# Circular Polarized Splatch Antenna

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# Acknowledgements

I would like to thank St. Jude Medical to give me the opportunity to research and work on my Splatch antenna design to be used for my Senior Project. I would like to thank Mr. Thermpon and Mr. Albu for being great mentors and answering questions that I ran into. Lastly, thank you Professor Cheng Sun for guiding me through my senior project and being a great professor and supporter up until your last quarter at Cal Poly.

# I. Introduction

An antenna is a device that transmits and receives electromagnetic waves. Electromagnetic waves are often referred to as radio waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band. An antenna must be tuned to the same frequency band that the radio system to which it is connected operates in, otherwise reception and/or transmission will be impaired.

The Splatch Antenna is a breakthrough in compact antenna technology. It combines excellent performance and cost-effectiveness into an antenna package that can be integrated. The goal of this project is to figure out how to connect two Splatch antennas to realize a Circular Polarized (CP) antenna. The advantage of CP versus linear polarization is that CP eliminates polarization mismatch losses caused by Faraday's rotation.

The Splatch embeddable antenna is now available in the Medical Implant Communication Service (MICS) frequency band. The antenna is centered at 403 MHz and designed to cover from 402-405MHz, making it well suited for MICS as well as a wide variety of general RF applications. Achieving Circular Polarization for the Splatch antennas will enable the medical devices that use these antennas to be more sensitive and not lose telemetry. Better device communications will allow medical devices to be more efficient in saving lives.

## II. Background

An antenna is a reciprocal device, and the same antenna can serve as a receiving or transmitting device. Antennas are structures that provide transitions between guided and free-space waves. Guided waves are confined to the boundaries of a transmission line to transport signals from one point to another, while free-space waves radiate unbounded. A transmission line is designed to have very little radiation loss, while the antenna is designed to have maximum radiation. The antenna is an important component in any wireless system. The RF/microwave signal is transmitted to free space through the antenna [1]. The signal propagates in space, and a small portion is picked up by a receiving antenna.

There are several parameters affecting an antenna's performance that can be adjusted during the design process. These are gain, axial ratio, directivity, radiation pattern, impedance, major and side lobes (Minor Lobes), and polarization [3].

### Gain:

Antenna gain is a measure of how strongly the antenna radiates compared to a reference antenna. An antenna that radiates poorly has a low gain. Some antennas are highly directional; it has more energy propagated in certain directions than in others [3]. When a transmitting antenna with a certain gain is used as a receiving antenna, it will also have the same gain for receiving. Gain must be measured and is related to directivity by an efficiency factor.

As a ratio Expressed in dB

Gain = directivity (ratio) x efficiency or = 10 log [directivity(ratio) x efficiency] (1)

**Axial ratio:**
Axial ratio is the ratio of the major axis to the minor axis of the polarization ellipse[11].

As a ratio Expressed in dB

$$\text{Axial ratio} = \frac{\text{major axis (Emax)}}{\text{minor axis(Emin)}} \quad \text{or} \quad = 20\log[\text{Emax/Emin}] \quad (2)$$

**Directivity:**
Directivity is a measure of the concentration of radiation in the direction of the maximum and is easily estimated from the radiation pattern [11].

As a ratio Expressed in dB

$$\text{Directivity} = \frac{\text{maximum radiation intensity (Umax)}}{\text{average radiation intensity (Uo)}} \quad \text{or} \quad 10\log[\text{Umax/Uo}] \quad (3)$$

**Radiation Pattern:**
The radiation pattern or antenna pattern describes the relative strength of the radiated field in various directions from the antenna at a constant distance. The radiation pattern is a reception pattern as well, since it also describes the receiving properties of the antenna [9]. See Figure 1: A rectangular plot of a radiation pattern.

**Impedance:**
An important consideration is how well a transmitter can transfer power into an antenna. The antenna impedance is the ratio at any given point in the antenna of voltage to current at that point [8]. For example, if the antenna tuning circuit on a

transmitter or receiver is designed for a 50 ohm load, the antenna should have impedance near 50 ohms for best results.

**Major and Side Lobes (Minor Lobes):**

The pattern shown in Figure 1 has radiation concentrated in several lobes. The radiation intensity in one lobe is considerably stronger than in the other. The strongest lobe is called major lobe; the others are (minor) side lobes [6]. Major lobes are those in which the greatest amount of radiation occurs. Side or minor lobes are those in which the radiation intensity is least.

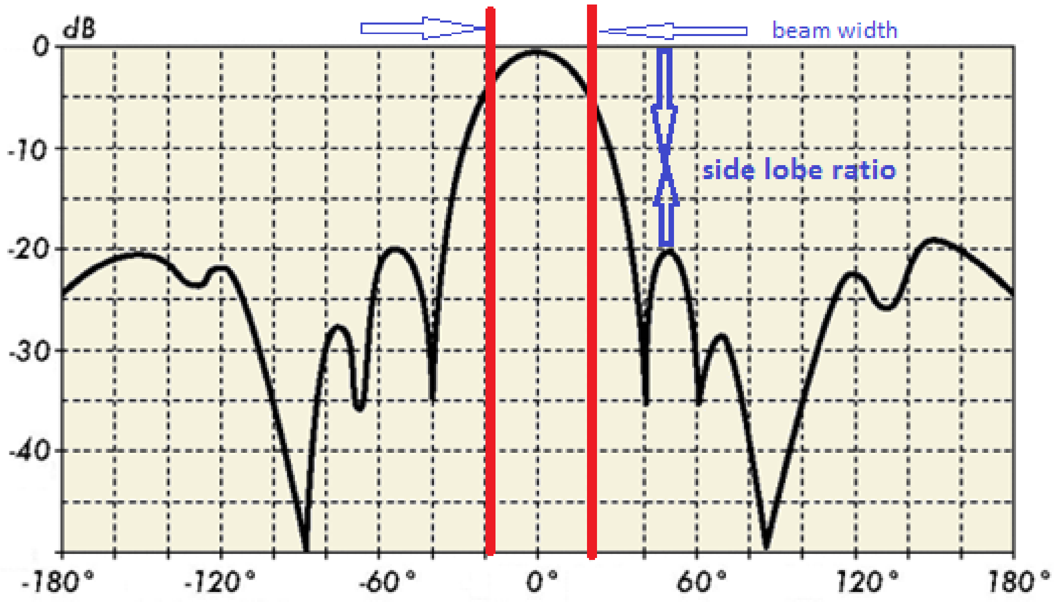


**Figure 1: A rectangular plot of a radiation pattern**

**Polarization:**

It is important that other antennas in the same communication system be oriented in the same way, that is, have the same polarization. Polarization is the orientation of the electric field of an electromagnetic wave[5]. Two often used special cases of polarization are linear polarization (Figure 2) and circular polarization (Figure 3). An antenna is vertically linear polarized when its electric field is perpendicular to the Earth's surface[4]. Horizontally linear polarized antennas have their electric field parallel to the Earth's surface.

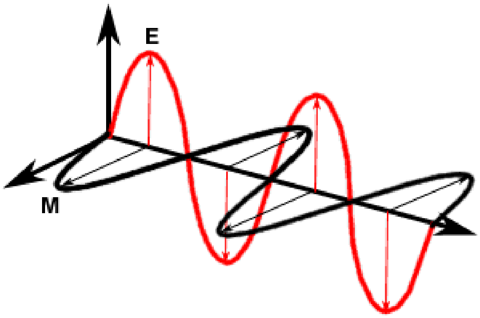


**Figure 2: Horizontally Polarized wave (Red), Vertically Polarized wave (Black).**

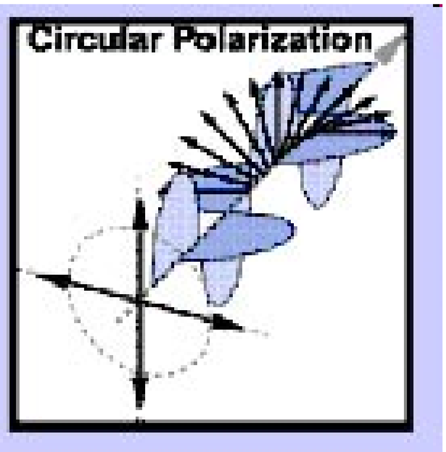


**Figure 3: Circularly Polarized wave**

If an antenna transmits a vertically polarized signal and the receiving antenna is horizontally polarized, this will result in a signal that is at least 20 db weaker at the receiver. When the antennas are 90 degrees different, it will result in the weakest signal possible. To make the antenna receive and transmit horizontal, vertical and every angle between horizontal and vertical polarization, circular polarization can be used [7]. Once the antenna is set up for circular polarization, it will be effective for dealing with talking to vertical and horizontally polarized antennas and for reducing signal fade. Although fade can be reduced, it can't easily be eliminated. There are two other conditions that cause signal fade: reflectiveness of the ionosphere and multipath fading. There is no way to control the reflectiveness of the ionosphere fading because the ionosphere is not a perfect reflector and it varies the signal quality[10]. Multipath fading is the signal that takes more than one path as the signal travels from the distant station. This results in the signal arriving at the antenna at slightly different times. If signals arriving at the driven element out-of-phase it will result in signal cancellation and will lead to signal loss[4]. Multipath is another factor that causes a signal to fade which the designer has no control over.

