Design and Characterization an Equiangular Spiral Antenna

Christopher Hastreiter, Andrew Mauragis, Kevin Nelson, Joseph P Seblonka

Department of Electrical Engineering
Michigan Technological University, Houghton, MI, 49931, United States of America
crhastre@mtu.edu, apmaurag@mtu.edu, knelson@mtu.edu, jpseblon@mtu.edu

I. INTRODUCTION

The equiangular antenna belongs to a very unique class of antennas which exhibit extremely high bandwidth ratios. We developed our antenna based upon the work of John Dyson, who claimed extraordinary results in his 1959 paper [1]. Dyson claimed to have built an antenna that maintained a VSWR under 2 from 600MHz to over 10GHz, and an antenna efficiency of over 90% across the spectrum.

Our goal was to verify the results presented by Dyson.

II. DESIGN OF THE ANTENNA

The antenna constructed here is the slot variant of the equiangular spiral antenna. The antenna itself consists of a logarithmic spiral slot cut out of a conducting plane.

The logarithmic spiral is defined by the equation (in the polar coordinate system)

$$\rho = ke^{a\phi} \tag{1}$$

where ρ_1 and ϕ are conventional polar coordinates, and k and a are positive constants.

The edges of the equiangular antenna are created by defining two curves

$$\rho_1 = ke^{a\phi} \tag{2}$$

and

$$\rho_2 = K\rho_1 \tag{3}$$

where

$$K = e^{-a\delta} \tag{4}$$

such that the second angle is a rotated version of the first angle, by the fixed angle δ. The K value for the antenna we designed was chosen to be 0.597.

The length of the spiral may be calculated from

$$L = \int_{\rho_0}^{\rho} \left[\rho^2 \left(\frac{d\phi}{d\rho}\right)^2 + 1\right]^{1/2} d\rho \tag{5}$$

which reduces to

$$L = [a^{-2} + 1]^{1/2}(\rho - \rho_0). \tag{6}$$

The maximum diameter of the antenna we designed was set to be 9 3/16 inches.

The center of the antenna breaks the logarithmic spiral pattern and must be designed separately. We chose one of the three spiral termination techniques given by [1], and estimated the shape of the termination for our antenna. The spacing between the two arms of the antenna is 0.0625, which was set based on the tolerance of the CNC machines available to us. Simulation showed that narrower gaps between the arms significantly improved the bandwidth of the antenna.

The outer edges of the antenna spiral also break the logarithmic pattern and must be designed. We chose to terminate the spirals with an arc such that the derivative of the arc and the derivative of the outer spiral were approximately equal. The arc center was chosen based on estimation and trial and error through simulation.

III. CONSTRUCTION

The antenna is constructed out of a 14x14 inch wide by 1/32 inch thick sheet of copper. The slot was machined using a CNC plasma torch, and all rough edges were removed manually. The copper sheet was fastened to an acrylic sheet for stability using a strong adhesive.

The logarithmic spirals for the antenna were generated using Wolfram Mathematica. The spiral was evaluated at a fine resolution, and then the points of the spiral were exported into the SolidWorks 3D CAD software. The inner spiral termination and outer spiral caps were designed in SolidWorks using an estimation procedure.

Figure 1: A photo of the completed antenna

The antenna is fed with standard coax hardline, bonded to the spirals of the antenna with solder. The coax chosen was donated by our department, and did not have a data sheet or specifications.

The antenna is driven by feeding one of the coax cables through an SMA connector. The outer edge of the hardline is bonded to one spiral, and the inner conductor is bonded to the other at the termination of the spiral. The second hardline is parasitic, and is provided only to balance the far field pattern. It is necessary because the coax cable approaches the diameter of the spiral near the inside of the antenna.

IV. SIMULATION AND THEORETICAL VALUES

The antenna models were created using the software package FEKO. FEKO was chosen due to its modeling interface that allows easy entry of these complex slot type geometries. The FEKO solver is a MoM solver which gives an efficient computation of the far fields for a plate antenna. This software allows geometry importing from external CAD software, so the model from SolidWorks was directly imported. From there, FEKO simply requires the inclusion of a feed point definition and the modeling portion was complete. Solutions at 1GHz and 10GHz were calculated to give a far field representation at both the bottom and top of the expected antenna bandwidth. Due to limitations in the solving computer, the antenna was meshed in a coarse mode, resulting in about 50,000 triangles. After meshing and calculation the far field results were plotted.

At 1GHz the model predicts the dual lobed pattern expected from [1].

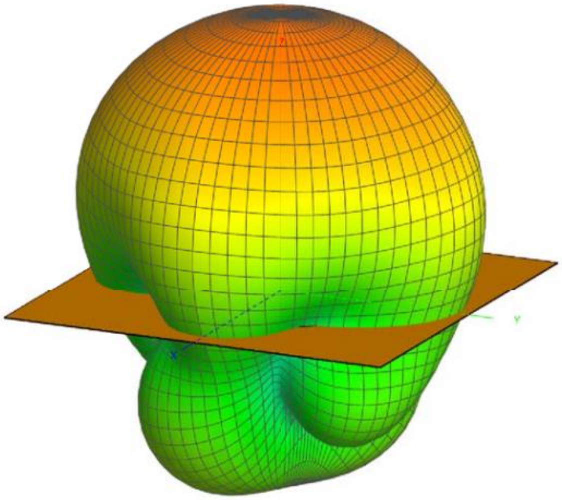

Figure 2: 1 GHz FEKO Farfield Simulation

However, at 10GHz the far field pattern begins to deviate from the expected pattern because of the bandwidth limitations imposed by the widening of the innermost spiral.

