Directed Cell Phone Antenna

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DIRECTED CELL PHONE ANTENNA

by

Benjamin Carroll

Thesis submitted in partial fulfillment of the requirements for the degree of DEPARTMENTAL HONORS in Electrical Engineering in the Department of Engineering

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Directed Cell Phone Antenna

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4 May 2012

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Abstract:

The purpose of this project is to design a Yagi-Uda antenna with a very high forward directivity. This antenna will be built to the parameters of the Motorola Razr v3 cellular phone. The designed antenna will have a much higher forward gain than the internal antenna in the phone. This means that when the antenna is connected it will have an improved range of reception as long as the antenna is pointing in the direction of a cell tower.

The impact of this project is that the signal reception of a popular model of cell phone will be drastically improved. While it is not ideal to carry this rather awkward antenna around everywhere to improve the signal, it could easily be mounted to improve signal. When situations are encountered that the phone consistently exhibits poor reception this antenna could be used to boost the reception at that location.
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1 Introduction

This section will introduce the issues that this project is attempting to solve and a summary of the overall paper.

1.1 Problem Statement

There are numerous instances where a cellular phone exhibits poor reception. The reasons for this come from two different problems:

- Distance to nearest cell tower is too far for the phones internal antenna to amplify the signal.
- Buildings or other solid objects are decreasing the strength of the signal so that it will not propagate through these objects to send or receive.

Both of these problems will diminish the strength of the signal in a cell phone, but can be decreased by changing the parameters of the antenna attached to the phone.

1.2 Summary of Design Process

The design process that I executed attempts to improve the signal reception of the phone by increasing the gain of an external antenna. The gain of an antenna has a multiplying affect on a signal and in some sense will appear to amplify it as it is transmitted or received. The parameters of my antenna design allow me to build an antenna with a gain that is much higher than that of the built in cell phone antenna. Thus by increasing the gain through the antenna I am able to improve the reception when it is decreased due to the two problems of distance and obstacles.

1.3 Summary of Final Results

The antenna that I built is not fully capable of integration with the desired cell phone because of some adapter issues. The antenna design was fully implemented and should exhibit only minor deviations from the simulations that can be attributed to minor measurement errors and mismatched transmission connections.
1.4 Organization of Report

This report will be organized with a reference of the contents, charts and tables used at the beginning. It will then provide a brief overview of the problem and solution. Subsequently the report will discuss the design parameters of the solution, why different materials were chosen and how the design was optimized. Then it will discuss how the solution prototype was built and tested. Finally it will include an overall assessment of results as well as budget and time reports of the full project.

2 General Antenna Design

This section will discuss the theory of the antenna design for this project and specifically the parameters of the general Yagi Uda antenna.

2.1 Antenna Theory

Wireless communication is the basis on which cellular telephones operate. The principle behind it is simple: a cell phone will first act as a transmitter creating internal electronic pulses that contain the information of the phone call. These signals are then turned into electromagnetic waves through the properties of the antenna connected to the phone. At this point the signals are being transmitted through air or "free space" without the use of a connecting wire.

These transmitted signals move through free space until they encounter the receiver antenna on the cellular tower. When the signals encounter the receiver antenna they propagate back through the receiver and turn back into regular electrical impulses and the information from the transmitted call can be recovered. (Figure 1)

Antennas also operate on the theory of reciprocity, meaning that any antenna can be used to either transmit or receive without changing any of the antennas properties.
2.2 Frii's Transmission Equation

Frii's Transmission Equation is a popular equation that discusses the parameters that affect the receiver power through an antenna. This equation can be used to find a solution to increase a cell phones signal reception. (Figure 2)

Signal reception could also be called received power (Pr) it is dependent on four parameters:

1. Pt or the power of the transmitted signal.
2. Gt or gain of the transmitting antenna.
3. Gr or gain of the receiving antenna.
4. R or range between the transmitter and receiver.

