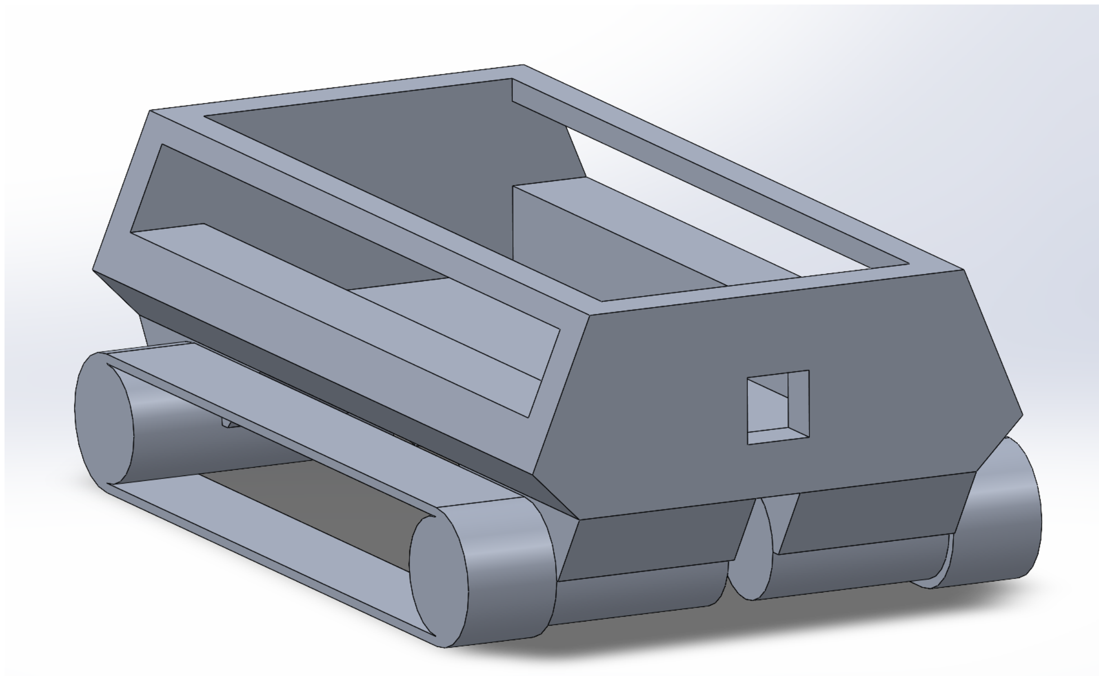
Aerojet Remote Controlled Rover Payload



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1. Executive Summary

This document will outline the project design phase of the Aerojet Remotely Radio Controlled Rover project that this senior design team chose. The following three broad sections will be in this document: the technical objectives, goals, and requirements of the project, the research and investigations made to inform the design of the project, the project constraints, and the project standards that surround and govern this project.

The Project Description (chapter 2) provides the information on technical objectives, goals, and requirements. It will outline the approach to the initial project definition including, the motivation of the project choice, and the literature that defines the project. It will then present the goals of the project that must be and can be met to suit the project definition. Thirdly, it will give a brief description of the system designed for the project, and then give then requirements that define the criteria for this description. Lastly, diagrams and other visual aids will be provided to give a clear view of the project discussed within the confines of this paper.

The Research chapter of the paper (chapter 3) will provide all of the knowledge acquired and decisions made through the gathering of knowledge surrounding the parts and technologies that will be used in this project. This chapter will provide the insight and background knowledge that was used to make a decision about all of the parts chosen for this project. This simultaneously provides a comprehensive list of the parts decisions made for this project that do not fit under simple commonplace linear circuit components. All parts decisions work in tandem with the Design chapter (chapter 5) that presents the design of each subsystem by describing in detail the intended and expected function of the subsystem, the interaction of its parts, how it was designed, and the actual physical or logical design.

The fourth important chapter of this document lies in the Constraints and Standards chapter (chapter 4). This chapter defines the constraints and standards defined by the group's research efforts and part selection that will govern the design of the final system. This chapter provides the important knowledge that the group used to succeed in creating a design that respects established standards and respects the constraints they believed to be important. Constraints that fit under the categories of engineering, manufacturing, environmental, ethical, and safety were all considered in this chapter. All standards that are explored are derived from research surrounding the selected parts and technologies that will be used in this project. The standards govern the organization and reliability of the design subsystems.

The other chapters of this document (chapters 6 - 8) provide tertiary knowledge surrounding the administration aspects of this project, the testing of the project design, and a conclusion.

2. Project Description

The project description will cover the motivation, goals, high-level description, requirements, and diagrams associated with the deliverables of the project.

The Project Motivation section will discuss what drives the deliverables of the project, who the shareholders are, and the motivations for project selection. The Project Goals section will explore what is planned to be accomplished to meet the deliverables, what can be done to expand on the deliverables, and what could be done to increase the scope of the project with benefits to its efficacy.

The System Description will give a high-level overview of the project hierarchy and how its multiple systems work together. The Engineering Specification section expands on the high-level overview, giving the measurable requirements that drive the deliverables of the system created for this project. Finally, the Sketches and Diagrams section presents useful figures to explain the interactions inside of the system, show preliminary designs, and present the system requirements in a visual way.

2.1. Project Motivation and Goals

This section will cover the driving forces behind the deliverables created throughout this project. It will first cover the motivations that drove the selection of the project and the main goals of the project. It will then cover what these main goals are, and then touch on the tertiary goals developed by the team that were believed to be positive additions to the project if time allows.

2.1.1. Motivation

Aerojet Rocketdyne Coleman Aerospace - the project sponsor - chose to fund this project idea with the intention of challenging students with an educational experience that they will encounter in the real world. The project requirements were developed by the FAR rocket competition owners, and Aerojet Rocketdyne is funding the project. The project requires the University of Central Florida colleges of MAE and EECS to make a rocket and payloads for the competition respectively.

The payload is intended to serve as a reconnaissance vehicle for it’s landing location. There were multiple options of payload for the team to choose from, but the remotely controlled radio rover was chosen with motivation stemming from the interest in implementing wireless video and communication with the rover and it’s controller, as well as the interest of having control over it’s movements compared to the autonomous option. The team also decided the RC rover was the most realistic fit and application for the team's division of skills in robotics, mechanics, electrical engineering, and programming.

2.1.2. Goals

This section will define the basic, advanced, and stretched goals of this project. The basic goals cover the deliverables and outcomes necessary for project success. Advanced goals fit under beneficial additions to the project deliverables, that come secondary to the basic goals and can be evaluated when the basic goals have been securely met. Finally, the stretched goals are tertiary goals which are not guaranteed to be explored. These goals would likely be addressed as future improvements upon the project, and sit outside the scope of the deliverables for the project.

2.1.2.1. Basic Goals

The main goal of this project is to create a deployable rover payload that has remote control and wireless video transmission available upon touchdown from rocket deployment for a 10,000 ft apogee IREC spec rocket. These goals were specified by the FAR rocket competition documentation to drive the final product of this project. The team's objective is to create a rover that is light-weight, compact, responsive, and has a reliable battery lifetime while meeting the main goals of the client and competition.

2.1.2.2. Advanced Goals

It could be useful to include a display to keep track of the rover's battery life, distance travelled, temperature, etc. Features to support low power modes could be added to increase mission lifetime by restricting power to areas that are being utilized. Additionally, features like object-detection or obstacle avoidance using computer vision could be added to this rover. The rover could also be set to save recordings of the live video transmission every 30 or 60 seconds.

