The Design Process of a Rectangular Microstrip Antenna

T. R. Harris

Abstract — **The primarily factors concerning the choice and design of this project are pedagogical in nature. In this study, the classic approach to antenna design is followed through its entirety. A rectangular microstrip antenna for operation at 900MHz is successfully designed, numerically analyzed through use of a commercial software package, fabricated, and ultimately tested in the real world. Invaluable experience and insight into antenna engineering can only be realized by a complete design sequence exercise. The project has been generally successful as a whole, and suffered shortcomings in minor points, all of which will be discussed in this paper.**

I. INTRODUCTION

O The microstip antenna has recently come into vogue as a research topic and commercial application. The increase in interest is due to their low profile, which can easily be integrated flush against a surface for durability. In the case of this study, the patch antenna was considered to replace a monopole antenna on a small robot to transmit a UHF video signal. The transmitter works on a frequency of 433.25MHz. After computation, it was determined that an antenna at this frequency would be prohibitively large, therefore 900MHz was arrived at as a design parameter as a proof of concept.

In the search for suitable substrates as a dielectric layer, it was desirable to use thee highest possible permittivity. Air, Styrofoam blocks, alumina, glass, sapphire, composite Duroid, silicon, ice, and liquid alcohol were all considered. Dictated by the availability of materials and desire to gain experience with the standard media, two composite Duroid materials were chosen. Additionally, silicon was also chosen, as it is of particular interest due to its high permittivity of 12.

II. DESIGN

The resonant frequency of a rectangular microstrip antenna can be designed for based on the width and length of the patch, given the height and permittivity of the dielectric material between the conductive microstrip and ground plane.

The three substrates were proposed as possibilities for construction were RT/ Duroid 5880 high frequency laminate with εr=2.2 and a thickness of .30mm; Isola FR404 with εr =4.26 at 500MHz and thickness of .20mm; and silicon wafers with εr=12 and a thickness of .525mm.

The practical width and length can be calculated by the transmission line method, as exemplified below,

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

The effective dielectric constant can then be found by

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

The extension length has been adapted into the form

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

The actual L, in meters is then determined using

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

A Matlab script was devised to study these relationships as far as possible frequencies to work with, and which dielectrics were feasible for a practical patch antenna size. Please refer to the appendix for the Matlab code.

III. EXPERIMENTAL EVALUATION AND ANALYSIS

Designs should be simulated before fabrication, if possible to gain agreement with specification. The Agilent Advanced Design System (ADS) was used to simulate the performance and functionality of the antenna. The layout suite supports microstrip lines, user specified dielectric, and conductive layers. The Momentum planar EM simulator is integrated into ADS for 3D analysis.

The below image illustrates a typical patch antenna in the CAD layout tool. This construct includes the feed port at the bottom, and the mesh grid lines. The meshing is automatically generated by momentum.

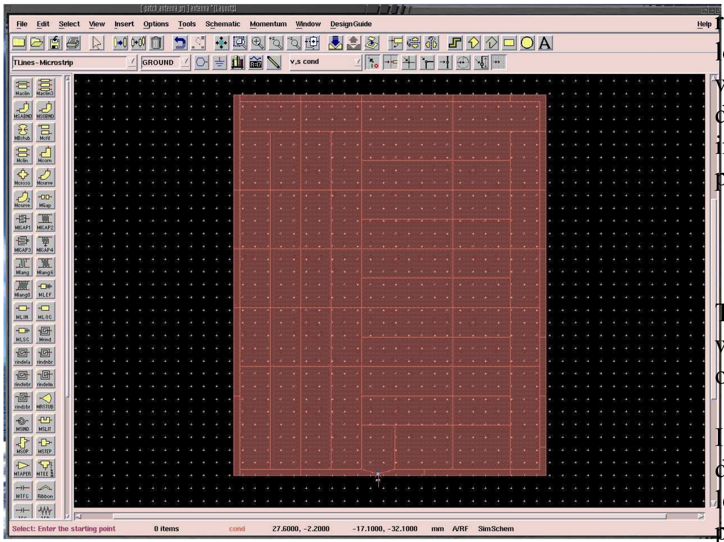

Fig. 3.1 The Patch Antenna in ADS with Grid Defined

Several antennas were simulated in the ADS. ADS proves to be a valuable tool in the iterative nature of design. Simulation of large antennas or over a large range of frequencies consumes large amount of CPU time and memory. The simulation of the patch antennas in this study were generally set to cover 1MHz to 1GHz to avoid long waits on computation.

