A Long-Range Transmission System for Sounding Rockets

Mei Qi Tang and Jake Peters (DP 19)

Electrical Engineering, McGill University

Supervised By Prof. Benoit Champagne

Abstract

The McGill Rocket Team (MRT) is having difficulty maintaining reliable communication links and recovering their 30 000 ft sounding rockets at the annual Spaceport America Cup (SAC). With the goal of helping the MRT solve its communications issues, this project aims to design a long-range transmission system for sounding rocket flights going up to 10 km. The first part of this project involves the design of a low-power long-range radio using a commercial transceiver chip and the second part consists of designing a beamforming phased array antenna. The radio part was able to reach the manufacturing phase but the antenna and beamforming stays purely theoretical. Prototyping microcontrollers and software for Printed Circuit Board (PCB) design, antenna modelling, and phased array simulation were used to complete this project.

Introduction

Problem Statement

The McGill Rocket Team (MRT) failed to recover their sounding rocket for three consecutive years due to communication loss.

- x Loss of the scientific payload
- x Not reusable

Our solution:

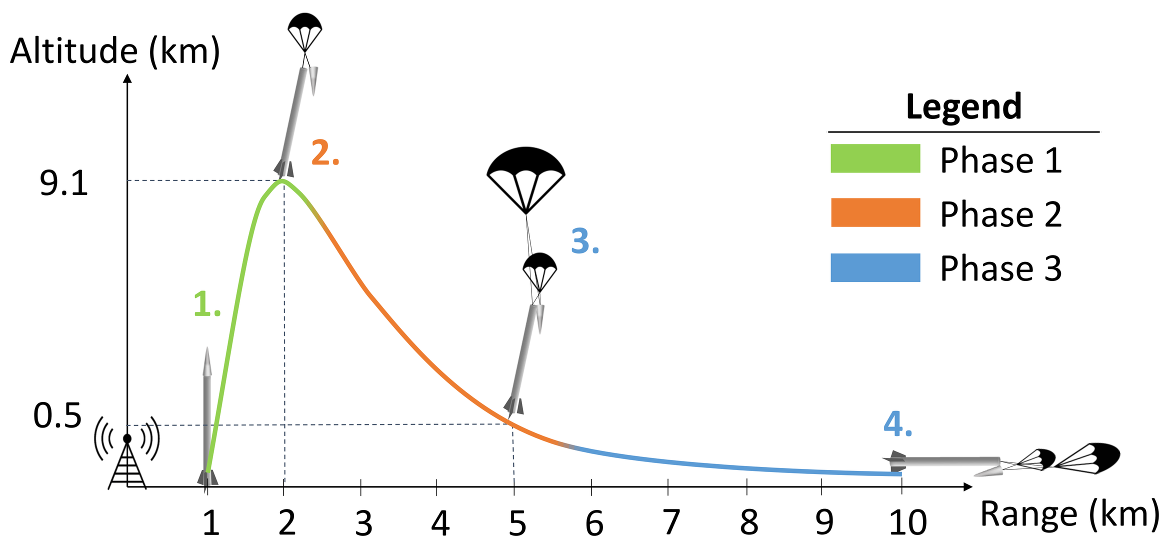
- ✓ A low-power long-range beamforming transmission system
- ✓ Reliable communication for a minimum of 10 km range

Frequency Requirements

Our solution operated at 915MHz center frequency.

- Restricted by the inverse relationship between antenna size and operating frequency
- Allowed operation only in dedicated amateur radio ISM band

Flight Outline



The rocket flight can be marked with four different events:

1. Launch (Phase 1)
2. Drogue Parachute Deployment (Phase 2)
3. Main Parachute Deployment (Phase 2)
4. Landing (Phase 3)

- Flight curve estimated as three linear trajectories
- The beamformer calculates the steering angle according to its current altitude and phase in flight.

Radio Design

There are two connected section of the radio design:

- Hardware: Focused on the choice of components and the supporting printed circuit board (PCB).
- Software: Focused on the delivery of instructions to allow us to communicate information between radios.

