Ham Radio High Altitude/Space Applications

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Abstract
Ham Radio has many applications in high altitude and space systems. This includes telemetry, remote control system and networking. To test the possibilities of radio communication in high altitude and space applications, the Arapahoe Community College spring Demosat project 2018 was proving that low power communication is possible to communicate with a high-altitude balloon both receiving and sending commands. We launched a payload on a weather balloon up to 100,000ft with the goal of sending and receiving data on the 433mhz Ham radio frequency at a power level of 100mw. We plan to implement the radio system into future payloads. Being able to receive live data from future payloads will allow us to know how the payload is behaving and if something goes wrong and correct and adjust the behavior to resolve any issues. To make the radio system practical in the application of future projects we had to make the structure as light as possible to allow us to stay under the 700-gram launch limit while allowing us to expand the capability of the payload.

1. Introduction

Radio is used in many devices today. Everything from a mobile phone to a Philips hue light bulb. Radio has become a crucial part of life for many people in developed countries such as the United States. There are many rules and regulations around radio. These include the type of data and what bands and frequencies they are allowed on. Ham radio is a section of a variety of these bands. The major Ham radio frequencies are 160, 80, 60, 40, 30, 17, 15, 12, 10, 6, 2, and 1.25-meter bands as well as the 70, 33, and 23-centimeter bands however there are many more. These numbers refer to the length of the radio wave. Many Ham radio operators refer to the band by their wave length because due to the equation for wavelength (wavelength = speed of light / frequency) the wavelength always correlates to a certain frequency when traveling through a vacuum. By referring to them by their wavelength it allows Hams(Amateur Radio Operator) to easily remember the frequency range they are mentioning.

1.1. Extra Class Operator

There are 3 classes of Amateur radio operator licenses currently being issued. These are Technician, General, and Amateur Extra class operator. Each of these require a test issued by volunteer examiners who are a part of accredited volunteer examiners coordinator system (VEC). These VEC’s receive approval from the Federal Communications Commission (FCC) to issue the Ham radio exams.

The first license issued is the technician which requires a 35-question test which draws from a pool of 400 questions mostly about rules and regulations, basic amateur operator practices, and basic radio equipment. Operators who have obtained their technician license are allowed on most UHV and VHF frequencies however are extremely limited in their HF capability’s. Once obtaining a Technician license the operator may opt to take his General test.

This allows the operator to operate on a sizable portion of HF frequencies as well as the frequencies allocated to them as a General. This requires the operator to have a Technician license and pass the Element 3 test. This test is a 35-question test. That draws from a question pool of 500 questions. This test has very similar content to the Technician test however goes into much further detail and requires a higher level of understanding about the material. This test also goes into a lot of detail about the different layers of the ionosphere and how they affect radio propagation.

Finally, there is the Amateur Extra class operator which requires a General license along with passing the Element 4 exam which is a 50-question test with a pool of 700 questions. Once obtaining this license the operator can use all frequencies allocations to Amateur Radio Operators. During the duration of this project I obtained my Amateur Extra Class license.

1.2. Rules and Regulations

As mentioned in Section 1. there are a variety of rules and regulations for radio frequencies. The major ones pertain to this project were, transmission of a call sign
every 10 minutes and at the end of every transmission, requirement of Ham radio license to operator on 433MHz frequency, and power regulations on the 433MHz frequency.

1.3. Applications of Ham Radio

Ham radio has many applications in the high altitude and space research projects. These applications include but not limited to telemetry, remote operation, and networking. Telemetry can be useful for monitoring data from payloads life in case of a failure in the data recording system on board, damage to the payload beyond recovery, or in case the payload is not recoverable can be benefit to allow the team to still receive information they otherwise would not have, allowing the team to improve on the issue they faced for future projects.

