A Patch Array Antenna Designed for Operation at 5.8 GHz

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Abstract**—A directional two-element recessed rectangular patch array antenna has been designed for operation at 5.8 GHz. The antenna was simulated in Ansoft HFSS and fabricated on an FR-4 substrate. While the simulation results predicted a sufficiently successful radiator at 5.8 GHz, the results of a chamber test reveal that the actual antenna is a better radiator at approximately 6.1175 GHz than at the design frequency.**

I. INTRODUCTION

A directional antenna is required to operate in the 5.725-5.850 GHz ISM band. The antenna interfaces with a standard 50 Ω SMA cable, uses no active electrical components, is designed for linear polarization, and has dimensions of approximately 9.3cm x 7.5cm x 0.5cm. A two-element rectangular microstrip patch array antenna is chosen as a balance between simplicity and peak gain.

II. DESIGN, ANALYSIS, AND FABRICATION

A. Initial Design

The antenna is designed to be fabricated using copper traces on an FR-4 substrate with a height of 59 mils. The substrate is assumed to have a relative dielectric constant of approximately 4.4 at a design frequency of 5.8 GHz. The first step of the antenna design process, an explanation of which is undertaken in greater detail in [1], is to use the substrate properties and desired resonant frequency to calculate the width, abbreviated by W, of the antenna. Fig. 1, adapted from [1], displays the dimensions of the antenna. The equation, which can also be found in [1] is

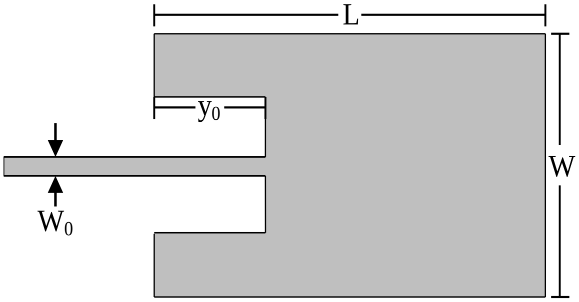


Figure 1. The dimensions of the antenna.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

Next, the effective dielectric constant of the microstrip patch is calculated before further design can be attempted, as the remainder of the equations needed require this value. Equation (2) gives the value for this effective dielectric constant under the assumption that the width of the antenna is greater than the height of the substrate. The equation is found in [1], and is

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{w})^{-1/2} \tag{2}$$

Because of fringing effects, the patch antenna will appear electrically longer than its physical dimensions [1], so this effect must be accounted for in the calculation of the desired patch length. The equation for this extension of length, abbreviated by ΔL is given in [1] and is found in (3).

$$\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3}$$

Since the ΔL lengthening effect appears on both sides of the patch, the process for determining the desired patch length involves subtracting twice the ΔL term from the effective half-wavelength of the substrate at the given frequency [1]. The equation for the physical length of the antenna is found in [1] and is given in (4).

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{4}$$

The input impedance of a rectangular patch is typically fixed at a given frequency, but by removing some of the metallization from the patch, a recessed microstrip-line patch can be created [1]. The input impedance of this patch is dependent on the physical dimensions of the patch and is given in [1] and (5).

$$R_{in} = \frac{\cos(\frac{\pi}{L}y_0)^2}{2\frac{W}{120\lambda_0}(1 - \frac{1}{24}(k_0h)^2)} \tag{5}$$

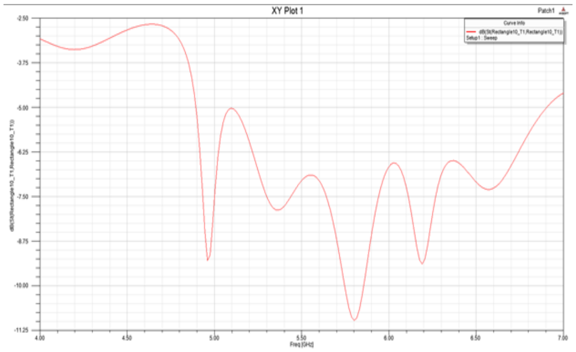


Figure 2. Input reflection coefficient simulated in Ansoft HFSS.

Since the overall input impedance must be 50 Ω for minimum power reflection from the SMA cable and the antenna is designed to have two patches in parallel, an appropriate value for the recess length is chosen such that the input impedance of each antenna is 100 Ω. In order to match the recessed patches to the microstrip lines which feed them, wavelength long 100 Ω lines are used to run from the patches to the half-wavelength 50 Ω line which attaches to the SMA connector. The total electrical length is chosen to be a multiple of one-half wavelength in order to most accurately transform the patch impedances to the 50 Ω line and the 50 Ω line to the SMA connector.

B. Simulation

Prior to fabrication, the antenna is simulated using the Ansoft HFSS software. The complete system is used, and an infinite ground plane is placed 1.5 mm, corresponding to 59 mils, below the antenna. The input reflection coefficient is first simulated to determine how much input power will reach the patches to be radiated. The results are shown in Fig. 2. The minimum is shown to be approximately -11 dB at 5.8 GHz.