Looking at these four parameters, for our problem it is not feasible to always change the range between the tower and phone to improve reception. It is also not ideal to increase the power of the phone when transmitting a signal since this would only solve half of the problem and would not affect signals being received into the phone.

It is possible though through the principle of reciprocity to build an antenna for the phone that will increase the gain of a received and transmitted signals. Therefore the solution
to the problem of poor reception in this case is to build an antenna with a much higher gain than the internal antenna.

![Gain equation](http://en.wikipedia.org/wiki/Fris_transmission_equation)

**Figure 2**

### 2.3 Yagi Uda Antenna

The Yagi-Uda antenna is a very popular antenna design for creating a very high gain. The gain of an antenna is basically how the power of the signal is shaped as it leaves the antenna. If that power can be focused in one direction it will have a much higher gain than if it has to spread out equally in every direction.

The regular cell phone antenna has to spread out its power in every direction, whereas a Yagi-Uda antenna can be directed meaning the majority of the power can be shaped into a specific direction resulting in a higher gain. (Figure 3)

The gain of an antenna is measured by looking at a field pattern, which is a two dimensional cut of how the power spreads out from the antenna. The field pattern is measured in decibels(db) which is a logarithmic rather than a linear scale.
2.4 Yagi Uda Design Parameters

A Yagi Uda antenna is very simple to design in principle. It is simply an array of conductive elements. Design considerations take into account four main factors when designing: (Figure 4)

1. Reflector Element
2. Feed Element
3. Directors or Parasitic Elements
4. Design Spacing and Element Amounts

Each of these factors has a basic 'rule of thumb' when designing a Yagi Uda antenna

The reflector element is measured out to be half of the wavelength of the antenna operating frequency. This is the largest element and provides the function of blocking all of the backwards energy to shape the field pattern.
The feed element is 5% shorter in length than the reflector and is the only element of the antenna that is electronically connected to a transmitter or receiver.

The directors are 5% shorter in length than the feed element and are spaced out evenly ahead of the feed element in order to shape the energy into a directed cone in front of the antenna. Depending on the design the amount of reflectors commonly ranges from one to twenty.

Finally the spacing of each elements is between .1 and .3 percent of the overall wavelength.

Each of these values is required to be optimized through trial and error in order to develop an antenna that is ideal for a specific task.

![Geometry of a K elements Yagi-Uda](image)

**Figure 4**

### 3 Optimized Antenna Design

This section will cover how the general parameters previously discussed were optimized and will include the design simulations showing antenna function. It will also discuss some remarks on justification for different design decisions.
3.1 Initial Design Optimization

In order to begin optimizing the antenna initial designs had to be calculated. In order to facilitate rapid calculations and quick changes as I altered different lengths, the design was calculated in a custom built excel spreadsheet. Using the spreadsheet I was able to create simple formulas from the general Yagi Uda antenna design parameters and then customize them to my specific frequency. (see Table 1)

<table>
<thead>
<tr>
<th>Element</th>
<th>Percentage Element(m)</th>
<th>Half(m) Element(in)</th>
<th>Half(in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>reflector</td>
<td>0.482</td>
<td>0.076</td>
<td>0.038</td>
</tr>
<tr>
<td>feed</td>
<td>0.428</td>
<td>0.068</td>
<td>0.034</td>
</tr>
<tr>
<td>D1</td>
<td>0.420</td>
<td>0.066</td>
<td>0.033</td>
</tr>
<tr>
<td>D2</td>
<td>0.407</td>
<td>0.064</td>
<td>0.032</td>
</tr>
<tr>
<td>D3</td>
<td>0.398</td>
<td>0.063</td>
<td>0.031</td>
</tr>
<tr>
<td>D4</td>
<td>0.394</td>
<td>0.062</td>
<td>0.031</td>
</tr>
<tr>
<td>D5</td>
<td>0.390</td>
<td>0.062</td>
<td>0.031</td>
</tr>
<tr>
<td>D6</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D7</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D8</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D9</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D10</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D11</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D12</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D13</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
<tr>
<td>D14</td>
<td>0.386</td>
<td>0.061</td>
<td>0.030</td>
</tr>
</tbody>
</table>

| radius (mm) | 1.34215 | Wavelength (m) | 0.1579 |
| spacing (m) | 0.03158 |           meters inches |
| spacing (in) | 1.24330776 | Boom | 0.50528 19.8929 |