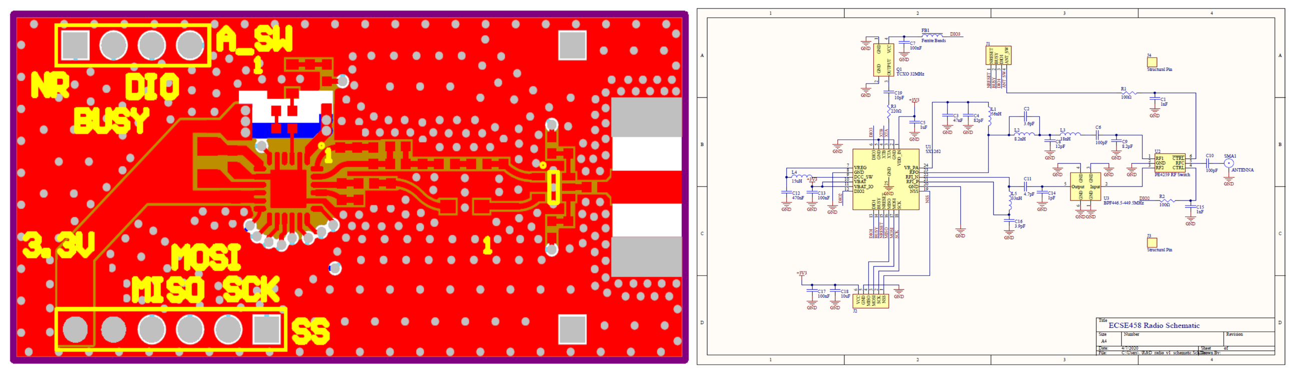
Hardware

Designed around Semtech's SX1262 long range and low power RF transceiver chip.

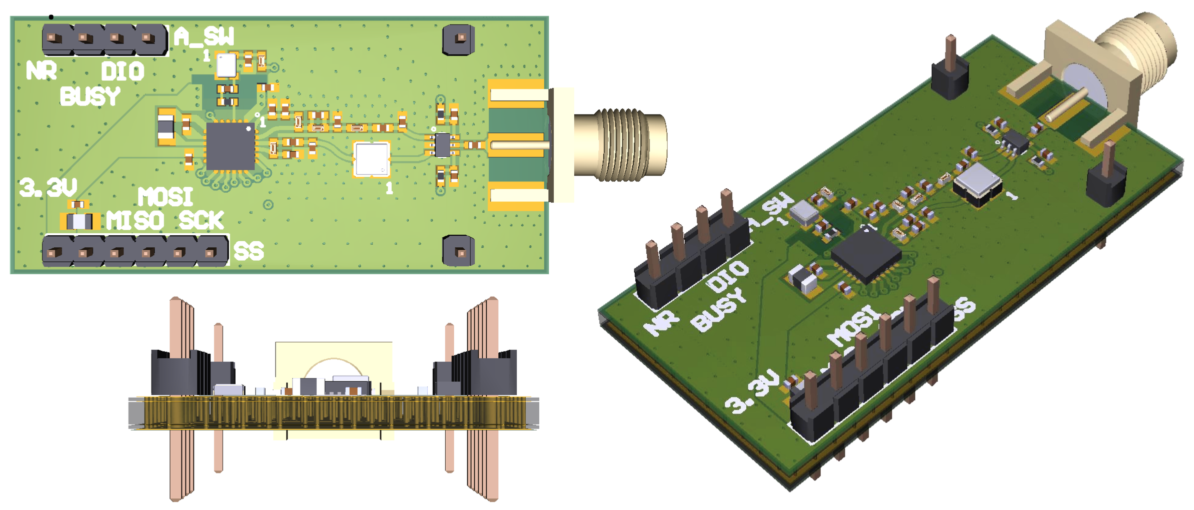
- LoRa modulation, derivative of chirp spread spectrum modulation, is resilient to fading and the Doppler effect.
- High receiver sensitivity and low power consumption.

Other Critical components:

- Temperature-compensated crystal oscillator: Allows us to compensate for frequency drift due to excessive heat.
- Narrow-band bandpass filter: Help alleviate noisy environment by attenuating unwanted frequencies.
- RF switch: Permit us to use a single antenna port for both transmitting and receiving packets.

