University of Utah
Department of Electrical Engineering

ECE 5324: Antenna Theory and Design

Design, Build, and Test of Dual-Band PIFA

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1 INTRODUCTION

The mobile phones industries are in high demand to build smaller and better antennas. Planar Inverted F Antennas, or PIFAs, are a major consideration in this type of application and thus, the focus of this project. There are advantages to PIFAs in cellular phones over other types of antennas. When a cell phone is place against the ear of the user, radiated power towards the user's head should be minimized, while maximum radiation should be in the opposite direction. PIFAs, in general, achieve this. Secondly, PIFAs, by definition, require a ground point on the patch, decreasing the size of the patch from a half-wave antenna to a quarter-wave antenna. This decreased size makes PIFAs simpler to conceal in today's cell phones that are only getting smaller, instead of the extension of a monopole antenna.

The goal of this project was to design, build, and test a dual band planar F antenna for cellular phones. This included the frequency ranges of 880MHz to 900MHz for GSM and 1710MHz to 1880MHz for DCS. Modern cell phones, however, have a third band, ISM ranging from 2400MHz to 2480MHz. Since these are the specifications of today's cellular antennas, we also sought to achieve this additional band.

2 DESIGN

In designing the dual band antenna, dimensions for the lengths and widths for each frequency had to be calculated. By definition, a PIFA is grounded on one side of the patch antenna, either at a single point or along the length of a side. An example for the simplest case of a rectangular patch is shown in figure 1.

To determine these, the following equations are used.

$$L + W = \frac{c}{4(f)} \qquad \text{eq. (1)}$$

Where L is the patch length, W is the patch width, c is the speed of light, and f is the desired frequency. Table 1 shows the determined lengths where the width is preset.

Table 1. Calculated Dual Band Lengths

Frequency	Width	Length
930MHz	4mm	76mm
1750MHz	9mm	33mm

After determining these dimensions, but before building the antenna, simulations had to be done to ensure that the calculations would yield the proper frequencies. Below is an illustration of this groups antenna design.

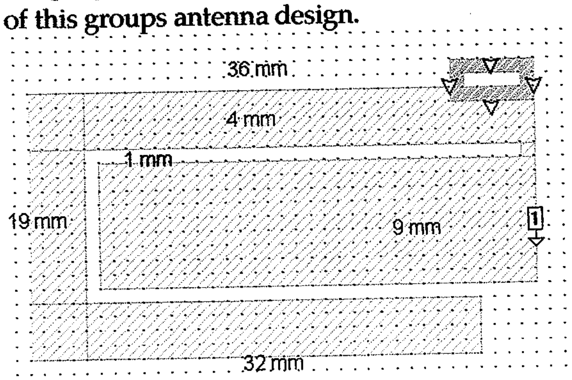

Figure 2. Dimensions of Dual Band Antenna

3 SIMULATIONS

The design of the dual band micropatach antenna was achieved with the assistance of a software called Sonnet Lite. The Sonnet Lite edition is downloadable online for free. This version allowed us plots of the return loss of the antenna and its current distribution at various frequencies. Unfortunately, we were limited in obtaining plots for the radiation patterns in the xy and yz directions. The simulation required many parameters to ensure accuracy in its calculations. These parameters are summarized below in Table 2.

in figure 2. The antenna was fed with a direct coupled coaxial feed for simplicity.

4 BUILDING THE PROTOTYPE

Building the dual band antenna for novice students performing this task for the first time introduced many problems that had to be overcome. Uncertainty lied in how to physically feed the antenna, what type of foam to use, how to get the right copper for the patch, how to cut the patch precisely to the dimensions specified by Sonnet, how to correctly calibrate and capture the data from the network analyzer.

The problem that arose when feeding the antenna was that the initial setup introduced large impedances. These large impedances were caused by even a simple turn in the copper wire, or the excessive length of the copper wire. Finally, a new set up, shown in figure 7, was used that gave promising results. The SMA connector was placed directly below the feed point and ground point allowing for a direct route for the copper wires.

The substrate dielectric between the patch and the ground plane was simulated to be foam. However, through numerous trials, we saw no significant difference between foam, no foam, and foam board (two layers of paper with foam in between). Therefore, we used the foam board since it provided adequate support for the patch antenna.

There were a few things to understand about the copper as well. Even though the copper that we used was flimsy, one should not assume that it is pure copper. Performing a resistance check between the top and bottom of the copper sheet showed that there was a very thin layer of substrate material in between the layers of copper. This was important to know since feeding one side and grounding the other would give inaccurate results.

Cutting the antenna required a significant amount of time to measure the dimensions with calipers, and cut out the antenna with an exacto blade. Putting everything together resulted in the dual band PIFA shown in figure 7.

5 TESTING THE ANTENNA

As stated earlier, the antenna was not able to get tested for radiation patterns due to lack of an available testing facility. However, we were able to get return loss plots for the antenna. Testing of the antenna was achieved with the help of an HP 8720C network analyzer. After calibrating the network analyzer, we were ready to attach the antenna. Initially, our frequency ranges were off. Off enough that they were not in the desired bands. Conceptually, we knew that by increasing the length would lead to the frequency band decreasing, while decreasing the length would lead to the frequency band increasing. Table 3 shows the changes made to the dual patch antenna.

Table 3. Dimension Changes to Dual Band Antenna

Frequency	Calculated L	Actual L
930MHz	76mm	81mm
1750MHz	33mm	29mm

Figure 8 shows the return loss for the designed antenna. We get a measured return loss of -18 dB at 936MHz and -12 dB at 1748MHz. The bandwidths are 70Mhz for the lower frequency and 320MHz for the upper. Figure 9 is an illustration of the smith chart with markers on the two resonant frequencies.

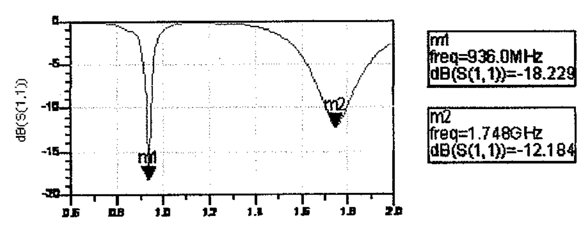

Figure 8. Return Loss of Dual Band Antenna

7 FUTURE IMPROVEMENTS

With more time given on this project, much more could have been improved. Although we know that in theory the radiation pattern is normal to the surface of the patch with more power radiated on one side of the patch, we would have liked to verify this by getting actual radiation patterns for the designed antenna. Secondly, we can only wonder what type of impedances were introduced into our antenna by outside sources and whether we could negate such sources. Such sources include nearby cell phones and computers radiating radio frequencies and even our hands and bodies as well. Perhaps a box surrounding the antenna with the capability of blocking out unwanted RF could be implemented. Thirdly, we could not help but notice how close we were at getting the resonant frequencies to land on the center of the smith chart. How much more could this have been improved? We believe that this could have been improved by selecting the ideal feed point where the antenna's impedance matches that of the transmission line. In fact, we made a contraption that allowed us to easily feed the antenna. This is shown in figure 13.

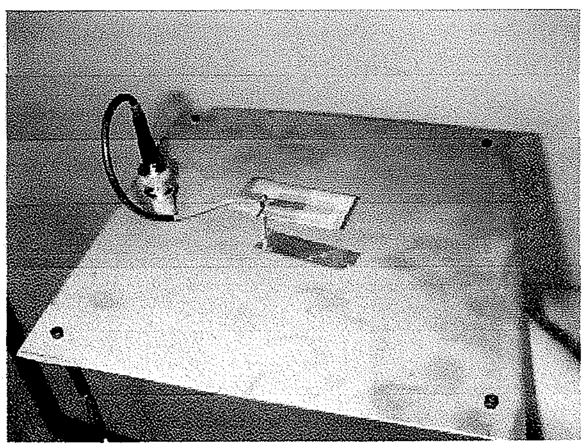

Figure 13. Finding the Ideal Feed Point

The problem with this is that the additional coaxial cable only introduced more impedance to the antenna. We were uncertain as to whether or not this was a valid method. Once again, due to lack of time, we decided to just solder our original feed point simulated in Sonnet Lite.

8 CONCLUSION

This project proved much more difficult than originally anticipated. The concepts seemed fairly simple, but implementing the antenna seemed more like "artwork". But in the end, we were able to achieve both a dual band and tri-band PIFAs. We found that using different widths allowed the separation needed to give different current distributions at the different frequency ranges. Adjustment of the lengths had to be made to the built antenna to achieve the correct frequencies. In general, shortening the length increases the resonant frequency while increasing the length decreases the resonant frequency. For both antennas, we achieved acceptable return loss values ranging from -12 dB to -18 dB. We would have like to see wider bandwidths for the GSM band which we could only achieve 75MHz to 100MHz. The DCS and ISM bandwidths were acceptable. Lacking from the testing are the radiation patterns for the dual band and tri-band antennas. More time for the project could have remedied this. Overall, we feel that this antenna would make a great addition for today's cellular phones.