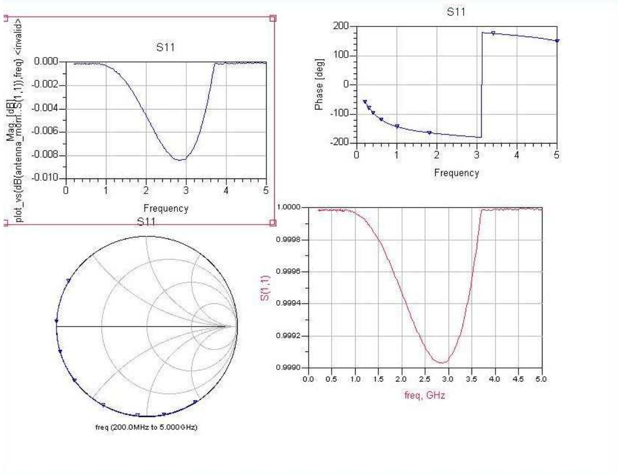

Fig. 3.2 Simulated Frequency Response of a 3GHz Antenna

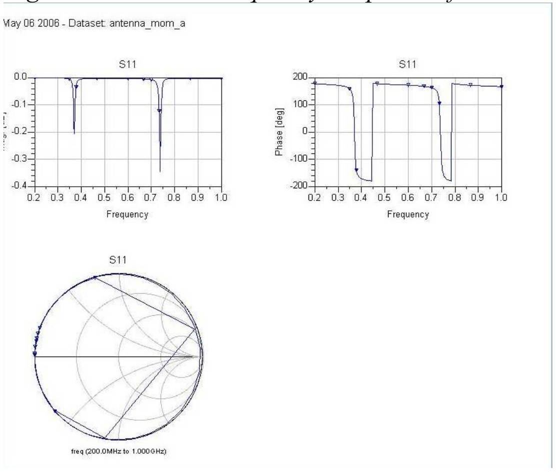

Fig. 3.3 Simulated Frequency Reponse of a 3.5GHz Antenna

These graphs are reproduced in the appendix for readability. It is interesting to note the secondary mode has lower impedance than the dominate of design. This agrees with the testing of the antenna designed for 900MHz, which is discussed in section 5. The presence of the secondary mode is incidental and has no know adverse effects to the final product.

IV. IMPLEMENTATION

The three substrates, duroid 5880, Isola FR404, and silicon wafers, with their aforementioned physical properties were obtained for construction.

A. Duroid Patch Antenna Fabrication

It is necessary to reduce the copper clad on one side of the dielectric to form the desired rectangular antenna, while leaving the back intact to function as a ground plane. The two possibilities for material removal are machining by mill or chemical etch. Copper PCB etchant was selected over milling due to unavailability of a mill and the tediousness involved in milling by hand with a rotary tool. It is possible to mask off the unetched portion with marker or to selectively remove the protective plastic coating from the laminate. Both methods worked in tests, and the later method was selected for ease of measurement of dimensions and homogeneity of the resultant metal patch. The 102.9mm x 74.3mm patch was successfully created on the Isola FR404. The feed point was chosen to be in the middle of the short dimension and ¼ the length on the long dimension due to impedance considerations. A hole was drilled at the desired location and an SMA connecter was soldered into place, taking care not to short the ground plane and antenna surface.

