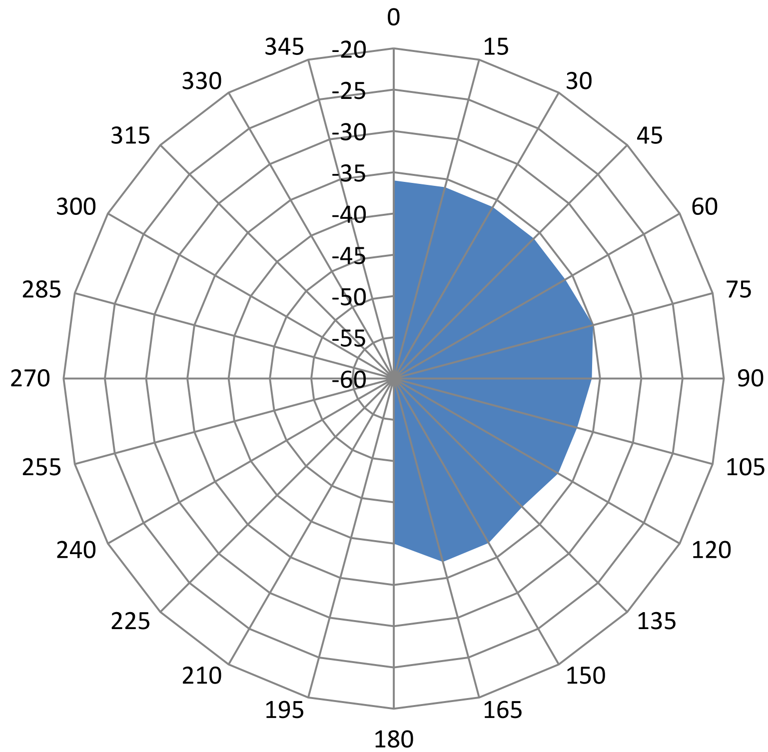
From both these sets of data it appears that there is little difference from the performance of both Return Loss Frequency spikes, although the Marker 1 indicates the maximal operating frequency.

The radiation patterns were plotted using excel, and are presented here.

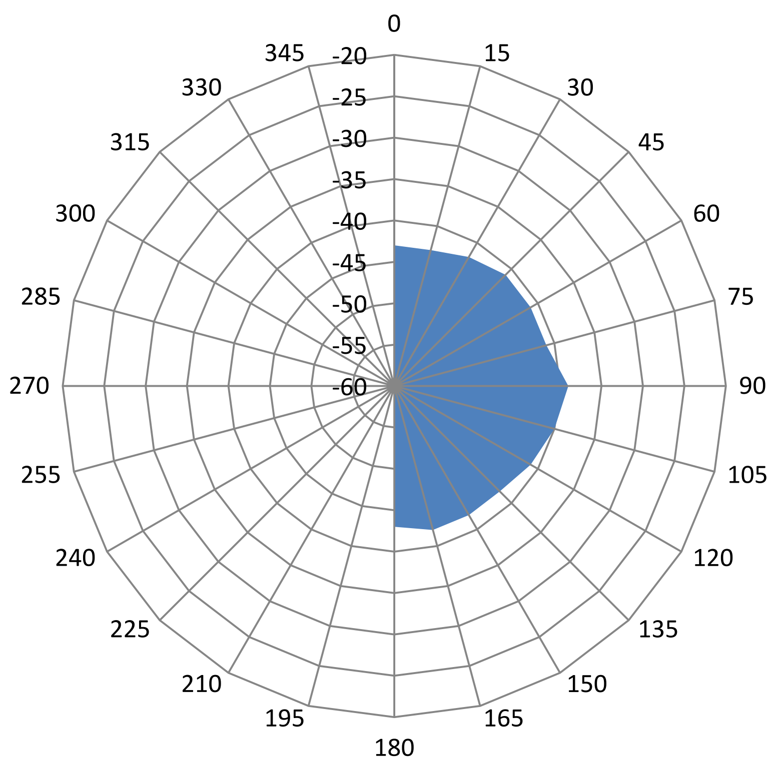

X-Z Plane (Marker 1) 0-Degree
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
-20
-25
-30
-35
-40
-45
-50
-55
-60


Y-Z Plane (Marker 1) 0-Degree
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
-20
-25
-30
-35
-40
-45
-50
-55
-60

X-Z Plane Marker1 90-Degree



Y-Z Plane Marker 1 (90-Degree)



From looking at the Marker 1's plots for both the x-z plane and the y-z plane together, it is possible to conceptually visualize the complete radiation pattern. I had made the width and length equal on the patch in hope of generating a half-sphere like radiation pattern. It turned out to be close but in reality, it is still a doughnut shape, even if the effects are very small. The smaller field on the y-z indicates that is where the concaving of the doughnut shape occurs. The radiation pattern found in the degrees of 180 to 360 for the X-Z plane(0-degree) measurements is most likely from the radiation pattern spilling over the ground plane and being picked up by the measuring antenna.

What is important to note is the difference in power from the 0-degree orientation at each measurement to the corresponding 90-dgree orientation. Below is the two data sets for X-Z and Y-Z planes comparing the power of the antenna orientation.

X-Z Plane			Y-Z Plane		
DEGREE	0-Degree (DB)	90-Degree (DB)	DEGREE	0-Degree (DB)	90-Degree (DB)
0	-37	-36	0	-42	-43
15	-37	-36	15	-42	-43
30	-37	-36	30	-41	-42
45	-36	-36	45	-41	-41
60	-36	-36	60	-39	-41
75	-36	-35	75	-38	-41
90	-35	-36	90	-36	-38
105	-36	-37	105	-38	-40
120	-36	-37	120	-39	-41
135	-37	-38	135	-41	-42
150	-37	-37	150	-41	-42
165	-37	-37	165	-42	-42
180	-37	-40	180	-42	-43

From the data it is clear the patch antenna operates correctly with a circularly polarized electric field.

References

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