Acknowledgements:
Much thanks to Professor Om Ghandi, Professor Cynthia Furse, and Sai Peruvemba for their assistance in the completion of this project.

References:

[1] W. L. Stutzman, G. A. Thiele, " Antenna Theory and Design, " 2nd ed., John Wiley & Sons, Inc., 1998

[2] PIFAs for Internal Mobile Phones Antenna

A Dual Band PIFA with Branch Line Slit

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University of Utah
ECE 6342 - April 14, 2008

1. INTRODUCTION

Since the advent of wireless communications, there has been a steady increase in demand for compact antennas that efficiently utilize the scarce space available in portable electronic devices. One very popular design is the planar inverted F-antenna (PIFA), which is simply a small patch antenna mounted over a large ground plane. The characteristic "F" shape results when a feed line and shorting wire are positioned somewhere next to each other at one of the patch edges. The major benefits to PIFA design are dual-band operation, ease of construction, and a geometry that allows electronic peripherals to wedge in between the spaces.

In this paper, we demonstrate a popular class PIFA design that utilizes a branch-line slit. The objective is to successfully demonstrate dual-band operation near 900 MHz and 1.8 GHz, which are commonly used bands for wireless telecommunications. The reflection coefficients at each resonance are less than -10 dB with respect to a 50 Ω system, and the electric field patterns along several cut planes demonstrate a reasonably omni-directional radiation.

2. ANTENNA DESIGN

The basic branch-line slit is a well-known design, and our antenna is based off the textbook layout given by Kin-Lu Wong.[1] Though the design itself is rather simple, the textbook specifies a layer of dielectric material between the patch and its ground plane. Because we do not have easy access to copper-clad laminate with known dielectric constants, we opted to remove the dielectric layer and then re-design the antenna without it. To aid in this process, we simulated our designs by using a trial-version of the AWR Microwave Office software.[2]

Because the original design utilized a dielectric layer underneath the patch element, the electrical size of the antenna was decreased by its removal. As a result, the resonant frequencies of the PIFA increased, and the entire design had to be re-scaled in order to place them back into the bands of interest. This was accomplished through a trial-and-error approach by slowly expanding the scale of the original layout until the simulated frequencies fell back into the desired bands. Shown in figure 1, the final dimensions are approximately 30% greater than those given by the textbook version.

Figure 2 shows a three-dimensional perspective which includes the ground plane. The air-filled gap between the patch and the ground plane is 10 mm thick, while the ground plane stretches out to an area of 65×50 mm^2. The shorting plate is positioned in the upper-left corner of the patch while the feed line is placed a few millimeters directly below (the exact dimensions of the feed not critically sensitive).

3. CONSTRUCTION

The branch-line slit in the PIFA antenna was constructed through the use of chemical etching. Using ink toner as an etch mask, the design was printed on a glossy surface and ironed onto a copper plate. The copper was then exposed to acid, which etched away the uncovered areas to produce the desired result. Because an air-filled gap is not mechanically stable, a 10 mm slab of Styrofoam was used for structural support (the dielectric constant of Styrofoam is very nearly 1). The feed line connected through a via in the ground plane to an SMA connector underneath, while the shorting plate was soldered onto the corner of the antenna. Finally, packing tape was used to cover the top-layered patch. This works well at protecting the components and physically binding them together. Figure 3 shows a photograph of the end product.

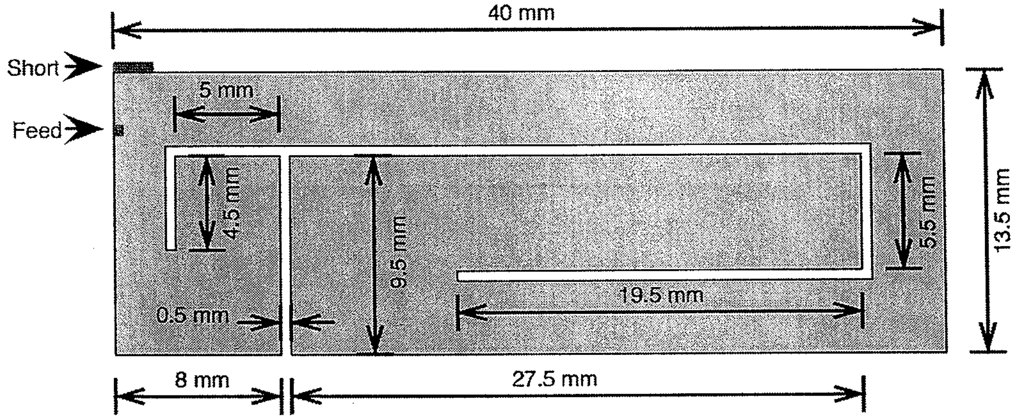

Figure 1. Schematic design for the PIFA with a branch-line slit. The rectangle in the upper-left corner represents the shorting plate while the little square represents the feed point.

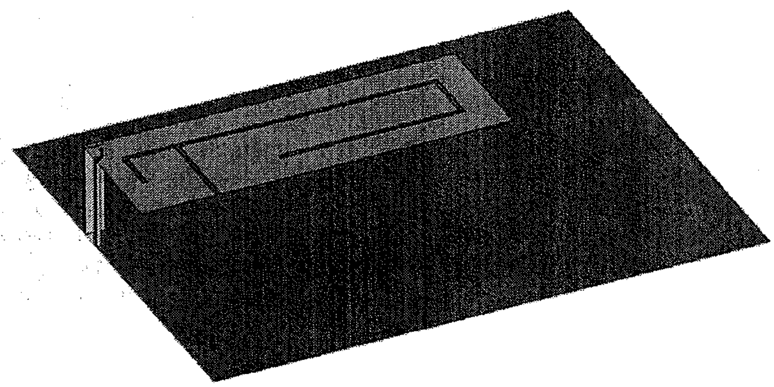

Figure 2. Three-dimensional perspective of the PIFA. The ground plane rests 10 mm below the patch and extends out to 65×50 mm^2.

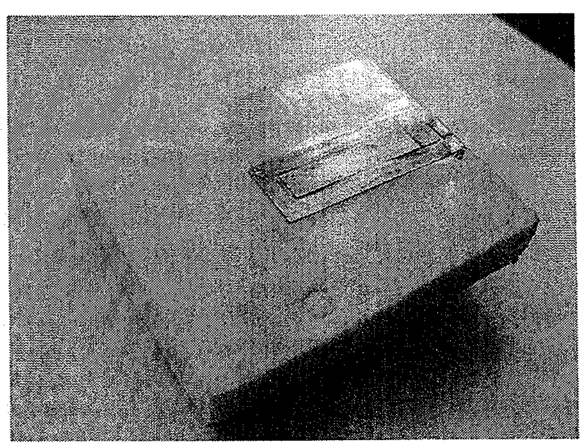

Figure 3. Photograph of the final PIFA design.

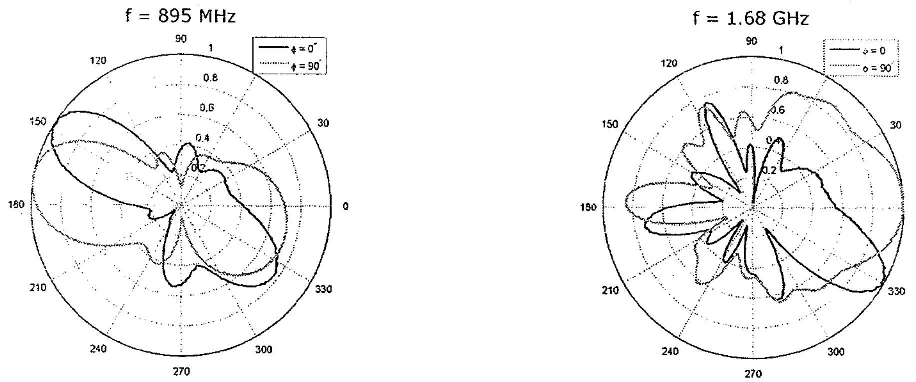

Figure 5. Electric field radiation patterns measured in the anechoic chamber. The plots are all $\hat{\phi}$-polarized along θ-plane cuts.

REFERENCES

1. Wong, Kin-Lu, *Planar Antennas for Wireless Communications*, John Wiley and Sons, Inc. 2003
2. http://web.awrcorp.com.Products_Microwave_Office_Overview.php

A

Dual Band Antenna Design for 2.45 & 5.50 GHz

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April 27, 2005

ABSTRACT

The design, fabrication and testing of a dual band patch antenna for the frequencies 2450 and 5500 MHz is presented. Actual measured results matched the model predictions. In addition, insights into high frequency antenna design are given, with its challenges and successes.