Polarization of an electromagnetic wave is defined as the orientation of the radiated electric field. For the case of plane wave propagating along the z-axis, the electric field may only have components in the x- or y directions. Equation (4) is the general equation for the electric field. $E_{0x}$ and $E_{0y}$ are the independent amplitudes of the x and y components [2]. If $E_{0x} = 1$ and $E_{0y} = 0$, the field is linearly polarized in the x direction. If $E_{0x} = E_{0y} = 1$, the field is linearly polarized in the direction of 45° between the x- and y axes. As long as $E_{0x}$ and $E_{0y}$have the same phase, the wave will be linearly polarized.

$$\bar{E} = (E_{0x}\hat{x} \;+\; E_{oy}\hat{y})e^{-jk_0 z} \qquad (4)$$

Equation (5) shows that when x and y components have equal magnitudes, and a 90° phase shift, the electric field still lies in the x-y plane, but now rotates counterclockwise when viewed toward the z-axis.

$$\bar{e}(x, y, z, t) = \mathrm{Re}\left\{(\hat{x} + j\hat{y})e^{-jk_0 z}e^{jwt}\right\} = \mathrm{Re}\{\hat{x}e^{j(\omega t - k0z)} + \hat{y}e^{j(\omega t - k_0 z + \pi/2)}\} \qquad (5)$$

$$= \hat{x}\cos(\omega t + k_0 z) - \hat{y}\sin(\omega t - k_0 z)$$

For a given point on the z-axis, equation (5) shows that the electric field vector rotates from the x-axis, to the y-axis as time increases [3]. Since the direction of rotation is counterclockwise when viewed toward the direction of propagation, this is known as left-hand circular polarization (LHCP). Right-hand circular polarization (RHCP) can be obtained by changing the sign of the $E_{0y}$ [3].

## III. Requirements

This project requires the connection of two Splatch Antennas to realize a Circular Polarized (CP) antenna. One challenge is how to properly feed the antenna to achieve Circular Polarization. An add-on to this project would be to realize CP using a trace on a printed circuit board. Table 1 lists the components and materials used for this project. Despite the Splatch Antenna’s simplicity and ease of use, its correct function is critical to the performance of the overall device. Just placing the Splatch anywhere on the board will likely yield dismal results (See Figure 6 for appropriate antenna layout).

| | Components | Description | Quantity |
|---|---|---|---|
| Prototype | 403 MHz Splatch Antenna | 712-ANT-403-SP | 2 |
| | SMA/SMA Cable | 5.12" | 1 |
| | SMA/SMA Cable | 10.12" | 1 |
| | Copper Tape | Copper tape for bare cardboard | 1 |
| Actual Board | 403 MHz Splatch Antenna | 712-ANT-403-SP | 2 |
| | SMA/SMA Cable | 6" SMA Cable | 2 |
| | SMA/SMA Cable | 12" SMA Cable | 2 |
| | PCB Conn Jack | 142-0701-801 | 2 |
| | Power Splitter | 20-3000MHz | 1 |
| | MHW Series Dipole Antenna | 418MHz Receiving antenna with 20MHz BW | 1 |
| | Splash Antenna Board Fabrication | Final PCB Board | 1 |

**Table 1: List of Components**

The antenna feed trace should be less than .25” and in all cases microstripped (1) (See Figure 4 and 5 for appropriate antenna feed connection and physical dimensions for PCB board design). Components placed in the area below the back edge of the antenna will have little effect since the antenna has a null at its back edge when referenced appropriately to groundplane [5]. The antenna may be

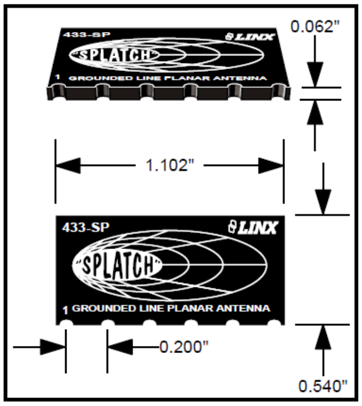


**Figure 4: Physical Dimension**

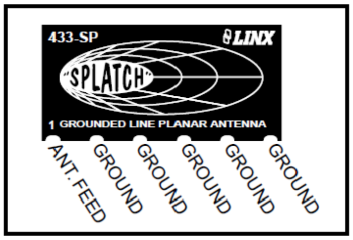


**Figure 5: Electrical Connections**

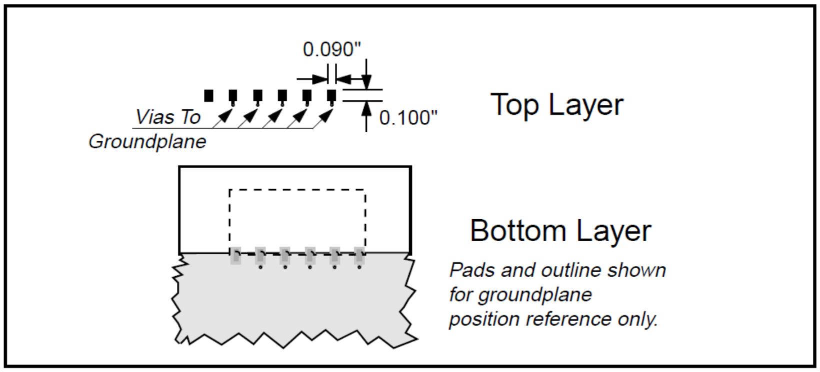


**Figure 6: Recommended Pad Layout**

referenced to groundplanes of all different surface areas. The best performance and lowest VSWR will be obtained when referenced to a plane with similar area.

## IV. Design

In order to achieve circular polarization with a vertically polarized antenna, both polarizations must be fed simultaneously. Most importantly, one polarization must be fed 90 degrees out of phase with the other one. This technique is similar to co-phasing in that a special harness is made. One coaxial cable has a ¼ wavelength longer than the other so there is a timing delay in which one polarization receives the energy first.

**Prototype for PCB Board:**

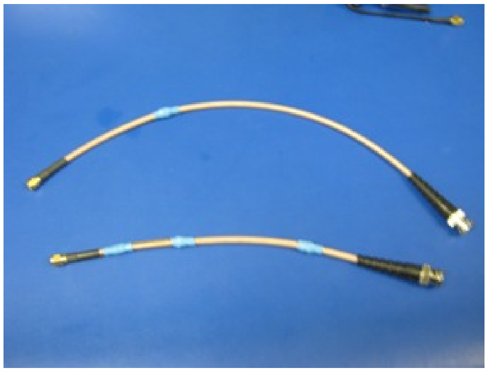


**Figure 7: Silver coated SMA/SMA cables**

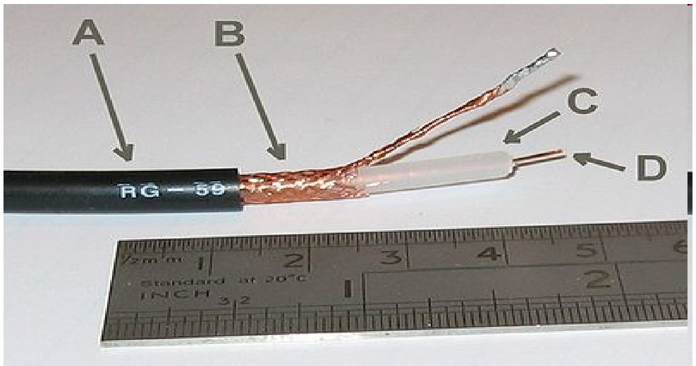


**Figure 8: Cable Parts – (A)Outer plastic shield, (B)Silver plated copper braid, (C)Inner dielectric insulator, (D)Silver plated copper core.**

The length of the SMA cables (Figure 7) for the prototype can be calculated using the dielectric constant of the cable materials (Figure 8). As long as the length difference of the two cables is a factor of 5.12 inches, the radiation will result in a 90 degree phase shift.

$$\varepsilon_r = 2.0,\ c = 3 \text{ x } 108 \text{ m/s},\ f = 403\text{MHz}$$

$$\lambda_0 = c/f = .74\text{m}$$

$$\lambda = \lambda_0 / \sqrt{\varepsilon_r} = .52\text{m}$$

$$\lambda/4 = .13\text{m} \approx \mathbf{5.12\ inch}$$

The prototype for the final project was made using a piece of cardboard (3” x 1.72”) wrapped with copper tape for the ground plane. The two Splatch antennas were soldered orthogonal to each other (Figure 9a).

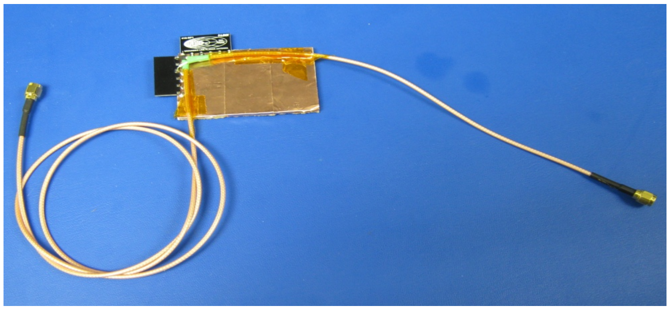
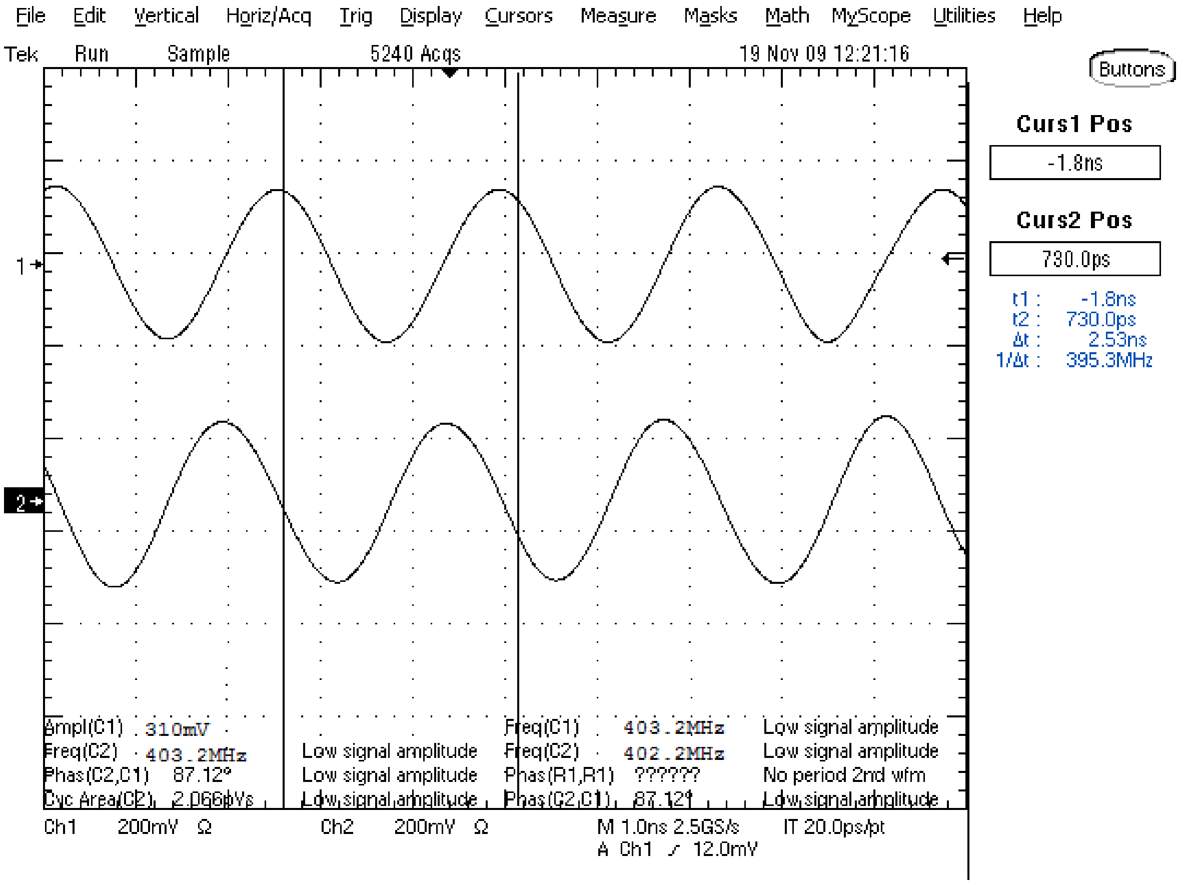