Having telemetry also benefits payloads that have the ability for remote operation because it allows teams to adjust values depending on the need of the project if something happens unexpectedly. For example, if a team has a heating element such as a thermal resistor and their original estimate of the loss of heat in the payload is off they can remotely adjust the rate of the heater.

Finally, another use for ham radio in high altitude and space research projects is to use networking between projects. An example of this would be to connect the payloads on a weather balloon to each other to allow teams to receive information from other team’s payloads without needing to implement a sensor on their payload. This would allow teams to launch a lighter payload on average because the teams will not need to have the same sensor on 5 different payloads.

2. Frequency Selection

We choose to use the 433Mhz frequency for the Arapahoe Community College Demosat Spring 2018 project “Stop being such a Ham”. This project was to allow for live telemetry and remote operation throughout the flight. The goal of this project was to create a system that would allow future Arapahoe Community College Demosat teams to implement our work with radio frequencies, so they can get live data about their project back during launch. To make this practical for future implementations the payload had to be light weight, small, and act reliably with little code required to allow for the radio communications. To fit all these criteria, we had to consider Ionosphere propagation, data rates, weight of equipment required to operate, and licenses/ rules and regulation to determine what frequency would be best to operate on.

One major consideration we had to make when choosing a frequency was making sure it will connect through the ionosphere. To penetrate the ionosphere (which is above the height of the Demosat payload launches. This is represented in Figure 2.) we had to choose a higher frequency. Higher frequencies have more energy in them allowing them to penetrate the ionosphere. Under many circumstances using lower frequencies that do not penetrate the ionosphere can be a good thing because the signal reflects to earth allowing for a skip contact to someone else on the ground beyond the radio horizon. However, when maintaining line of sight with the payload and the altitude of the communication payload the higher frequency was better. There are currently lower frequencies that would pierce the ionosphere due to the current time in the sunspot cycle. The sunspot cycle is a 11-year cycle [3] in which the conditions of the ionosphere change allowing for radio signals to skip off the ionosphere easier. The year of this writing (2018) the sunspot cycle is at minimum, meaning that the ionosphere reflects the fewest signals back to earth. At the peak of the sunspot cycle skips are often found on frequencies as high as 6 meters. We wanted to be able to implement this on any future Demosat project, so we made sure that the frequencies were high enough that at any point in the sunspot cycle the payload would be able to maintain contact with the ground station.

Another thing that we took into consideration when determining the frequency of operation is the allowed frequency data rates. Frequencies have different allowed data rates, this prevents over use of the band. The larger the amount of data a transmitter sends the larger the portion of the spectrum that the transmitter is forced to transmit on. To prevent over congestion of the busier bands the FCC had implemented some rules and regulations that prevent people from transmitting over a certain data rate on different bands. On 70cm band (433MHz) people can transmit at 56000 baud rate meaning that they send information at 56000 times per second [4]. This is fast for the information we intend to transmit for this project and future projects. The default input rate for Arduino microcontrollers tends to be around the 9600-baud rate. The lower the frequency the more data rates tend to shrink to accommodate for the smaller operating room on the band along with an increase in traffic on those bands.

Another benefit to the frequencies we chose is the size and weight of the antenna. The length and therefore the weight of an antenna required to transmit is directly proportional to the wave length of the frequency transmitting on. The higher the frequency the lower the wavelength. This means that by picking a higher frequency as we did allow us to use an antenna that was about one and a half inches in length. This help us reduce the weight of the project which makes it easier for future Demosat teams to implement in the future. We chose to use a duck antenna for the payload and a Yagi antenna for the ground station. With the frequency being higher than...
most Ham radio frequencies, it tends to mean that the distance of communication is decreased. We are also only transmitting on 100mW which is extremely low compared to most Ham radio uses. To overcome these issues, we use a highly directional antenna on the ground to pick up the signal from the payload. We chose not to make the payload directional because of the extra weight and when the payload is spinning it would not always point towards the receiving station.