INTRODUCTION

With the proliferation of wireless devices and their transition from convenience to necessity, demand has increased for small, low-cost antennas that can fit within an ever smaller package. Patch antennas known as Planar Inverted-*F* antennas (PIFAs), fill this need. The objective of this project was to design and test a 2.45 and 5.5 GHz PIFA antenna. This was accomplished by simulating multiple antenna designs in the Sonnet Electromagnetic Simulator, and fabricating various designs until the desired characteristics were displayed by the antenna. The final result was a U-shaped slot antenna, which operated within the given 3% frequency specifications. Overall, this project has demonstrated the complexity of antenna design, the perceived randomness of antenna modifications and the perseverance necessary to be a successful antenna designer. This paper will guide the reader through the various steps we took to converge on the final product.

RESEARCH

Research in the area of PIFAs is well developed. The authors' research commenced with the reading of papers recommended by the class professor Dr. Gandhi.[1] Additional research on the web yielded many different designs. The prospective antenna design engineer may choose from a variety of antenna designs. The frequencies dictate the use of PIFAs as they can easily be designed for multiple operating frequencies. The ability to utilize two or three independent frequencies has become a basic requirement for integration modern wireless equipment.

ANTENNA DESIGN

The antenna design is a rectangular patch with a u-shaped slot cut out from the interior. The slot acts as the higher frequency element where as the outer perimeter of the patch acts as the lower frequency element. The frequencies specified require that the entire patch not exceed 200 square millimeters for a quarter wave design or 800 square millimeters for a half wave design. Although a half wave design would have been easier to fabricate, the software tools used were demo versions incapable of modeling larger designs. Due to the antenna's small dimensions, the authors' chose three different designs. Each was chose for ease of fabrication. The over all shape and dimensions of the three designs are presented below.

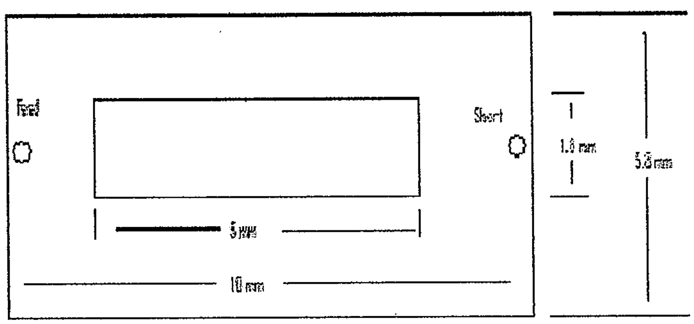

Figure 1 – Prototype 1

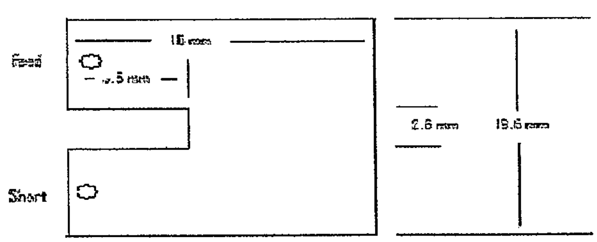

Figure 2 – Prototype 2

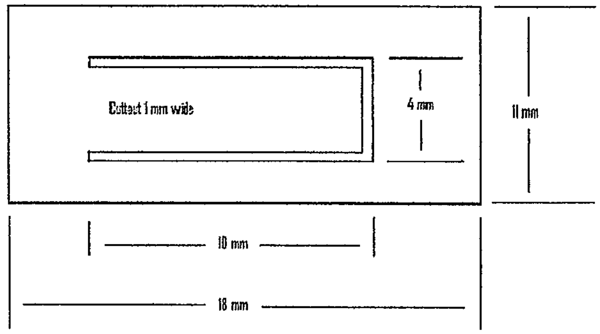

Figure 3 – Prototype 3

The equations used to calculate the required dimensions are presented as follows,[2]

$$Freq = c/4(L + W)$$

Where Freq is the desired frequency, c is the speed of light, L is the length and W is the width. Adjustments to compensate for the fringing fields were also included in the calculations by reducing the dimensions by 5%. The patch antenna must be located above a ground plane with a maximum spacing of one quarter wave length. The spacing of the ground plane controls the bandwidth of the antenna. The authors chose a distance of 12.5 mm which is somewhat less than the one quarter wave length of 13.6 mm.

SIMULATION

Given a real world situation a competent engineer would want to use the best tools available. An exhaustive comparison of the leading brands of antenna software yielded a clear leader, FEKO of Stellenbosch, South Africa. However this application is very costly and has a steep learning curve and for this project only limited simulation was carried out. For various reasons, simplicity, familiarity and others, most of the simulation for this design, the authors' chose to use the less comprehensive Sonnet of North Syracuse, NY.

SONNET SIMULATION

Sonnet is best suited to design challenges involving predominantly planar (3D planar) circuits and antennas. The Pro version of Sonnet allows any number of dielectric/metal layers. Sonnet provided electromagnetic (EM) modeling of the layout dimensions. Sonnet is able to calibrate internal ports and compute S-parameter or lumped element models. Using this tool yielded a high-confidence EM simulated model for later construction and testing. Each of the three designs provided excellent models for the specified frequencies. The frequency response as modeled by Sonnet of Prototype 3 is shown below. This will later be compared to the reflection coefficient from the actual measured data.

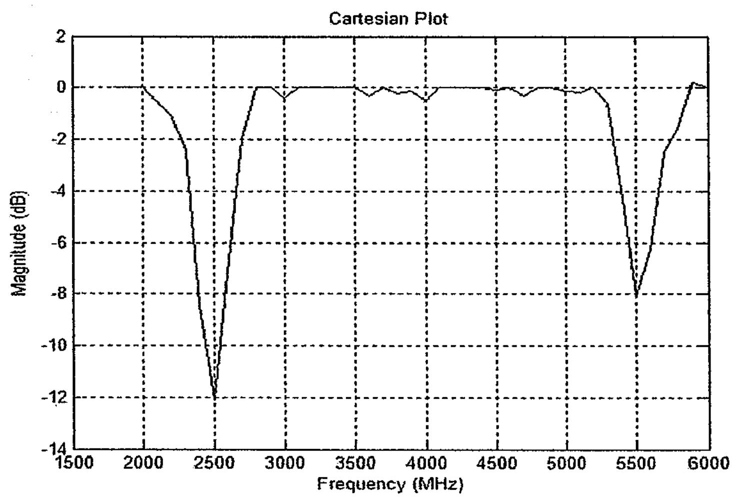

Figure 4 – Sonnet Simulated Reflection Coefficient

FEKO SIMULATION

It was desired to verify the Sonnet Simulations taken as well as explore other software possibilities. A very robust option is the FEKO electromagnetic simulator. This software is a full wave, method of moments (MoM) based, computer code for the analysis of electromagnetic problems and has a very steep learning curve. We were fortunate enough to know a student who was much experienced with this software and agreed to help us simulate our antenna. Due to late design changes the FEKO simulations below are from an earlier antenna version. These results are included to illustrate the ever changing process we undertook to achieve our end result.

Below is the FEKO display of a dual band patch and slot antenna. The small triangle division are used by FEKO for the discrete calculation of the various antenna parameters.

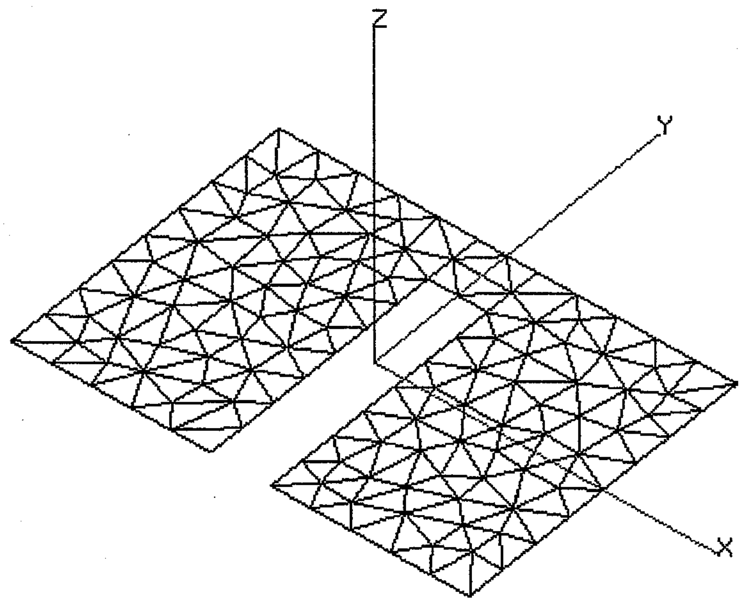

Figure 5 – FEKO Antenna Display

Below is the linear antenna gain in the 5.5 GHz frequency band. This shape is similar to the calculated results we obtained for the 5.5 GHz slot antenna.

