

ULTRA-WIDE BAND SPIRAL ANTENNA

FINAL PROJECT REPORT



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1. ABSTRACT

The goal of this project is to design and develop an ultra-wide band antenna which can receive signals from 800 MHz to 6 GHz. An equiangular spiral antenna topology is chosen to be modeled using Microwave Office RF simulation tool. An antenna prototype is built and measured to see if it meets all specifications. The antenna gain, input and output return losses and radiation patterns for various frequencies are measured, compared and properly documented in this report.

2. INTRODUCTION

The first very wide-band antenna using spiral topology was invented by Ed Turner in 1950s. Rumsey advanced the equiangular spiral theory in 1954 and then, Burdine and Jones, et al. helped explain its performance in 1960s. [6]

The spiral antenna can be left-hand or right-hand circularly polarized. The advantage of the spiral antenna is that it has a very wide band but its weakness is that it has a very low gain.

The spiral antenna can be excited by driving opposite arms with equal amplitude opposite phases 0° & 180° . The most popular design is based on the Archimedean Spiral Equation such as:

$$\begin{aligned} r_1(\phi) &= (d+w) \phi / 360^\circ + r_a, & \varphi_i < \phi < \varphi_e \\ r_2(\phi) &= (d+w) (\phi - 180^\circ) / 360^\circ + r_a, & \varphi_i + 180^\circ < \phi < \varphi_e + 180^\circ \end{aligned}$$

where, $r_1(\phi)$ is the radial distance from the origin to the arbitrary point on the centerline of the spiral, $r_1(\phi)$ the winding angle , and d the radial distance between initial point and ending points after one turn. r_a is the radial distance from the origin to the initial point of the spiral line, with w the line width designed as 50Ω . [10]

The Spiral Antenna can be built using a Copper sheet or Microstrip Lines. An example of a spiral antenna built is shown in figure (1).



Figure (1) A Sample Microstrip Spiral Antenna

2.1. S-Parameters

S-parameters are pretty critical in the Microwave Engineering projects because all RF design simulations are applied and analyzed using these parameters. S-Parameters are the Scattering Parameters defined from the incident voltage (V_i), the reflected voltage (V_r) and the transmitted voltage (V_t). The voltage at each port of the network is equal to the summation of the incident and reflected voltages. The maximum power is transferred to the network when the impedance of the source and network are equal.

The S-parameters of the n-port network can be shown as $[V_r] = [S] [V_i]$, where $[V_r]$ is the matrix of reflected voltages, $[S]$ is the matrix of S-Parameters and $[V_i]$ is the matrix of indent voltages from each port.

Then, the S-parameters of the 2-port network are given by:

$$S_{11} = V_{r1} / V_{i1}, S_{12} = V_{t1} / V_{i2}, S_{21} = V_{t2} / V_{i1}, S_{22} = V_{r2} / V_{i2}$$

Matching impedance of the antenna to 50Ω so that it will be equal to the source impedance to get a decent input return loss (S_{11}) is the goal of my project. The relationship of Input Return Loss (S_{11}) and Voltage Standing Wave Ratio (VSWR) table is also mentioned in the Appendix A.

2.2. Specifications

The project proposed model should meet the following specifications:

- Frequency Range: From 800 MHz to 6 GHz
- S11: < 15 dB
- Size: 8" x 8"
- Circularly Polarized
- Unidirectional
- 50Ω Impedance

3. DESIGN AND SIMULATIONS

A Microstrip line of width 40 mils and length 10 mils is used as a center point for 2-arms spiral antenna simulation in Microwave Office as shown in figure (2) below.

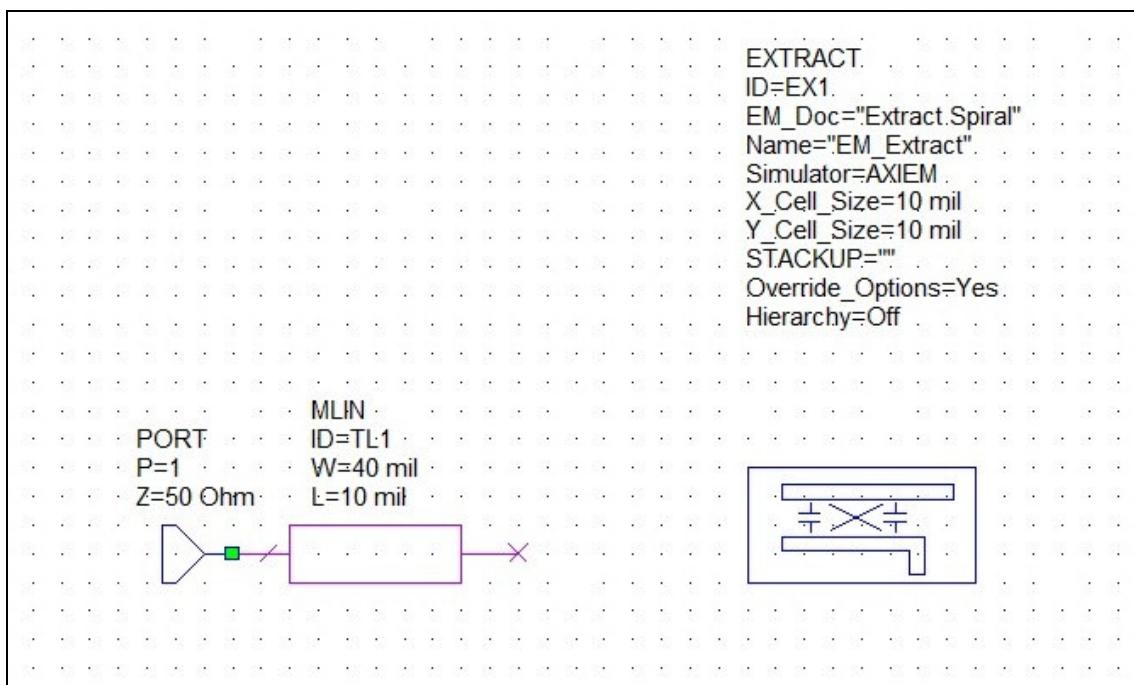
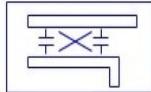


Figure (2) Spiral Schematic in Microwave Office

Then, an extraction block as shown in figure (3) is used to apply the schematic element for the simulations Microwave EM Structure.

Extraction Control Block: EXTRACT

Symbol



Summary

The EXTRACT block is a simulation control that allows a group of associated schematic elements to be electrically modeled via a physical simulation (for example, EM simulation or parasitic extraction) of the layout of these components. Upon simulating, the layout cells of all of the associated components are ported to an EM document and simulated. After this simulation is complete the electrical results are automatically merged back into the schematic and simulation of the entire schematic is performed. See [Section 8.1, “Creating EM Structures with Extraction”](#) for a detailed explanation of the EM-extraction process.

Figure (3) Extract Control Block

A spiral-shaped microstrip with two arms as shown in figure (4) is drawn in the EM structure so that the input return loss and radiation pattern of the antenna can be simulated using AWR AXIEM features.