**Figure 9a: Prototype for the final board.**

To be sure that the length of the coaxial cable were calculated correctly to produce a 90 degrees phase shift, the prototype was connected to the Agilent N5181A MXG Analog Signal Generator (Figure 9b) and the Tektronix TDS5054B Digital Phosphor Oscilloscope to produce a 90 degrees phase shift waveform (Figure 9c). The waveforms in Figure 9 show that the prototype produces a 90 degrees phase shift.

**Figure 9b: Prototype set up to obtain a 90 degrees phase shift. Agilent N5181A MXG Analog Signal Generator (Frequency 400 – 413 MHz. Amplitude: 0.0 dBm).**

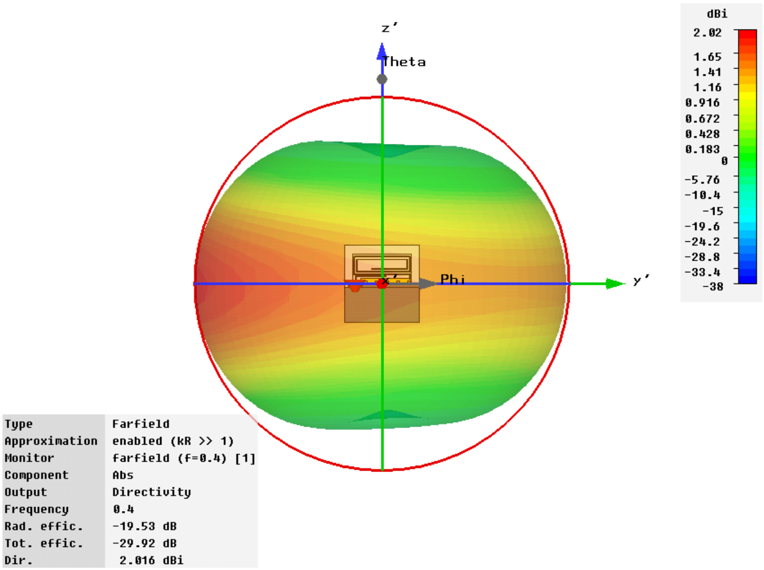


```
Tek   Run   Sample   5240 Acqs   19 Nov 09 12:21:16

Curs1 Pos
-1.8ns
Curs2 Pos
730.0ps
t1 :     -1.8ns
t2 :   730.0ps
Δt :     2.53ns
1/Δt :  395.3MHz

Ampl(C1)      310mV                              Freq(C1)      403.2MHz   Low signal amplitude
Freq(C2)      403.2MHz   Low signal amplitude    Freq(C2)      402.2MHz   Low signal amplitude
Phas(C2,C1)   87.12°     Low signal amplitude    Phas(R1,R1)   ??????     No period 2nd wfm
Cyc Area(C2)  2.066pVs   Low signal amplitude    Phas(C2,C1)   87.12°     Low signal amplitude
Ch1   200mV  Ω        Ch2   200mV  Ω        M 1.0ns 2.5GS/s     IT 20.0ps/pt
                                            A  Ch1  ⟋  12.0mV
```

Figure 9c: Oscilloscope result with a 90 degrees phase shift.

## Actual PCB Board:

Mounting the Splatch antenna on a PCB board can be challenging because the antenna feed for the Splatch is the left-most pin.  This could be a slight problem for the Splatch antenna on the right. This problem can be mitigated by putting the right antenna on the backside of the board.  Simulation shows that feeding both of the Splatch antennas at the same phase will result in the same radiation pattern. Shifting the phase will change the radiation pattern and more gain can be obtained in certain direction. Figures 10-14 show the different radiation pattern that resulted depending on different phase shifts and how the Splatch antennas are mounted on the Merlin Mobile board (MM board).



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.4) [1] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.4 |
| Rad. effic. | -19.53 dB |
| Tot. effic. | -29.92 dB |
| Dir. | 2.016 dBi |

Figure 10a: Splatch antenna mounted on a PCB board.

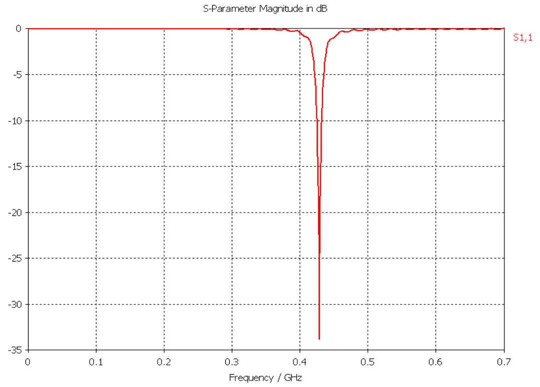
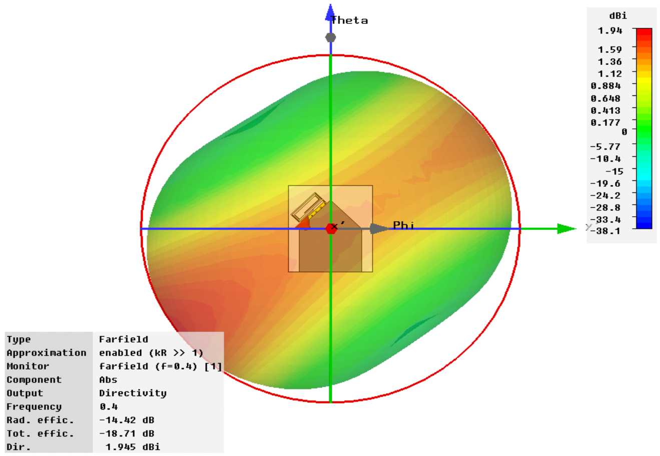


Figure 10b: Simulation for a Splatch antenna mounted on a PCB board.



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.4) [1] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.4 |
| Rad. effic. | -14.42 dB |
| Tot. effic. | -18.71 dB |
| Dir. | 1.945 dBi |

Figure 11a: One Splatch antenna mounted on a Merlin Mobile board (MM board).

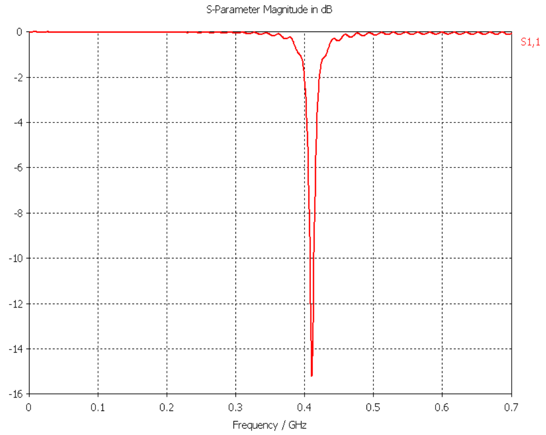
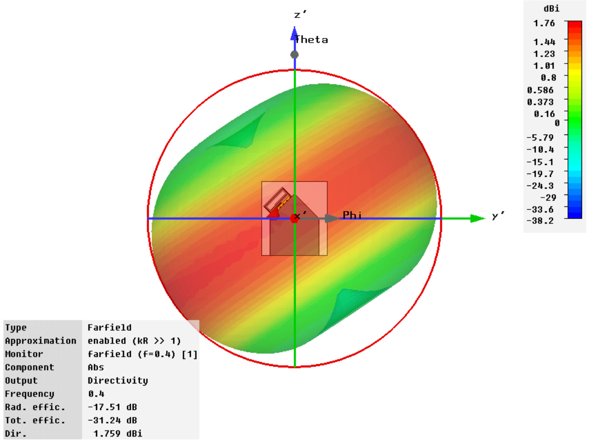


Figure 11b: Simulation for one Splatch antenna mounted on a MM board.



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.4) [1] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.4 |
| Rad. effic. | -17.51 dB |
| Tot. effic. | -31.24 dB |
| Dir. | 1.759 dBi |

Figure 1a: Two Splatches on MM board (mirror).