Overall FEKO is an effective tool in the hands of an experienced antenna designer. For our purposes FEKO proved too complex, if this antenna project was to progress further than our prototypes we would have done more FEKO simulations

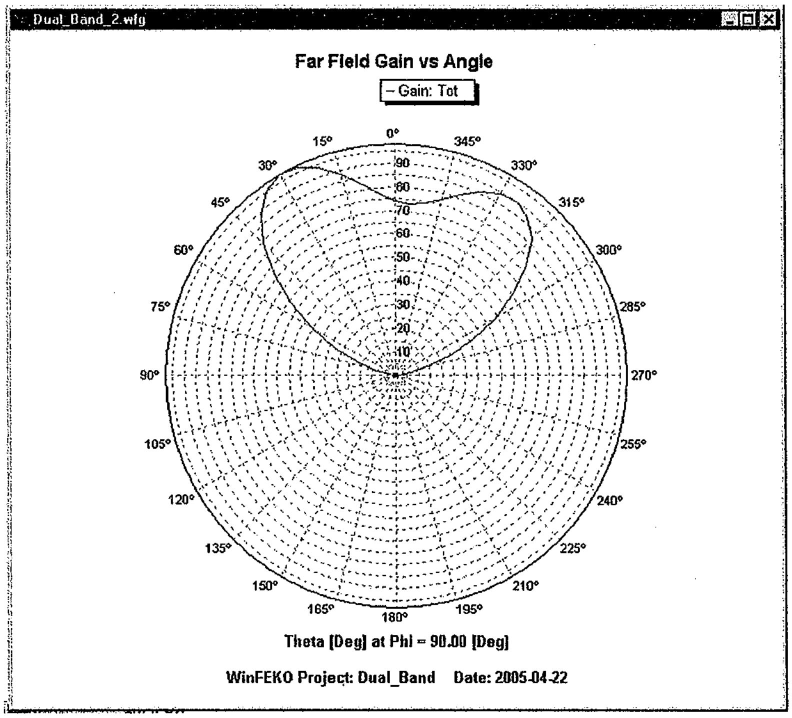

Figure 6 – FEKO simulated results

FABRICATION

The more precise the fabrication techniques the less tweaking is necessary and the less precise the fabrication process the more tweaking is required. Ideally, we would have liked to use a very precise copper etching technique to create our antenna but due to the prohibitive cost and the lack of ability to properly simulate and modify the etched antenna, a more crude approach was adopted. This involved cutting the antenna out of copper foil tape and connecting it to our feed points and ground plane with adhesive.

Since precise fabrication was not possible, multiple designs and multiple realizations of these designs were created by the team to cover our bases. These were each in turn attached to the soldered ground plane and feed points. Each design was tested on a Network Analyzer to measure the antenna's reflection coefficients and subsequent return loss. The various designs were even tested while attached to the analyzer to give real time responses to the various cuts and dents we made on the antennas. This was initially was very interesting to see the responses but when antenna dimensions were modified and the desired result was not displayed this caused some dismay. These sort of experiences show how temperamental antenna design is. Below is a picture of the fabricated antenna and various prototypes.

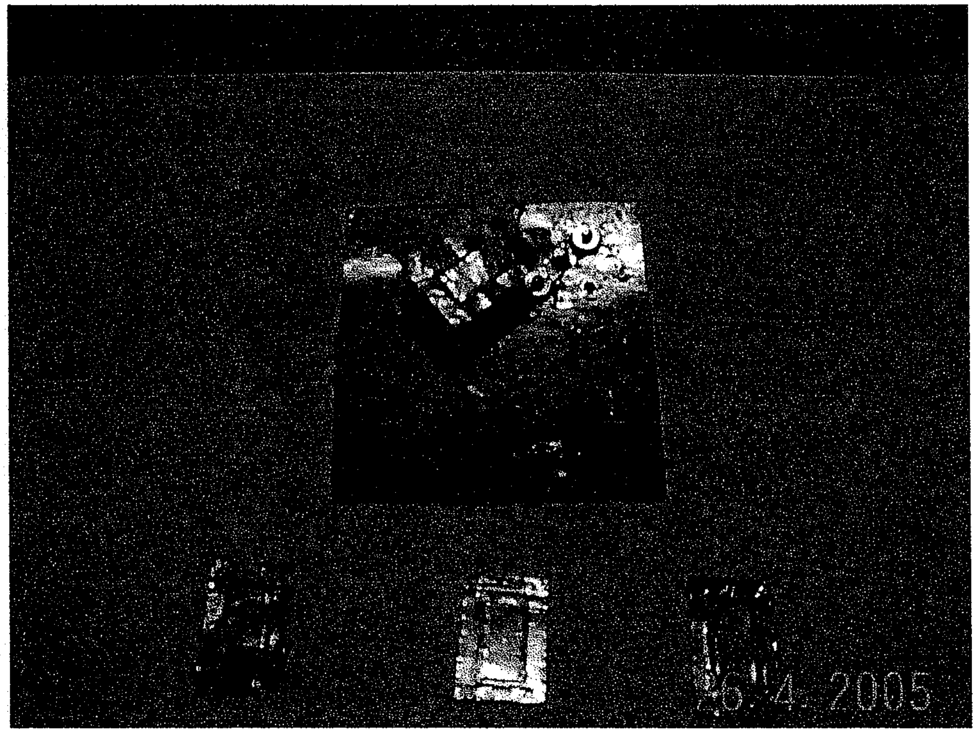

Figure 7 – Final Antenna Prototype

ANTENNA TESTING

Each antenna design was tested and measurements collected twice: once on the HP 87700 Network Analyzer and then in the Anechoic Chamber. Testing on the network analyzer was done prior to testing in the anechoic chamber to ensure the design would resonate at the specified frequencies. Following calibration of the network analyzer, the designs were connected and the analyzer one at a time, and S_{11} was measured while the frequency was swept from 2 to 6 GHz.

If the measured resonant frequencies of the design being tested did not match the specifications the design was "tweaked" to adjust where it would resonate. The dimensions of the antenna correspond to the resonant frequencies, the outside measurements control the lower resonant frequency and the inside (slit) dimensions control the higher frequency. If the measured frequency was too low, the dimensions were decreased and theory tells us the resonant frequency should go up, or if the measured frequency was too high, the dimensions were increased and the resonant frequency should go down. In practice through, changing the antenna dimensions didn't always produce the desired change in resonance. This is probably due to factors such as the copper foil bunching up, creating unwanted resonances, and the varying of ground plane spacing or varying feed impedance.

The reason for the inverse relationship between the dimensions of the patch and the resonant frequencies is related to the length of the current path around the patch, with a longer path length corresponding to a longer wavelength and therefore a lower frequency and vice versa. Figure 8 and Figure 9 show the student team members measuring the resonant frequencies on the network analyzer and tweaking the dimensions with the help of the teaching assistant and Figure 10 shows the S_{11} measurements of the final tweaked antenna design.

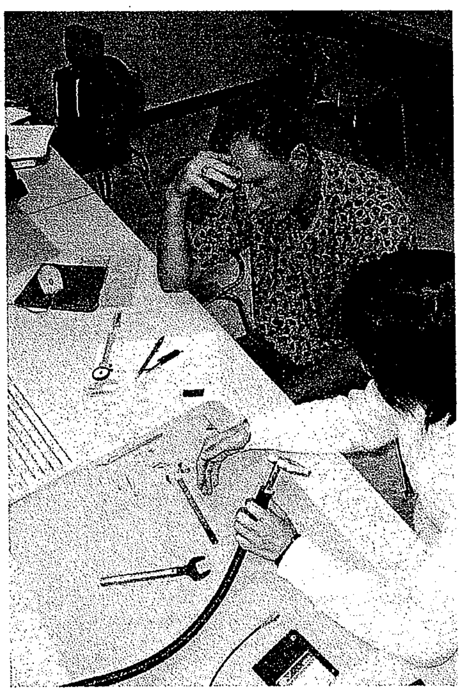

Figure 8 - Tweaking the antenna dimensions

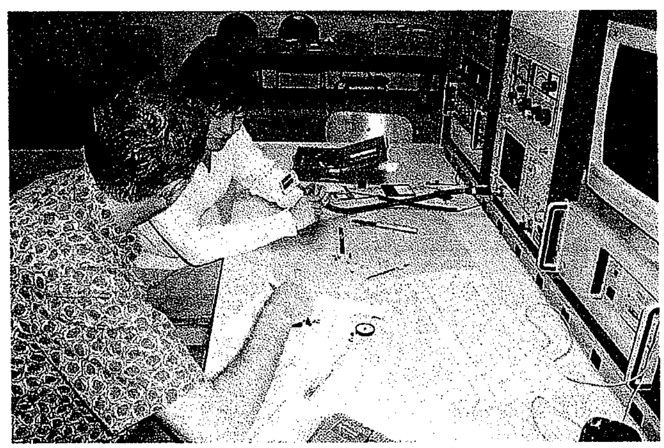

Figure 9 Measuring the resonant frequencies.