2.1.2.3. Stretched Goals

After all basic goals and advanced goals are met, the team can work on incorporating more complex ideas into the RC rover. To make this rover multifaceted, an autonomous option could also be incorporated. By pressing a button or setting a path, the rover could traverse autonomously when there is no person available to control the rover.

2.2. System Description

The team will create a rover chassis that contains the rover's traversal systems, main PCB, and a secondary controller and video receiver PCB. The team will also be responsible for all deployment duties for the payload after it leaves the rocket, which will be discussed in this section.

The rover chassis will be a light frame that mounts the PCB, video camera, motors, tracks, and the power supply. The team intends to create a tank track movement system to allow the rover to avoid terrain hazards that could severely limit movement. The frame will be made of a light and sturdy material to leave as much free weight as possible for the electrical and moving mechanical hardware, while still being able to handle the stresses of operation and touchdown. The power supply for the rover chassis will power the PCB, camera, and motors. A rechargeable battery cell will be used to avoid recurring costs and keep vehicle weight down.

The main PCB mounted to the rover will control all of the moving operations, the video camera, and signal transmission and reception. Wireless signals from the controller will be received by the PCB, and the microcontroller will take the incoming data and use it to control the motors for the rover's movement. The video camera output will be encoded and transmitted by the primary PCB to the secondary PCB at the location where the launch will be observed. The main PCB will also have sensors to measure different environmental values during the rover's active duty.

The secondary PCB - the controller and video receiver - will be free standing from the rover. It will have it's own rechargeable power source to allow it to be moved freely. It will receive and decode a wireless video signal from the rover to be displayed to a screen at the launch observation location. The board will also have a joystick controller on it that will provide the data to be transmitted to the rover for movement control.

The two teams in charge of the FAR rocket have supplied requirements and constraints for the payload to fit their design. This team is responsible for all duties of the payload after it is deployed from the rocket airframe. The team will design a sturdy and lightweight payload capsule and sled for the payload to rest in while the rocket is in flight. When the capsule is deployed, this team takes full responsibility for the payload. On deployment the rover payload will automatically turn on and wait until landing. The team will design the capsule so that it can open when it lands and the rover will leave the capsule to complete its mission as described. The team members will continuously meet and work with the FAR rocket teams to track any changing restraints and requirements throughout the lifecycle of the project.

The final rover product will provide remote controlled, live video reconnaissance to launch control and it may act as a prototype for larger and more high-powered applications. The sensors, and video camera will work together to provide data about the rover's location and experience to launch control. The team will work with the FAR rocket team and their advisor throughout the length of the project to meet their goals and the FAR rocket competition goals.

2.3. Engineering Specification

This section details the requirements that drive the design of the rover and capsule for this project. The requirements were driven by the FAR competition rules, the team's self-imposed success criteria, the pre-existing requirements of the FAR rocket team, and the input of the team's faculty advisor. These requirements were also in part driven by the constraints given to the team by the FAR rocket team, the expected environment of the rover and capsules operation, and the FAR competition rules. These constraints will be explored in section 4, along with the standards related to meeting the system requirements that drive and support the project design and implementation.

All requirements listed in the following table are functional requirements that are measurable, impactful, necessary, and system critical. The requirements highlighted in yellow are what the team believes to be the best representations of the project that can reasonably be demonstrated to an audience.

Requirement Number	**Requirement Description**
1	Payload will be 1 kg in mass minimum
2	Payload capsule will be fit within the 15.67 cm inner diameter of the rocket
3	The rover will establish a video feed within 5 seconds of landing
4	Rover will leave the landing site within 5 seconds of landing
5	The live video will transmit at a minimum of 480p 24 fps
6	The secondary PCB will be able to display the video from the rover to a display with an HDMI input
7	The rover will respond to controller input within 1 second
8	The rover will be able to travel at a minimum speed of .40 m/s (~1mph)
9	The rover will have tank tracks that are capable of traversing most common terrains
10	The rover will be able to turn 360° (CCW or CW) and move forward and backward
11	The rover will travel a minimum distance of 3.05 meters (10 feet) from the landing site
12	The rover will be able to transmit video while traveling a minimum of 3.05 meters
13	The rover will be able to sit idle for 1 hour minimum and have enough power remaining to travel 3.05 meters while transmitting video
14	The rover will have an altimeter to measure its altitude during its descent

Table 1.a: Requirements Specification Table

Requirement Number	Requirement Description
15	The rover will have an accelerometer to measure its acceleration during its descent and its ground mission
16	The maximum mass of the Payload, Sled and capsule must be no more than 4.31 kilograms
17	The capsule door will open when the rover detects that it has landed

Table 1.b: Requirements Specification Table Continued

2.4. Sketches and Diagrams

This section will show preliminary block diagrams that outline the parts of the system, and the system interactions in both hardware and software. Breakdowns of which project member holds primary responsibility for a part of the system are provided and highlighted. A preliminary sketch of the rover design is also provided to show the design that will be expanded throughout the paper. A house of quality is also presented to visualize the interactions between the requirements specified in the previous section.

2.4.1. Rover Sketch

Pictured below is the initial and tentative design for the rover chassis. Major features include battery storage bays, frontal cavity for housing a camera, mounting surfaces for PCB's, cable passages for sending power to the motors, and a sturdy yet compact frame. This sketch takes into account dimension constraints for being contained in the payload bay of the rocket. Not including the payload sled, the payload and container must fit within a 12.7 cm diameter by 40.64 cm long space. This sketch shown in the figure below measures 12.35 cm wide by 26 cm long by 8.8 cm tall. Next design iterations will include part specific mounting surfaces and geometries.

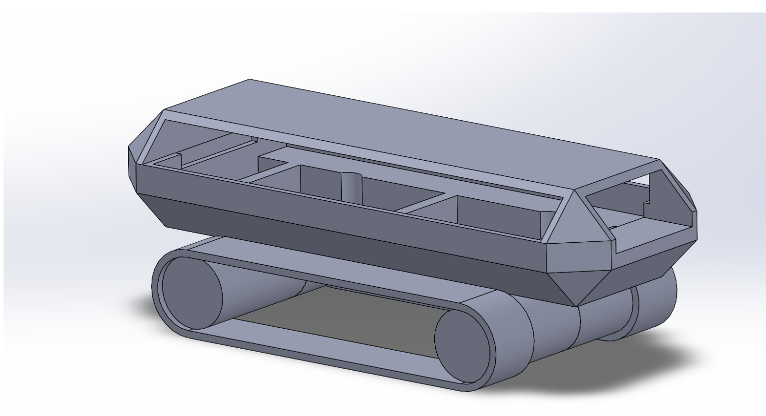


Figure 1: Initial Chassis Design Sketch

2.4.2. House of Quality

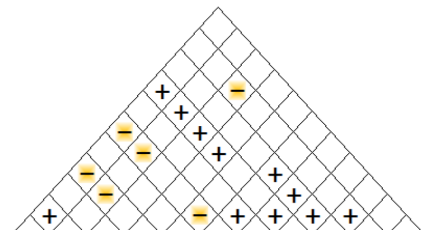
The House of Quality is a diagram that is used to relate engineering requirements to market and customer requirements. It contains matrices of relationships between the two types of requirements to help define how all system requirements function together and rely on one another. It is also used to determine where compromises can be made in the system based on the interactions of the requirements and their respective importance. The legend and the house of quality are seen in the two figures below.