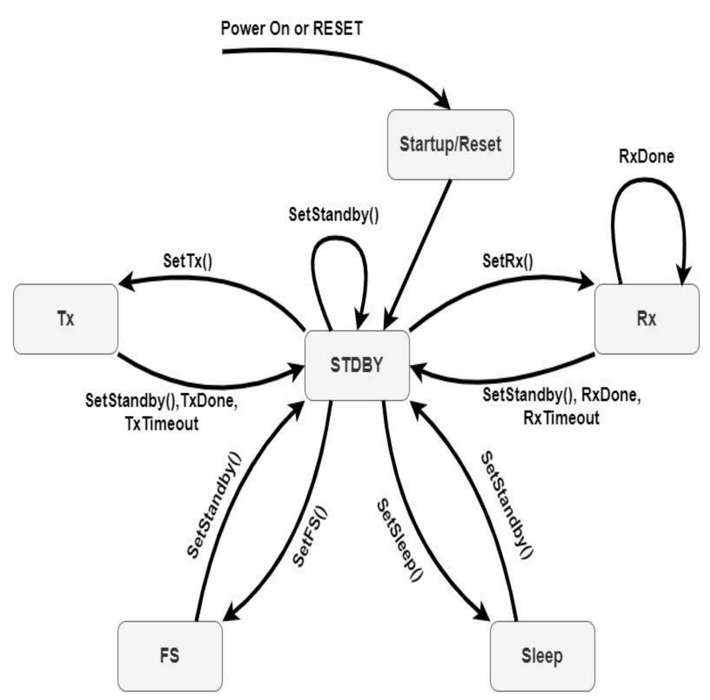


- The PCB design was created in Altium Designer.
- Manufactured by OshPark
- Due to school closure from COVID-19, we were unable to solder on the necessary components.



Software

- Software design was tested on an evaluation kit from Semtech.
- The transceiver chip is configured by sending instructions via SPI communication.
- The transceiver's six states and transitions can be modeled as the FSM to the right.