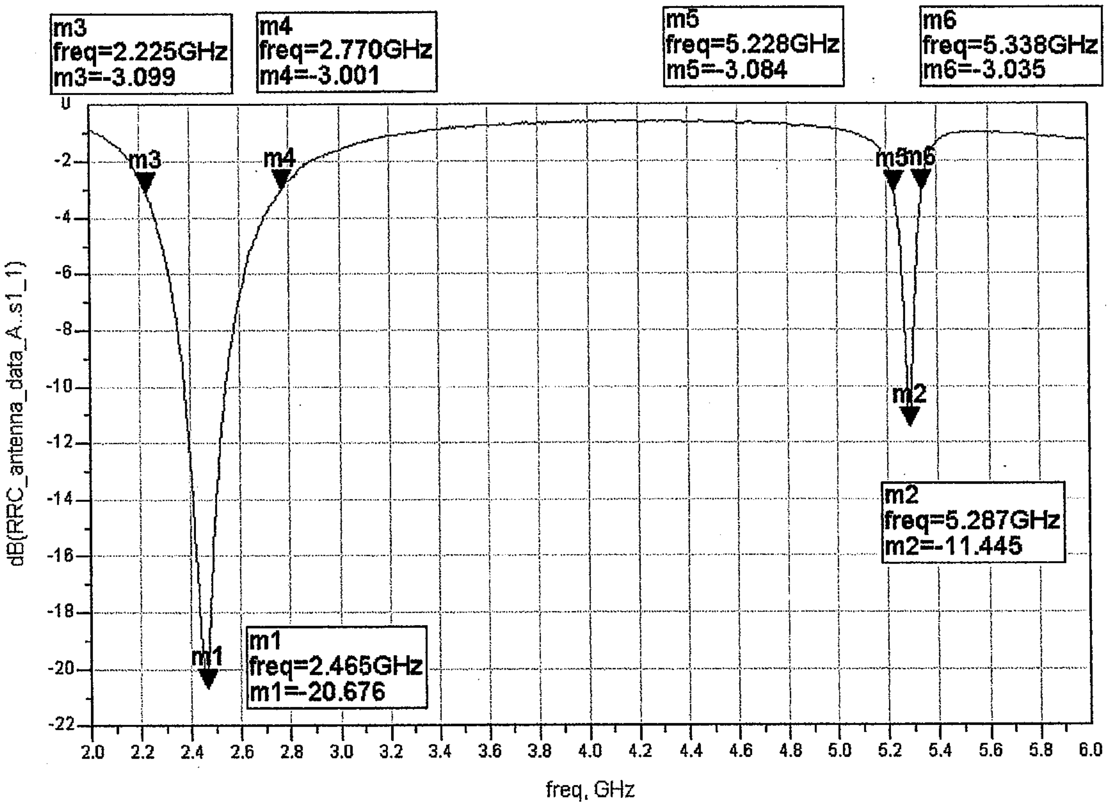

Figure 10 – Measured Reflection Coefficents

Once the measured resonant frequencies were within the specifications, the antenna was tested in the anechoic chamber. The name "anechoic" literally means "without echo" and a lack of echoes is desirable when testing an antenna's radiation pattern to eliminate reflections that would result in incorrect pattern measurements. The antenna was placed in the anechoic chamber and connected to a signal generator that provided 17 dBm of power to the antenna. At the other side of the chamber a small dipole antenna designed to resonate at 2450 MHz was connected to the measuring equipment with the dipole oriented in the direction of the E-field being radiated by the patch.

The patch antenna was then rotated through 360° and the power received by the dipole was recorded every 3°. The dipole antenna was then rotated to measure the H-field, and the patch was rotated and measurements taken as for the E-plane. The dipole was then replaced with a short length of WR-187 waveguide, which resonates well from 3950 MHz to 5850 MHz. The wave guide was set to measure the E-field and the patch antenna was rotated and measurements taken as before. Finally the waveguide was oriented to the H-field and the measurements were again taken as before. The data for each measurement was imported into MATLAB® and the plots in Figures 11 – 15 show the measured gains of the patch antenna.

