Sp4ce_P!r4te Radio:
Establishing Long Range Communication with Fractal Antennas

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Revision Log

<table>
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<tr>
<th>Revision</th>
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<th>Date</th>
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<tr>
<td>A</td>
<td>Kick Off Telecon</td>
<td>01/24/2018</td>
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<td>Preliminary Design Review</td>
<td>02/17/2018</td>
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<td>03/09/2018</td>
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1.0 Mission Overview
The purpose of this experiment was to design a lightweight, two-dimensional, fractal antenna to implement with a low power, long range radio transceiver as a means to establish two-way radio communication. A two-way uplink would allow for real time data collection, telemetry updates, and even remote control of payload components.

2.0 Design
2.1 Payload Build
Our payload utilized an ultra-lightweight two-dimensional antenna based on the Sierpinski gasket. Also known as a Sierpinski triangle, this design is a fractal and attractive fixed set that take on the form of an equilateral triangle, with each internal triangle divided into smaller equilateral triangles. This shape was first traced onto the outside of a foam box which had been covered in spray on primer. Then, the gasket outline was filled in with a conductive graphite paint. Once the paint had dried, copper wire was pressed against the surface, covered in another layer of graphite paint, and finally covered in hot glue for integrity. After testing the paint and wire with a multimeter to test for conductivity and a potential circuit, the copper wire was soldered onto our Dragino radio shield’s antenna fixtures.

Figure 1. First Fractal Antenna Prototype

Setup of the interior include three major component clusters. Figure 2. shows these clusters in their orientation as they were in flight. The Arduino and its shields were affixed to the upper right-hand side of the enclosure, while the battery pack and heater remained on the lower left-hand side. This is due to our findings in low temperature experiments where our batteries would begin to fail with lower temperatures, creating a cascading failure as the heater would then also fail. It is
interesting to note that our Arduino continued to operate for an hour in negative 80-degree Fahrenheit environment after loss of supplemental heat.

![Figure 2. Internal Payload Layout](image)

It is very possible that this is due to our design’s emphasis on insulation. It had been an early goal of ours to develop a self-regulating internal environment that would preserve power. While we later abandoned that goal in pursuit of better antenna range, the setup for such a system proved to be extremely effective. A review of our collected data indicates that internal temperature on launch day never dropped below 40 degrees Fahrenheit. Half inch-thick black foam siding attached to foam board siding with super glue, two layers of tape, two layers of paint and a generous coating of packing tape seem to have sealed the payload very comfortably.

![Figure 3. Final Payload Design](image)
2.2 Base Station Build

The nature of our experimentation necessitated the construction of a powerful, concave ground station antenna capable of being aimed at our payload. We had discovered that directionality and line of sight were very important to the maintenance of communication between our transceivers. We used a pattern on our base station antenna similar to that which we used on our payload shell. Obviously, alterations had to be made to accommodate the ovoid shape of the dish.

Figure 4. Base Station Antenna
2.3 Block Diagram

![Block Diagram](image)

Figure 5: A simple block diagram that illustrates the basic build structure of our payload.

2.4 Transceiver Pin Layout

![Pin Layout](image)

Figure 6: Dragino Lora Shield Pin Layout
3.0 Management

The Space Pirates is a three-member team consisting of Alex Morones, Mickey Jackson, and Colby Waterhouse. The idea for the project stemmed from Colby’s passion for radio as well as his ambition to use his newly acquired knowledge to pass his HAM radio certification.

3.1 Responsibilities

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibility</th>
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<tbody>
<tr>
<td>Colby</td>
<td>Radio Communication Captain</td>
</tr>
<tr>
<td>Alex</td>
<td>Range Expansion First Mate</td>
</tr>
<tr>
<td>Mickey</td>
<td>Design Quarter Master</td>
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3.2 Schedule

<table>
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<tr>
<th>Time Frame</th>
<th>Plan</th>
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<tbody>
<tr>
<td>Week 1-2</td>
<td>Project Ideas/Preliminary Research</td>
</tr>
<tr>
<td>Week 3-4</td>
<td>Construction of payload/ordering parts</td>
</tr>
<tr>
<td>Week 5-6</td>
<td>Testing/Project review/Reduction of Goal</td>
</tr>
<tr>
<td>Week 6-7</td>
<td>Payload Revisions/Testing</td>
</tr>
<tr>
<td>Week 8-9</td>
<td>Payload Revisions/Testing</td>
</tr>
<tr>
<td>Week 9-10</td>
<td>Final range tests/Code modifying</td>
</tr>
</tbody>
</table>
4.0 Budget

The dish used for the ground station was provided by team member Colby Waterhouse. All other items were provided by the Colorado Space Grant Consortium and Pikes Peak Community College.

4.1 Expenses Report

<table>
<thead>
<tr>
<th>Item</th>
<th>Supplier</th>
<th>Quantity</th>
<th>Unit Price (US Dollars)</th>
</tr>
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<tbody>
<tr>
<td>Seeedstudio Dragino LoRa Shield</td>
<td>Amazon</td>
<td>2</td>
<td>19.00</td>
</tr>
<tr>
<td>Mg Carbon Paint</td>
<td>Amazon</td>
<td>6</td>
<td>14.99</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>8</strong></td>
<td><strong>127.94</strong></td>
</tr>
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</table>

Figure 7. Expenses Report

4.2 Mass Budget

In order to get the most surface area for our antenna, the payload had to be large even though we did not have many items within. The need for surface area therefore increased the mass of our payload significantly as the payload itself was the heaviest.