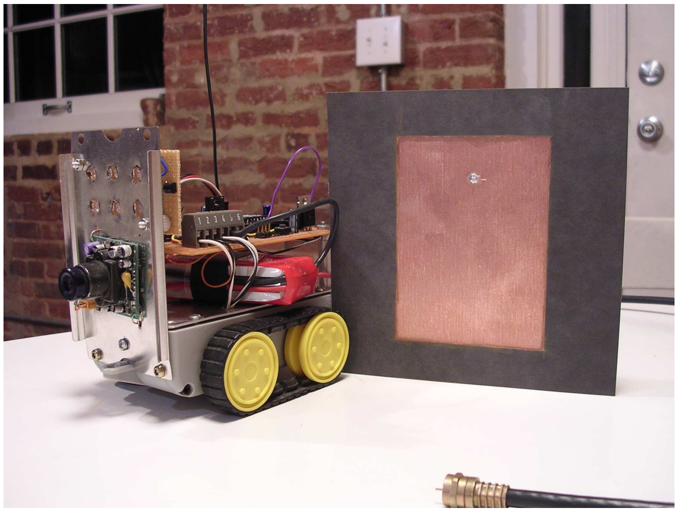

Fig 4.1 Patch Antenna Next to Camera Robot

B. Silicon Patch Antenna Fabrication

Silicon was chosen as a substrate of interest because of its high dielectric constant of 12, allowing for more compact planar antennas for a given wavelength. Two techniques of fabrication were tested as suitable methods, a metal lift-off, and a metal etch. Two wafers were processed for each method. Positive and negative masks of the patch antenna were made by laser printing on overhead transparency. The negative mask is needed for the lift-off. In a lift-off, photoresist is left under the unwanted metal so that a solvent may undercut and lift off the areas where metal is not desired.

All wafers are RCA cleaned and spin-dried. Two coats of Shipley 1813 photoresist are spun onto the lift-off wafers at 4kRPM for 40s. The wafers were softbaked at 115ºC between coats in order to drive the solvent out of the polymer. The wafers were exposed to UV light through the negative mask for 15s at a dose of 14mW/cm2 in a Karl Suss MA6 aligner. This is a higher than typical dose adjusted for the facts that the plastic mask is expected to absorb a significant portion of the UV, the negative mask is darkfield, and the feature is macroscopic so any change in photobias would be insignificant. The wafers were then developed it MF318 developer solution for 2mins to remove the photoresist from the rectangle where the metal patch would ultimately be. Wafers were then rinsed. No oxygen plasma clean descum step was deemed necessary.

Both sets of wafers were then metalized in a resistive heat vaporization chamber. 1700Å of aluminum was deposited on the top of all wafers. After the metallization, the lift-off wafers proceeded to the lift off step, and the etched wafers proceeded to photolithography. The lif-off wafers were placed in a solution of n methyl pyrrolidone and sonicated with ultrasound to promote undercutting of the solvent, and removal of the metal. This process was successful in creating the desired metal patch on silicon.

Shipley 1813 photoresist was spun onto the wafers to me etched at 4kRPM for 40s to produce a 18kÅ film. Wafers were then exposed to UV light through the positive patch antenna mask for 8s at a does of 14mW/cm2. This shorter exposure time was arrived upon because the aluminum layer is quite shiny and reflects most of the light back up into the photoresist. These wafers were then developed it MF318 developer solution for 2mins. The exposed aluminum metal layer was then wet etched in a phosphoric acid and surfactant solution for 20mins at 40ºC. The remaining photoresist was then stripped of with n methyl pyrrolidone, after which wafers were rinsed in DI water. This method was also successful in fabricating the desired patch antenna.

944Å of aluminum was deposited on the backs of the wafers to act as the ground plane in the same metallization manner as previously described. A crippling setback to the investigation of the silicon substrate was the difficulty involved in attaching a feed point. Aluminum grows a native oxide, which makes soldering to the surface impossible. Plumber's soldering flux did not alleviate the problem. Possible solutions to this problem include the use of a proper wire bonder, probe station, or clamping devices. Drilling through a silicon wafer is also not trivial, so a method of deep trench plasma etch through the wafer is recommended.