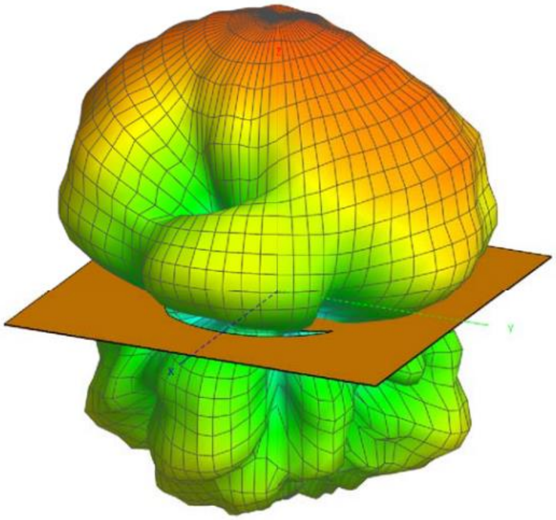

Figure 3: 10 GHz FEKO Farfield Simulation

FEKO estimated the VSWR of the antenna to be about 3:1, which is much higher than the expected results. This is likely due to the fact that the integrated feedline's shape and location on the antenna act as a balun to match the antenna to 50 Ohm coax, while the model assumed a 50 Ohm feed directly at the antenna. Modeling this feed system was attempted, but at this time FEKO does not support the creation of coax lines within the radiative model for the impedance calculations so the results were inconclusive.

V. CHARACTERIZATION RESULTS

The antenna was taken to an electromagnetic anechoic chamber where it was characterized from 400MHz to 3GHz, stepping in 100MHz increments. While the theoretical bandwidth of the antenna is higher, our equipment was only capable of reaching 3GHz.

Azimuthal slices of the antenna were taken at each of the frequencies in both feed-down and feed-right orientations. From the gathered data set, polar plots of the magnitude of the antenna far field radiation pattern were generated. These plots were not normalized, though the scale of the plots is essentially meaningless because the chamber was not calibrated prior to use. However, the plots do give an accurate representation of the shape of the far field pattern.

The VSWR of the antenna was measured prior to taking the frequency sweeps. The antenna exhibited a VSWR of under 2.0 for all frequencies higher than 600MHz. Our equipment was capable of measuring the VSWR up to 3GHz.

At 920 MHz, the antenna displays the expected field.

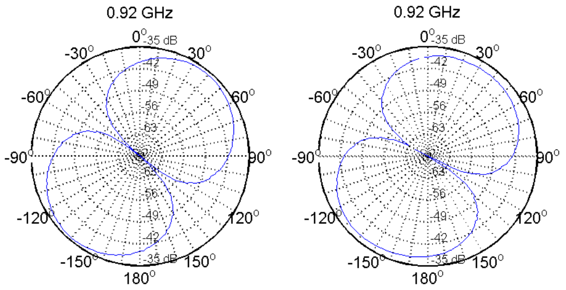

Figure 4: Down and Right Feed, Far-field at 920MHz

The far-field pattern is dipole like, and shows two symmetric about the antenna plane.

The antenna shows a similar pattern at 608MHz and 504Mhz. At 400MHz, the pattern begins to break down, as shown below. This is because the antenna spiral is not resonant to wavelengths this long.

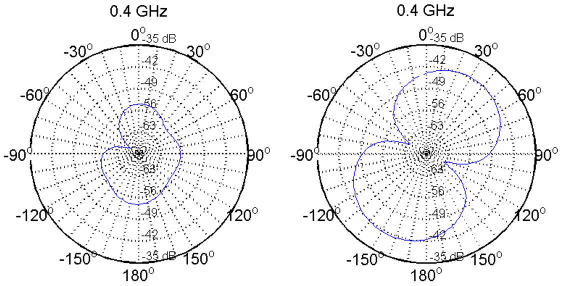

Figure 5: Down and Right Feed, Far-field at 400MHz

The lower bound on our antenna was accurately predicted by our model.

The antenna produced predictible patterns up to 3GHz. The attenuation seen in these plots most likely comes from the feedline connecting our network analyzer to the chamber. To verify this, more calibration work would need to be done on the chamber.

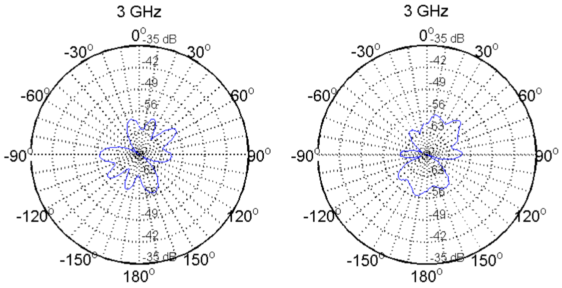

Figure 6: Down and Right Feed, Antenna Far-Field Pattern

The directivity of our antenna was calculated by finding the approximation to the solid angle of the antenna using the half power beam widths.

$$D \approx \frac{41000}{HP_{\phi} HP_{\theta}}$$

By inspection, the half power beam widths of our antenna were 55 degrees and 60 degrees at 920GHz, producing a directivity of $D \approx 12$ (10.9dB).

VI. CONCLUSIONS

Our antenna produced excellent results from 600MHz to 2.792GHz. Above that frequency our results were possibly inclusive due to the losses in the feed line of the chamber. Further work could be done to characterize the equiangular spiral antenna above 3.0 GHz. More detailed VSWR measurements could be recorded. Also, the chamber could be calibrated to determine the exact losses inherent in the antenna, which would be necessary to determine the antenna efficiency.

Our results did not verify the full claims by Dyson in his paper, but our antenna exhibited impressive results across the frequencies we were able to measure.

References

[1] John D. Dyson, “The Equiangular Spiral Antenna,” *IRE The Transactions of Antennas and Propagation*, vol. AP -7, pp. 181-187, April 1959.