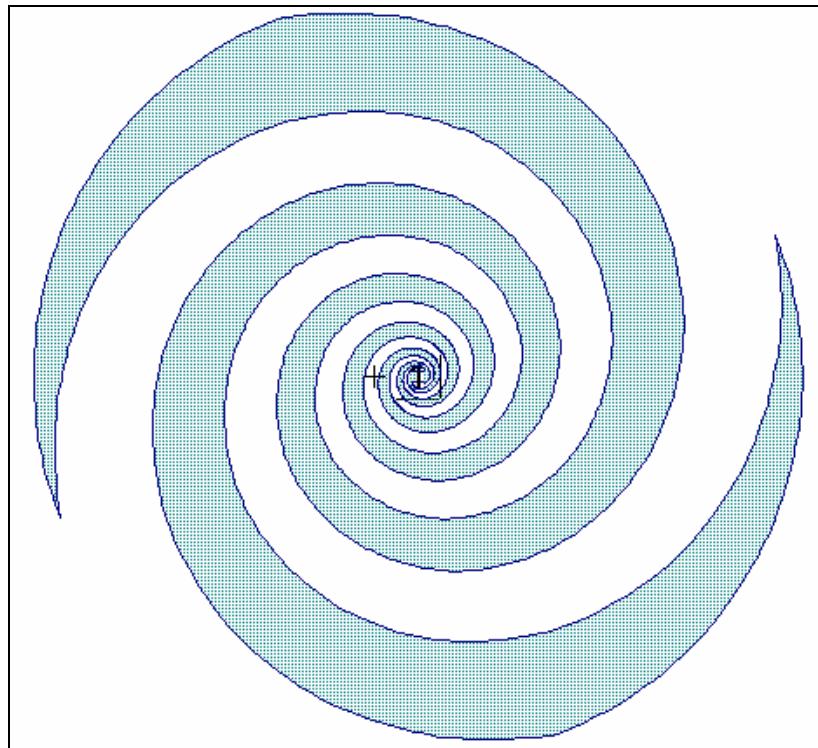


Figure (4) Spiral EM Structure

Actually, this spiral-shaped metal is an 1-oz copper strip on a di-electric substrate with a copper ground plane as seen in the following figure (5).

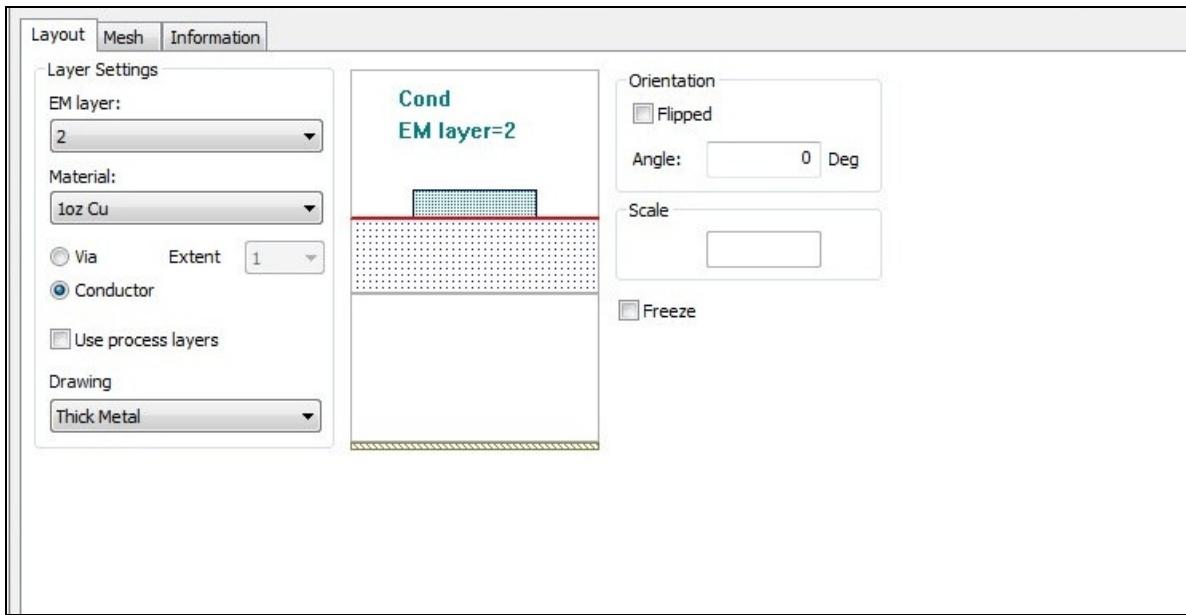


Figure (5) Spiral Copper Layout

Initial simulation results of Right-Hand Circularly Polarized Radiation Patterns, Left-Hand Circularly Polarized Pattern and Input Return Loss (S_{11}) of the spiral EN Structure are shown in the figure (6) as follows.

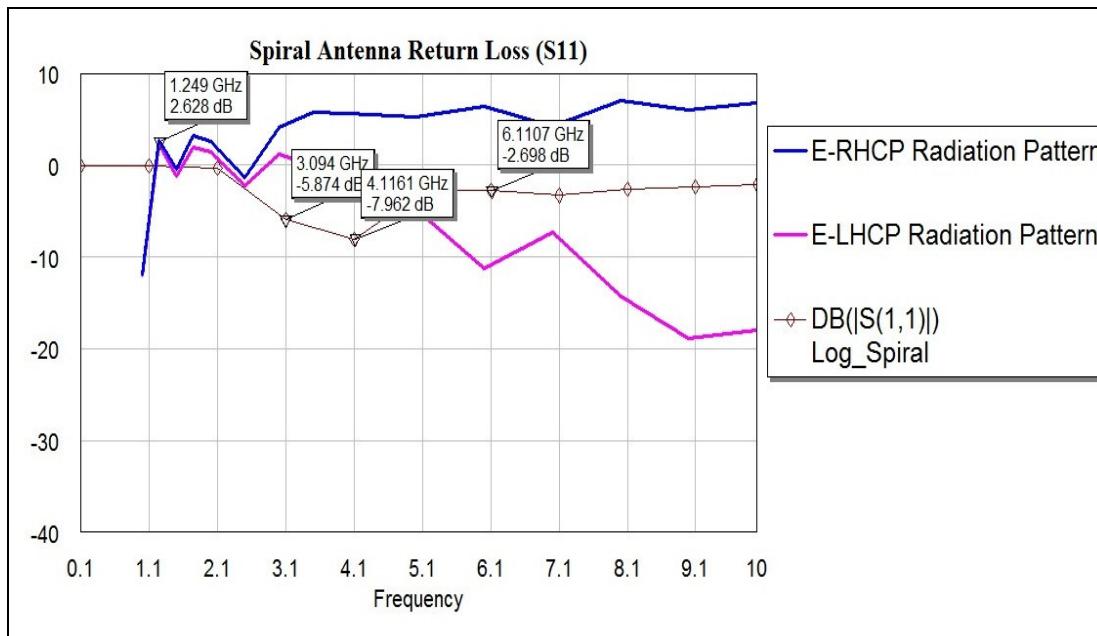


Figure (6) RHCP, LHCP radiations Patterns and Initial Simulation S11

Then, the RHCP and LHCP radiation patterns are simulated and plotted in the Azimuth degrees as seen in the following figure (7).

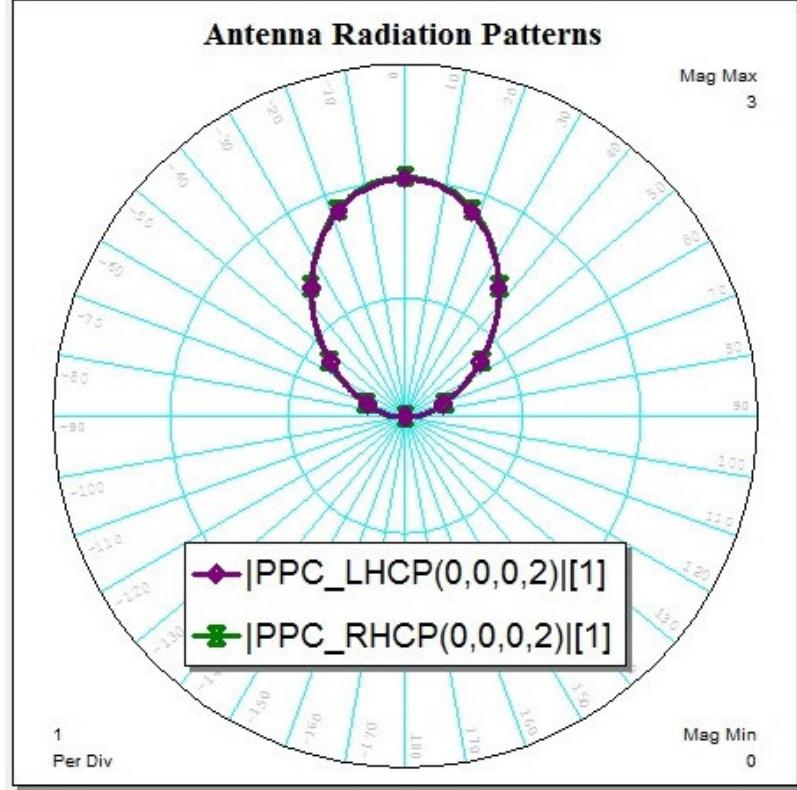


Figure (7) LHCP and RHCP Radiation Patterns in Azimuth system

After trying a couple of simulations in the AWR EM Structure, the following S11 graph represents the best result in a couple of trials.