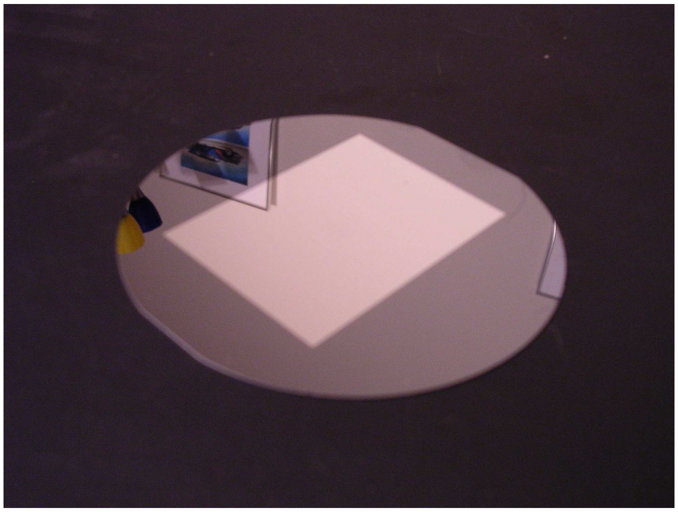

Fig 4.2 Al Patch Antenna an Si Wafer

V. ANTENNA CHARACTERIZATION

The patch antenna was connected by RF coaxial cable to an Agilent Technologies E5071B Network Analyzer. Prior to antenna connection, the network analyzer was calibrated to open, short and 50 ohm load at the length of cable to normalize the measurements of the cable length so that the antenna alone would be characterized.

The network analyzer is set to output sinusoidal signals at a range of frequencies while measuring the reflected amplitude. Thus the resonant frequency of the patch can be determined.

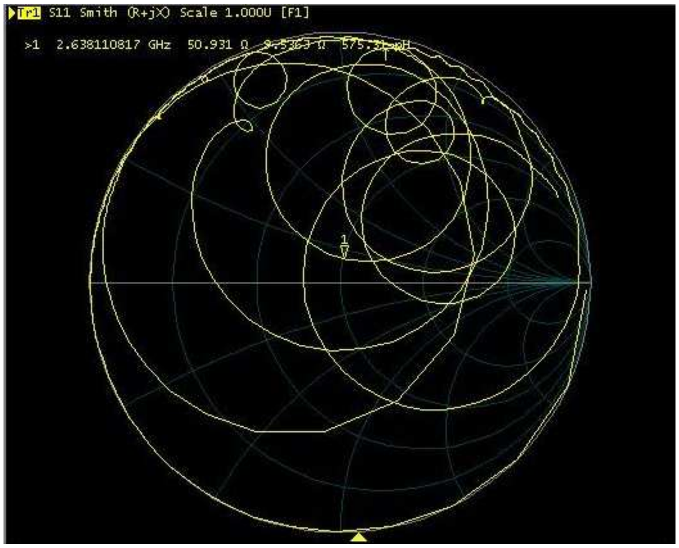

Fig 5.1 Smith Cart of the Patch Antenna

Please note that this is a rather zoomed out smith chart, showing many interesting resonant modes over a large frequency. The patch antenna was measured to have the best response of -5.69dB at 960MHz, 60MHz deviation from the design goal of 900MHz. A mode was also found at 4.7GHz with an even lower impedance, reading -29dB.

VI. CONCLUSION

The design, simulation, fabrication, and testing proved to be successful on some strata. The original goal of creating an antenna for TV signal broadcasting was not meet due to the large size required. The testing of the aluminum antenna on silicon substrate was regrettably not realizable due to limited availability of equipment; however it could prove to be an area of interesting future study. The rectangular planar antenna on Duroid substrate did function according to the design, and simulation with a resonance of 900MHz. Further research could include optimization of the location of the feed point.

VII. ACKNOWLEDGMENTS

Mr. Harris wishes to acknowledge the invaluable help of Mr. Ajit Rajagopalan who helped greatly with the testing of the antenna and the ADS software package; Mrs. Joan O'Sullivan and the NNF cleanroom for offering the fabrication support and facilities to process the silicon patch antennas; Drs. Lazzi and Schmidt, who offered guidance, and help; and Mr. Jonathan Wilkerson for numerical analysis support.