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Figure 2.a: House of Quality Legend



Column #	1	2	3	4	5	6	7	8	9	10	11
Direction of Improvement	▼	▼	▼	▲	▲	▲	▲	▲	▲	▲	▲
Engineering Requirements / Customer Requirements (Explicit and Implicit)	Weight	Size	Response Time	Structural Rigidity	Video Quality	Battery Life	Movement Speed	Manueverability	Distance Moved	Communication Distance	Sensor Accuracy
Lightweight	●	●	▽	●	▽	●	●	●	○	▽	▽
Compact	●	●	▽	●	▽	●	●	●	○	▽	▽
Responsive	▽	▽	●	▽	▽	▽	▽	●	▽	○	▽
Deployable	●	●	▽	●	▽	○	▽	▽	▽	○	○
Remote Controlled	▽	▽	●	▽	▽	○	▽	▽	▽	●	▽
Wireless Video Transmission	▽	▽	▽	▽	●	○	▽	▽	▽	●	▽
Battery Life	●	●	▽	▽	○	●	●	○	●	▽	▽
Mobility	●	●	●	●	▽	●	●	●	●	○	▽
Movement Range	▽	▽	○	▽	▽	●	○	○	●	●	▽
Communication Range	▽	▽	○	▽	○	▽	▽	▽	○	●	▽
Sensing	▽	▽	▽	▽	▽	○	▽	▽	▽	●	●
Targets for Engineering Requirements	<= 1kg	76mm x 76mm	<= 200ms	Withstand 1.5m/s descent	>= 480p 24 fps	1hr idle + 3.05m travel + videc	>= 1.35m/s	360 degrees of movement	>= 3.05m	>= 300m	<= 5% accuracy

Figure 2.b: House of Quality

2.4.3. Block Diagrams

The following three block diagrams break down the high-level organization of the project hardware and software. The diagrams also include a legend to distinguish hardware and software, as well as show the distribution of responsibilities between team members.