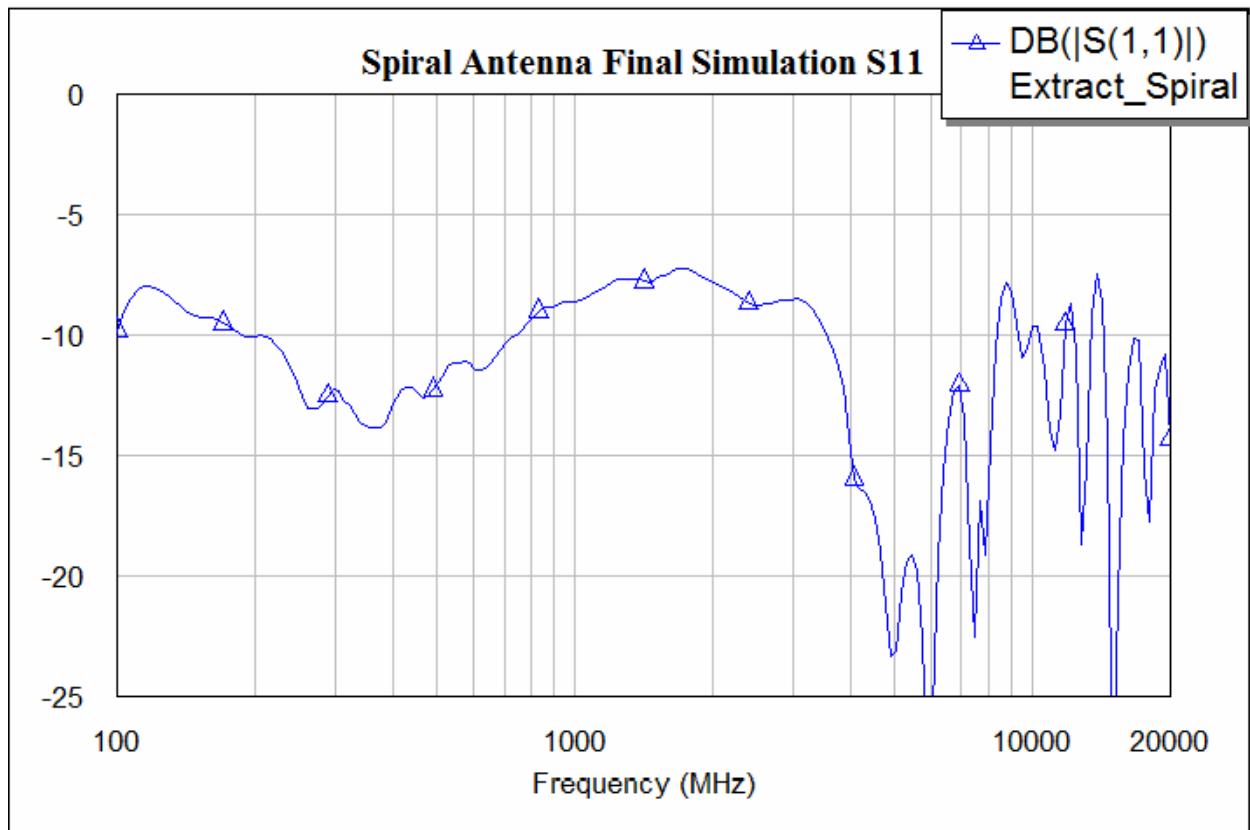


Figure (8) Initial Simulated Input Return Loss (S11)

Even though, this simulation doesn't meet initial S11 specification as desired, I decided to give it a try with building a prototype.

4. PROTOTYPE DEVELOPMENT AND TESTS

The proposed spiral antenna structure has exactly 8 inch from the center point of the spiral to the end point of each of the arms. An actual-sized paper of the spiral antenna structure is printed to mark the patterns on the copper sheet as seen in figure (9) and the finally incised spiral patterns can be seen in figure (10).

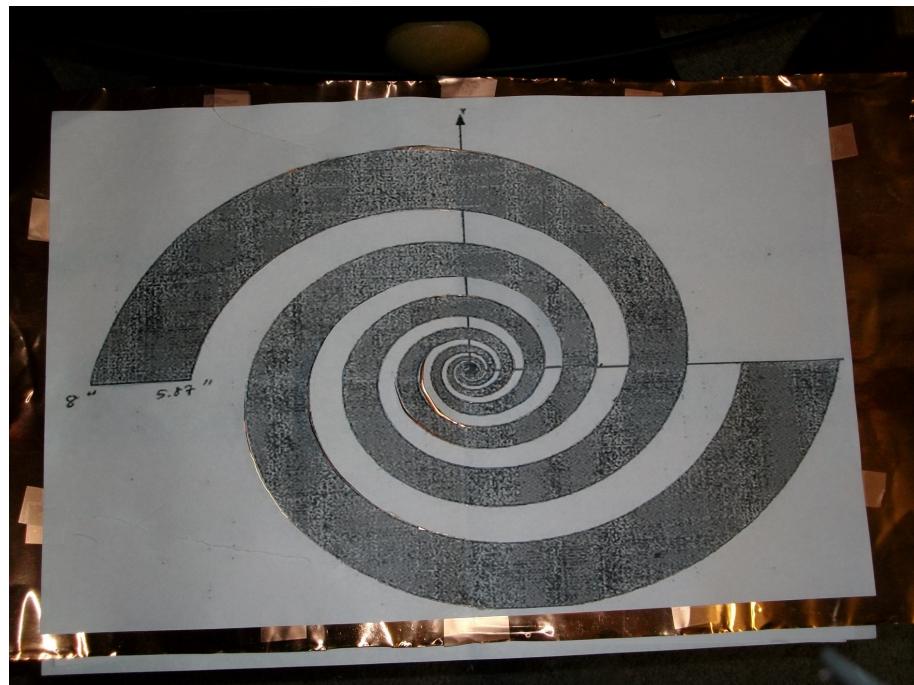


Figure (9) Spiral Pattern printed on paper



Figure (10) Spiral Patterns on Copper Sheet

Finally, 2 copper arms of the spiral antenna were cut and put together on an 1.5 inch thick white foam as seen in figure (11).



Figure (11) Two Spiral-shaped Copper Arms on a white foam

A semi-rigid cable was used to connect the spiral arms, one with the center connector of the cable and another with the ground of the cable as shown in figure (12).