3.2 Software Simulation

After values were calculated for each element on the spreadsheet, the gain could be calculated using antenna design software. Antenna design can be simulated in a computer program called 4NEC2 or NEC. This is a free software available online that easily assists in the simulation of many different kinds of antenna. Using this software I was able to plug in different values for various element lengths and through trial and error see how it affected the antenna.
The first step in the NEC design is to draw each element in free space to the calculated lengths. This is done by arranging each element on a coordinate axis and then plugging in the information. (Figure 5)

![Diagram of an antenna array]

**Figure 5**

After each element in the array is drawn a field pattern can be simulated to observe the direction and magnitude of the gain at those parameters. (Figure 6) The field pattern will show in decibels how the energy spreads out from the antenna and help to optimize the design. The design considerations for the field pattern are:

- Overall gain at the front of the antenna
- Value of the half power bandwidth
- Size of the first side lobes
- Gain at the rear of the antenna

When optimizing the antenna ideally a very high forward gain is wanted. Also, very low side lobe gains is desired. Side lobes are bulges where the gain is higher in a direction other than the forward direction. If the side lobes get to large then the antenna may begin to pick up signals from a direction of the side lobe instead of the main forward lobe. The half power bandwidth shows how wide the main lobe is spread out. A smaller bandwidth value allows for a more directed antenna. And last the rear gain should ideally be zero and all the energy would be reflected forward. In reality some energy will be lost at the back but that value is designed to be minimized.
3.3 Finalized Antenna Optimizations

After trial and error, I was able to design an antenna that satisfied the objectives of my project. I was able to design a Yagi-Uda array with the following characteristics:

- Operates at 1900 MHz (frequency of Sprint cellular phones)
- Has a high forward gain of 13.14db
- Side lobe gain of 1db
- Rear gain of -5db
- Half power bandwidth of 30 degrees
- Element designed with 16 elements (1 reflector, 1 feed element, 14 directors)
- Antenna lengths were optimized in simulation (see Antenna Table)
- Spacing between elements of .03m
3.4 Antenna Design Justifications

I decided to implement this design for multiple reasons. First the design parameter discussed resulted in the highest gain I was able to achieve. I initially started with a gain of around 8db and as I adjusted the lengths of the directors and continued to add more I was able to observe an increase in the gain. After the fourteenth director was added the gain did not alter anymore though and in fact I was able to observe a decrease in the forward gain as more directors were added.

Altering the spacing of the elements also affected some of the parameters. When the elements were spaced farther apart there was a smaller half power bandwidth value and a noticeable decrease in the side lobes, but the overall gain was lower. As I moved the elements closer together the gain increased to an extent along with the half power bandwidth and side lobe presence.

Tapering the lengths of the directors to subsequently smaller sizes also improved the forward gain and decreased the half power bandwidth. Although after a certain amount of tapering was done it again didn't affect the gain.

My strategy in forming this design was to push the forward gain to the highest value by altering a specific value. Such as the amount of directors, lengths of directors, spacing of each element, etc. I would then find the point where the gain began to decrease other parameters begin to change. By following this method of increasing an individual parameter until that aspect was optimized and then changing the next aspect I was able to fine tune the antenna to the highest gain possible using the materials I had selected.

4 Antenna Construction

This section how the designed antenna prototype was built. It will include information on all necessary materials, justification of material choices, fabrication instructions, and summary of final design results.