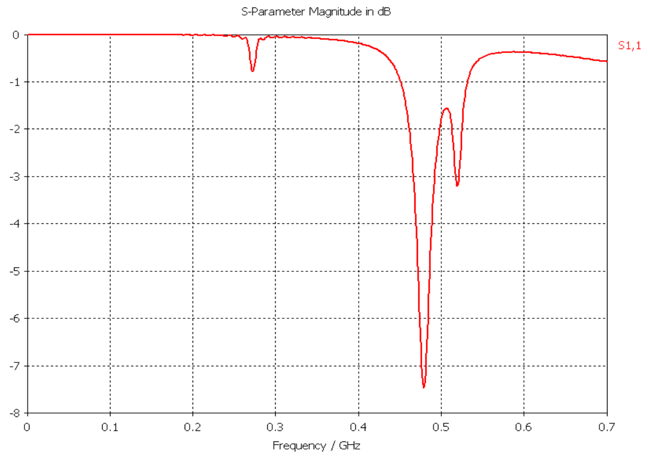


Figure 12b: Simulation for two Splatches on MM board.

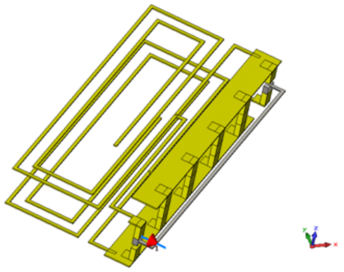


Figure 12c: Feed connected by trace.

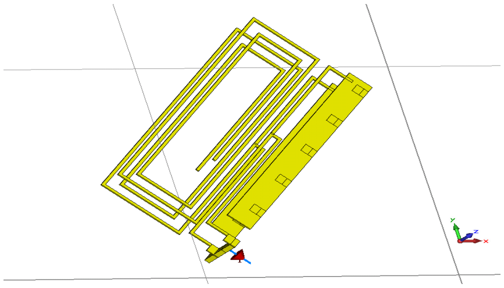
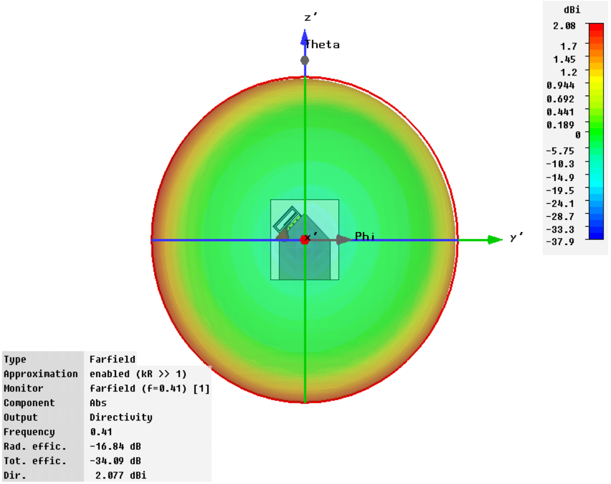


Figure 13a: Feed point at the same position



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.41) [1] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.41 |
| Rad. effic. | -16.84 dB |
| Tot. effic. | -34.09 dB |
| Dir. | 2.077 dBi |

Figure 13b: Two Splatches on MM board (not mirror)

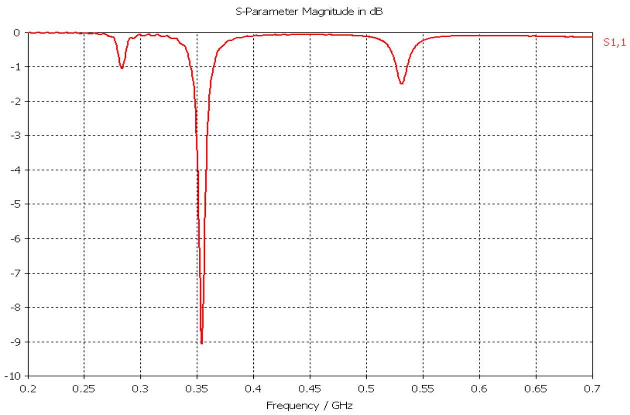


Figure 13c: Simulation for two splotches on MM board.

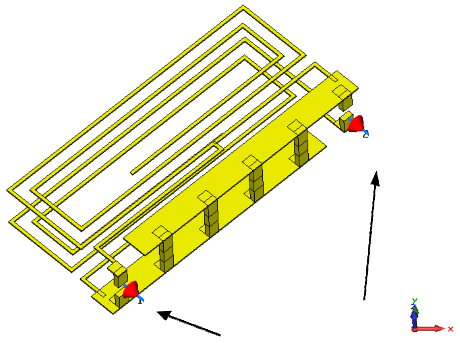
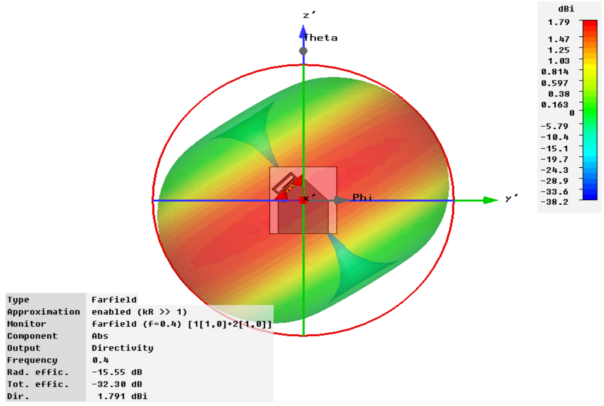


Figure 14a: Feed point at the same position.



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.4) [1[1,0]+2[1,0]] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.4 |
| Rad. effic. | -15.55 dB |
| Tot. effic. | -32.30 dB |
| Dir. | 1.791 dBi |

Figure 14b: Two Splatches on MM board (mirror). Feed with same phase.

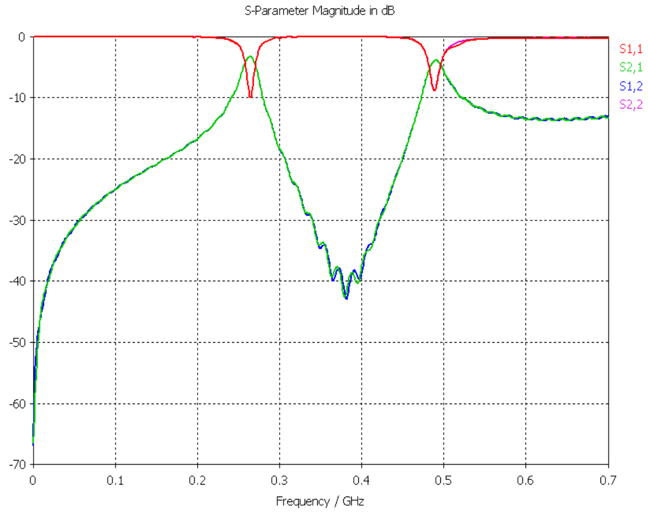
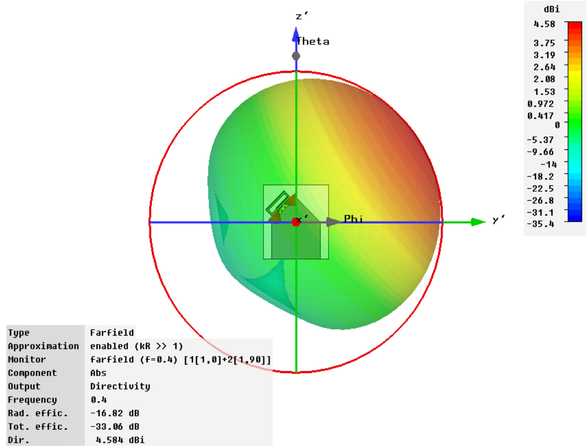


Figure 14c: Simulation for the two Splatches on MM board with two ports separately.



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=0.4) [1[1,0]+2[1,90]] |
| Component | Abs |
| Output | Directivity |
| Frequency | 0.4 |
| Rad. effic. | -16.82 dB |
| Tot. effic. | -33.06 dB |
| Dir. | 4.584 dBi |

Figure 14d: Two Splatches on MM board (mirror). Feed with 0 and 90 degree phase.

The simulations demonstrate that the two Splatch antennas could be mounted on different sides of a PCB board that shares a common ground plane. See Figure 15 for the Splatch design on a PCB board. The right antenna is mounted on the top layer of the board, and the left antenna is mounted on the backside of the PCB board.

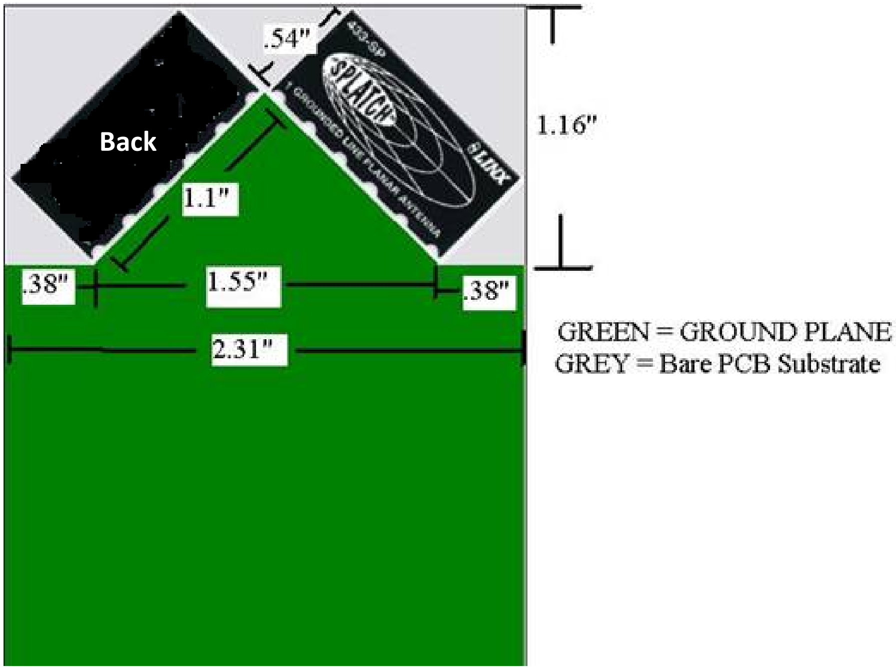


Figure 15: Splatch antenna PCB design.

ExpressSCH was used for drawing a schematic of the design (See appendix A). The ExpressPCB program was used to lay out the PC board. Figure 16 shows the whole design layout and Figure 17 a, b, c shows each layer of the design layout.