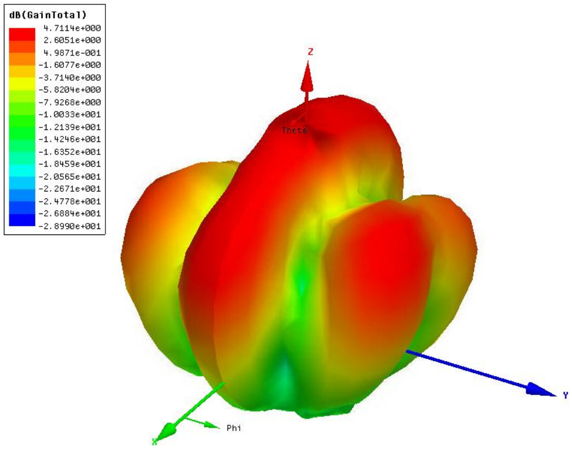


Figure 3. Antenna gain pattern simulated in Ansoft HFSS.

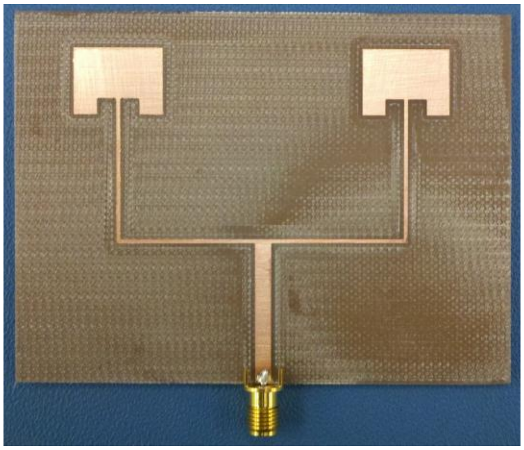


Figure 4. Photograph of the fabricated antenna.

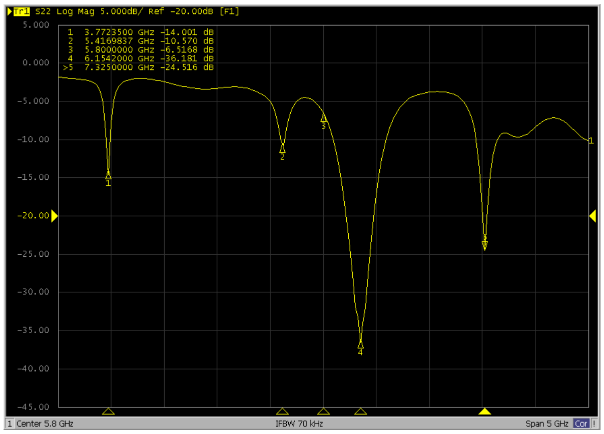
Next, the three-dimensional antenna pattern is simulated in order to determine the expected peak gain at 5.8 GHz. The results are given in Fig. 3. As shown by the plot, the expected peak gain is approximately 4.71 dBi.

C. Layout

After the antenna is simulated, the design is transferred to the Design Spark layout software in order to generate a file useable by the fabrication equipment.

D. Fabrication

Using the file generated by the Design Spark layout software, the final design is fabricated on a 59 mil thick FR-4 substrate at the Georgia Institute of Technology. Fig. 4 displays a photograph of the fabricated antenna.



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Tr1 S22 Log Mag 5.000dB/ Ref -20.00dB [F1]
  1   3.7723500 GHz -14.001 dB
  2   5.4169837 GHz -10.570 dB
  3   5.8000000 GHz -6.5168 dB
  4   6.1542000 GHz -36.181 dB
 >5   7.3250000 GHz -24.516 dB
1 Center 5.8 GHz          IFBW 70 kHz          Span 5 GHz Cor
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Figure 5. Network analyzer measurement of the antenna input reflection coefficient.

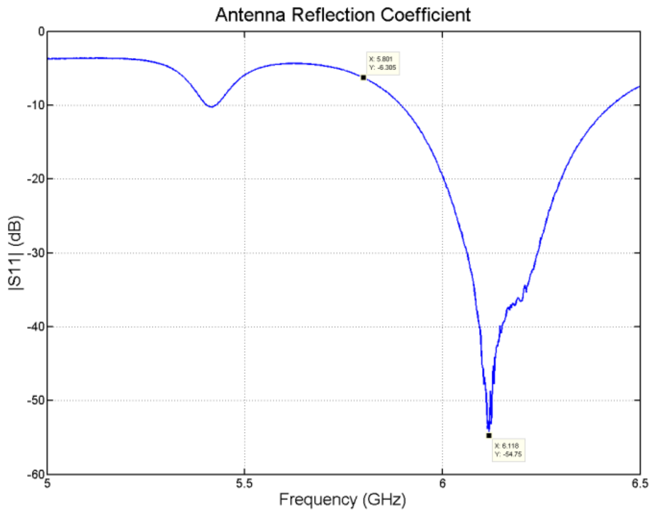

Figure 6. Range measurement of the input reflection coefficient.