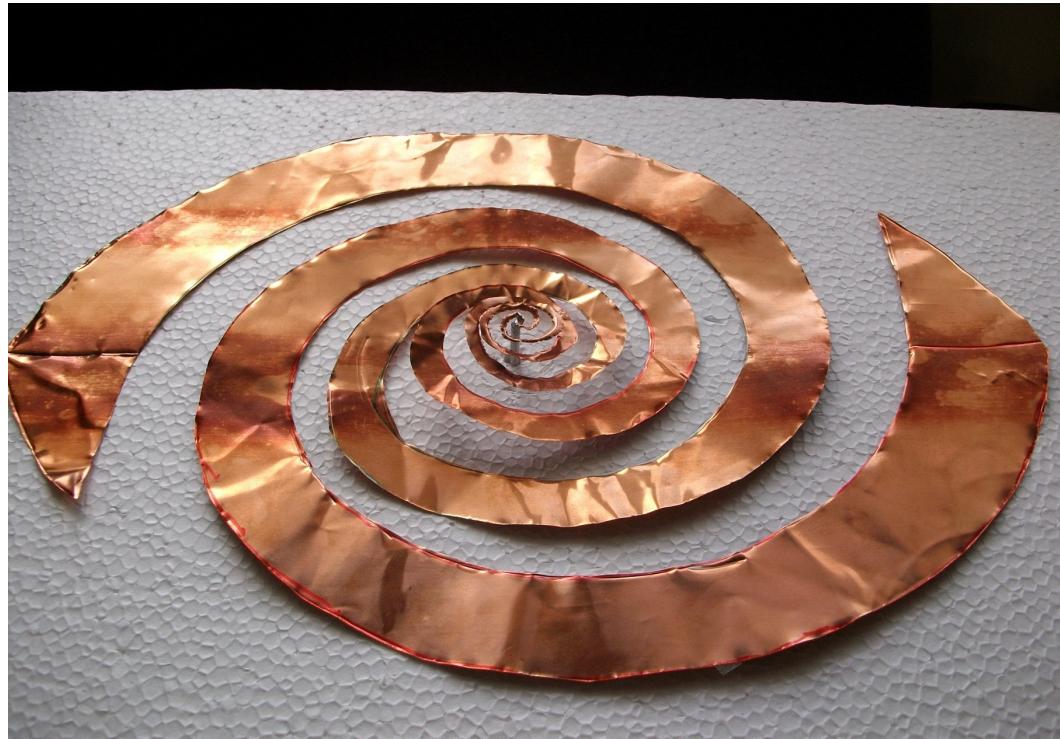


Figure (12) Copper Arms Connected with SMA Cable

The other end of the cable is protruding at the bottom of the foam and connected with an SMA connector as seen in figure (13).



Figure (13) SMA Connector from the Bottom

Then, the spiral antenna prototype is ready to be tested with a network analyzer test set-up as shown in figure (14).



Figure (14) Spiral Antenna Test Setup

5. RESULTS

5.1. First Prototype Measurements

The measured S11 graph is depicted in figure (15) in Magnitude plot. It was around -6 dB from 500 MHz to 8 GHz and it gets better with around -8dB until 20 GHz.

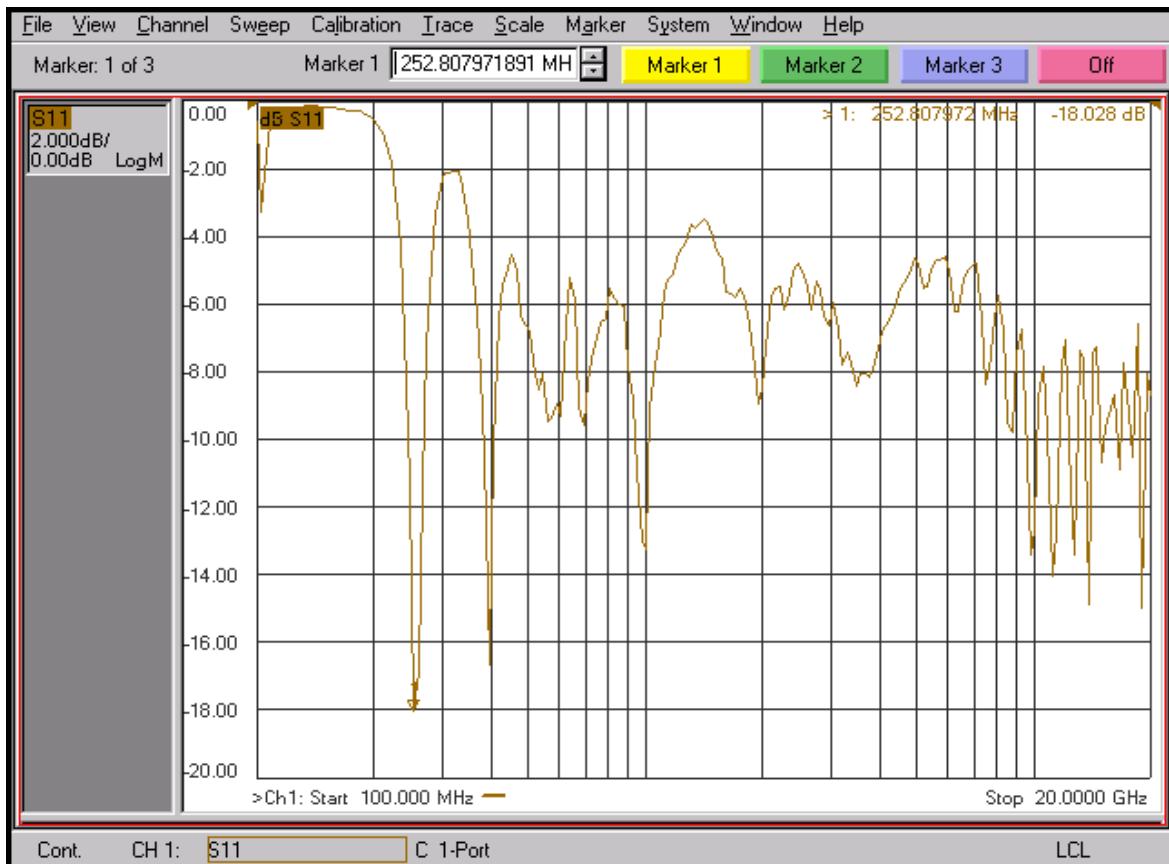


Figure (15) Spiral Antenna Input Return Loss (S11)

The measured S11 graph in Smith Chart is also shown in figure (16) as follows.

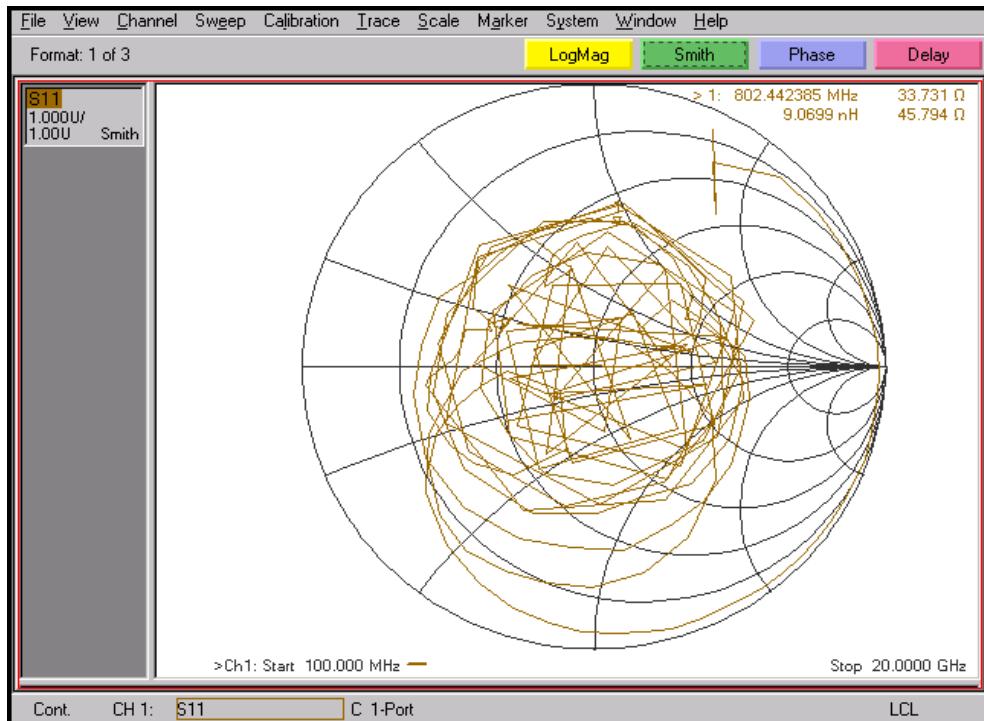


Figure (16) Spiral Antenna Input Return Loss (S11) Smith Chart

Even though, the result is not bad, it certainly is not satisfying. Then, I was reminded to put a ground plane at the foam and try it again by Professor Kwok. Aluminum tapes are used to put ground plane at the bottom of the foam and connected to the ground of the cable as shown in figure (17).