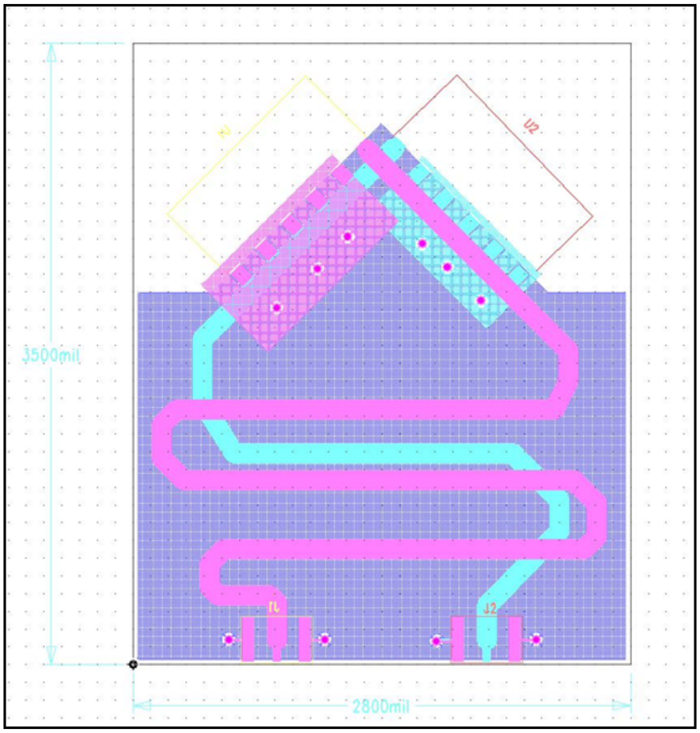


**Figure 16: Splatch antenna layout.**

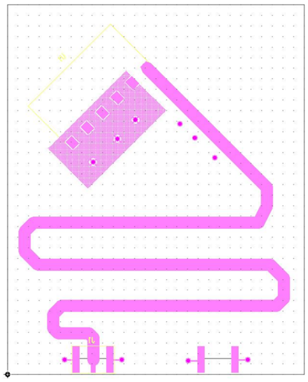


**Figure 17a: Splatch antenna bottom layer.**

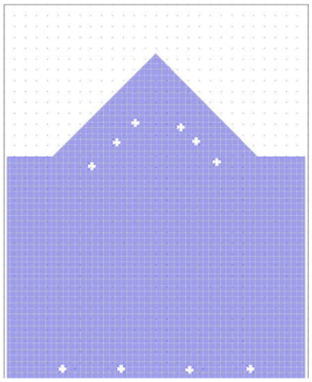


**Figure 17b: Splatch antenna ground layout.**

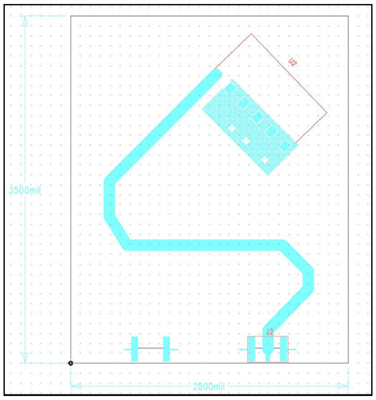
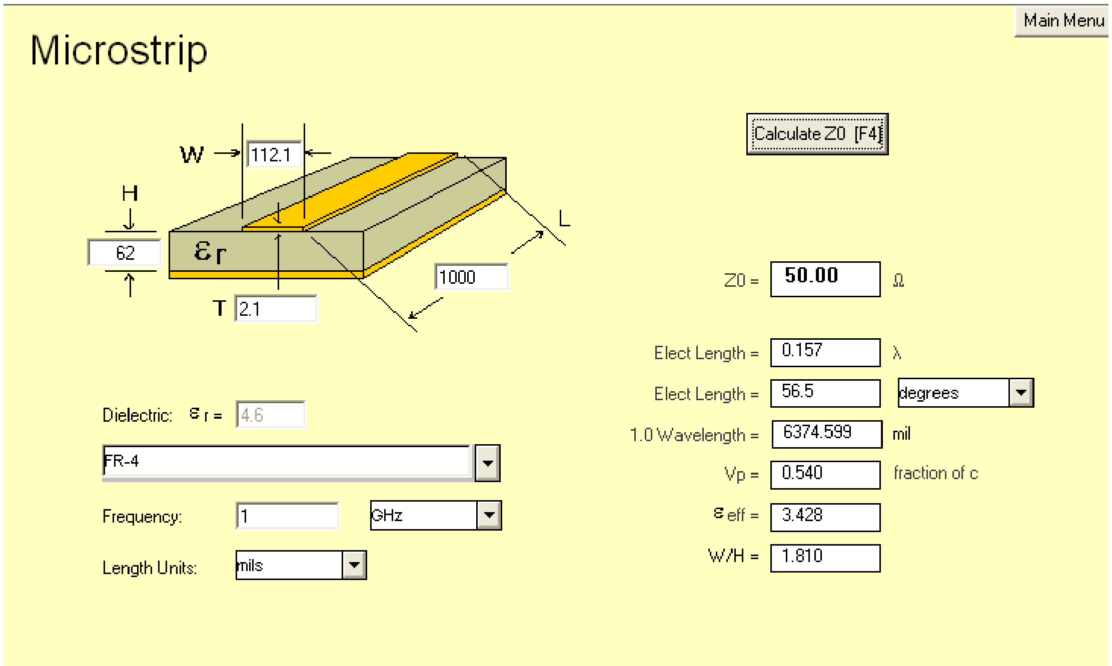


**Figure 17c: Splatch antenna top layer.**



Microstrip

W = 112.1

H = 62

T = 2.1

L = 1000

Dielectric: εr = 4.6

FR-4

Frequency: 1 GHz

Length Units: mils

Z0 = 50.00 Ω

Elect Length = 0.157 λ

Elect Length = 56.5 degrees

1.0 Wavelength = 6374.599 mil

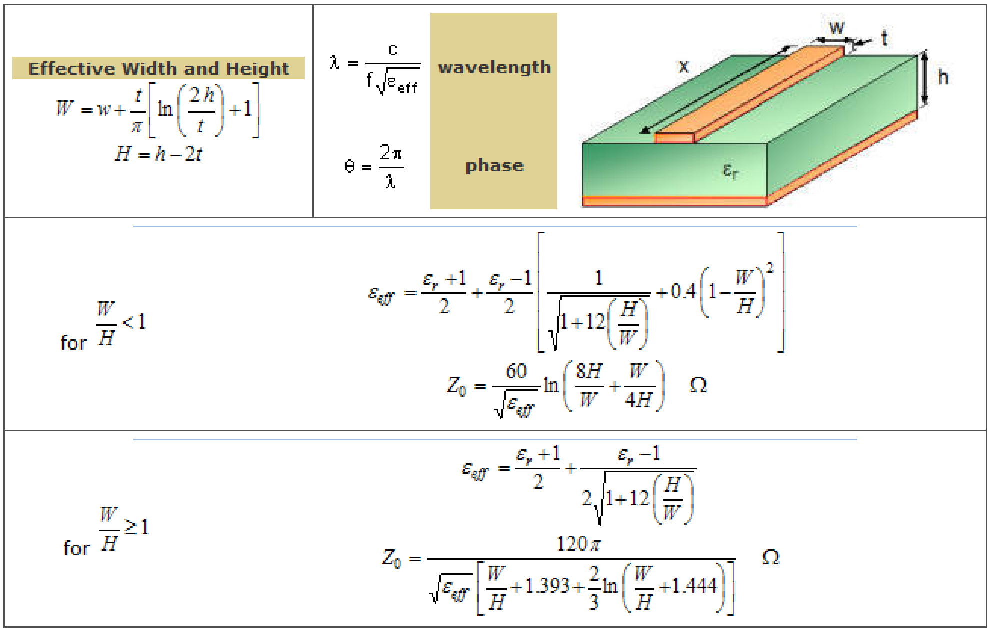
Vp = 0.540 fraction of c

εeff = 3.428

W/H = 1.810

**Figure 18: Microstrip design for the traces on the PC board**

The equations below were used to calculate the effective width and height prior to plugging the dimensions into the Microstrip calculator for the effective dielectric constant [6].



| | |
|---|---|
| **Effective Width and Height**<br>$W = w + \frac{t}{\pi}\left[\ln\left(\frac{2h}{t}\right)+1\right]$<br>$H = h - 2t$ | $\lambda = \frac{c}{f\sqrt{\varepsilon_{eff}}}$ **wavelength**<br>$\theta = \frac{2\pi}{\lambda}$ **phase** |
| for $\frac{W}{H} < 1$ | $\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{H}{W}\right)}} + 0.4\left(1-\frac{W}{H}\right)^2\right]$<br>$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(\frac{8H}{W}+\frac{W}{4H}\right) \quad \Omega$ |
| for $\frac{W}{H} \geq 1$ | $\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1+12\left(\frac{H}{W}\right)}}$<br>$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{H}+1.393+\frac{2}{3}\ln\left(\frac{W}{H}+1.444\right)\right]} \quad \Omega$ |

## V. Construction

Figure 19 is the construction for the prototype board. Using the length from the above calculations, the prototype should produce a 90 degrees phase shift.

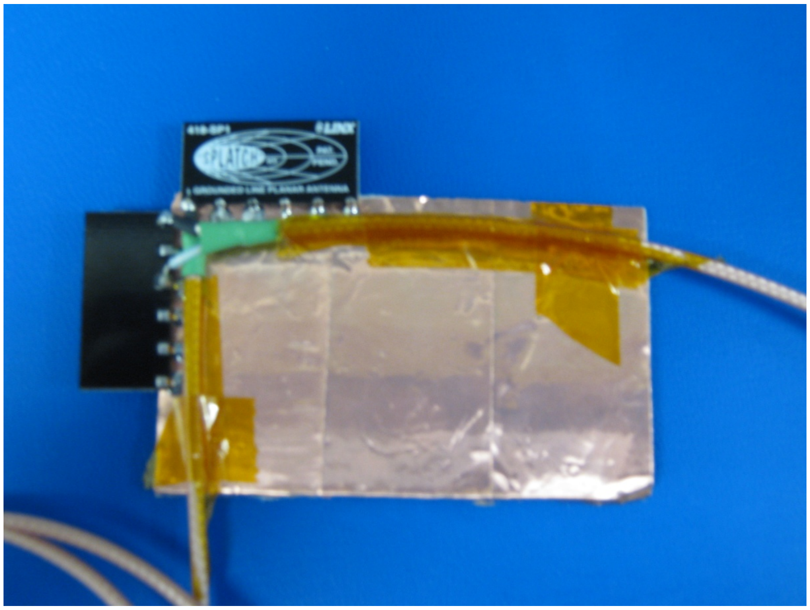


Figure 19: Construction of the prototype board.