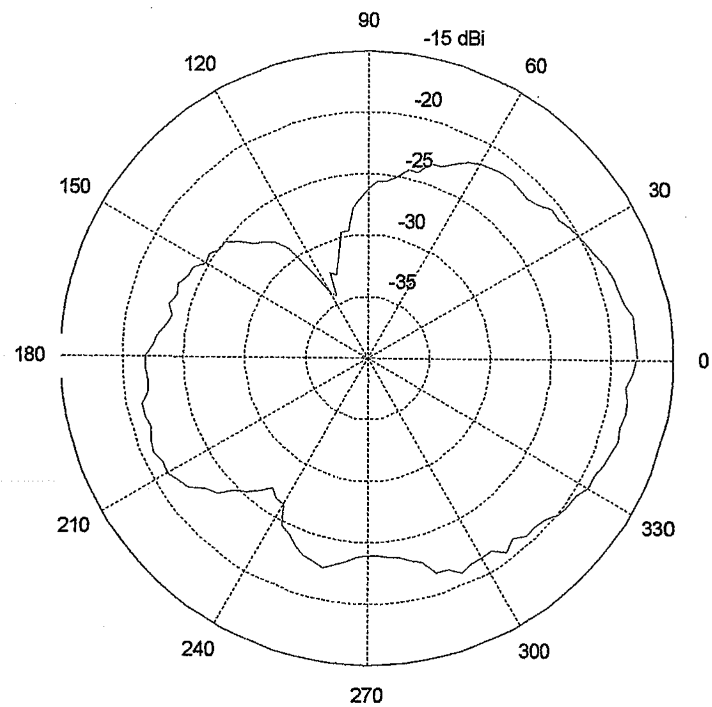

Figure 11 - Normalized E-field antenna gain at 2450 MHz

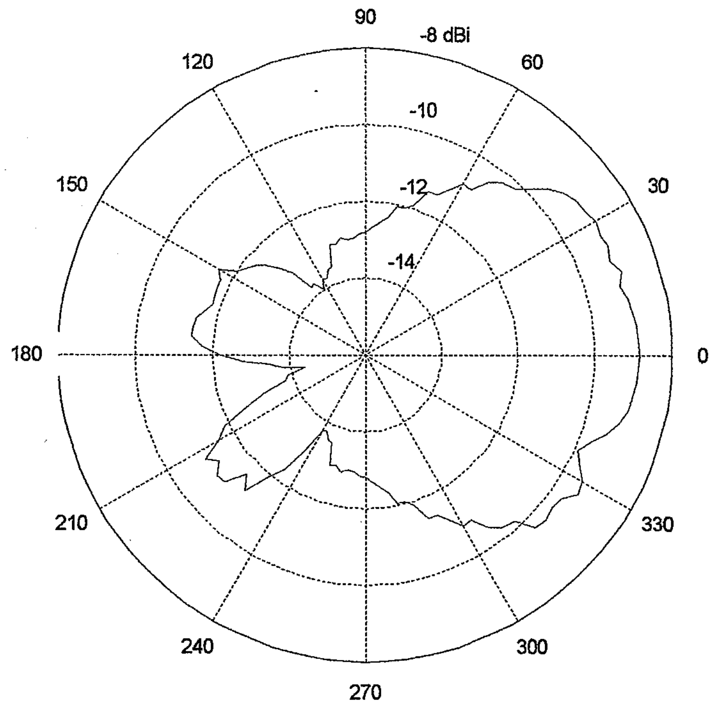

Figure 12 - Normalized H-field antenna gain at 2450 MHz

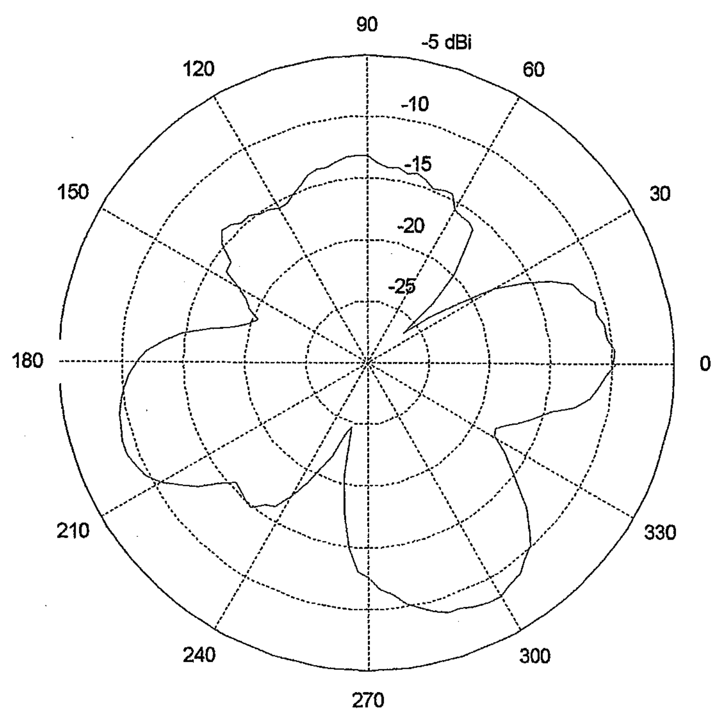

Figure 13 - Normalized E-field antenna gain at 5300 MHz

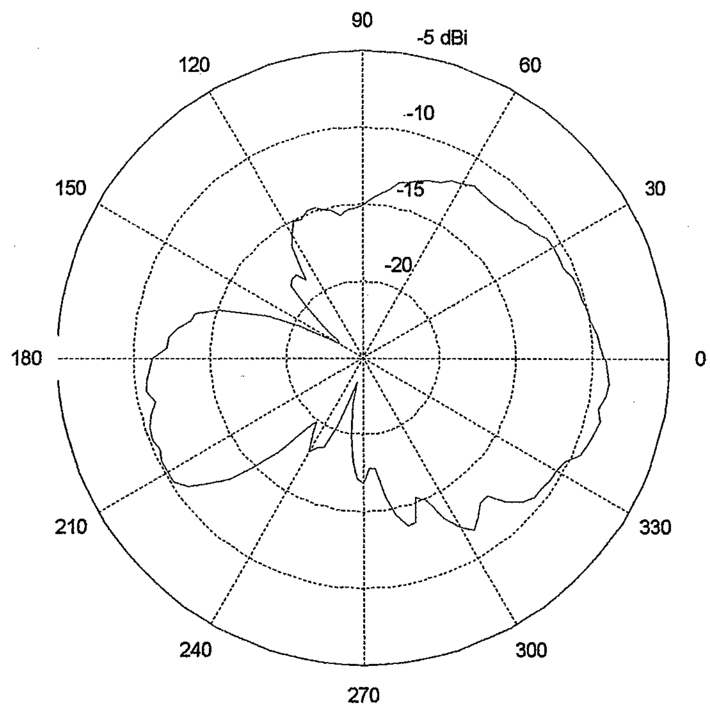

Figure 14 - Normalized H-field antenna gain at 5300 MHz

CONCLUSION

This report has shown the design, fabrication and testing of a dual band patch antenna for the frequencies 2450 and 5500 MHz is presented. Simulated results compared nicely to the measured results. In addition, insights into high frequency antenna design were given, with its challenges and successes.

REFERENCES

[1] http://www.ece.utah.edu/~ece5324/

[2] Planar Antennas for Wireless Communications, Kin-Lu Wong, 2002, Wiley, Hoboken, NJ.

Dual Band Microstrip Patch Antenna

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ECE 5324
Dr. Gandhi

Dual Band Microstrip Patch Antenna

Introduction

Microstrip antennas are very simple antennas that can be easily manufactured and tested. They are frequently built by using printed circuit board technology. This also allows the manufacture of microstrip antenna arrays to be made quite easily since many can be fitted to one board. This is the report of a microstrip antenna design that we have developed for our Antenna Theory and Design class. In this report, we will report how we designed the antenna, how we manufactured of the antenna, and how we tested the antenna (and its results). We also will cover the manufacture and testing of a second antenna of the same design, which was built using printed circuit board technology rather than copper tape.

Design of the Antenna

Our design specifications of the microstrip antenna required a dual-band antenna with a bandwidth of 10%. The frequencies that we needed the antenna to work at were 835 MHz and 1.9 GHz. The antenna needed to be built using the same general layout as described in the book: a ground plane with the actual antenna suspended above it.

We tried several designs for our antenna layout. Each design was simulated with the software "Sonnet." This software allowed us to see how the antenna would behave before we had to manufacture it. Several of the designs included:

- Dual-Frequency Slotted Patch Antennas with 1 Slot or 3 Slot and 4 Shorting Pins: It would not resonate correctly for both frequencies. However very minimal reflection!
- Dual-Frequency Dual-Linearly Polarized Microstrip: It was an unsuccessful design, but harder to manufacture.
- Stacked Patch: This works well at desired frequency, however not enough bandwidth and harder to manufacture due to multi-layer stacking.
- Slotted-Square microstrip: Another unsuccessful attempt
- Slotted-Crosspatch for dual-polarization: Unsuccessful
- Cross-Slot microstrip to obtain dual-frequency: Unsuccessful
- Rectangular Ring Microstrip: It wouldn't resonate on second frequency.
- Dual Frequency PIFA: It couldn't obtain the correct frequency ratio, sometimes missing the first or the second frequency all together. Also not enough bandwidth.

As shown above, we tried many designs and found that they all were insufficient. Designing patch antennas was more work than previously assumed. With the permission of Dr. Gandhi, we decided to build an antenna that was very similar to the example design demonstrated to us in class. This general shape of this outline is shown in figure 1. Its exact dimensions are listed in figure 5.

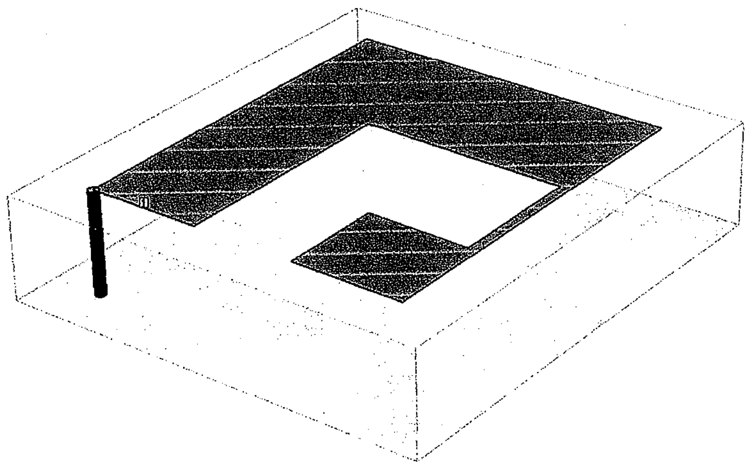

Figure 1

Using the Sonnet software, we were able to make some simulations of the antenna with FDTD analysis. This procedure required us to break the antenna into several sub-sections and simulate each one at a time. The subsections are shown in figure 2. The current densities for each frequency, as calculated by sonnet, are displayed in figure 3 and figure 4.

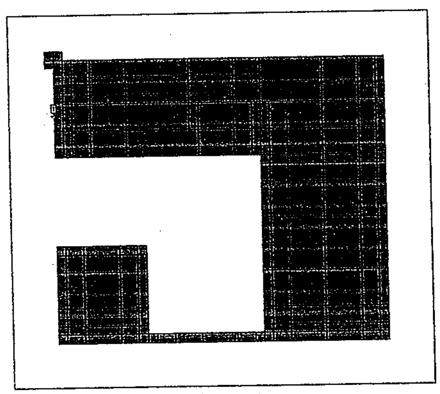

Figure 2

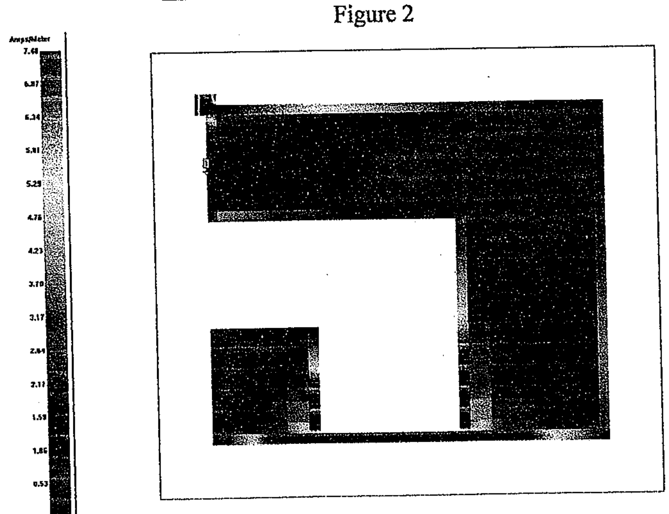

Figure 2 (1.9 GHz)

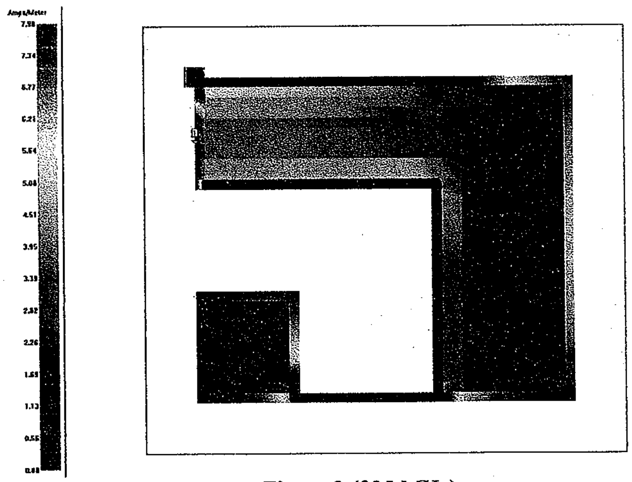

Figure 3 (835 MHz)

These graphs seem to be consistent with the theory that we have learned in class on microstrip antennas. From Sonnet, we also plotted the simulated reflection coefficient graph, which is shown in figure 4. As can be seen, this simulated antenna should match our design parameters perfectly.