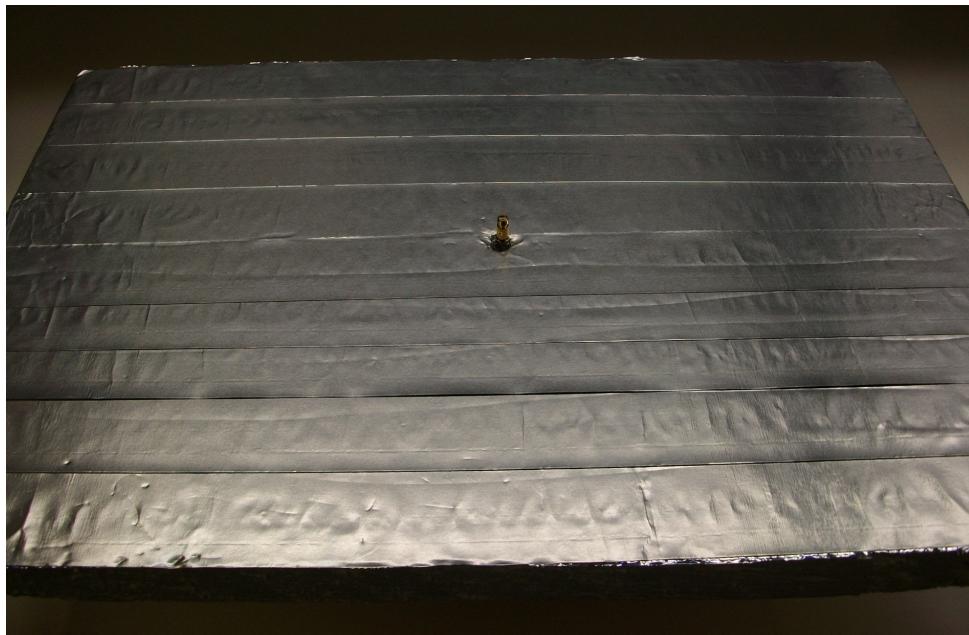


Figure (17) Ground Metal Tape at the Bottom

The result got absolutely better as shown in figure (18). All the S11 frequencies are now matched down to -7.5 dB from 800 MHz to around 12 GHz. The measured spiral S11 and S22 graphs are also compared in this figure.

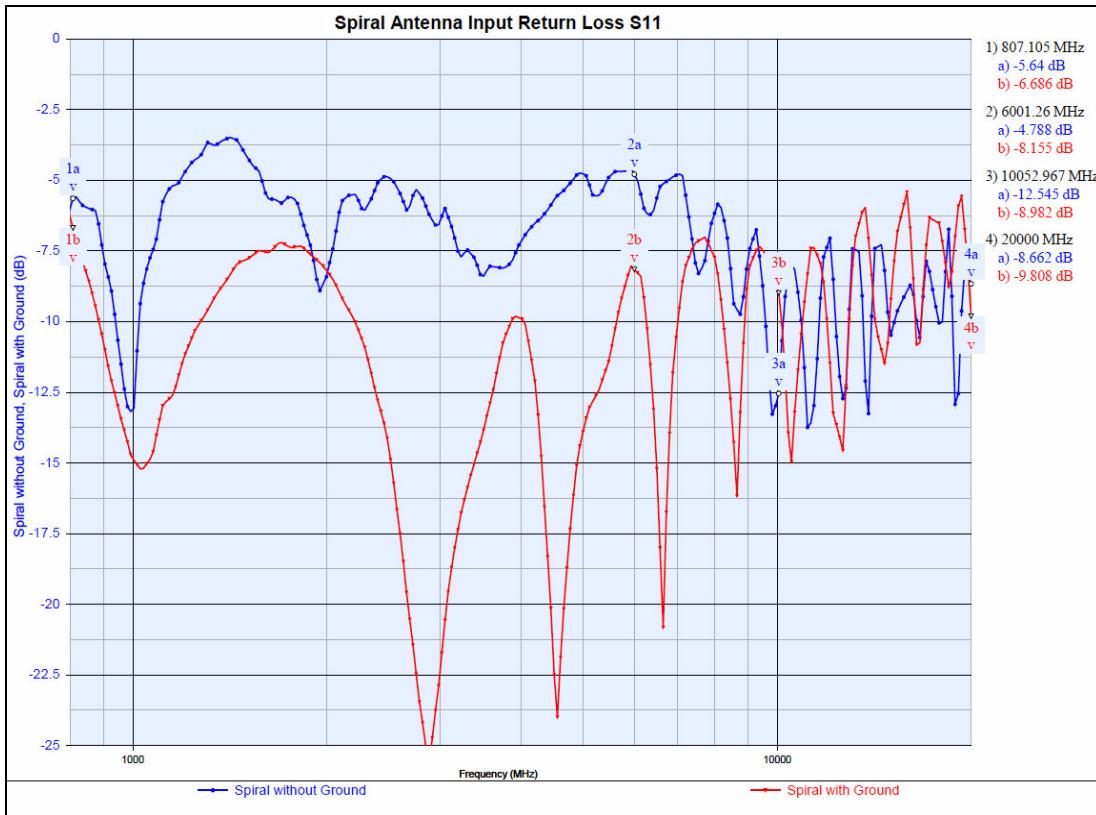


Figure (18) S11 Comparison of Spiral Antenna with GND and without GND

5.2. Final Measurements

The results are satisfying although they don't quite resemble the simulation graph. It might be because the first spiral prototype is rather an elliptical shape than an exactly circularly spiral shape. Thus, an exact circular –shaped antenna was built and measured again in hope of getting a better antenna matching than the first try.

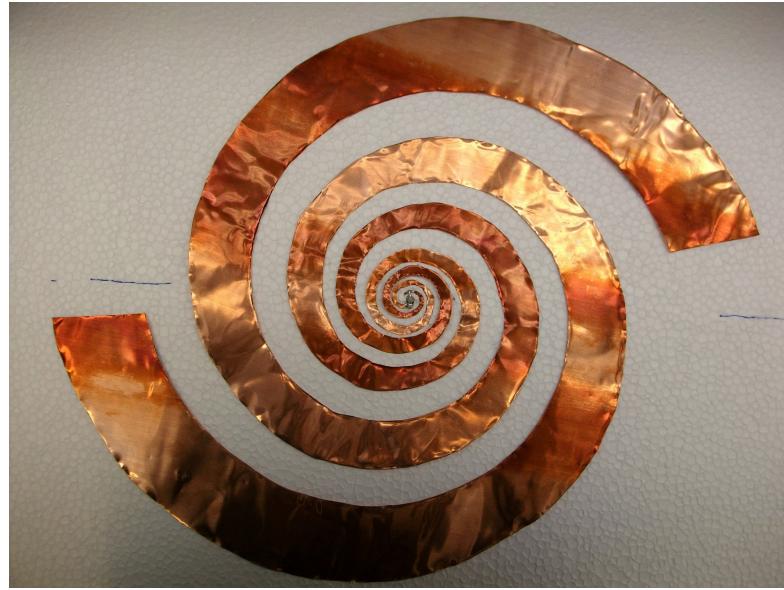


Figure (19) Second Spiral in Circular Shape

The second spiral prototype was shown in figure (19) and its measured S11 results are depicted in figure (20) and figure (21) respectively.