III. TESTING AND RESULTS

A. *Network Analyzer*

The antenna is first connected to an Agilent E5071C network analyzer calibrated for one-port measurements in order to determine the input reflection coefficient. The results are given in Fig. 5. Marker 3, in the middle of the plot, shows a reflection of -6.5168 dB at 5.8 GHz. As this is approximately 25% power reflected, it is determined that an error has been made in the assumptions or calculations used to design the antenna. Marker 4, however, displays a reflection of -36.181 dB at approximately 6.1175 GHz. Although this is well out of the ISM band which is the goal of the design, it does present information which hints at an effective antenna around 6.1175 GHz.

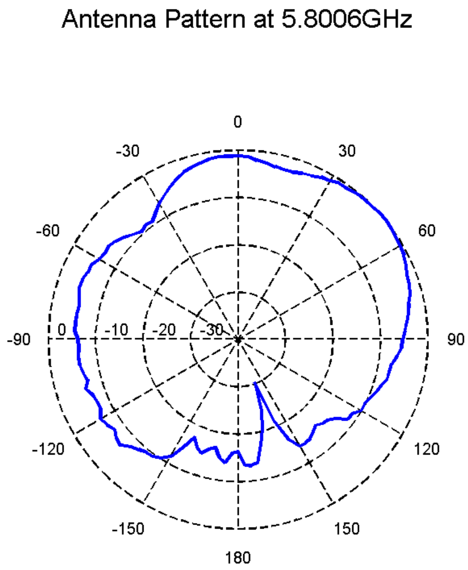

Figure 7. Range measurement of the antenna gain pattern at 5.8 GHz.

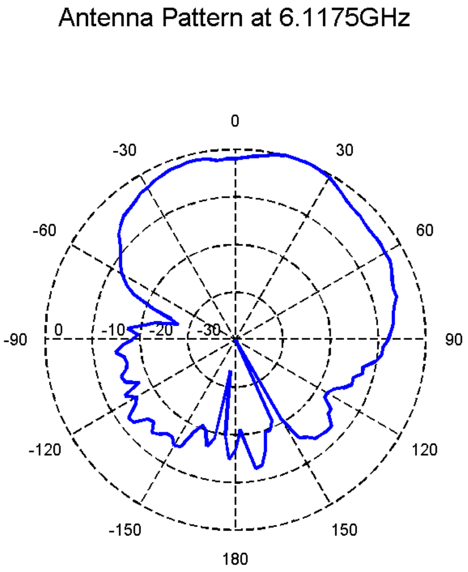

Figure 8. Range measurement of the antenna gain pattern at 6.1175 GHz.

B. *Antenna Range*

The antenna is tested at the North Carolina State University Remote Educational Antenna Laboratory to determine the peak antenna gain, gain pattern, and input reflection coefficient. Data are collected at 3 degree angle increments on the theta-axis. Because of the large drop in reflection coefficient around 6.15 GHz, tests were conducted at multiple frequencies. The magnitude of the reflection coefficient, as measured by the antenna range, is shown in Fig.6. The markers show both a poor reflection coefficient at 5.8 GHz and a large drop in reflection occurs at 6.1175 GHz, both of which are fairly consistent with the results obtained from the network analyzer at the Georgia Institute of Technology. This result, though, is very inconsistent with the simulation results which predicted a strong drop in reflection at 5.8 GHz. The antenna pattern measured at 5.8 GHz is given in Fig. 7 and the pattern measured at 6.1175 GHz is given in Fig. 8. Neither pattern is symmetrical which may be supposed from the design of the symmetrical patch array. The results of the tests at 5.8 GHz and 6.1175 GHz are summarized in Table 1. Of note is that the peak gain of the antenna at 6.1175 GHz is nearly twice that of the same device at 5.8 GHz.

TABLE I. SUMMARY OF TEST RESULTS

Frequency (GHz)	***$\|S_{11}\|$ (dB)***	***Peak Gain (dBi)***	***Angle of Peak Gain (degrees)***
5.8	-6.305	3.332	51
6.1175	-54.75	6.163	18

IV. CONCLUSIONS

A directional two-element recessed rectangular patch array has been designed, analyzed, fabricated, and tested. Though the theoretical mathematics predicted a peak gain of approximately 4.71 dBi at the design frequency, the fabricated antenna achieves 3.332 dBi of peak gain at the design frequency. Because the antenna achieves a peak gain of 6.163 dBi at 6.1175 GHz, it is believed that the frequency error can be attributed to a poor approximation of the relative dielectric constant of the FR-4 substrate on which the antenna was fabricated.

ACKNOWLEDGMENT

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REFERENCES

[1] C. Balanis, “Microstrip Antennas,” in Antenna Theory, 3rd ed. John Wiley & Sons, Inc. Hoboken, New Jersey: 2005, pp. 811–825.