REFERENCES

[1]. Antenna Theory Analysis and Design, Restricted not for sale in North America Edition, Constantine A. Balanis, Wiley, 2005
[2]. The Electrical Encineering Handbook, Richard C. Dorf, IEEE Press, 1997
[3]. Isola FR404 Data Sheet, Data Sheet #5021/9/99, Isola Laminate Systems Corp, 1999
[4]. RT/duroid Data Sheet, Data Sheet 1.50000, Rogers Corporation, 2005
[5]. www.fcc.gov

VIII. APPENDIX

A. Matlab script

```
%patch.m
%Theodore Harris
%Studies possible frequencies, dielectrics, and calculates
patch size.

clear;
c=299792458;
%cable channel 59 UHF 433.25

fr=900e6;
%fr=433.25;
%epsr=2.2;

%epsr=10;
%Si 11.7-12.9
%epsr=12.9;

%duroid 1
epsr=4.25;
h=15e-3;

%Duroid 2, RT Duroid 5880
%epsr=2.2;
%h=30e-3;

%h=.001588;
%4" Si wafers are 525u
%h=525e-6;
%6" 675u
%h=675e-6;

%find practical width
w=(c/(2*fr))*sqrt(2/(epsr+1))

%effective dielectric const
eps_eff=((epsr+1)/2)+((epsr-1)/2)*(1+12*h/w)^(-1/2);

%extenstion length
DeltaL=h*0.412*((eps_eff+0.3)*((w/h)+0.264))/((eps_eff-
0.258)*(w/h+0.8));
%DeltaL=8.1e-4;
%actual L
L=c/(2*fr*sqrt(eps_eff))-(2*DeltaL)
%convert to inches for American engineers
w*39.3700787402
L*39.3700787402
```