Figure (20) Final Measured Input Return Loss (S11)

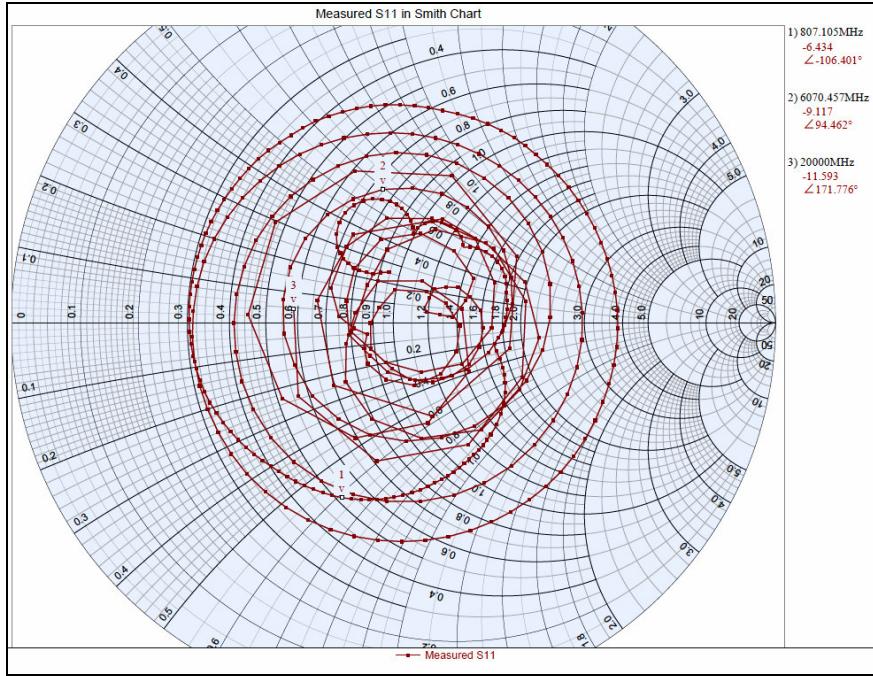


Figure (21) Final Measured S11 in Smith Chart

The final prototype measurement didn't improve much in terms of matching up to around 4 GHz but it definitely resembles the simulation graph and get better at high frequencies up to 20 GHz as compared in figure (22) shown below.

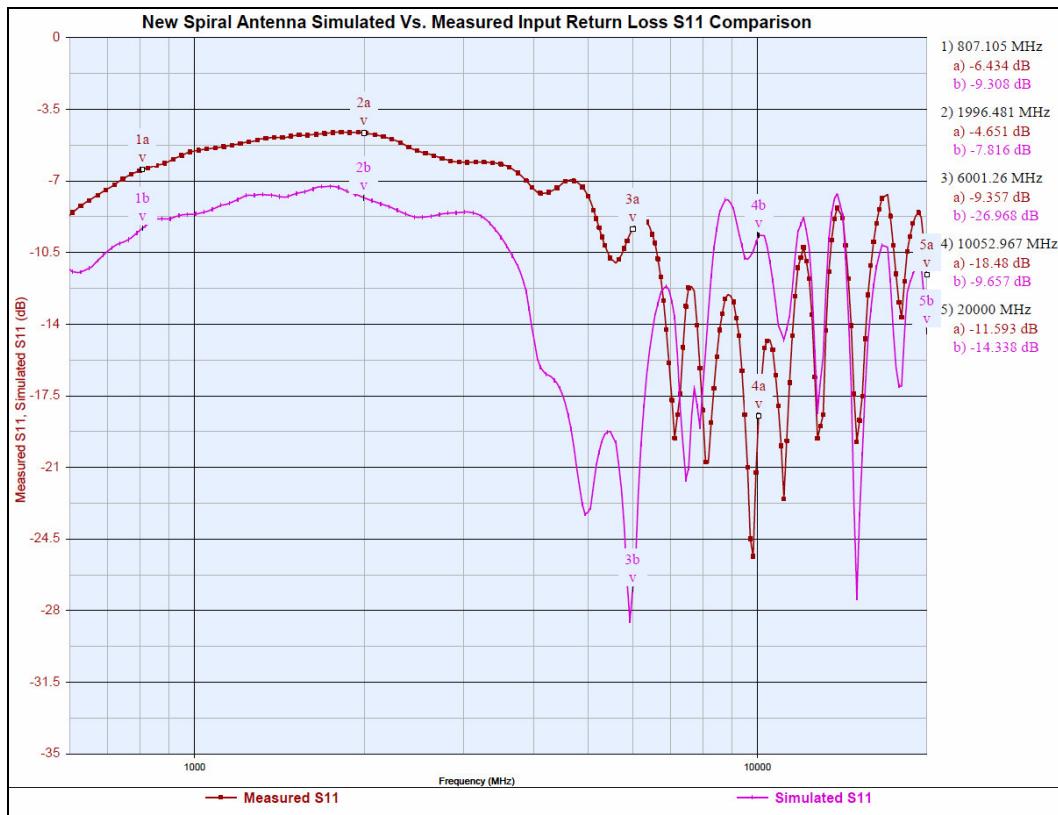


Figure (22) Simulated Vs. Measured Final Input Return Loss (S11)

The following figure (23) shows the Gain (S21) of the spiral antenna. The graph peaks at around 800 MHz with about -11 dB and decreases as the frequencies goes up to 20GHz.

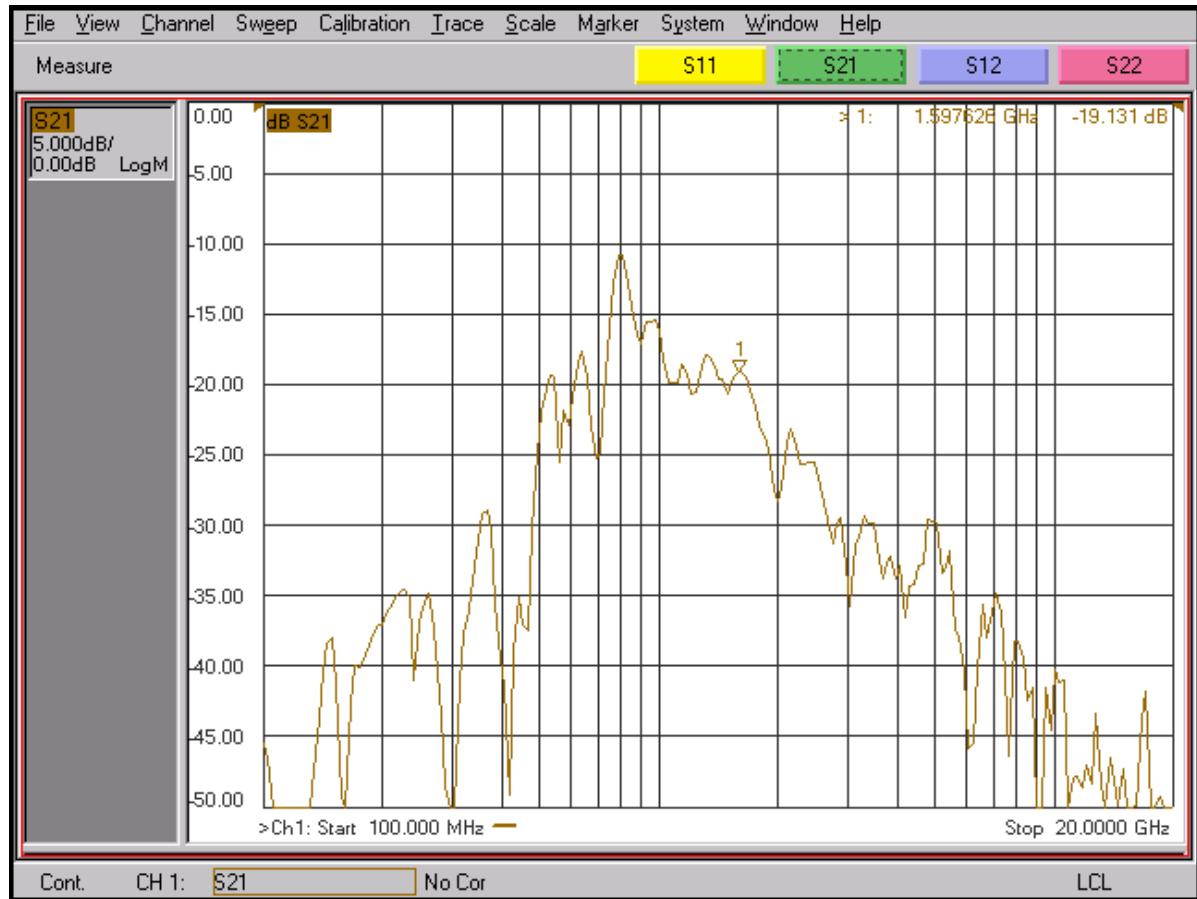


Figure (23) Final Measured Antenna Gain (S21)

And then the antenna radiation patterns are plotted in Spreadsheet using the measured gain data at 800 MHz, 6 GHz and 20 GHz respectively as shown in figure (24).