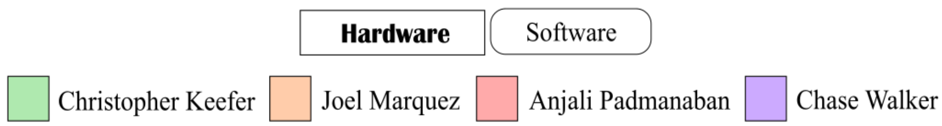


Figure 3.a: Block Diagram Legend

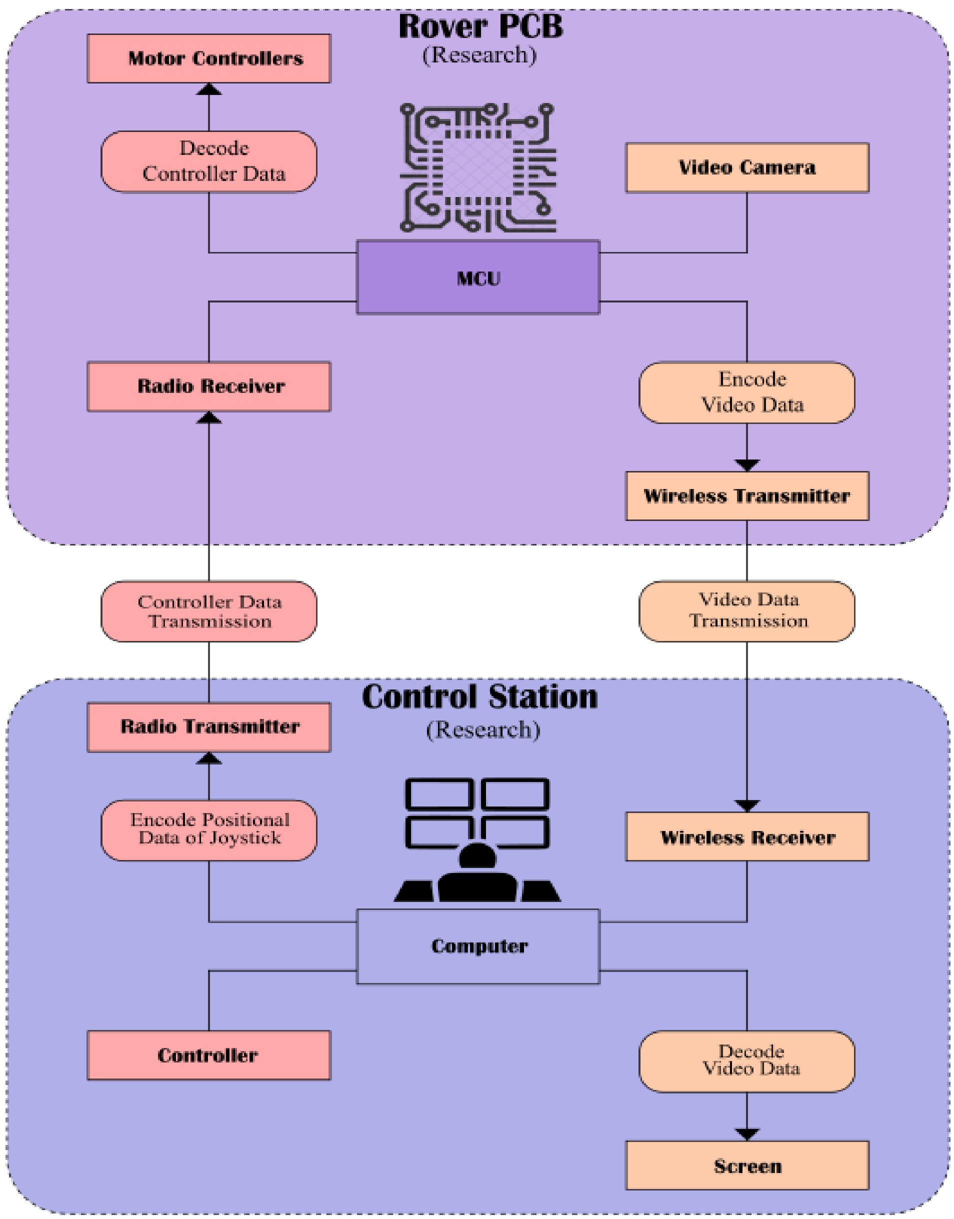


Figure 3.b: Block Diagram Showing Hardware and Software Components of PCBs

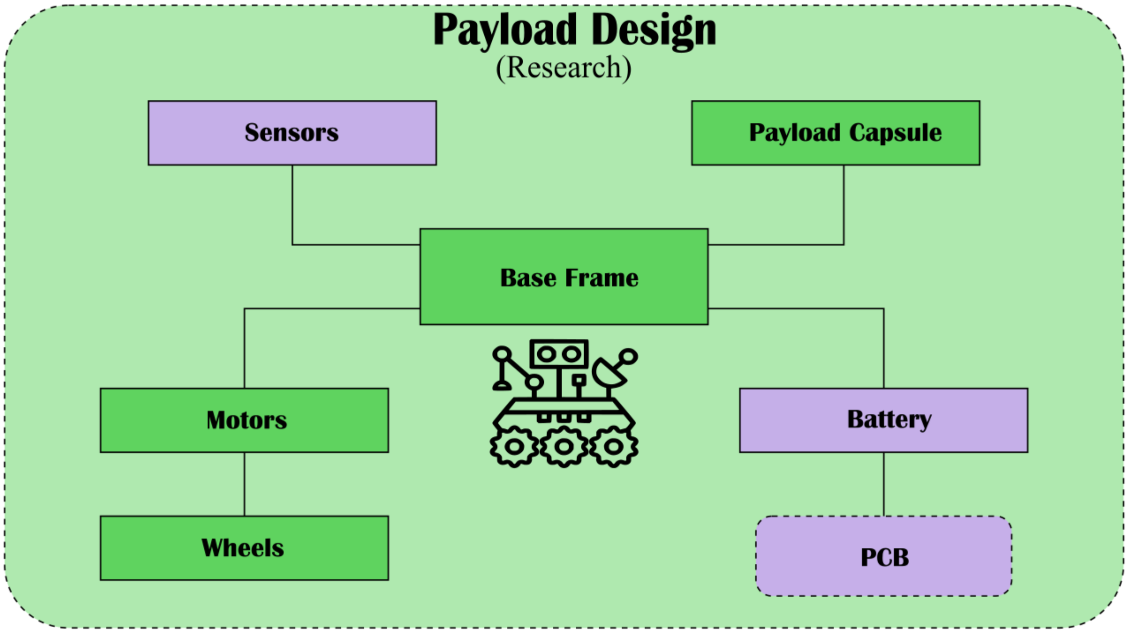


Figure 3.c: Block Diagram Showing Rover Systems and Hardware

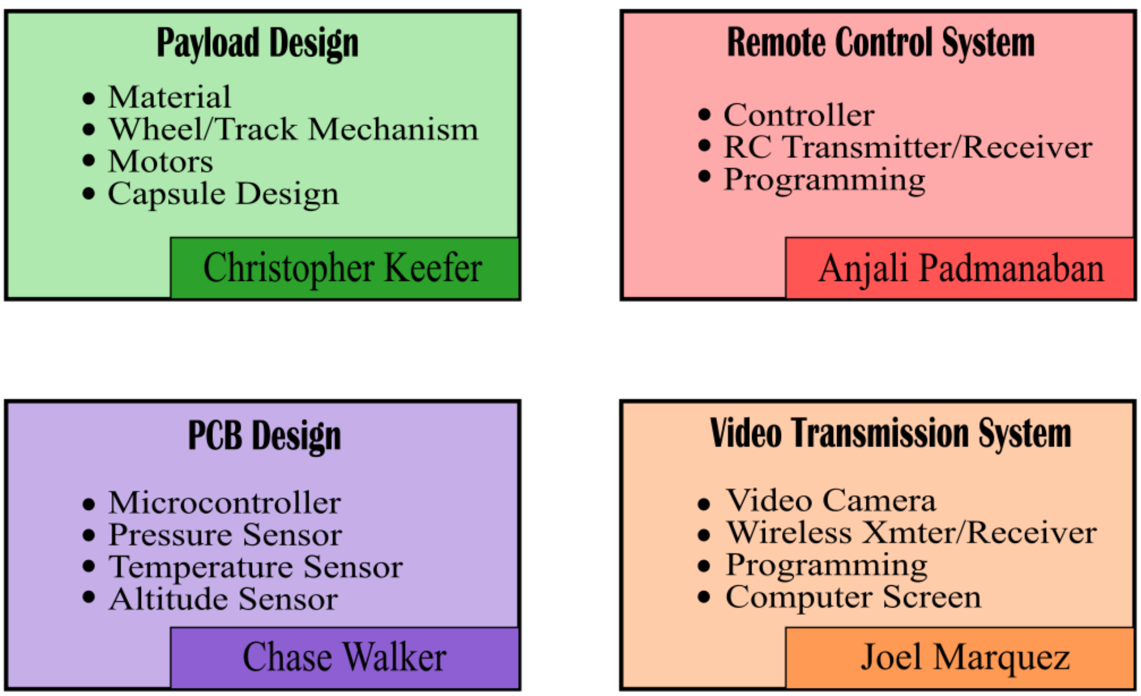


Figure 3.d: Teammate Project Responsibility Breakdown

3. Research

The remote controlled rover and rover deployment systems are complex and have many constraints and requirements to consider when selecting parts. The parts chosen in this system must not only meet the specified requirements and system constraints, but must also be compatible, and function together. This chapter will present the main components of the system and show, explain, and compare the choices considered for each component. It will also allow an understanding of the options that were available for implementation of the project, give insight to the function of the options, and explain the decision behind the final parts selected.

3.1. Parts Comparison

This section presents the non-trivial components of the system and shows the decisions made for picking these parts from the existing market. For each part, the use of the part in the system will be described and background information will be given to explain the parameters for selection, the way the part functions if necessary. Following this, at the end of each part section, all considered market parts will be listed, described, and compared to show the reasoning for the selection that was made.

3.1.1. Motor

This system will use tank tracks instead of wheels as will be discussed in chapter 5 and four DC motors will be needed to drive the tracks. To ensure success in navigating the sand and gravel terrain, the motors must possess enough torque to drive the tracks. As such, motors with a high RPM value (greater than 300 RPM) will not be a useful candidate for motor selection as increasing RPM values correlate with lower torque values in the small DC motor market. Additionally, high speeds are not suitable nor necessary for navigating terrain with unknown physical obstacles. The selected motor must also be small enough to be oriented back-to-back underneath the rover so that the motor housings do not protrude from the sides of the rover. This constraint is due to the dimensional restrictions placed on this project by the size and diameter of the rocket. Accounting for space between the two motors on the forward and rear ends of the rover, each motor housing must not exceed 6 centimeters in length. Per the design of the electronics aboard the rover, a voltage higher than 12V will not be acceptable for selection.

An highly valuable parameter when selecting a motor for purposes such as those in this report is motor torque value. For the rover to go from a resting state to having a constant velocity, the motors will need to have a combined torque high enough to overcome the friction generated by the rover traveling along the ground. To select an appropriate drive motor a minimum drive torque will have to be found that can accommodate the weight of the vehicle. The below equations assume the rover to be 2 kg in mass, starting from zero velocity on a flat, gravel terrain using 1.8 cm radius wheels.

$Minimum\ drive\ torque\ for\ a\ 2kg\ rover$:
$F_w =\ Force\ exerted\ by\ wheel$
$F_f\ =\ Force\ of\ friction\ against\ track$
$T_T =\ Minimum\ Total\ Torque\ required$
$\mu =\ coefficient\ of\ friction\ (0.5\ for\ loose\ gravel)$
$M\ =\ Mass\ of\ rover\ (2\ kg\ assumed)$
$g\ =\ Acceleration\ due\ to\ gravity\ (9.81\ m/s^2)$
$r\ =\ wheel\ radius\ (1.8\ cm)$

$$\Sigma F_x =\ F_w - F_f = 0$$

Equation 1: Sum of the Forces in the x-Direction

$$F_w = F_f =\ \mu\ *\ M\ *\ g\ =\ 0.5\ *\ 2\ kg\ *\ 9.81\ m/s^2\ =\ 9.81\ N$$

Equation 2: Force Exerted by Rover on the Travel Surface

$$T_T = F_w * r\ =\ 9.81\ N\ *\ 1.8\ cm =\ 17.658\ N.cm\ =\ 1.8\ kg.cm$$

Equation 3: Torque Exerted by Rover on the Travel Surface

The minimum total torque required by the drive motors is 1.8 kg.cm or 0.45 kg.cm per drive motor. This value was reached using a conservative estimated mass of 2 kg.