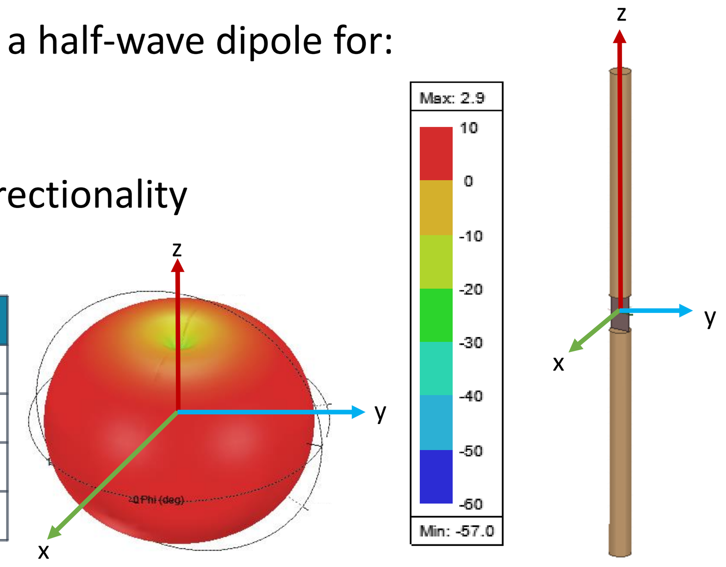
Antenna and Beamforming Design

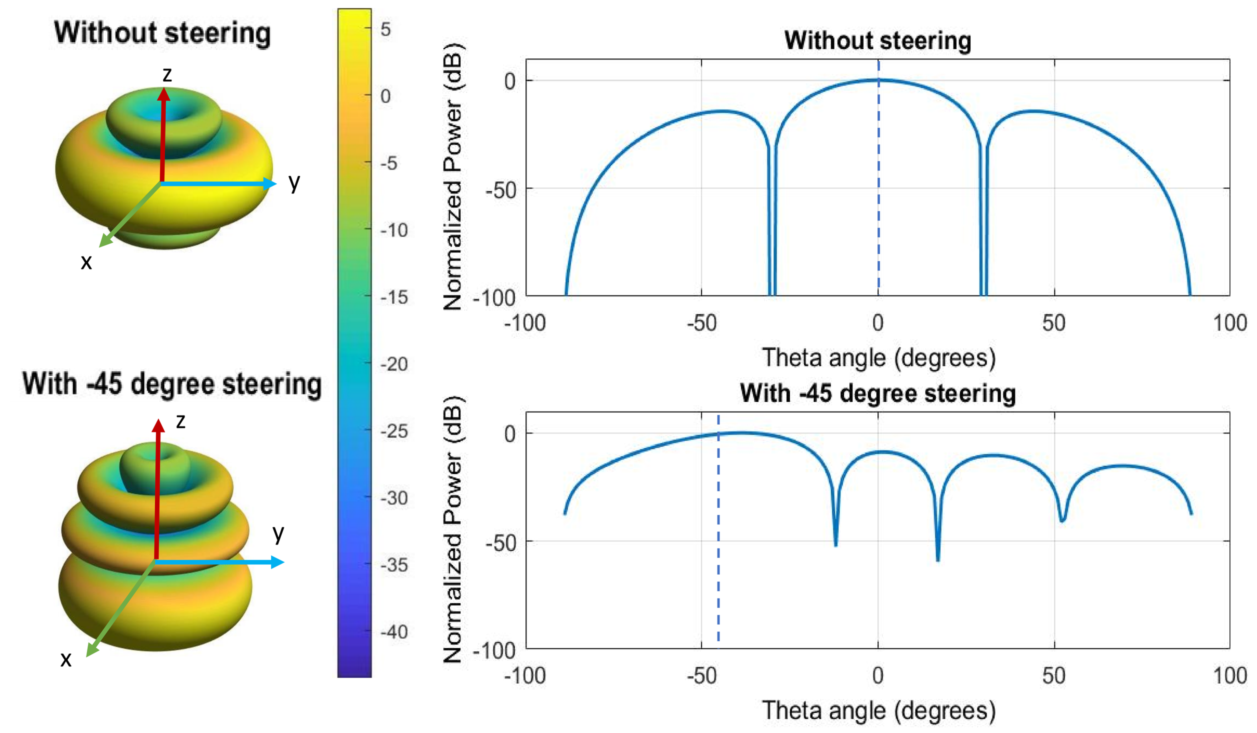
Antenna Element

Each array element is a half-wave dipole for:

- ✓ Design simplicity
- ✓ Low-cost
- ✓ Horizontal omnidirectionality

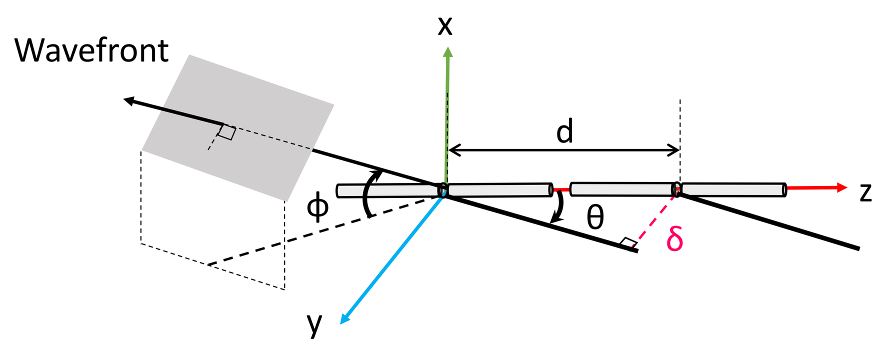
Specification	Value
Length	16.4 cm
Width	2 mm
S-parameter (S11)	-17.8 dB
Peak gain	2.9 dBi