B. Reproduction of Figures

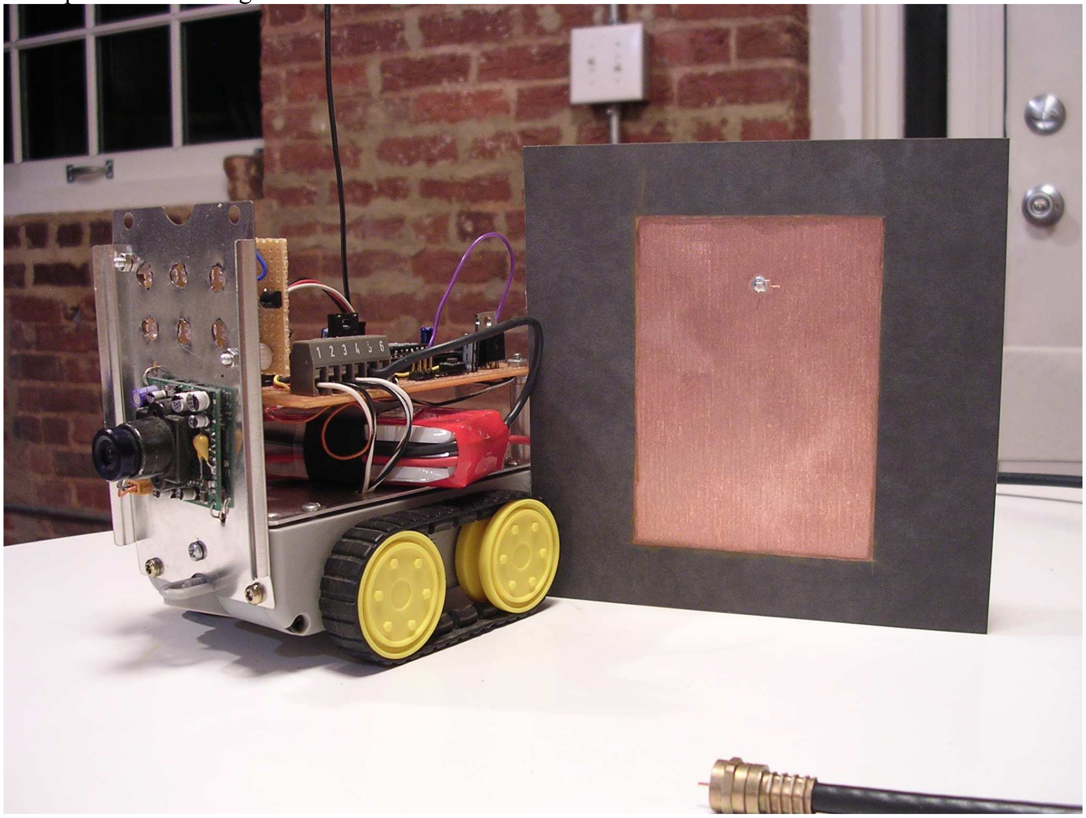

Fig 4.1 Patch Antenna Next to Camera Robot

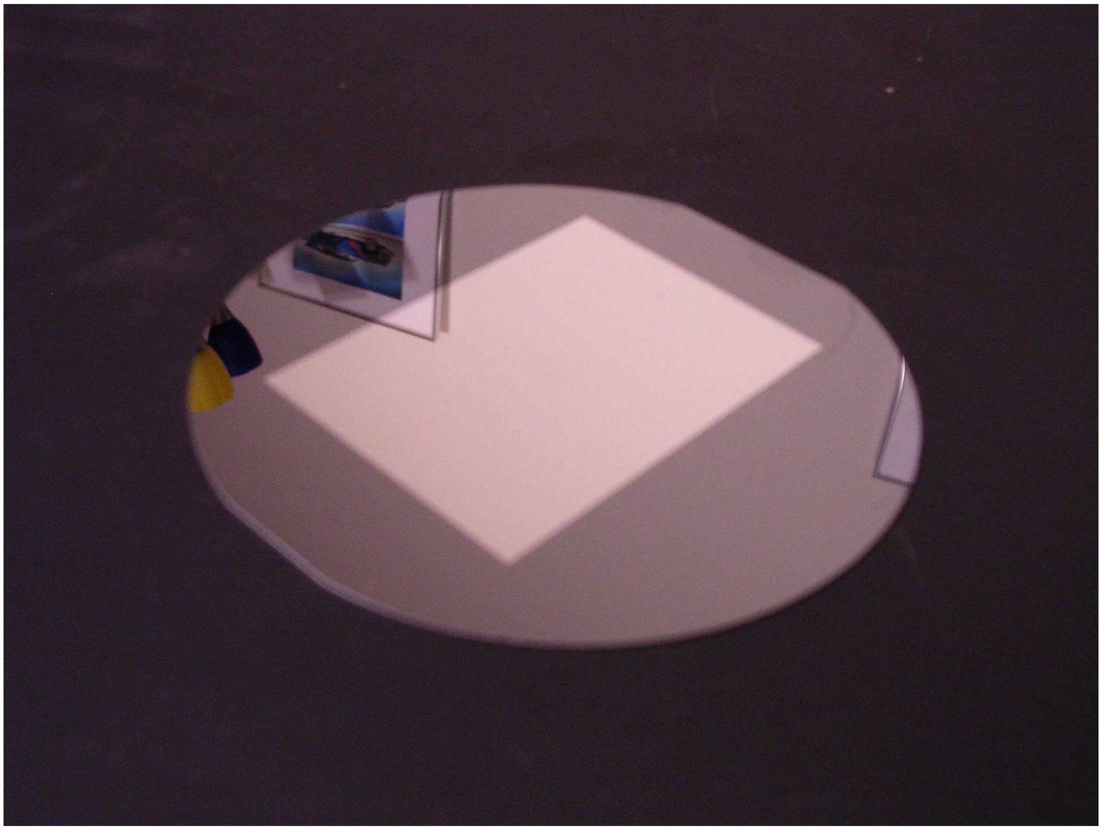

Fig 4.2 Al Patch Antenna an Si Wafer