A secondary and important parameter when choosing a motor is the rotations per minute. High revolutions per minute are unnecessary and can possibly compromise the stability of the rover. Avoiding obstacles and turning are more easily done at lower speeds. As such, RPM values that are too low will unnecessarily extend mission completion time. A goal max rover velocity of 0.1524 m/s (0.5 ft/s) with a wheel radius of 1.6 cm requires an angular velocity of 9.525 rad/s or 90.96 RPM. Therefore a desired motor will be able to achieve 90.96 revolutions per minute.

3.1.1.1. DFRobot FIT0441

This motor is a 12V brushless DC motor capable of 159 RPM unburdened. It includes a built-in motor driver. The stall torque is very high at 2.4 kg.cm. The rated speed, or speed at which the motor will first produce its maximum power output is 159 RPM. The stall torque is 2.4 kg.cm. This motor is made from an unspecified metal and its mass is unknown.

3.1.1.2. E-S Motor 25SG-2418BL-4.4

This is a 6V brushless DC motor capable of 1360 RPM unburdened. It includes a built-in motor driver. The rated torque is 0.07 kg.cm and the rated speed is 840 RPM. The stall torque is 0.2 kg.cm. This motor is made from an unspecified metal and its mass is unknown.

3.1.1.3. E-S Motor 37SG-520-30

This 6V DC motor capable of 266 RPM does not include a motor driver. It is also unspecified if it is brushless or brushed. Its rated torque is 0.3 kg.cm and its rated speed is 212 RPM. The stall torque is 1.2 kg.cm. This motor is made from an unspecified metal and its mass is unknown.

3.1.1.4. E-S Motor 25SG-2418BL-20

This motor is a 6V brushless DC motor capable of 300 RPM unburdened. This motor includes a built-in motor driver. The rated torque is 0.32 kg.cm and the rated speed is 185 RPM. The stall torque is 1.1 kg.cm. This motor is made from an unspecified metal and its mass is unknown.

3.1.1.5. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Model Number	**Speed**	**Load Current Draw**	**Stall Torque**	**Input Voltage**	**Housing Dimensions (mm)**	**Cost**
FIT0441	159 RPM	~330 mA	>2.4 kg.cm	12V	25D x 39L	$19.90
25SG-2418BL-4.4	840 RPM	~450 mA	>0.2 kg.cm	6V	24D x 37L	$13.95
37SG-520-30	212 RPM	~500 mA	>1.2 kg.cm	6V	37D x 45L	$7.58
25SG-2418BL-20	185 RPM	~450 mA	>1.1 kg.cm	6V	24D x 37L	$13.95

Table 2: Comparison of Motor Options

The motor selected for use in this project is the DFRobot FIT0441. This motor satisfies the torque requirements outlined previously in this section as well as the speed and length requirements. Of the selected motors this option has the highest stall torque. This higher torque will be useful in overcoming more resistance forces associated with the makeup of the terrain and potential inclines. Additionally this motor comes with a built-in motor driver. This relieves the need for an external motor driver and will help save space aboard the rover. This motor option is sufficiently compact with a housing length of 39 mm and a diameter of 25 mm.

3.1.2. Motor Driver

The rover will use four DC brushless motors to control the movement and rotation of the vehicle and motor drivers will be needed to control the motors. Typically one driver is needed per motor to allow individual control, or multi channel drivers can be used to control more than one motor at a time. Motor controllers do not need to be specifically used for this project since the microcontroller will provide the PWM and direction signals needed to control the motors through the drivers. Motor drivers commonly use transistors to effectively translate a PWM signal to changes in voltage and current that can vary the direction and speed of a motor's rotation.

For standalone drivers, an H-bridge circuit is most common. It usually takes two PWM (pulse width modulation) input signals, and the voltage to power the motor, and supplies output control to the motor for speed and direction. The PWM signals can be supplied by a separate controller IC as discussed before, or by an MCU using PWM signals from the GPIO pins. The H-bridge circuit relies on four FETs that are switched on and off to control motor direction and braking (Core Electronics)[1]. For motors with built-in controllers they use the same transistor system internally but typically have a header that requires one PWM input, a direction input, motor power, and return a speed signal as an output.

Choosing motors with built-in controllers has a handful of benefits over buying motors and drivers separately. They do not inherently use any more pins of an MCU than standalone ICs, they save PCB space, and they can be the same price or only slightly more costly than implementing individual motor driver ICs. However, the main benefit of motor driver ICs is the freedom of choice in motor selection, where only a voltage range must be conformed to in choosing the motor or IC compared to finding a motor/driver combination that suits system requirements.

Since the rover will have two banks of two motors, and the banks will need to move in opposite directions and opposite speeds, the drivers chosen must take in and output a minimum of one input for two motors. This means two to four drivers would need to be purchased as well as the linear components needed for their operation. The price and time needed for this approach was considered in the parts selection.

3.1.2.1. Texas Instruments DRV8833 Dual H-Bridge Motor Driver

This motor driver from TI implements the H-bridge control system described earlier and allows for two inputs and two outputs. It was chosen as an option since only two would be needed for the entire system, and theoretically one input could be fed to this driver to power two motors at once with the same signal allowing each motor bank to be individual but allow the motors in the bank to be synchronized while only using four GPIO pins total instead of eight.

The downsides of this option are the PCB space taken by the components, the space needed for pin headers for the motors, and the extra time it would take to design and route these parts.

3.1.2.2. Brushless DC Motor With Motor Driver

A motor with a built-in driver circuit requires no board space outside of the headers to connect it to the board. This motor functions as described in the overview of this section and uses a simple PWM and direction signal from the MCU. This choice provides the benefits of time savings as well since the programming for this motor will be just as involved as programming for the driver.

The downside for using an all-in-one solution is that cost may rise due to the higher price of a motor with the integrated circuitry. It is also possible that this method may lead to an increase in use of GPIO pins, but since the four motors will be controlled in pairs, one signal for PWM and one signal for direction can be split to both motors of a bank resulting in four GPIO pins being used like the DRV8833.

3.1.2.3. Conclusion

Due to the nature of these being two different types of components, they cannot be easily compared with a table. The deciding factor for the choice made was based on cost and time analysis of choosing each part. When a motor was found that fit the requirements and had a built-in motor driver, it was decided that the slightly higher cost of this solution was worth the time and space savings provided by this solution. Due to this, the brushless DC motor presented in section 3.1.1 was the part that was selected for both the motor and motor drivers.

3.1.3. Capsule Door Lock

In order for the capsule door to remain closed for descent and landing, a locking mechanism is required. This locking mechanism will be a part of the Capsule Landing Automated Sequence System (CLASS) which includes solenoid door locks, a magnetic locking mechanism to keep the rover in place during flight, as well as a PCB with sensors and a power source (this system will be described in chapter 5 of this document).

The capsule door must stay closed throughout descent to reduce the drag forces on the capsule as this could lead to instability which could potentially result in an overturned capsule upon landing. The capsule door must also stay closed as a failsafe measure in case the rover becomes detached from its electromagnetic coupling. This would preserve the mission should this unlikely event occur.