4.1 Material List

For the construction of the antenna prototype I needed the following materials:

- 48 inches of 1/4" Copper 145 Round Rod, Half Hard Temper, ASTM B249
- Non conductive plastic boom 20 inches length
- 7 inches of #14 Gauge AWGN bare copper wire
The materials used were:

- 3 feet of 50 Ohm coaxial cable
- 50 Ohm SMA connector

### 4.2 Material Justification

I selected my materials because I wanted my antenna to be as accurate as possible. I chose copper rods because they are more than 99.9% conductive with a very small center to center electrical conductivity. I could have selected aluminum rods or another cheaper metal, but to achieve the same conductivity with aluminum I would have needed to have rods with a larger radius then if I had built the same design with copper. Copper exhibited a higher gain during simulation, I was able to actually change the metal type of my elements and select different radius dimensions for those elements and then observe different simulations.

Copper rods of 1/4" diameter were used because they are more robust than smaller rods. The gain simulation didn't noticeably change when I incremented the radius by small amounts. Because of this I selected 1/4" rods because they are more robust. In order for the antenna to operate it has to be cut accurately and then the elements cannot be bent out of alignment with each other. The 1/4" rods did not bend like the smaller gauge wire tended to.

In order to connect to a 50 Ohm SMA connector I will be required to match all of my impedances to that value. I used #14 gauge copper wire for my L-shape matching stub on my antenna because it would allow me to manipulate it easily and bend it out of the way.

I selected a non-conductive plastic boom made of PVC pipe to mount my elements on because in my design I built the elements to be floating in 'free space'. Therefore I could not have any metal elements that they would conduct with the copper rods.

### 4.3 Antenna Construction

Construction of the antenna was done very carefully because if the elements are not shaped to exactly the right length and built to specific dimensions then the antenna will not operate at the fully desired point.

I began construction by drilling holes evenly spaced into my boom every 1.24 inches. In order to ensure that they were all perfectly aligned I used a level and brace with a drill press to achieve exact measurements. Then I used a similar process to cut all 16 elements to length using a saw. The elements were then slid into the holes and a dab of glue was used to secure their positions. (Figure 7)
4.4 Impedance Matching Overview

Impedance is an issue that must be considered when designing an antenna. It refers to the effect of when energy is traveling from one substance to another. (Figure 8) If the material resistance is different for the substances (ZL and ZS) then not all of the energy will pass through but will instead be reflected back and lost.

Figure 8
There are three different connections on this project that require impedance matching: (Figure 9)

1. Connection Between the antenna and coaxial cable
2. Connection between SMA connector and cell phone adapter cable
3. Connection between cell phone adapter cable and cell phone receiver

4.4 L-Stub Impedance Matching

The connection between the antenna and the 50 Ohm coaxial cable was achieved by using an L-stub matching network. (Figure 10)
The theory behind the L-Stub is that the antenna itself has an internal resistance and the coaxial line has a 50 Ohm internal resistance. The matching stub is designed at an impedance between the two so that less energy is reflected back because the differences are minimized.

To calculate the length of the stub the resistance of the antenna, and characteristic impedance ($Z_o$) of the wire used as the stub must be known. $Z_o$ can be calculated by finding the radius of the stub wire (a) and the center to center conductor spacing (d).

$$Z_o = 120 \ln \left( \frac{d}{a} \right)$$

The #14 copper wire had a measured radius of 1mm and a center to center conductor spacing of 1cm. Using the equation $Z_o$ was calculated to be 276.310 Ohms.
To find the length of the stub the characteristic impedance must be inserted into the equation for the length:

\[ l = \frac{c}{2\pi f} \tan^{-1}\left( \frac{X_L}{Z_0} \right) \]

- \( c \) = speed of light at \( 3 \times 10^8 \) m/s
- \( f \) = frequency antenna is designed for at 1900 MHz
- \( Z_0 \) = characteristic impedance of the stub at 276.310 Ohms
- \( X_L \) = impedance of the antenna measured in design

\( X_L \) was found by looking at the NEC simulations for the impedance of the antenna. (Figure 11)
The impedance of the antenna was designed to be 30.2 - j39.3 Ohms and that impedance needs to be stepped up to 50 Ohms. So plugging those values into the equation above results in length(L) = 5.5mm. This value is very small though and hard to manipulate so a full wavelength of the antenna was added to create a distance of 16.35cm for the split stub.