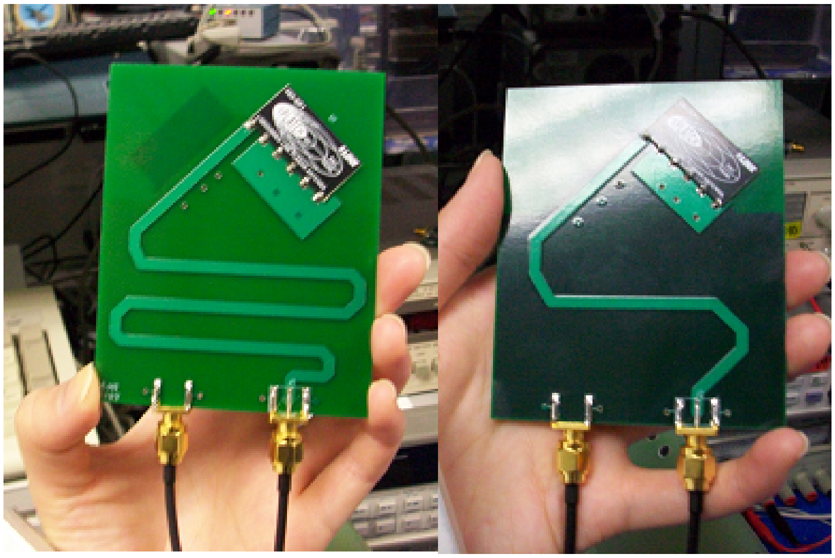


Figure 20: Final board design. Left: Front of board, Right: Back of board.

## VI. Testing and Recommendations

Unlike many electronic devices, any change in nearby materials or dimensions can affect antenna performance. Testing an antenna design is necessary and tuning tuning is usually required.

A network analyzer is normally used to test the impedance or VSWR of the antenna. Some antennas that have impedance near 50 ohms can be tuned by looking at return loss or a VSWR display [5]. There are other options, such as a spectrum analyzer with a tracking generator that can be used with a directional coupler[7]. The coupler will feed power to the antenna while feeding the reflected power from the antenna back to the analyzer.

To perform the polarization measurement, the test circular polarization Splatch antenna is used as the source. The linearly polarized receive antenna (Figure 21) will be rotated, and the received power is recorded as a function of the angle of the receive antenna. In this manner, the polarization of the test antenna can be obtained. The basic setup for polarization measurements is shown in Figure 22.

**Figure 21: Basic setup for polarization measurements.**

The power is recorded for the fixed position of the receive antenna. It is then rotated about the x-axis as shown in Figure 23, and the power is recorded again. This is done for a complete rotation of the linearly polarized receive antenna.

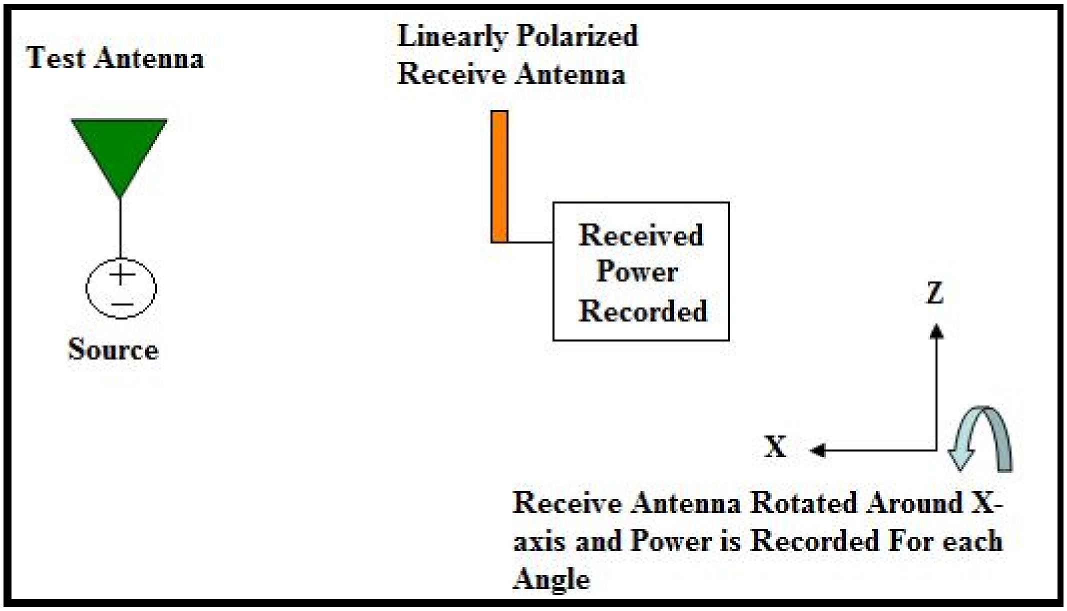


**Figure 22: Basic setup for polarization measurements.**

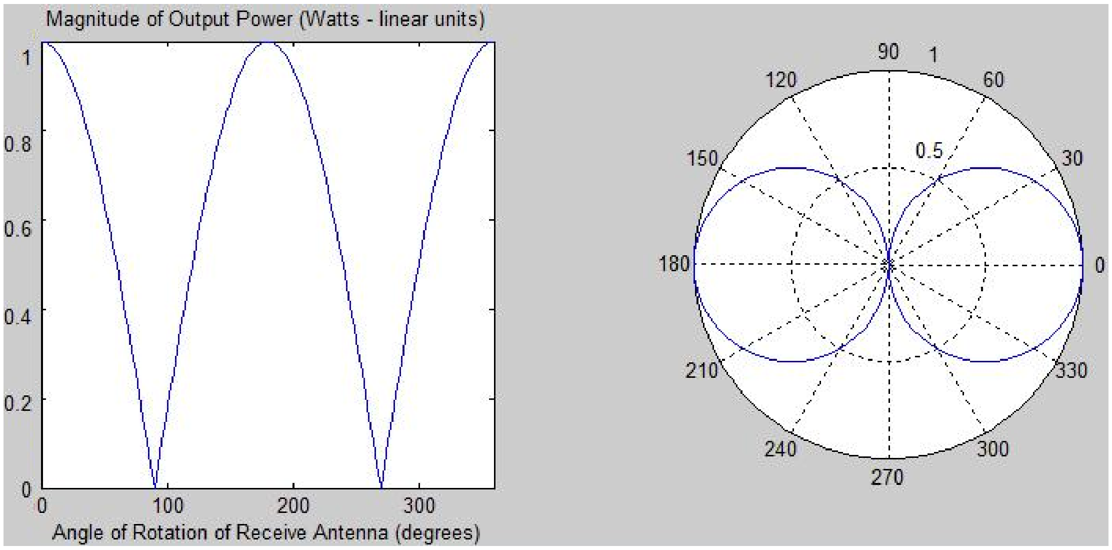


**Figure 23: Output Measurement of Linearly Polarized Test Antenna (Vertically Polarized). Left: Rectangular Plot. Right: Polar Plot.**

The plot in Figure 23 gives two views of the output. The left side gives an x-y plot of the output and the right side gives a polar plot. The result is periodic when the receive antenna is rotated 180 degrees [8]. The receive antenna is vertically polarized so the received power is identical.

When the test antenna is horizontally polarized, the plot will resemble that of Figure 24. The shape of the resulting measurements is the same, but the peaks of the received power occur for different angles [8]. As a result, the test antenna is linearly polarized when the shape of the received power resemble the shapes in Figure 23 and 24.

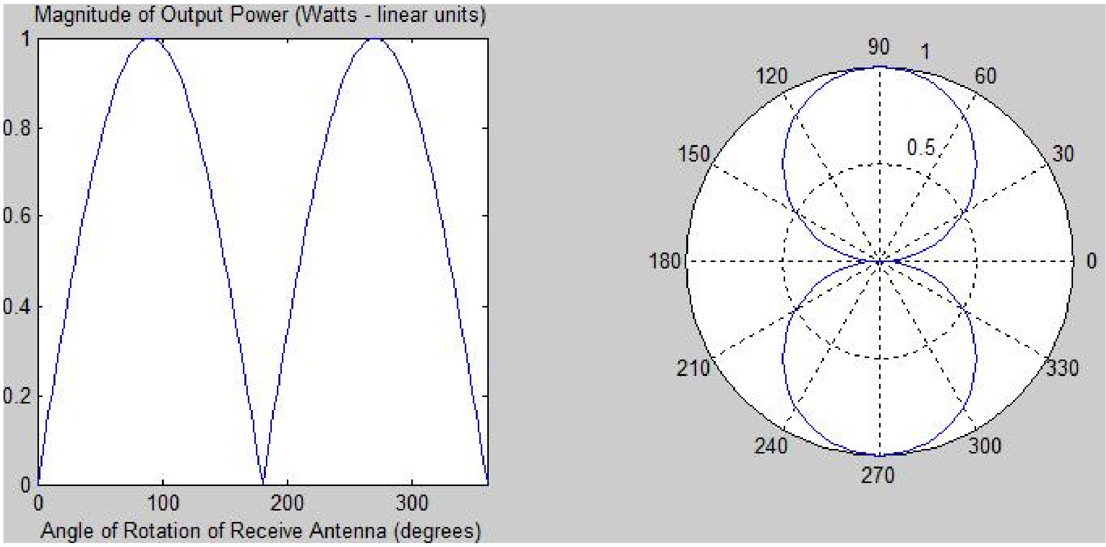


**Figure 24: Output Measurement of Linearly Polarized Test Antenna (Horizontal Polarized).**

When the test antenna, radiating in circular polarization, is subjected to the same measurement as above, the normalized output power will look like the plots in

Figure 25. The received power is constant for a rotated linearly polarized antenna because a circularly polarized wave has equal amplitude components in two orthogonal directions. With circular polarization, there is no worry about getting the orientation right.