The chosen solenoid locks should be small enough to be attached on the inside top of the “scoop” feature at the end of the capsule opposite to where the parachute is attached. These locks will be oriented 45 degrees from the top of the capsule and must allow for a clearance of at least 8 cm between the lock body and the inside of the door when it is open (in the down position). Given that 12V batteries will be used to power the electromagnetic coupler, the solenoid locks shall not require greater than 12V to operate. The chosen lock shall only require power when retracting the piston and thus will only need to be powered for around 1 second to allow the door to fall by its own weight. Priority will be given to locks that are smaller and light weight.

3.1.3.1. ATOPLEE Electromagnetic Solenoid Lock

This lock utilizes electromotive force to retract a cylindrical piston when powered. The stroke length of the piston is 10mm. This mechanism has a mounting face with 4mm diameter screw holes. The mass is approximately 160g. This product costs $22.99 per unit.

3.1.3.2. Driak Electric Lock Assembly Solenoid

This mechanism is a solenoid lock of metallic that features a rectangular piston with an angled face between the bottom face and the top face of the piston. When powered the piston retracts. This lock weighs approximately 142g. This product costs $4.88 per unit.

3.1.3.3. SARY Electromagnetic Lock

This lock also features a rectangular piston with an angled face much like the Driak Electric Lock. This lock features a stroke length of 12mm. This module features a mounting plate with 3.5mm screw holes. The manufacturer does not include the mass of this product. This product costs $3.85 per unit.

3.1.3.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	**Voltage and Current**	**Weight**	**Dimensions**	**Cost**
ATOPLEE Electromagnetic Solenoid Lock	12V, 0.8A	160g	55 x 42 x 39mm	$22.99
Driak Electric Lock Assembly Solenoid	12V, 0.6A	142g	53 x 26 x 23mm	$4.88
SARY Electromagnetic Lock	12V, 0.8A	Unknown	53 x 41 x 28mm	$3.85

Table 3: Comparison of Capsule Door Locks

All three of the above locking mechanisms satisfy the dimensional constraints imposed by the design of the capsule. However, it is notable that the Driak Electric Lock is the smallest of the three products and presumably the lightest since the SARY Electromagnetic Lock does not include a mass. Furthermore all locks satisfy the voltage and current constraints imposed by the battery selected for use. Finally, the ATOPLEE

Electromagnetic Solenoid Lock will not be suitable due to its high cost of $22.99 per unit. The Driak Electric Lock has a significantly cheaper price at $4.88 per unit. As such, this project will move forward with and make use of the Driak Electric Lock due to its small size, weight, and cheap cost.

3.1.4. Coupling Mechanism

During flight the rover will need to be coupled to the inside of the payload capsule. Due to the design of the payload capsule, the rover will need to be suspended at the top of the capsule. This constraint is in place to create a force balance conducive to landing the capsule in the correct upright orientation and promoting a stable descent. Two methods will be considered in this comparison.

The first method, option A, makes use of a single point of attachment by way of an electromagnet. This magnetic force will hold the rover in place during flight and descent until the Capsule Landing Automated Sequence System shuts off power to the component and frees the rover so that it may complete its mission. As acceleration up to 8 times that of Earth's gravity is expected during flight, for a 4kg payload the magnetic force can be no less than 32 kgf. Any mechanism chosen for this option must require less than or equal to 12V and 1A to operate.

The second solution, option B, is to anchor the rover at multiple points by small solenoid locks. This method is advantageous as these locks do not have to be powered during flight and require less power. In order to implement this method, the rover will need dedicated anchor points in its design where the solenoid pistons can hold onto the chassis during flight. Upon landing the CLASS will direct the solenoids to retract and free the rover long enough for the rover to exit the capsule. One further advantage of this method is that the same solenoid locks for the capsule door can be used to hold the rover in place. However, one disadvantage to a multi-point payload integration mate is that this consumes valuable space within the capsule and will complicate the fabrication of the capsule in order to accommodate the lock bodies.

3.1.4.1. Option A Vs. Option B

These two methods both have individual strengths and weaknesses and both are viable for the purposes of this project. Option A offers an elegant solution with one point of attachment, but needs to constantly receive power throughout the flight and descent. Also as this method has a single point of attachment, it also can represent a single point of failure. If the coupling fails during flight the rover will drop and disrupt the stability of the flight or be damaged as it impacts the capsule door at the far end. Option B requires the use of multiple mechanisms and increases the complexity of the coupling aspect of the capsule. Furthermore, this option is invasive and more severely impacts the design of the rover itself to accommodate anchor points for the solenoid pistons to grab onto. On the other hand option B provides a multi-point of contact coupling system that can still keep the rover in place if one of the locks were to fail. Despite this, this project will pursue Option A as a coupling strategy as it takes up less space and is the more simple option from a design point of view. In order for Option A to succeed, a part matching the description above will need to be sourced and scrutinized.

Option A requires a cylinder and plunger style of electromagnetic lock assembly typically used to lock containers. This locking mechanism cannot use more than 12V and 1A. It also must feature a holding force of more than 32 kgf in order to withstand a maximum of 8G's during flight.

3.1.4.2. MATEE Metal Electric Cabinet Lock

This product features a metal cylinder or plunger which will be attached by screws to the frame of the rover and an electromagnet encased in a metal housing will be placed at the part of the capsule opposite of the capsule door. These two parts will be mated and locked together by sending current through the magnet body via a battery mounted on the outside "bottom" of the capsule. The current will travel through the plunger and interact with the coils inside the lock body to create an electromagnetic field and resultant magnetic force normal to the direction of the current. This product offers a holding force of 50 kgf. This product costs $30.06.

3.1.4.3. LIBO Electric Magnetic Lock

This rectangular electromagnet would require a large metal face on the rear end of the rover. Current will travel across the face of the electromagnet and direct the magnetic force toward the rover. The metal face attached to the rover will stick to the face of the electromagnet until landing. This electromagnet has a holding force of 60 kgf. This product costs $16.89.

3.1.4.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	**Voltage and Current**	**Weight**	**Dimensions**	**Cost**
MATEE Metal Electric Cabinet Lock	12V, 100mA	Mass: 180g	50 x 30.2 x 26.8mm	$30.06
LIBO Electric Magnetic Lock	12V, 380mA	Mass: 520 g	81 x 42 x 25mm	$16.89

Table 4: Comparison of Coupling Mechanisms

The MATEE Electric Lock has many advantages over the LIBO Electric Magnetic Lock and many other products similar to the latter. The MATEE electromagnet draws only 100mA and is consequently capable of being engaged for longer periods of time than the LIBO lock. The LIBO Magnetic Lock also requires a heavy plate to be attached to the rover, whereas the MATEE lock requires a small metal plunger easily mounted by screws and a bracket. The LIBO lock is also much heavier. Though the LIBO lock is nearly half the price of its competitor, the significant advantages of the MATEE Electric Lock along with its smaller profile and reasonable weight justify the higher price. It is for these reasons that this project will move forward with the use of the MATEE Electric Lock as a rover-to-capsule coupling mechanism.

3.1.5. Altitude Sensor

The rover payload inside of the capsule will be deployed from the rocket 1000 ft in the air and will use a parachute to descend back to the ground. The rover itself does not need to deploy and start it's reconnaissance until the capsule is on the ground. To track the current altitude of the payload capsule, an altitude sensor will be used on the main PCB to allow the rover to track it's current altitude. The goal of this use case is to allow the payload to know when it is safe for the capsule to open and allow the rover to depart and start its mission without danger of it departing in the air. Both common types of altimeters, pressure altimeters and radio altimeters will be explored.