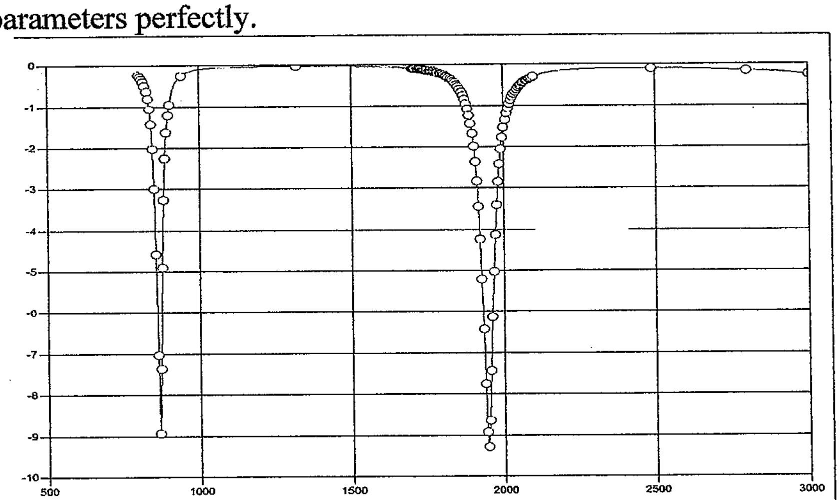

Figure 4

Manufacture of the Antenna

Manufacturing the antenna was accomplished with the wonderful help of Bryan Steinquist. With our design in hand, he was able to give us a ground plane and antenna feed point. The upper plane we completed ourselves. The pattern was cut from copper paper to fit the dimensions. Figure 5 demonstrates what these dimensions are. This copper paper was separated from the ground plane by a piece of foam. The separation distance was designed to be 10mm.

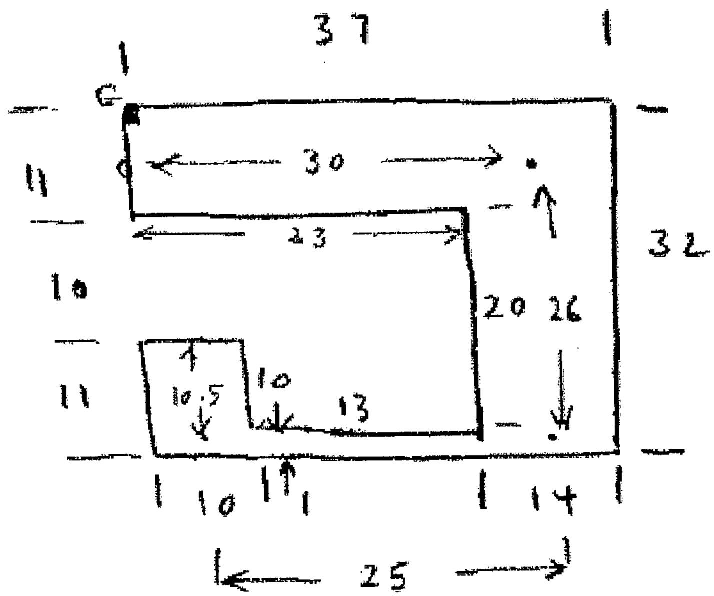

Figure 5

This method of manufacturing allowed us to change the antenna if needed by putting additional copper tape on any chosen side or cutting small strips off the sides. This ability to easily change the antenna shape dynamically proved to be quite useful in the testing of the antenna. It became very clear to us why this copper tape is used in prototyping antennas.

Printed Circuit Board Antenna

In addition to the antenna we constructed with Bryan, we also set out to build a microstrip antenna of the same design, but by using printed circuit board techniques. Such antennas are sometimes referred to as "printed antennas." The reason behind this jargon is the fact that they are actually printed from a printer. The process we used to manufacture this second antenna is described in four steps:

1. We first printed the antenna design onto a transparency, taking extra care to verify that the dimensions were correct when printed.
2. The transparency was used as a mask for ultraviolet exposure to a printed circuit board. The board was covered with a thin photo-resist film that protected the copper. The transparency served to cover any area that we wanted to be copper. The exposure time was about one minute.
3. The board was then soaked in a development solution (a mixture of water and lye). This caused the areas of the film that were exposed to the ultraviolet light to be dissolved away.
4. The board was then soaked in an acid bath for several minutes. The copper was eaten away by the acid, except any areas that were covered by the film. This left us with a board that had precisely the correct antenna pattern on it.

Because we had much more area on the board than what was needed, we were able to fit three antenna patterns on it (The actual mask is shown in Appendix A). The pieces on the board were cut out and assembled. We used nylon screws to separate the board from the ground plane, so they would not conduct or interfere with the fields. We felt that this antenna should be able to work very well because it met the design specifications so accurately.

Testing Methods and Results

The antennas that we had built were tested with the help of the T.A., Qingxiang Li. The first test to the antennas was with a network analyzer. We connected it to the analyzer and measured the reflection coefficients. This determined the frequencies and bandwidths of the antennas. It also allowed for us to make adjustments to the antenna and test it in a quick manner, so the testing cycle was quick.

We had to work with the first antenna to get it to the match the right frequencies. We adjusted the thin part of the antenna from 1 mm to 2 mm to make it work with the higher frequency, and from 14 mm to 16 mm on the right side to make it work properly with the lower frequency. We also needed to extend the ground plane several centimeters to make it work properly. These adjustments allowed us to make good measurements. We found that our reflection coefficient graph was remarkably similar to the simulated graph. Figure 6 shows our returned spectrum. We achieved frequencies very close to the specifications, the bandwidths also turned out to be close to 10% (the lower frequency had a bandwidth of 70 MHz and the higher frequency had a bandwidth of 100 MHz).

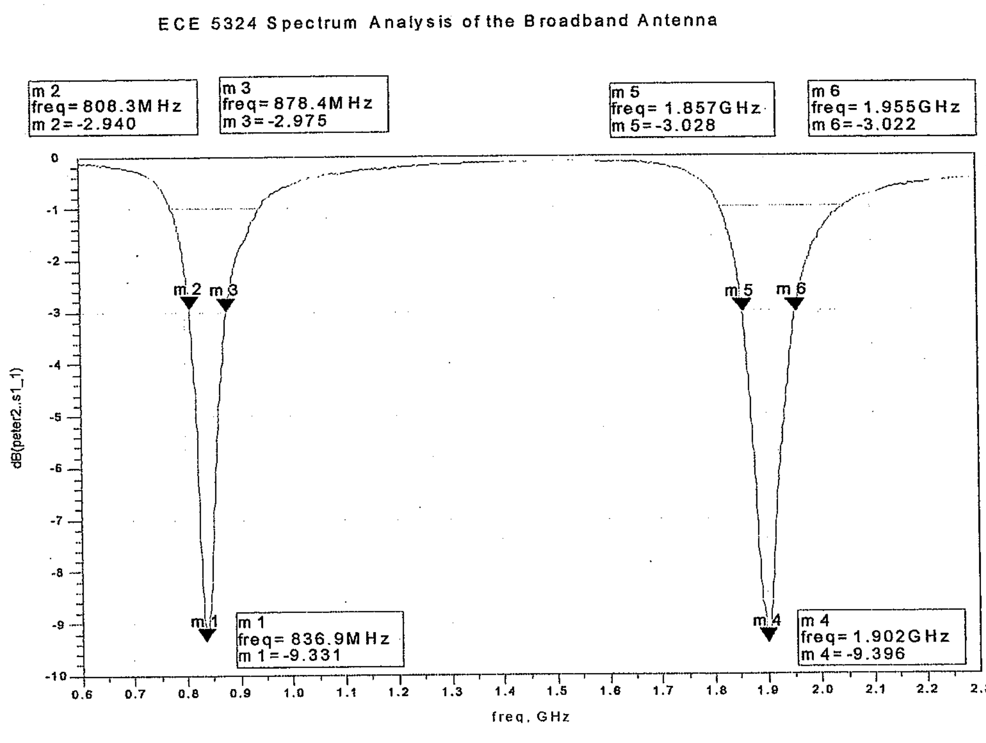

Figure 6

The second test that was performed was by an apparatus in the anechoic chamber in the MEB building. This room was designed to absorb all radiation in its walls. The apparatus measured the signal strength of the antenna at various angles to produce the radiation pattern for us. The receiving antenna was a half wave dipole placed at 3.4 meters from the microstrip antenna. The antenna was rotated by a motor and measured every three degrees. From this we could measure the E-field and the H-field of the antenna at each of its frequencies. The radiation patterns of the E and H fields of the first antenna for the 835 frequency are displayed in figures 7 and 8. The radiation patterns of the E and H fields for the 1.9 GHz frequency are displayed in figures 9 and 10.