The split stub then had to be attached to the feed element. This was done by cutting the feed element in half and then connecting the stub to the ends. Initially I attempted to connect the stub by just soldering the two points together but the soldered connections were not strong enough for the robust antenna design I wanted. To solve this problem I used a rubber insulator and plastic sleeve to keep the feed element connected and then used electrical connection clamps to attach to the ends. (Figure 12) This design introduced a little bit more loss due to the different parameters of the clamps but was much more robust than direct solder so I accepted the trade off.
4.5 Impedance Connection at Phone

Connecting the antenna to the cell phone was a process that took a lot of research and had multiple options for solution. The solution I ended up selecting was to use a commercially made cable to connect into the phone. (Figure 13)

Most old cellular phones have a antenna adapter port on the back of the phone. This port is used by the company to test that signals are being transmitted and received and to verify that the internal antenna is working. This port can also be used though to connect an external antenna such as the one designed above. The company Wilson Electronics builds these antenna cables for many of the common phones on the market. I selected the cable for the Motorola Razr v3 because that was the phone I was designing to. The cable attaches into the rear of the phone by pulling out the plug and inserting the adapter.

Figure 13

4.6 Impedance Connection for SMA to FME

The cell phone cable end has a proprietary connection made by Wilson Electronic called an FME connector. This connector was made to connect to Wilson Electronic Antennas and is a very hard part to find an adapter for. I was able to find and order an adapter that connects a 50 Ohm FME connector to a 50 Ohm SMA connector which is the connector on the antenna side of
my design. (Figure 14) This connector will match the impedances between the phone and the antenna

![Figure 14](image)

5. Antenna Performance

This section will discuss different aspects of the antenna design testing and discuss issues that arose causing some tests to not be completed.

5.1 Antenna Designed Field Pattern

Using NEC software I was able to develop an antenna field pattern in three dimensions that shows the gain at different points. After adding the integration of my impedance matching network I was able to generate an antenna field pattern with a gain of over 12db. (Figure 15)
Unfortunately I ran into problems trying to test this field pattern in the lab. The antenna is designed to operate at 1900 MHz because that is the frequency at which the cell phone operates, but in the lab the only instruments to measure field patterns run at 1GHz and 10GHz so I was not able to perform a test on the real field pattern.

5.2 Frequency Sweep

The antenna is designed to pick up signals at 1900 MHz and is optimized for that frequency but will also achieve some gain at lower frequencies. By running a frequency sweep pattern in NEC I was able to see what the maximum gain level was a range of frequencies. (Figure 16)
The Sweep ran from 0Hz to 4GHz and the relative gain was measured at each point. A positive gain was measured from about 1200MHz to 2200MHz but the gains are not high enough to really consider until values are considered between 1800MHz and 2000MHz. This means that this antenna will operate very well at the designed frequency of 1900 MHz but will unfortunately not pick up signals very well at the 800MHz range which is another cell phone frequency.

The sweep also measured the gain at the front of the antenna compared to the gain at the rear. Ideally this rear gain would always be lower than the forward antenna gain. The frequency sweep showed that over the range of frequencies the rear gain was always lower.

Figure 16
5.3 Impedance Matching

Using the L-Stub matching I was able to simulate what a good impedance match would be that could be compared to a measured value on the spectrum analyzer. The simulation sweeps through a range of frequencies and measures how much of the energy going into the antenna is reflected back out from impedance matching. Ideally that value will be extremely low for the designed frequency.