The 433 MHz frequency is in the Ham radio spectrum which requires a Ham radio license. However, it only requires a technician license to operate on this frequency. As mentioned in section 1.1 the technician license is the lowest level Ham radio license currently being issued at the time of this writing. In the process of obtaining this license people learn a lot about frequency allocation, operating procedures, antenna types and much more, this will benefit the team when operating on these frequencies to help trouble shoot any issue they may run into. Another benefit to using the Ham radio spectrum is that it is less congested than a lot of other frequencies such as 2.4 GHz were Wi-Fi and many other devices operate on. On top of having fewer people on those frequencies, most of the people who use these frequencies have the equipment and knowledge to detect signals on this frequency and to stay away from them. Another benefit when using the ham radio frequencies is that there are a lot of Elmers (a ham radio mentor) that are happy to help answer questions, trouble shoot issues, or even help set up stations. The Parker Radio Association had helped us get the information we needed to conduct the project successfully. Finally, only one member is required to have a ham radio license and the rest of the team can operate on that frequency legally using that call sign if the licensee is in attendance.

3. Radio Selection

Selecting a radio took a large amount of research for the team. We had to reach the requirement of maintaining contact with the weather balloon throughout the entire flight while also minimizing weight and size of the radio. Things we had to consider were power consumption, transmitting power, and size of the antenna. The more the power the radio consumes the larger the battery required to power it throughout the flight becomes. The more transmitting power the radio has the less of a concern distance becomes. Finally, the size of the antenna that the radio requires to operate was another requirement, we choose radios that all used the same antenna so it was less of a concern than if we were operating on different frequencies.

3.1. Featherwing LoRa Radio

The Featherwing LoRa radio is an Arduino microcontroller with a built-in ham radio 100mW transmitter. This was the transmitter we chose for our Demosat launch due to its tiny weight and size. It measures 2.0” X 0.9” X 0.3” without headers soldered on [5] it weighs in at 5.8 grams without the antenna or pins soldered on. It also has a low power draw of 120mA during peak transmit. This will allow us to use a very small battery to run the transmitter for the 3 hours required for this project. Another benefit we found for using this board is that it has a built in Arduino which allows us to monitor the heating control system, read sensors, and customize the transmitted content for the use of the project without needing to add an additional Arduino board. Even though it is light it does not lack features, this tiny board features:

- 3.3 volt regulator with 500mA peak current output
- 20 GPIO pins
- Hardware Serial, Hardware I2C, Hardware SPI support
- 8 PWM pins
- 10 Analog inputs
- 1 Analog output
- Built in 100 mA lipo charger (1s battery only)
- Built in pin 13 led (helps for troubleshooting.)
- M0 Processor which is a fairly quick processor for such a small board. [5]

3.2. Ardupilot 433Mhz telemetry

The Ardupilot 433MHz telemetry module is a module that hook up to an Arduino or raspberry pi using a serial or micro USB (serial) plug to communicate. This is a 100mW transmitter, so it does not draw a large amount of power. There is a 500-mW variant of this project that draws more power. They advertise this module working 300m out of the box [6]. This is no more near what we would need in order to maintain communication for our Demosat project however we predicted that this module would have much greater range line of sight and because we maintain line of sight communication with the payload for the majority of the flight we assumed we would be able to receive data with a high gain antenna. They mention on their product page that using a small patch antenna on the ground and even using an antenna tracker would help improve range. Another option they gave to improve range was to replace one of the two radios with the higher power RFD900 radio. The final solution they mention for improving range is to decrease the rate of communication sent in order to increase range but at the expense of data transfer [6].
3.3. Orange RX Transceiver

The Orange RX Transceiver was another option we looked at. It is a separate transmitter like the Ardupilot 433MHz telemetry module, so it would require an additional microcontroller to manage the on-board flight management system. It does have a built in Arduino however does not have access to the pins required to. This module is more complicated to wire into the flight management system than the other options listed. Figure [8] represents the wiring schematic of how to wire this module into and Arduino. This module has the highest transmitter output, so it will maintain the longest range. This transmitter transmits up to 1W of power which is 10 times as much power as some of the other options. The Orange RX Transceiver features:

- 3.3v FTDI interface
- Serial port for firmware upload and telemetry application
- I2C port for sensor applications
- 16MHz at mega 328 processor with Arduino pro mini compatible bootloader
- 1 W output
- Voltage input 6.8 – 12V dc

3.4. Ham Shield

The Ham radio shield was another option we considered. This was the most expensive option we considered. The Ham radio shield is an Arduino uno shield that allows it to transmit on 134MHz – 174MHz , 200MHz – 260 MHz and 400MHz – 520MHz. This would have been nice because it would have allowed us to change frequency and band if on the day of launch we find the frequency we are using in congested. The main downside is the size, because this mounts on an Arduino Uno it takes up a larger form factor than the other options. This product was also new to the market so there was not a lot of documentation on how it works or troubleshooting potential issues we could encounter. This transmitter offered a lot more options for operating on each frequency than the other transmitters. This transmitter features: [9]

- 500mw Power output
- Arduino Audio PWM+ ADC (filtered
- Audio jack type trrs(smartphone)
- Computer interface USB + Arduino
- Modulation FM
- Digital Modes: AFSK and custom
- Sub Audio CTCSS, CDCSS (allowing us to use repeaters)
- Bandwidth 12.5KHz or 25KHz
- Squelch Digitally controlled
- Cox digitally controlled
- Emphasis filters can be disabled.

4. Wiring and Electrical Components

We had several major electronic components, these include the LoRa Transmitter, 2 sensor boards, a thermal resistor, a MOSFET, microSD card board, and 2 batteries. The wiring of the LoRa radio, a battery, and a sensor board is show in Figure 4. This does not show one of our sensor boards, and the heating element and wiring.

The LoRa Transmitter was used for our communication along with flight management system. This was responsible for managing power to the thermal resistor, reading sensor values from the 2 sensor boards, maintaining communication with the ground station, and logging all the data transmitted to a microSD card.

We wired the 2 sensor boards to the LoRa microcontroller using I2C ports allowing us to hook up the data pins in series simplifying our wiring and reducing the amount of wire on board. The two sensor boards were responsible for collecting information on temperature, humidity, pressure, gas, acceleration, magnetic fields, and gyroscopic movement. This was the data that we sent back to the ground station where we monitored the characteristics of the flight.

Finally, we had the thermal resistor and MOSFET. The thermal resistor provided heat for the batteries because they do not function properly under freezing conditions. To prevent this, we supplied them with heat from the thermal resistor. However, this heating resistor went from -70 degrees C in the dry ice to 150 degrees C in under 5 minutes when hooked up to the battery during our original test. To prevent over heating of the payload we wired in a MOSFET to help prevent over heating of the payload. Both of our sensor boards received temperature, so we used both of those values averaged together to keep the temperature of the payload. We wanted it to stay around 40 degrees C.

5. Programming

This project required a variety of sensors, communication, and heating elements programmed to succeed. Each aspect of this project had to integrate to allow the system to function as it is supposed to. The heating element had to be adjustable from a command sent through the radio. The heating element had to read the sensor data to adjust heat. The transmitter had to read sensor data to transmit back to the ground station. In order
to integrate all of these systems it required there to be a lot of communication among the programming group in order to make sure all aspects of the program integrated nicely into each other.

5.1. Transmitting Signal

The transmitting signal for this project is using packet. Packet is a form of digital communication that allows for radios to communicate in a form that makes it easy for computers to understand. By making the connection digital, signal degradation will be significantly less until the drop out at the end of its range. This is beneficial because it allows for the communication to avoid errors however it tends to have very little warning when loosing signal. This concept as shown in Figure 5. For the transmitting aspect of the code we used the RH_RF98.h library to help with the built-in interface between the Arduino and RF transmitter. This library takes care of all of the measuring of packets and decoding them.