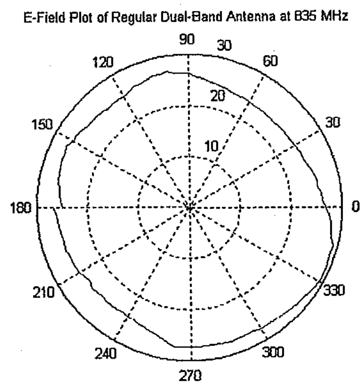

Figure 7

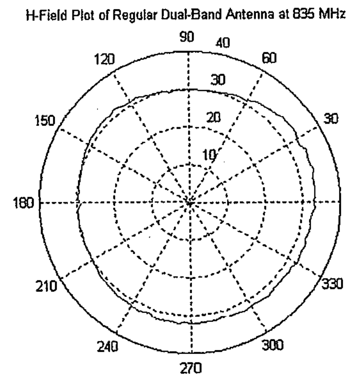

Figure 8

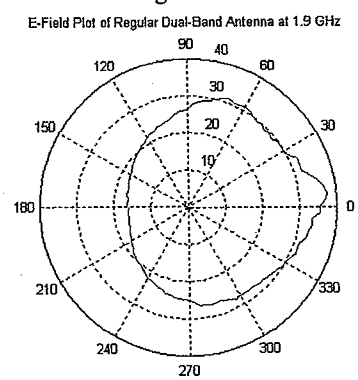

Figure 9

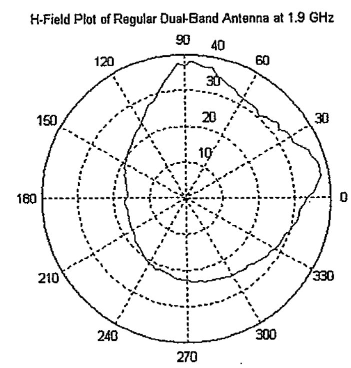

Figure 10

The radiation patterns show that the pattern is very uniform for the 835 MHz band, but much more lopsided for the 1.9 GHz frequency. On both frequencies, the gain is not very high, but that was to be expected with microstrip antennas.

The printed circuit board (PCB) antenna was tested next. Surprisingly, the antenna was not as close to the simulated results as we had planned. We theorized that if we were to build the antenna as closely as possible to the design, it would yield very accurate results. The lower frequency tested very well and matched our specifications. The higher frequency was much lower than expected (1.67 GHz). Another surprise was that no amount of adjusting the antenna's parameters seemed to help raise the frequency. We tried to change the length of many sides. We were restricted, of course, to only adding length. The best we could get from the PCB antenna was the original design. The final reflection spectrum is shown below in figure 11. It is interesting to note how little reflection is achieved on the higher frequency. It reflects only 0.25% of the signal!

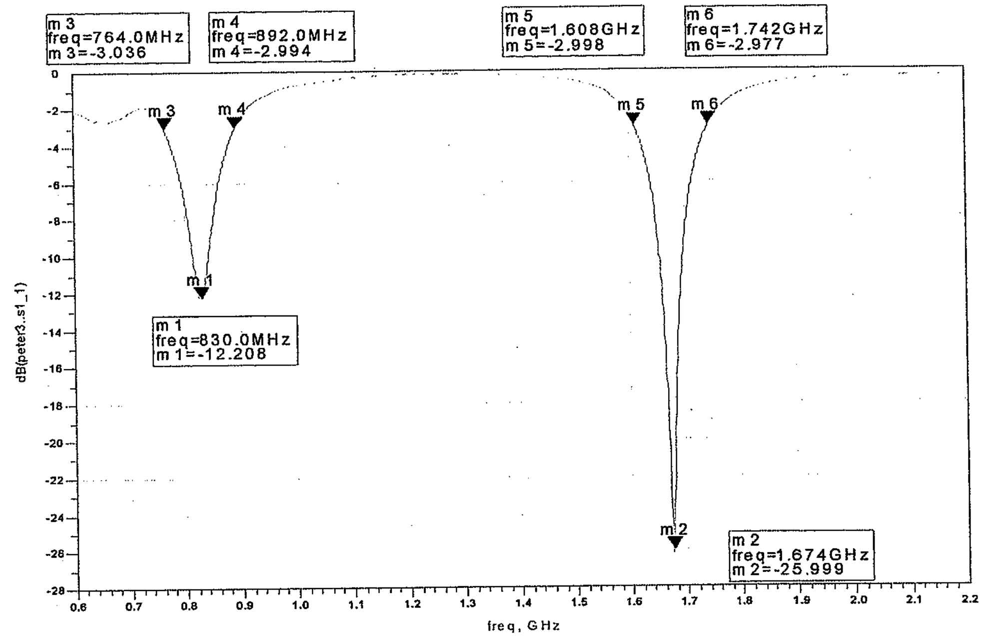

Figure 11

The PCB antenna was also tested in the anechoic chamber for its radiation patterns. The pattern itself was very uniform. The major difference was that the gain of the PCB antenna was much less than the first antenna. We measured a drop of about 5 dB in the PCB antenna compared to the first. The higher frequency was also measured at a very low gain, but this is because the frequency we were radiating, 1.67 GHz, wasn't received well on the half-wave dipole designed for 1.9 GHz. The E-field patterns for the two frequencies are shown in figures 12 and 13.

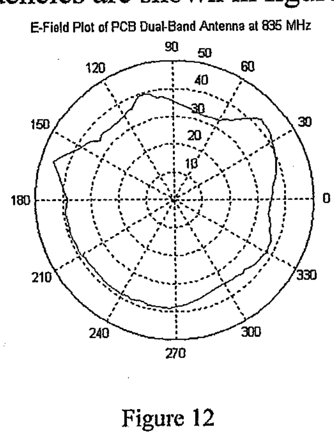

Figure 12

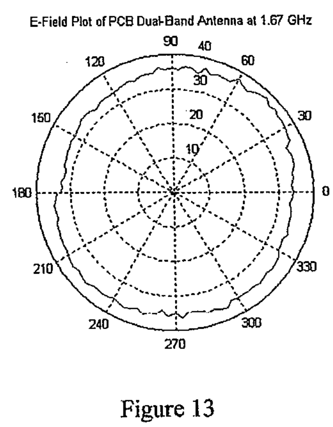

Figure 13

Possible Improvements

The regular microstrip antenna that we build performed very closely to specifications and improvements made to it are nominal. There were only a few adjustments made to it that might be taken into the design. These adjustments were most likely made to compensate for the dielectric of the foam and the irregular spacing of the feed and the ground post. We are uncertain what more could be done to improve this antenna.

The PCB antenna had a major problem with the higher frequency and the lower gain. We have done some research into why this happened and believe we have the answer. The PCB that we printed our antenna onto was made out of Phenolic material. This material is useful for creating low-frequency printed circuit boards because it can handle a large range of temperatures and it is also cheap. The downside to it is that it is dismal for working with frequencies greater than 1 GHz. The dielectric constant for Phenolic is too high and it is too lossy for use in a high frequency device, such as an antenna.

When we first manufactured the PCB antenna, we assumed that for such a thin piece of material, it would not make much of a difference in the performance, but we were mistaken. For a microstrip antenna, it is better to use a Teflon board, which has a much more stable dielectric constant and is much less lossy. Such an improvement would improve the gain and raise the upper frequency closer to the designed value.

Conclusion

Microstrip antennas are simple, yet complex to design. The best method for design is to do a lot of testing. We successfully designed, manufactured, and tested a dual-band microstrip antenna that operated at 835 MHz and 1.9 GHz. We also used the same design to manufacture and test an antenna made from a printed circuit board. We found that very small differences in the material substrate or the dimensions of the antenna made large changes in the antenna performance. From the actual tests, it could be seen how the antennas performed and what could be done to make them better (such as changing to a Teflon substrate, or extending the ground plane). There are many possibilities and applications that have been realized in the course of this project.

Appendix A

Printed Circuit Board Mask