Running a sweep from 1800 MHz to 2000 MHz the simulation showed that at 1900 MHz a value of -55db was measured for the reflected energy back out, also called the S11 parameter. Ideally in real life values below -20db are considered valid so this design is validated. (Figure 17)

In the lab I measured the actual S11 impedance reflection and observed a much different value. I was able to get a dib of about -6dB near 1900 MHz but it was nowhere near a low enough value to assume that the majority of the energy is getting through. Reasons for this could be that the electrical connectors on the stub were changing the parameters of the stub. Also at the time of measurement my antenna was connected to the SMA cable with simple #22 copper wire instead of a coaxial cable so that would have introduced another impedance difference.
5.4 Cell Phone Connection Testing

Ideally this antenna would simply need to be connected to the cell phone cable through the adapter and a rise in the number of bars could be observed as the antenna is pointed towards a cell tower. The bars would drop as the antenna is then oriented to a different direction.
With the timeline in this project though that was not the case. The FME/SMA adapter I initially ordered did not connect in the way I intended. Another connector has been ordered that should connect the two section together but at this period of time no data is available for testing of this connection.

6 Final Scope of Work Statement

This discuss what has been done on the project, what still needs to be done, lessons learned and options for future development on this project.

6.1 Completed Results Summary

This project was to develop an antenna that would connect to a cell phone to increase reception. The main part of this project, the development of the antenna, has been completed. A antenna has been designed to operate at a frequency of 1900 MHz that is fully ready for integration with existing cell phone technology. The antenna is built so that it can be connected to Wilson Electronics cell phone cables through the use of an SMA/FME adapter.

6.2 Tasks for Future

The design still needs to be tested using a female FME to male SMA adapter. This part has been ordered and in the near future will be tested to see if the antenna to cell phone connection will improve reception. If that works then the project will be finished, if it doesn't than design considerations will need to be done to derive a new way of connecting the antenna to the cell phone.

The antenna does not have a perfect impedance match at this point which results in losing some energy and having a much lower gain. Two options to improve this are first to rewire the antenna to SMA connector section with 50 Ohm Coaxial cable instead of copper wire. Second is to redesign the stub matching network to improve the match there. Possibly rewiring and removing the robust electrical connectors would reduce this issue.

6.3 Lessons Learned

The biggest lesson I learned as just how quickly time passes and the ability to solve problems decreases. Many of the issue I encountered arose because I did not have enough time to fix the problem. For example I focused on designing the antenna for the majority of the time, wrongly assuming that the FME connection would be a simple matter. By the time I realized how hard that part was to find I could measure my time left in days instead of weeks. While I was able to find places to order the parts, I was not able order them to arrive in time.
I also learned how difficult it can be to test antennas in real life. While the lab on campus has instruments to measure the antennas, I struggled finding options to measure the antenna at the frequency I had designed. It would have been nice to be able to just plug it into different instruments I had used in the past and test different parameters but because of my frequency constraints I was not able to use the instruments I was familiar with.

6.4 Future Development

This antenna is designed to connect to Motorola Razr v3 which was a very common phone but is now an older model. Future development needs to consider the option of expanding the phones this project will connect to. It is a simple matter of finding cell phone cables that attach or couple to cellular phones that operate under the antenna frequencies.

Also as time progresses cell phone companies may being expanding their use of frequencies to those other than 1900 MHz (the frequency Sprint operates at now). With this expansion the antenna may begin missing data transmitted at different frequencies.

This antenna also is just a prototype. Designing a future antenna that is weather proof and much more robust than the prototype is necessary for actual day to day use.

7 Benefits Over Other Designs

This section will discuss situations in which this antenna would be considered over other design option on the market.

7.1 Cost

This antenna can be built after design for under $20. Commercially made cell phone antennas cell from a range of $20 to $100 and especially for the directed Yagi Uda antennas they can be on the higher end of that range. So when considering the cost of using this antenna it would be beneficial over commercial models.