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass (grams)</th>
</tr>
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<tbody>
<tr>
<td>Payload (foam core, insulation, electric tape, flight string tube, 2 washers, etc.)</td>
<td>247</td>
</tr>
<tr>
<td>Batteries (5)</td>
<td>177</td>
</tr>
<tr>
<td>Sensor Shield</td>
<td>81</td>
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<tr>
<td>Seeedstudio Dragino LoRa Shield (2)</td>
<td>100</td>
</tr>
<tr>
<td>Arduino Uno</td>
<td>18</td>
</tr>
<tr>
<td>Heater Component (3)</td>
<td>35</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>658</strong></td>
</tr>
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</table>

Figure 8. Mass Budget
5.0 Test Plan and Results

5.1 Drop Test
Two drop tests were conducted during a period of several weeks. The first drop test was performed by dropping our payload from a height of three stories. The payload suffered minor scrapes and indentation as to be expected when pinning a cardboard box against a hard, unforgiving floor.
The second drop test was performed by chucking the payload down four flights of stairs. Again, nothing of note happened for our payload was victorious.

5.2 Whip Test
A single whip test was performed by Mickey. The test was performed for 90 seconds. The payload remained intact during the entire test.

5.3 Cold Test
A cold test was conducted before launch. The payload containing the sensor array and radio transceiver was placed in a negative 95 °F freezer for 90 minutes. The internal temperature reached a low of 32 °F, which was good considering that the payload was not sealed in the manner that it would be for launch. The packing tape that was used to seal the payload was intact as well.

5.4 Range Tests
Several range tests were conducted during a period of several weeks. Two of our team members remained stationary while the third member walked away, increasing the range between the transmitter and receiver.
The first range test we conducted was using the stock antennas that came with Dragino transceivers. We were able to establish communications for the length of one city block in downtown Colorado Springs.
The second range test was performed at Goose Gossage Park with our first prototype pictured in Figure 1. The efficiency of communications dropped to less than fifty percent, after walking a distance of 254 meters measured by using google maps, meaning that less than half of communication loops were successful.

Figure 9. Range test at Goose Gossage Park
6.0 Expected Results

We expect communication between the payload and the ground station to continue until the distance between them is approximately three thousand feet, as we concluded in our last range test. We hope that some signals may be received past this distance, but there are no guarantees.

7.0 Launch and Recovery

7.1 Pre-Launch

A total of four balloons were launched the morning of April 7th, 2017. Our payload was launched on the third balloon at 8:00 AM.

Figure 10. Eaton Middle School Launch Site

7.2 Post-Launch

Our team expected to stay at the launch site in order to keep transmitting a signal to our payload from our base station. Unfortunately, we failed to receive replies from our payload just minutes after launch and proceeded to retrieve our payload from the landing site. The payload was tracked by Edge of Space Sciences and was successfully recovered from Vona, Colorado. As we approached the landing site, we noticed that we were once again receiving signal from our payload. Upon inspection, we discovered that our payload was still intact, and the components were still running.
8.0 Results, Analysis, and Conclusions

As anticipated, once our payload was about three thousand feet in the air, communications ceased and were not re-established until we retrieved our payload later in the day.

In retrospect, we conclude that our antenna and our code were major limiting factors to the overall effectiveness of our payload. We later found out that the antenna material that we selected was not best suited to pick up magnetic fields. All radio waves function on both electric and magnetic fields. It is possible that our carbon paint, while electrically conductive, was missing out on the magnetic component of the radio signal. This could be further exacerbated by the firmware of our Dragino Radio Shield. It is possible that the Dragino is dependent on magnetic components of radio transmission, therefore, only part of our signal was being transmitted or received.

We decided to use the stock code for the Dragino Lora Shield. While in the testing stages, we determined that the code was not suitable for long range communication. We made several attempts to alter this code, including changing the intensity of the signal and the draw of the current. These alterations, however, proved to minimally useful. The range did increase, but not enough to satisfy the maximum parameters for launch day.

9.0 Ready for Flight

Although the payload itself is intact and has little to no damage, the experiment itself should not be ready for flight without a full comprehensive study in radio frequency and antenna. The code also requires attention, as the stock code was not good enough to gain long range communication. Should we wish to collect sensor data, however, five fresh batteries should get the payload up and running mechanically for future flights.
10.0 Conclusions and Lessons Learned

Our team has made a few conclusions. Each member of our team played to their strengths to come together and make a successful launch. Our overall results could have been improved by selecting a research topic that we were more familiar with, but we have attained a different kind of success. DemoSat has allowed us the time, resources and framework to learn about so many different things. We learned how to make and keep a timeline as a group. We also learned so much about radio science and its underlying concepts.

Success can have many different metrics, and we believe that our success can be measured in our growth as students and scientists. Each of us was able to learn and apply new concepts, and that experience will carry forward in each of lives, both professionally and personally.

11.0 Message to Next Year

If you are reading this message, then it is possible that you are about to embark on quite the journey. It will take many hours of hard work, and there will be times when you try and fail. The best advice we can offer to the teams of the 2019 DemoSat is to push through these times. You will learn a lot about yourself just by having the tenacity to reach the end.