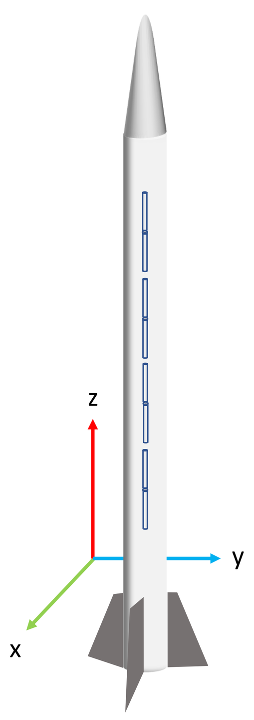




Beamforming Phased Array

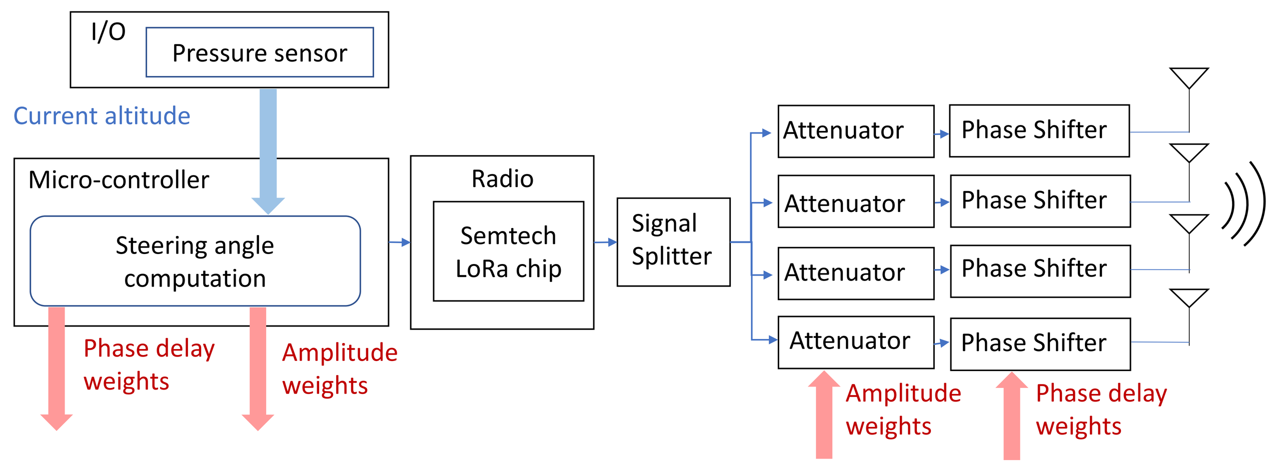
- 4-element dipole array
- Vertically mounted along the rocket body (z-axis)
- Half-wavelength distance (d) between elements





Steps to beamform the transmission signal:

1. Read real-time altitude from the pressure sensor
2. Calculate the steering angle depending on the current flight phase
3. Send appropriate amplitude or phase delay weights to the attenuators and phase shifters.



The total transmitted signal's power level is expressed by:

$$G(\theta_0,\theta,\varphi) = \left|y(t,\theta_0,\theta,\varphi)\right|^2 = \left|\frac{1}{N}\sum_{m=1}^{N} w_m x_m(t)\right|^2$$

$$= \left|\frac{1}{N}\sum_{m=1}^{N} e^{jm\pi(\cos\theta_0-\sin\theta)\cos\varphi}\right|^2, \quad m = 0, 1, \ldots, N$$

- θ_0: steering angle
- **w**: weights (only phase delays in above equation)
- N: number of elements
- θ: azimuth angle
- ϕ: elevation angle

The steering angle is mapped linearly with altitude with a different slope for each flight phase:

- 0° ↔ 0 km
- -90° ↔ 9.1 km

Methodology

1. Radio design: Jake Peters
   Research → Design → Revision → Manufacturing → Test
2. Beamforming antenna design: Mei Qi Tang
   Research → Design → Simulation

Tools and Technologies

- Altium Designer - For PCB design
- Teensy 4.0 – Microcontroller to operate the SX1262 transceiver chip
- SX1262 – Semtech Transceiver chip
- Arduino IDE with Teensyduino software add-on – To program radios
- OshPark – Manufacture printed circuit boards
- Ansys HFSS – Antenna modelling and simulation
- MATLAB – Antenna and Phased Array simulation
- Python, NumPy, and Jupyter Notebook – Programming beamforming simulator

Conclusion

Work accomplished:

- ✓ Manufactured radio PCBs and they are ready for assembly
- ✓ Completed software scripts to operate the SX1262 transceiver chip as a transmitter or receiver
- ✓ Designed antenna elements
- ✓ Derived and simulated the beamforming and beamsteering behavior using a 4-element phased array

- Further testing work cancelled due to COVID-19 pandemic
- Development will resume for SAC 2021, once the pandemic resolves.

Acknowledgement

We would like to thank our supervisor for this capstone project, Prof. Benoit Champagne, for helping us throughout the design process, and thank all the MRT's sponsors, specifically Altium, Semtech, Golledge Electronics.