F = 800 MHz		Y loop					X loop				
Azimuth (deg)	Gain (dB)	nor	x	y		Gain (dB)	nor	x	y		
0	-18.99	30.00	30.00	0.00		2.18	30	30.00	0.00		
45	-19.62	29.37	20.77	20.77		-0.69	27.13	19.18	19.18		
90	-34.77	14.22	0.00	14.22		-0.99	26.83	0.00	26.83		
135	-40.40	8.59	-6.08	6.08		-1.31	26.51	-18.75	18.75		
180	-41.38	7.61	-7.61	0.00		-1.66	26.16	-26.16	0.00		
270	-32.61	16.38	0.00	-16.38		-2.04	25.78	0.00	-25.78		
315	-19.63	29.36	20.76	-20.76		-2.44	25.38	17.95	-17.95		
360	-18.99	30.00	30.00	0.00		-2.87	24.95	24.95	0.00		

F = 6 GHz		Y loop					X loop				
Azimuth (deg)	Gain (dB)	nor	x	y		Gain (dB)	nor	x	y		
0	-42.30	30.00	30.00	0.00		6.52	30	30.00	0.00		
45	-45.26	27.04	19.12	19.12		6.52	30	21.21	21.21		
90	-60.55	11.75	0.00	11.75		6.5	29.98	0.00	29.98		
135	-62.42	9.88	-6.98	6.98		6.48	29.96	-21.18	21.18		
180	-63.48	8.82	-8.82	0.00		6.44	29.92	-29.92	0.00		
225	-66.01	6.29	-4.45	-4.45		6.39	29.87	-21.12	-21.12		
270	-67.39	4.91	0.00	-4.91		6.33	29.81	0.00	-29.81		
315	-52.12	20.18	14.27	-14.27		6.26	29.74	21.03	-21.03		
360	-42.30	30.00	30.00	0.00		6.18	29.66	29.66	0.00		

F = 20 GHz		Y loop					X loop				
Azimuth (deg)	Gain (dB)	nor	x	y		Gain (dB)	nor	x	y		
0	-57.04	30.00	30.00	0.00		4.76	30	30.00	0.00		
45	-60.07	26.97	19.07	19.07		4.76	30	21.21	21.21		
90	-69.78	17.26	0.00	17.26		4.74	29.98	0.00	29.98		
135	-76.74	10.30	-7.28	7.28		4.71	29.95	-21.18	21.18		
180	-82.99	4.05	-4.05	0.00		4.68	29.92	-29.92	0.00		
225	-75.38	11.66	-8.24	-8.24		4.63	29.87	-21.12	-21.12		
270	-67.90	19.14	0.00	-19.14		4.57	29.81	0.00	-29.81		
315	-63.71	23.33	16.50	-16.50		4.5	29.74	21.03	-21.03		
360	-57.04	30.00	30.00	0.00		4.42	29.66	29.66	0.00		

Figure (24) Measured Antenna Patterns Calculation in Excel

Figure (25) is the measured Radiation pattern at 800 MHz, very similar to the simulation pattern.

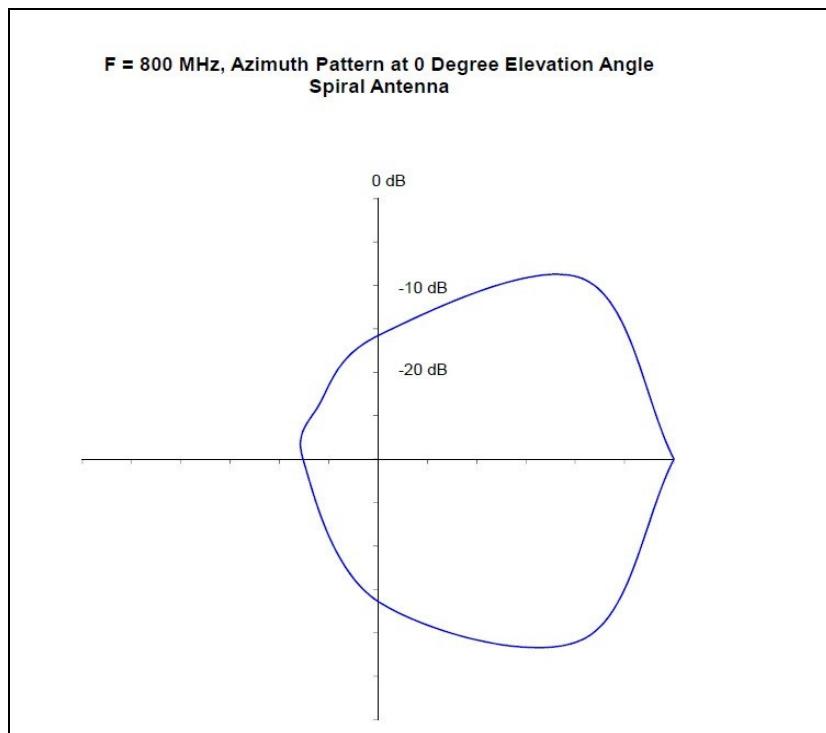


Figure (25) Measured Spiral Radiation Pattern at 800 MHz

Figure (26) is the measured Radiation pattern at 6 GHz. Even though, it was a little different with the pattern at 800 MHz, it is still unidirectional and resembles the simulation pattern.

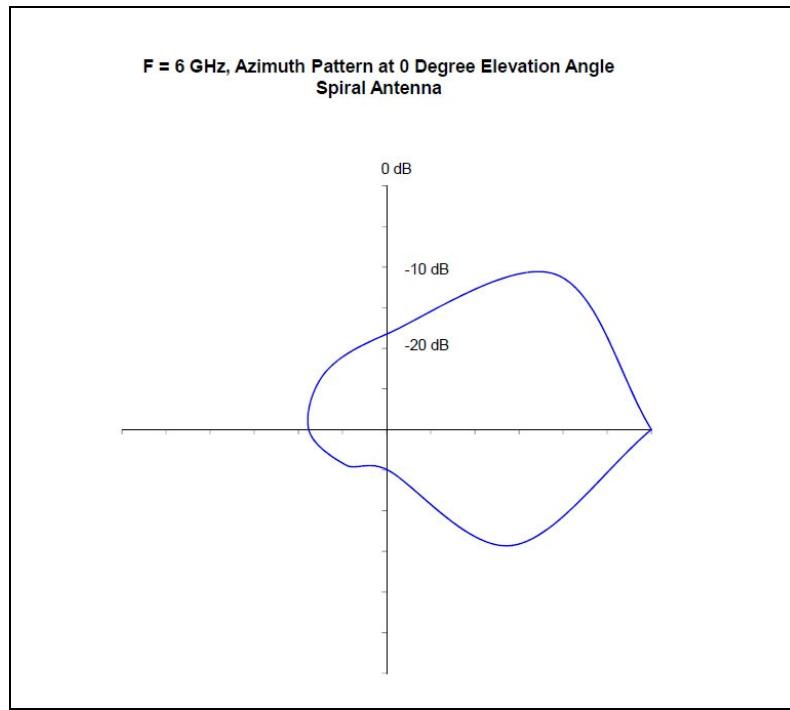


Figure (26) Measured Spiral Radiation Pattern at 6 GHz

The last figure represents the antenna Radiation Pattern at the 20 GHz. It still maintains the circular pattern although it has a dent at the 180° in Azimuth system graph as shown in figure (27).