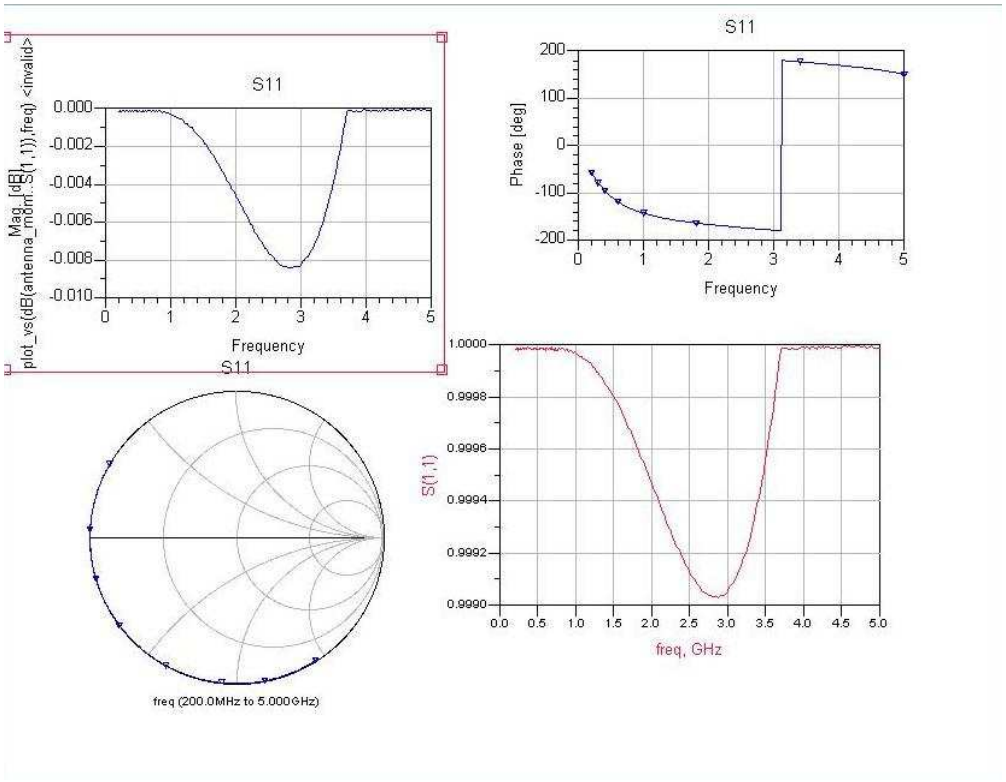

Fig. 3.2 Simulated Frequency Response of a 3GHz Antenna

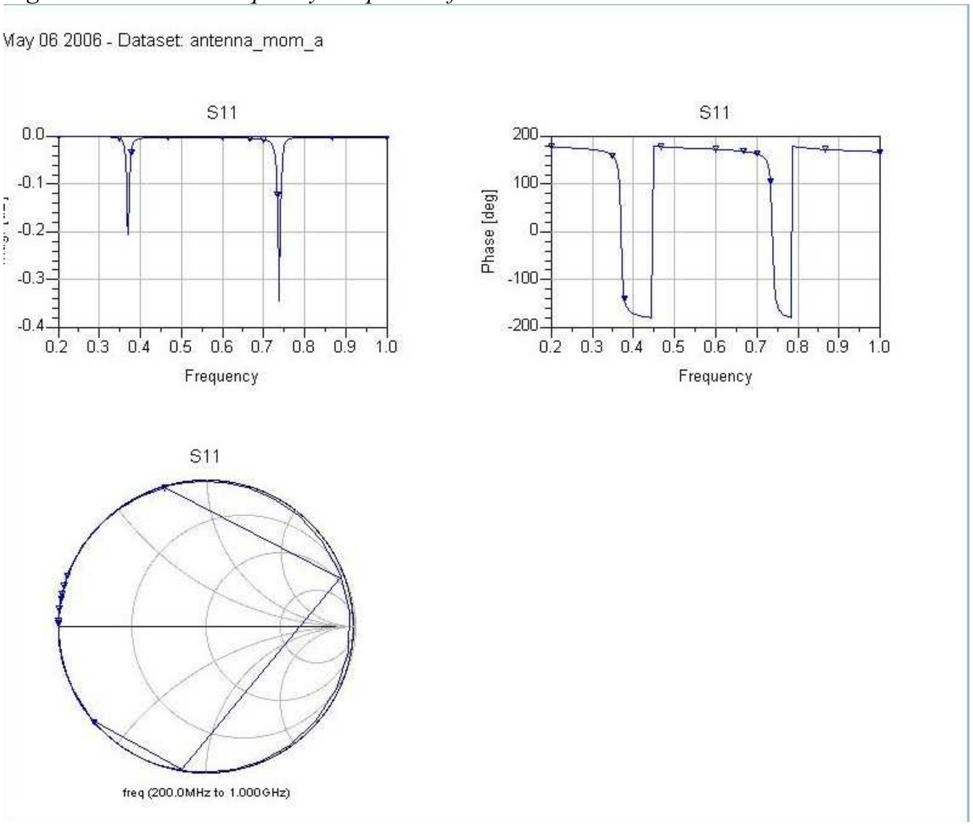

Fig. 3.3 Simulated Frequency Reponse of a 3.5GHz Antenna