Pressure altimeters use the nature of pressure decreasing linearly with altitude (Encyclopædia Britannica)[2] to determine the current altitude of the sensor. These altimeters measure altitude from sea level, and since they rely on pressure, they are affected by the local climate of their use (Encyclopædia Britannica)[2]. This inaccuracy in the altimeter could provide trouble for the use case of this system. However, the dangers involved with this inaccuracy can be avoided with smart coding and a sanity check sensor such as an accelerometer. Another issue that may arise with the use of a pressure altimeter comes from it's sea level altitude sensing nature. The launch site of the FAR rocket competition is in Mojave, California which has an elevation of roughly 2000 ft (Weather Underground)[3]. While the code could roughly offset this starting elevation, there is no surefire way to make the system fully accurate for any location without reprogramming the rover for every new location's elevation.

Radio altimeters continuously send radio signals to the ground underneath the object and use the return time of the signal to determine height above ground level. In the use case of tracking payload height from the ground, this type of altimeter would be the most useful for an accurate reading regardless of weather, or elevation of the launch location. This sensor type would theoretically provide the rover with a much more accurate representation of its distance from the ground. However, there were very few options for compact radio altimeters and the price for radio altimeters are much higher than pressure altimeters.

Due to the much lower price and form factor of pressure altimeters, they will be the only altimeters further explored for this system. Inaccuracies caused by elevation and weather will be remedied with failsafe code and a sanity check accelerometer.

At an estimated 13000 ft max height (apogee height above ground level + elevation of Mojave, California launch site), air pressure will be 63 kPa (Mide)[4], and temperature will be 5℃ using a rough -3.3℃ per 1000 ft elevation calculation. These two values of pressure and temperature are important in choosing candidates for the sensor as it must be able to operate and survive in these ranges.

3.1.5.1. TDK InvenSense ICP-10110 Barometer/Altimeter

This part provides sensing of pressure, altitude, and temperature. It provides measurements through I2C at up to 400 kHz. The sensor returns raw temperature and pressure data that must be converted to usable values using these formulas:

$$T = -45°C + \frac{175°C}{2^{16}} \times t\_dout$$

Equation 4: ICP-10110 Temperature Equation

$$P = A + \frac{B}{C + p\_dout}$$

Equation 5: ICP-10110 Pressure Equation

In formula 2, A, B, and C are temperature dependent function outputs that need to be grabbed from the sensor to calculate the pressure. This is done in a verbose function in the code provided on the datasheet in C and Python. It provides these measurements of pressure with an accuracy of +/- 1 Pa, temperature with an accuracy of +/- .4℃, and altitude with an accuracy of up to +/- 8.5cm when operating in ultra low noise mode at its highest power.

This part measures at 2mm x 2.5mm x 0.92mm using an LGA package. The main disadvantage of buying this part is it is a SMT part that does not have any leads making hand soldering extremely difficult, and the datasheet warns that reflowing this part can cause inaccuracies in it’s measurements that require a recalibration.

3.1.5.2. TE Connectivity MS560702BA03-50

Like the ICP-10110 this part provides sensing of pressure, altitude, and temperature, and it provides measurements through I2C. The sensor returns temperature, pressure, and altitude data in celsius, pascals, and meters respectively that can be used directly. It also captures the maximum and minimum temperature and pressure experienced. It provides these measurements of pressure with an accuracy of +/- 1.5 Pa, temperature with an accuracy of +/- 1℃, and altitude with an accuracy of up to +/- 20cm.

This part has a larger footprint than the previous part, it measures at 5mm x 3mm x 1mm using an LGA package as well. The main disadvantage of buying this part is difficulty to solder as stated in the previous section, but reflow causes minimal inaccuracies in this part's performance.

3.1.5.3. Part Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Sensor	**Interface**	**Altitude Accuracy**	**Supply Voltage**	**Power**	**Pressure Operating Range**	**Cost**
ICP-10110 Sensor	I2C 0x63	8.5cm	1.8V	1.8 V 5.2 uA	30 - 110 kPa	$1.30
MS5607-02BA03	I2C 0x60 SPI	20cm	1.8V - 3.6V	3 V 3.2 uA	1 - 120 kPa	$4.05

Table 5: Comparison of Altimeter Options

The ICP-10110 sensor was eliminated due the calculations it requires of the microcontroller for its use compared to the MS5607-02BA03, as well as the need to recalibrate if it is soldered using reflow. The MS5607-02BA03 was chosen due to its provided calculations that will save a large amount of computing power and make altitude sensing much easier. The altimeter measures 3 x 5mm.

Breakout boards were also researched to possibly acquire while prototyping the system. The two boards found and selected are for the Xtrinsic MPL3115A2.

3.1.5.4. Adafruit MPL3115A2 Pressure/Altitude/Temperature Breakout Board

Both the Adafruit and SparkFun breakout boards use an Xtrinsic MPL311512 which uses I2C like the above choices and has a similar altitude accuracy but is unavailable for individual purchase and could not be considered for the parts selection. This board measures at 18mm x 19mm x 2mm with two mounting holes and 7 pins for power and data. The given pins are Vin, GND, 3vo, INT2, INT1, SCL, and SDA. This would allow easy hard soldering using a pin header to the rover PCB or allow it to be mounted elsewhere on the rover and connected to the rover PCB with wires. The breakout board uses DC-DC voltage regulation to allow any voltage input in the common embedded systems range of 3.3V - 5V.

3.1.5.5. SparkFun MPL3115A2 Altitude/Pressure/Temperature Sensor Breakout Board

This board measures at 18mm x 16mm x 2mm, measuring slightly smaller than the Adafruit board. It has two mounting holes and 6 pins for power and data. The given pins are VCC, GND, INT2, INT1, SCL, and SDA. This would allow the same ease of mounting and soldering as specified in 3.1.1.3.

The breakout board uses DC-DC voltage regulation to allow any voltage input in the range of 1.95V - 3.6V which is less common than the range provided by the Adafruit counterpart.

3.1.5.6. Prototyping option comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Sensor	Interface	Altitude Accuracy	Supply Voltage	Power	Pressure Operating Range	Cost
Adafruit MPL3115A2 Breakout Board	I2C Address 0x60	30cm	3V - 5.5V	2.5 V 40 uA	50 - 110 kPa	$9.95
Sparkfun MPL3115A2 Breakout Board	I2C Address 0x60	30cm	1.95V - 3.6V	2.5 V 40 uA	50 - 110 kPa	$14.95

Table 6: Comparison of Altimeter Prototyping Options

The final decision made was to eliminate the SparkFun board since it offers the same features and a less common input supply voltage range for a higher price. Therefore the Adafruit MPL3115A2 Breakout Board would be a good choice for prototyping and breadboard testing the system.

3.1.6. Accelerometer

The accelerometer used in this system will be in charge of capturing acceleration data in multiple scenarios. The first use of the accelerometer will be to perform a sanity check for the altitude sensor to determine when the payload has landed. To compensate for environmental and elevation discrepancies the accelerometer can be used to determine when the capsule has stopped moving and compare with the rate of change of the altitude to determine if the capsule is at rest on the ground. The second use of the accelerometer will be to track the movement of the rover during its mission.