Another option that improves reception is an antenna booster that is installed in a location. These boosters will receive all of the signals and then rebroadcast them to improve your range and reception. In a sense they act like miniature cell phone towers. These will also improve reception but again tend to be more expensive. Generally ranging at about $150.
7.2 Power

Using a booster will improve reception but they also require being installed and run on their own power supply. An antenna is a passive element that will simply use the power already being used to transmit and receive so no extra power is used.

7.3 Portability

This antenna is portable because it does not need a power supply, and while it is not small enough to carry around in a pocket, it could easily be attached to a car or house. It could also be used by hand to increase reception. Using a booster would not work in this case because of the need of a separate power supply.

8 Cost Estimation

This section will cover the overall cost of this project, presented in a table format with explanations of other costs to be considered in the future.

8.1 Budget

The budget for this project was tracked in a table (Table 2) and expenses were added as they came up.

<table>
<thead>
<tr>
<th>Table 2</th>
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</thead>
<tbody>
<tr>
<td>Materials</td>
</tr>
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<td>Antenna Components</td>
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<tr>
<td>Copper Rods 48”</td>
</tr>
<tr>
<td>Poster</td>
</tr>
<tr>
<td>Impedance Connections</td>
</tr>
<tr>
<td>SMA Connection</td>
</tr>
<tr>
<td>Connection Cable</td>
</tr>
<tr>
<td>PVC Boom</td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
</tr>
</tbody>
</table>
8.2 Explanation of Costs

The biggest factor that raised the price of this project was the impedance connections, trying to find a connector for the FME/SMA connection. Once the right part was found, in the future that value could be greatly decreased. The copper rods were also fairly expensive, but in the future those could be built out of a much cheaper aluminum without sacrificing too much of a gain.

9 Project Management

This section will discuss what tasks were assigned and when they were completed using a GANTT chart and will also discuss issues that arose during this management.

9.1 GANTT Chart

The GANTT chart (table 3) shows the initial plan for my project in black and as things got pushed together tasks that were delayed are shown with a w and when tasks are completed are marked with an x.

<table>
<thead>
<tr>
<th>GANTT Chart</th>
<th>12-Feb</th>
<th>19-Feb</th>
<th>26-Feb</th>
<th>4-Mar</th>
<th>11-Mar</th>
<th>18-Mar</th>
<th>25-Mar</th>
<th>1-Apr</th>
<th>8-Apr</th>
<th>15-Apr</th>
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<th>6-May</th>
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<td></td>
<td>W</td>
<td>W</td>
<td>W</td>
<td>X</td>
</tr>
</tbody>
</table>

x= old schedule  x= updated schedule  o= didn't happen
w= won't happen on schedule  z = ordered gain
9.2 Time Issues

Issues arose in this project towards the end of the semester as everything in other classes became due. Initially I was able to focus on building my antenna but then I got caught up in optimizing that design and building the prototype and spent way too much time on that section.

I also was required to order many parts online as well as finding a great price online for copper rods which meant I usually had to wait a week for shipping of the parts.

Overall I discovered that working by myself it was very easy to become complacent and not worry about parts of my project until I was out of time to think about it.

10 Conclusion

This section will include the main point and importance of this subject, as well as future recommendations and contact information.

10.1 Main Point

The purpose of this project was to build an antenna that would increase the reception of the Motorola Razr v3 cell phone with Sprint cellular phone services. The designed antenna was a highly directional Yagi Uda antenna, and using the parameter of the gain I was able to design an antenna that could improve the reception into the phone.

This subject is important because there are many situations where low reception can be observed for a cell phone. As society becomes more dependent and cellular devices it makes always having reception more important. In an area that consistently suffers from poor reception it would be very easy to mount this antenna and improve reception in that spot.

10.2 Future Recommendations

Future designs of this antenna should include options to expand the amount of phones that it connects to. This could be done by designing for other types of cell phone connecting cables or by making generic cell phone coupling connections that attach to the back of the phone. It would also be possible to make the antenna more robust and weatherproof for outdoor use.
10.3 Contact Information

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