5.2 Communications Formatting

Our original program receiving code very unorganized in its print statements. This made it so using the serial monitor in Arduino was hard to understand. The serial monitor was just printing out the numbers with no labels. This had forced the reader to know exactly what every value correlated to. On our second revision of the code we added labels and separated out values to allow it to be significantly more readable.

5.3. Reading Sensor Values

The sensor readings were added to the code to simulate what future transmissions if this radio system in implemented onto future payloads would look like. We are reading in basic orientation information, temperature, and pressure. Then we are taking this information and transmitting it back as if it was implemented into a future project and was transmitting data back that was important to the experiment.

5.4. Heating System Adjustments

Finally, we had to add in a heating control aspect of the program. Due to the power of our thermal resister if we did not implement a control aspect to the heating element it would risk causing a fire on the payload due to extreme temperatures. We discovered this during one of our cold tests in which we put the thermal element in a dry ice bath with a heating probe attached to it. Then allowed the heater to reach the temperature of the dry ice. Then we plugged in the battery to the heater and watched the temperature quickly rise from -70 degrees C to 150 degrees C in under 5 minutes at which point we decided to turn it off to avoid risk of a fire. The graph of this data as shown on figure 6.

6. Structural Accommodations

Building a structure to carry the radio took some careful planning. There were several accommodations that were by the structural group to accommodate the radio. These were insulation, unique antenna mounting, and strength to keep electronics for reuse upon hard landing while working with environmentally friendly materials.

The transmitter we were using ran on lipo batteries. Lipo batteries do not like to operate efficiently under freezing conditions. The colder they get the less voltage they put out. This means that we had to have insulation to keep the heat in the payload at launch and the heat from the heating element in the payload with the greatest efficiency possible. To accomplish this, we used cork board as an insulation material because it showed similar thermal properties to the insulation foam we used to use for Demosat payloads while maintaining the ecofriendly aspect of the project.

Another thing the structural group had to accommodate in their design was the placement of the antenna. To optimize radiation of the antenna towards the ground station we did not want any obstruction. This meant that the structure group had to have an open pocket on the design to allow for radiation towards the ground while still protecting the antenna and maintaining heat. To do this, they chose to have a cubby in which the antenna slots into as seen in figure 7

Finally the structure group had to build a structure that was strong enough to survive the whipping around of the flight string once the high altitude balloon but also survive impact with the ground to allow us to reuse the electronics on future projects which helps with the environmentally friendly aspect of the project because the circuit boards are not being put in the trash but instead are being reused on future projects. After lots of testing and a variety of prototypes they decided on using a balsa frame with a super thin plywood outside coat inlayed with cork board. The balsa structure allowed for impact resistance. The plywood outside helped protect the payload from piecing objects and incase the payload was dragged upon landing. Finally, the cork board was laid on the inside to allow for insulation as seen in figure 8.
7. Figure and Table Captions

Figure 1. ARRL Band Plan [1]

Figure 2. Ionosphere Layers [2]
Figure 3. Ionosphere Layers [7]

Figure 4. Wiring Diagram

Figure 5. Analog Vs Digital Communication [10]

Figure 6. Temperature of Heating Element

Figure 7. Payload structure
8. References


[8] “OrangeRX Open LRS 433MHz Transmitter 1W (JR/Turnigy Compatible).” Hobbyking, HobbyKing, hobbyking.com/en_us/orangerx-open-lrs-433mhz-transmitter-1w-jr-turnigy-compatible.html?gclid=Cj0KCQiA5t7fBRAIARIsAOreQtjKczH1uFb1YexXbZeEZ7lGNtg2iHJ8iudpD3FaDyM8D29is7wEAwApZNEALw_wcB&gclsrc=aw.ds.