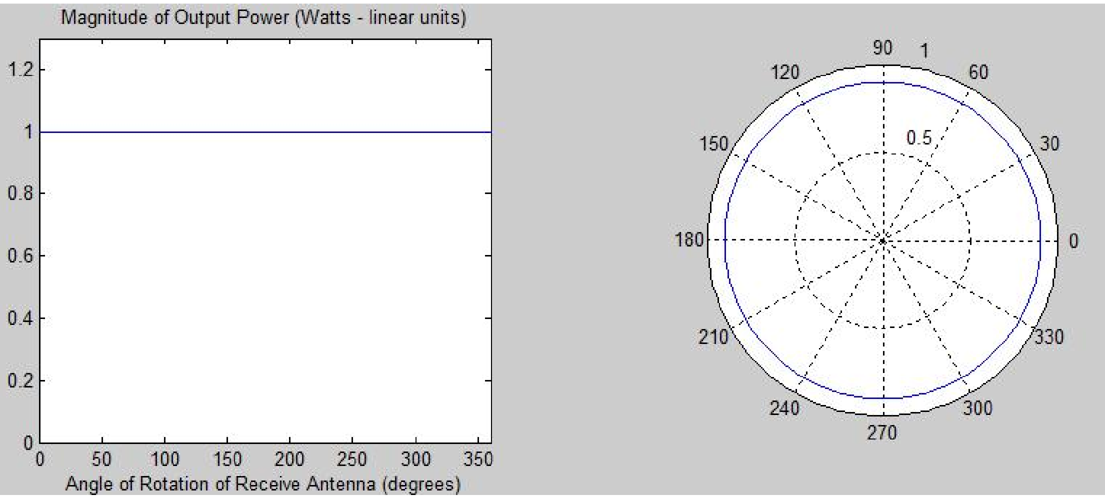


**Figure 25: Output Measurement for a circularly polarized test antenna.**

The received power is the same whether the test antenna is left-hand or right-hand circularly polarized. The measurement above cannot determine the sense of rotation for the polarization. To determine the sense of polarization for the antenna under test, use an antenna that is known to be RHCP or LHCP as the receive antenna [8]. The measurement is performed again after the result is recorded. The power for the sense of rotation for the polarization can be determined depending on the result of the receiving antenna with a larger power.

Figure 26: Receiving Antenna

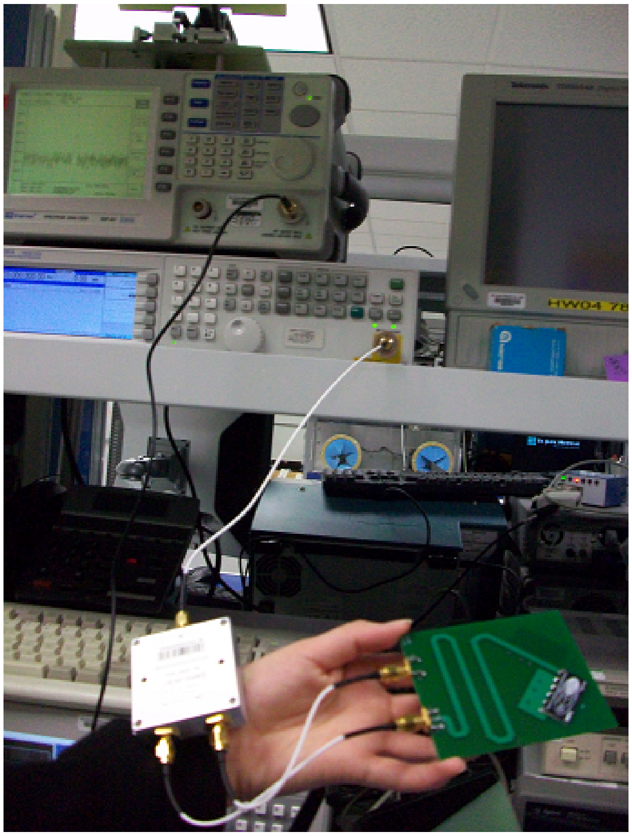


Figure 27: Circularly Polarized Splatch Antenna as the Transmitter.

The receiving antenna (Figure 26) is connected to the Agilent Analog signal generator. The Splatch antennas that were used to test for circular polarization were connected to the spectrum analyzer via a power splitter to measure the magnitude of the output power (Figure 27 and 28). Figure 28 is a close up at the signal generator and the spectrum analyzer.

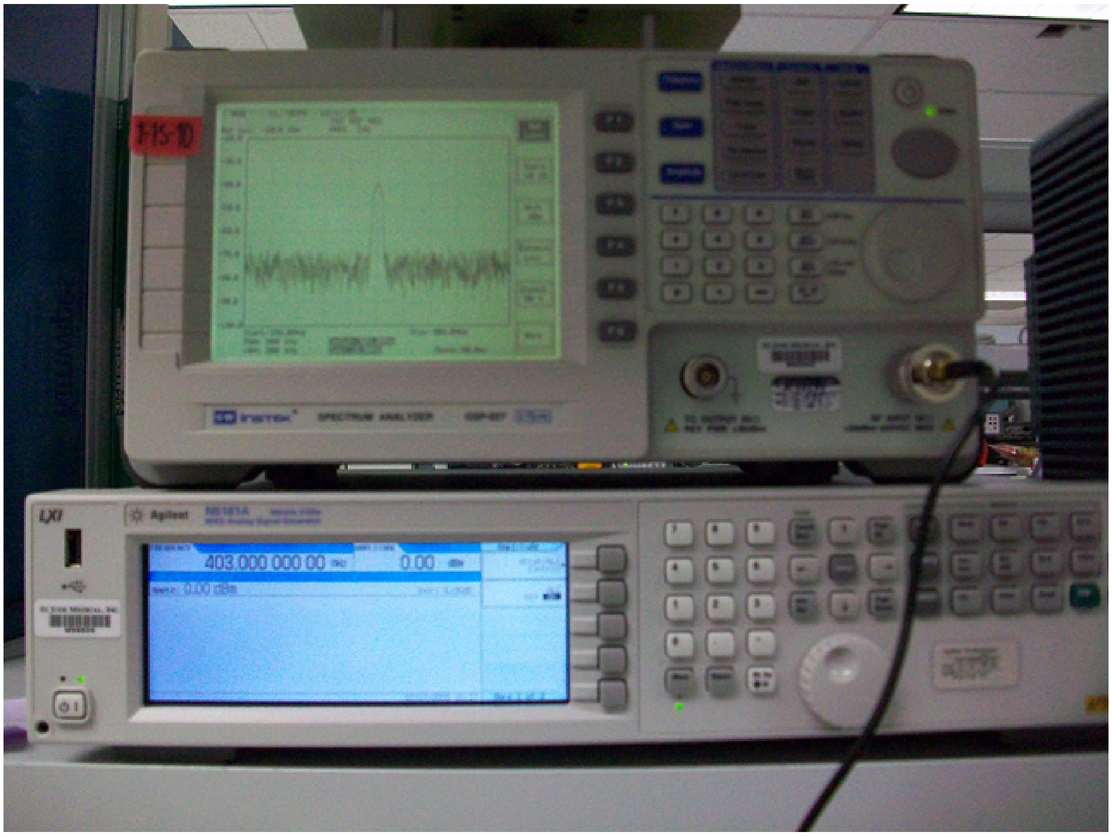


Figure 28: Spectrum Analyzer (top) and Source Generator (bottom).

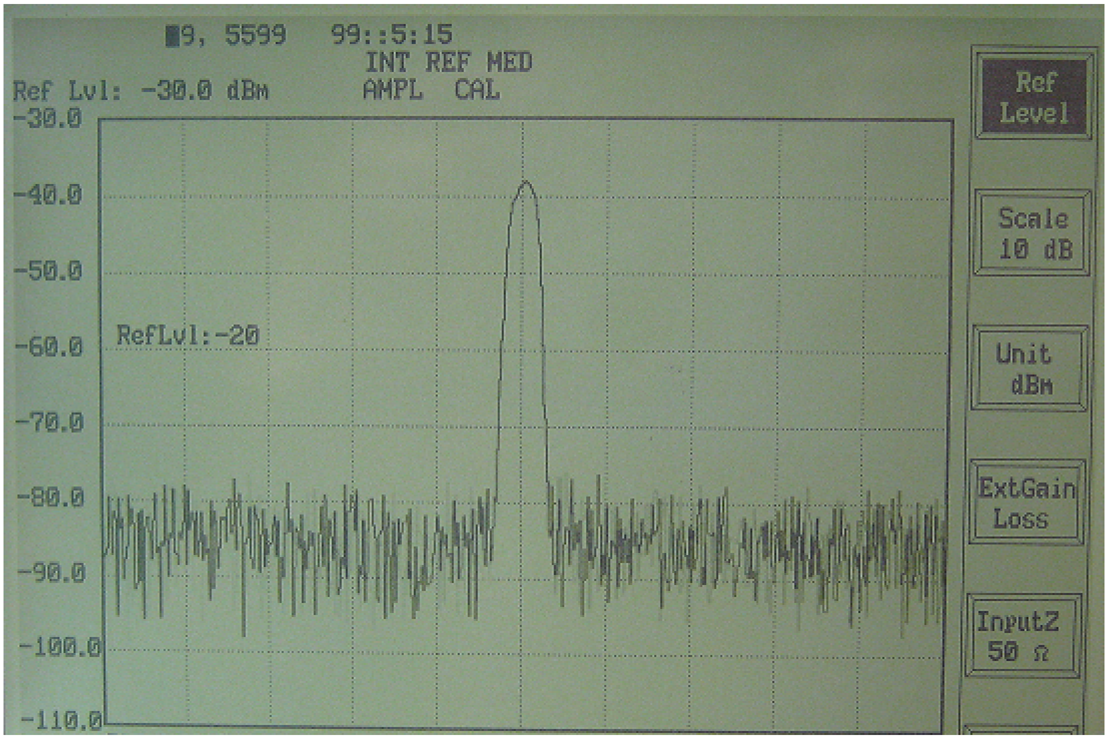


Figure 29: Spectrum Analyzer result for the test antenna (Start: 400MHz , End: 410MHz, Span: 10MHz

Figure 29 was produced by using the spectrum analyzer and the signal generator to sweep the antenna to find its frequency of the highest output. The highest output was determined to be -38dBm. Using the Splatch design as the source antenna, the receiving antenna (Figure 21) was rotated and the received power on the spectrum analyzer was recorded. Points were recorded as the receiving antenna was rotated and the result shows that the test antenna is radiating circular polarization (Figure 27).