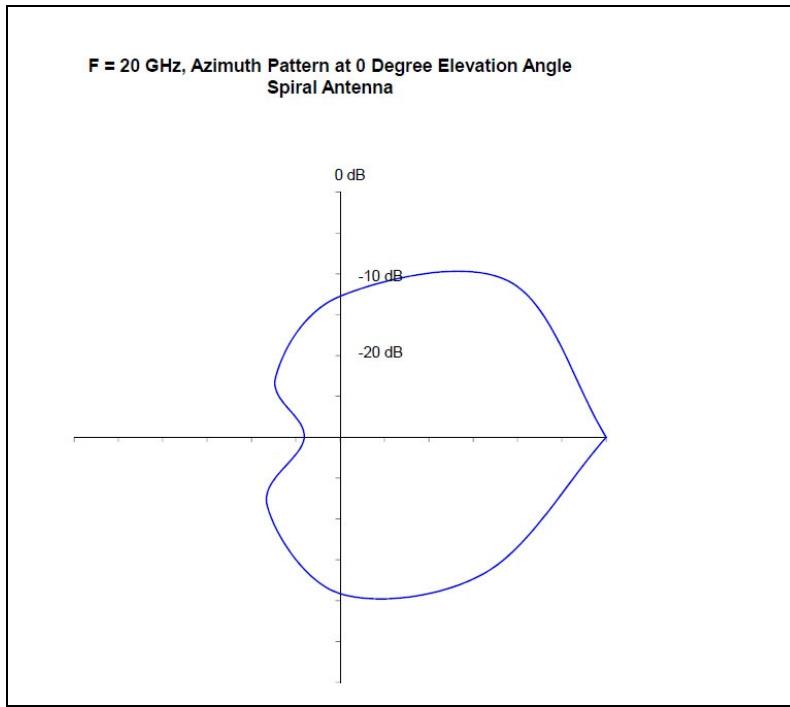


Figure (27) Measured Spiral Radiation Pattern at 20 GHz

6. CONCLUSION AND FUTURE WORK

The ultra-wide band spiral antenna prototypes are successfully built and measured using 2 copper arms, a white foam and an SMA cable.

Even though, their measured input and output return losses do not go down as specified, they have at least 3:1 VSWR ratio and their working frequency range of 100 MHz to 20 GHz far exceeds the specification range of 800 MHz to 6 GHz!

The future work includes improving the antenna matching by fabricating 2 spiral copper arms on the Printing Circuit Board (PCB) with a definite di-electric substrate and more exact antenna patterns. It would definitely yield better S11 performance results than these hand-made prototypes do.

7. ACKNOWLEDGEMENT

I would like to extend my heartfelt gratitude to Dr. Ray Kwok for his invaluable guidance, continued support and patience shown to us throughout the semester of Spring 2011.

Wai Phyo

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9. APPENDIX A

return loss Vs. VSWR

table of return loss vs. voltage standing wave ratio

RETURN LOSS (dB)	VSWR								
46.064	1.01	13.842	1.51	9.485	2.01	7.327	2.51	5.999	3.01
40.086	1.02	13.708	1.52	9.428	2.02	7.294	2.52	5.970	3.02
36.607	1.03	13.577	1.53	9.372	2.03	7.262	2.53	5.956	3.03
34.151	1.04	13.449	1.54	9.317	2.04	7.230	2.54	5.935	3.04
32.256	1.05	13.324	1.55	9.262	2.05	7.198	2.55	5.914	3.05
30.714	1.06	13.201	1.56	9.208	2.06	7.167	2.56	5.893	3.06
29.417	1.07	13.081	1.57	9.155	2.07	7.135	2.57	5.872	3.07
28.299	1.08	12.964	1.58	9.103	2.08	7.105	2.58	5.852	3.08
27.318	1.09	12.849	1.59	9.051	2.09	7.074	2.59	5.832	3.09
26.444	1.10	12.736	1.60	8.999	2.10	7.044	2.60	5.811	3.10
25.658	1.11	12.625	1.61	8.949	2.11	7.014	2.61	5.791	3.11
24.943	1.12	12.518	1.62	8.899	2.12	6.984	2.62	5.771	3.12
24.289	1.13	12.412	1.63	8.849	2.13	6.954	2.63	5.751	3.13
23.686	1.14	12.308	1.64	8.800	2.14	6.925	2.64	5.732	3.14
23.127	1.15	12.207	1.65	8.752	2.15	6.896	2.65	5.712	3.15
22.607	1.16	12.107	1.66	8.705	2.16	6.867	2.66	5.693	3.16
22.120	1.17	12.009	1.67	8.657	2.17	6.839	2.67	5.674	3.17
21.664	1.18	11.913	1.68	8.611	2.18	6.811	2.68	5.654	3.18
21.234	1.19	11.818	1.69	8.565	2.19	6.783	2.69	5.635	3.19
20.828	1.20	11.725	1.70	8.519	2.20	6.755	2.70	5.617	3.20
20.443	1.21	11.634	1.71	8.474	2.21	6.728	2.71	5.598	3.21
20.079	1.22	11.545	1.72	8.430	2.22	6.700	2.72	5.579	3.22
19.732	1.23	11.457	1.73	8.386	2.23	6.673	2.73	5.561	3.23
19.401	1.24	11.370	1.74	8.342	2.24	6.646	2.74	5.542	3.24
19.085	1.25	11.285	1.75	8.299	2.25	6.620	2.75	5.524	3.25
18.783	1.26	11.202	1.76	8.257	2.26	6.594	2.76	5.506	3.26
18.493	1.27	11.120	1.77	8.215	2.27	6.567	2.77	5.488	3.27
18.216	1.28	11.039	1.78	8.173	2.28	6.541	2.78	5.470	3.28
17.949	1.29	10.960	1.79	8.138	2.29	6.516	2.79	5.452	3.29
17.690	1.30	10.881	1.80	8.091	2.30	6.490	2.80	5.435	3.30
17.445	1.31	10.804	1.81	8.051	2.31	6.465	2.81	5.417	3.31
17.207	1.32	10.729	1.82	8.011	2.32	6.440	2.82	5.400	3.32
16.977	1.33	10.654	1.83	7.972	2.33	6.415	2.83	5.383	3.33
16.755	1.34	10.581	1.84	7.933	2.34	6.390	2.84	5.365	3.34
16.540	1.35	10.509	1.85	7.894	2.35	6.366	2.85	5.348	3.35
16.332	1.36	10.437	1.86	7.856	2.36	6.341	2.86	5.331	3.36
16.131	1.37	10.367	1.87	7.818	2.37	6.317	2.87	5.315	3.37
15.936	1.38	10.298	1.88	7.781	2.38	6.293	2.88	5.298	3.38
15.747	1.39	10.230	1.89	7.744	2.39	6.270	2.89	5.281	3.39
15.563	1.40	10.163	1.90	7.707	2.40	6.246	2.90	5.265	3.40
15.385	1.41	10.097	1.91	7.671	2.41	6.223	2.91	5.248	3.41
15.211	1.42	10.032	1.92	7.635	2.42	6.200	2.92	5.232	3.42
15.043	1.43	9.968	1.93	7.599	2.43	6.177	2.93	5.216	3.43
14.879	1.44	9.904	1.94	7.564	2.44	6.154	2.94	5.200	3.44
14.719	1.45	9.842	1.95	7.529	2.45	6.131	2.95	5.184	3.45
14.564	1.46	9.780	1.96	7.494	2.46	6.109	2.96	5.168	3.46
14.412	1.47	9.720	1.97	7.460	2.47	6.086	2.97	5.152	3.47
14.264	1.48	9.660	1.98	7.426	2.48	6.064	2.98	5.137	3.48
14.120	1.49	9.601	1.99	7.393	2.49	6.042	2.99	5.121	3.49
13.979	1.50	9.542	2.00	7.360	2.50	6.021	3.00	5.105	3.50

Table (5) Table of Return Loss Vs. Voltage Standing Wave Ratio