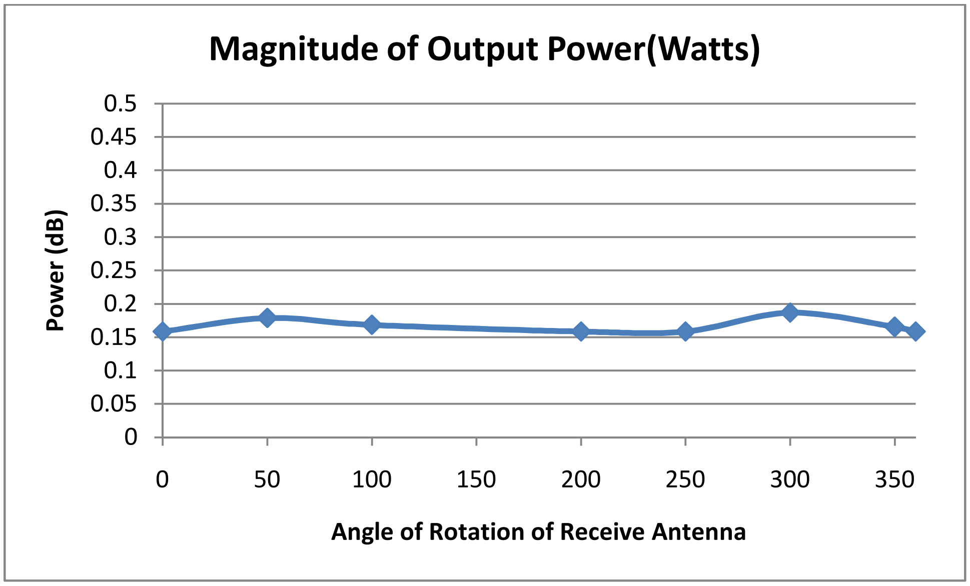


**Figure 27: Plot of the Output Power vs. Angle of Rotation**

The plot in Figure 27 shows that the test antenna is radiating in circular polarization. Ideally, the plot in figure 27 should resemble that of Figure 25, but Figure 25 is not a perfect straight plot because of the conditions mentioned in the Background section.

It is very difficult to control the reflectiveness of the ionosphere and the multipath fading. Antenna measurements of any kind are tricky since the antenna is affected by nearly objects, including the size and shape of the circuit board, and even by the cable connections to the network analyzer. Find a place to locate the transmitter that is away from metal and a few feet away from the analyzer. Always locate the transmitter in the exact same spot when testing. If you have a desk that is wood, mark it's position with a pencil or tape. If hand held, hold it in your hand just above the marking on the desk. Be sure to position your hand and the rest of your body the same way during each test. Take the reading of the power level, and tune the antenna to achieve maximum radiated power.

Common problems usually involve insufficient free space around the antenna. The antenna cannot run close to ground or any other trace without affecting the antenna performance. This includes traces on the other side of the board, batteries, or any other metal object.

## VII. Conclusion

This paper presents a circularly polarized Splatch antenna design with good performance for the applications of medical devices. The obtained circularly polarized Splatch antenna has many advantages. Radio signals are reflected or absorbed depending on the material they come in contact with. Because linear polarized antennas are able to attack the problem in only one plane, if the reflecting surface does not reflect the signal precisely in the same plane, that signal strength will be lost. Since circular polarized antennas send and receive in all planes, the signal strength is not lost, but is transferred to a different plane and is still utilized. Absorption is another advantage in circular polarization. Signals can be absorbed depending on the material they come in contact with. Different materials absorb the signal from different planes. As a result, circular polarized antennas give a higher probability of a successful link because it is transmitting in all planes. Circularly-polarized signals are much better at penetrating and bending around obstructions. If used in medical devices, the circularly polarized Splatch antenna will allow medical devices to be more efficient in saving lives.

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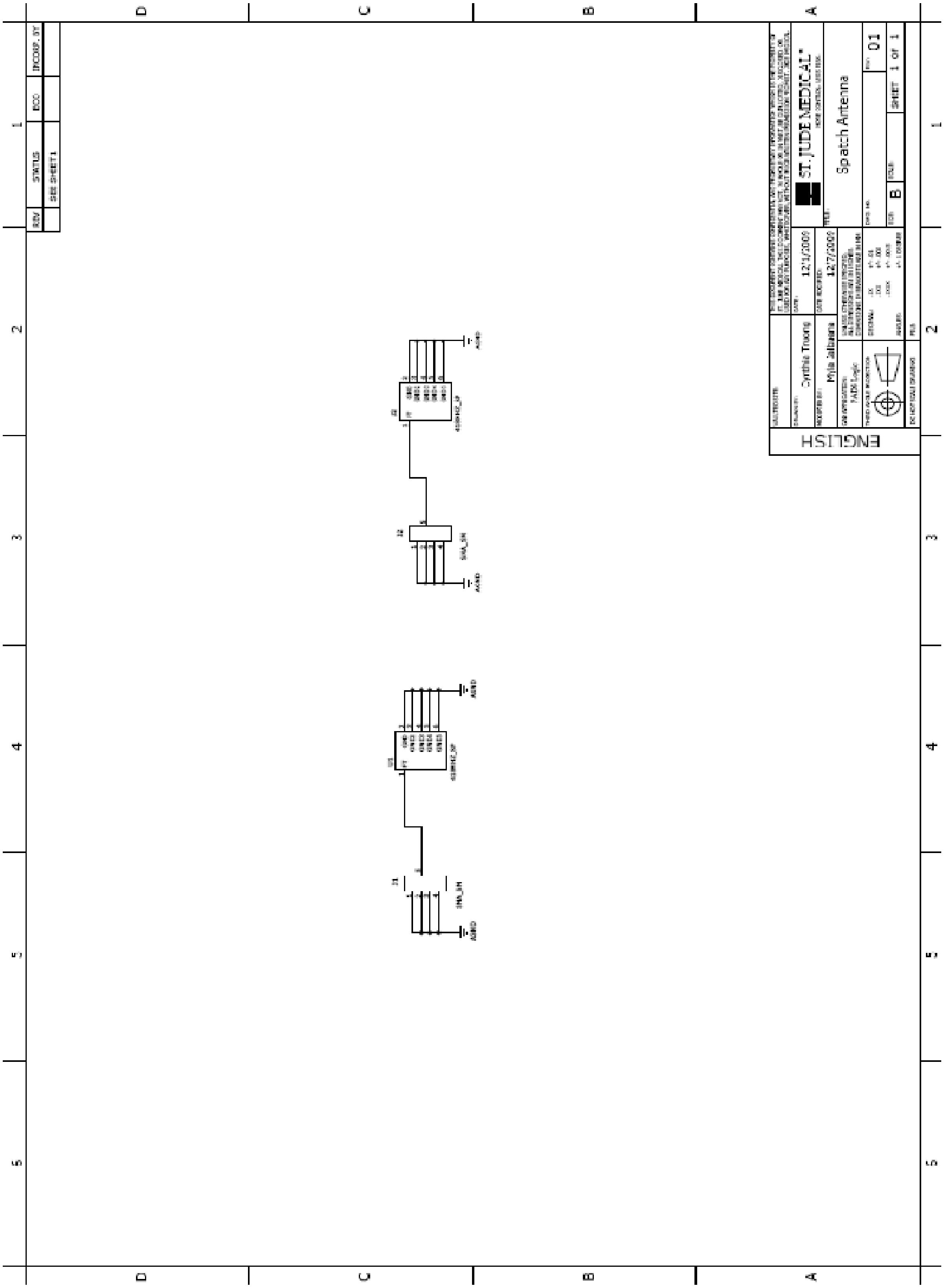
# Appendices

## Appendix A: Schematic of the circuit board design.



**Appendix B: Part quantities and cost.**

| Parts | Description | Quantity | Unit Price | Total |
|---|---|---|---|---|
| SMA/SMA Cable | 12" SMA Cable | 4 | 18.86 | 75.44 |
| SMA/SMA Cable | 6" SMA Cable | 4 | 18.86 | 75.44 |
| 403 MHz Splatch Antenna | 712-ANT-403-SP | 4 | 2.08 | 8.32 |
| PCB Conn Jack | 142-0701-801 PCB Mount | 4 | 5.1 | 20.4 |
| Splatch Antenna Board Fabrication | Final PCB Board | 2 | 157 | 314 |
| | | Total Cost | | 493.6 |

**Appendix C: Time schedule allocation**

| Task | Hours Required | Description |
|---|---|---|
| Research | 50 | Time to reserve library books and online research. |
| Design | 30 | Consider different design options. |
| Build | 15 | Build a prototype for the design. |
| Integration | 8 | Assemble chassis and components. |
| Test /Troubleshoot | 8 | Test and troubleshoot prototype. |
| Final Integration | 8 | Build the final PCB board base on a functioning prototype. |
| Final Test /Troubleshoot | 7 | Test and troubleshoot final PCB board design. |
| Operation/ Maintenance | 4 | Incorporate into an operational environment in which personnel are trained in its use and maintenance. |

## Appendix D: Splatch Antenna X-ray