There are multiple general options of accelerometers to choose between before deciding between parts. The first choice to make is between an AC or DC accelerometer. DC accelerometers measure both static and dynamic acceleration while AC can only measure dynamic (Machine Design)[5]. For this system AC accelerometers will be ruled out as static measurements will be needed to determine when the rover is at rest.

The next decision is choosing between three types of DC accelerometers - capacitive, thermal, and piezoresistive. Capacitive accelerometers measure using the function of capacitance. They utilize a moving mass that causes a change in the distance between capacitor plates that is then measured through capacitance to extrapolate acceleration (Machine Design)[5]. They are well suited for embedded systems due to their low cost and can measure up to 200 G.

Thermal accelerometers are implemented in a CMOS package. A heater is surrounded in gas and thermopiles are arranged around this location to measure changes in temperature. Acceleration upsets the temperature of the heater and the changes in temperature determine the acceleration value. These devices are also available at a low cost with high accuracy. This type of accelerometer can be seen in Memsic's proprietary design (MEMSIC Semiconductor)[6].

Piezoresistive accelerometers utilize strain gauges to measure a wide bandwidth of information (Machine Design)[5]. They have great measurement sensitivity, but are sensitive to temperature change - which is corrected internally in modern devices. They are typically much more expensive than their capacitive counterparts and can measure up to 10,000 G.

The accelerometer must be able to measure acceleration of up to 8 G and all three types of devices easily meet this requirement. Due to their low cost in comparison to piezoresistive options, only the capacitive and thermal types will be explored.

3.1.6.1. Memsic MXC4005XC

This part is a 3-axis thermal accelerometer with range settings of +/-2, 4, and 8 G with 12-bit measurement output. It can safely operate in the environment of the rover mission lifecycle and measure the proper ranges of acceleration. It returns data through 400 KHz I2C with 7 address options to choose from.

The device operates in the range of 1.8 - 3.6V supply voltage. The acceleration measurements from the device can also be used to calculate the rover's instantaneous velocity and orientation.

3.1.6.2. Memsic MC3419

This part is a 3-axis capacitive accelerometer with range settings of +/-2, 4, 8, 12, and 16 G with 16-bit precision. It can safely operate in the environment of the rover mission lifecycle and measure the proper ranges of acceleration. It offers the option of SPI or 1MHz I2C with 2 address options for data reading.

The device operates in the range of 1.7 - 3.6V supply voltage. This device is optimized for motion detection and comes with algorithms for this detection. The acceleration measurements from the device can also be used to calculate the rover's instantaneous velocity and orientation.

3.1.6.3. Analog Devices ADXL343

This part is a 3-axis capacitive accelerometer with range settings of +/-2, 4, 8, and 16 G with 10-bit precision. It can safely operate in the environment of the rover mission lifecycle and measure the proper ranges of acceleration. It offers the option of SPI or I2C with 2 address options for data reading.

The device operates in the common embedded systems range of 2 - 3.6V supply voltage. The device also provides motion activated functions, tap detection, and free-fall detection. The acceleration measurements from the device can also be used to calculate the rover's instantaneous velocity and orientation.

3.1.6.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Part	**Interface**	**Power**	**Measure 8 G**	**Supply Voltage**	**Cost**
MXC4005 XC	I2C 0x0H - 0x7H	1.8V 1.6mA	Yes	1.8 - 3.6V	$1.64
MC3419	I2C 0x4C or 0x6C, SPI	2.8V 77uA	Yes	1.7 - 3.6V	$1.80
ADXL343	12C 0x1D or 0x53, SPI	2.5V 140uA	Yes	2 - 3.6V	$3.10

Table 7: Comparison of Accelerometer Options

Since all of the devices can measure the appropriate range and accept a standard 3.3V supply voltage, the main considerations will power consumption. With the second lowest power consumption and a reasonable weight as well as breakout board availability for testing, the ADXL343 will be used. The accelerometer measures 3.3 x 5.3 mm.

3.1.7. IC Load Switch

It may be desirable that while the payload sits idle and powered on during the launch sequence and flight, that all components except the MCU and sensors are disconnected from the power source to save energy. To do this IC switches can be used to keep components and the motors separated from the power source until the MCU closes the switches at the time that the ground mission begins.

IC load switches come in multiple forms but load switches will be examined due to their out-of-the-box function and ease of setup. The typical, most basic load switch has 4 pins: Vin, Vout, logic level enable, and GND (Courtesy Texas Instruments)[7]. The switch acts as a physical throw switch but it is triggered by a signal to its ON pin using MOSFETs as the internal pass elements to control the current flow and simulate a physical switch (Courtesy Texas Instruments)[7].

The main concerns when choosing this part will be to target a low operating resistance value to reduce voltage drop and power consumption, ensuring the part can handle the power supply voltage of 3.7V, and ensuring the enable pin can accept the signal it will be given. The parts comparison is narrow due to issues in finding devices that fit the goal of low on-resistance, the power supply voltage, and maintained a low cost. The selected parts that fit these needs will be evaluated.

3.1.7.1. Diodes Incorporated AP2401MP-13

This is a 1:1 load switch that accepts input voltage in the range of 2.7 - 5.5V, and has a low 70mΩ on-resistance. It also has useful features such as a built-in short-circuit response, soft start, and a flag output that provides over-temperature and over-current warnings.

3.1.7.2. Vishay Siliconix SI1869DH-T1-E3

This is a 1:1 load switch that accepts input voltage in the range of 1.8 - 20V, and has a medium 200mΩ on-resistance. It does not supply the same warning and harmful conditions checking as the Diodes Incorporated selection.

3.1.7.3. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Part	**Input Voltage**	**Max output I**	**On-Resistance**	**Cost**
AP2401MP-13	2.7 - 5.5V	2A	70mΩ	$0.42
SI1869DH-T1-E3	1.8 - 20V	1.5A	200mΩ	$0.48

Table 8: Comparison of IC Load Switch Options

Due to its lower on-resistance, built-in warnings and harmful operation condition checking, and lower cost, the Diodes Incorporated AP2401MP-13 is the best option for this part choice. The only downside to this part is the lower input voltage range, but this is inconsequential due to the system power supply not being outside of this range.

3.1.8. Camera

The camera for the rover will be used to livestream a video of the surrounding area from within 5 seconds of the payload landing. The camera must at least transmit live video at 480p, 24fps. To accomplish a livestream of 480p, 24fps, cyberlink recommends having a bitrate between 1000 - 4000 Kbps. The lowest bitrate possible will be the goal to minimize power usage. Ideally when choosing a camera, the system has a camera that captures in low resolution natively so that no processing power is used on downscaling the resolution. The camera will also record in the visible band for better viewing on the receiving end, as opposed to an infrared camera. All considered options for the camera will be presented below.

3.1.8.1. BetaFPV C02 2.1mm 1200TVL FPV Micro Camera

This BetaFPV $15 camera was a small 1.4g camera intended for use in a drone. It has a resolution of 1280 x 1024 which exceeds the requirement of 480p. The device transfers video on a signal system of NTSC (National Television System Committee) which operates at 29 - 30 frames per second. The device draws 120mA of current at 3.3V and 110mA of current at 5V. It has a field of view of 160°. All things considered it looks like a viable option. The camera is cheap ($15), it meets the video quality requirements, is lightweight, and power efficient.

3.1.8.2. RunCam Nano2 FPV Camera

This RunCam $20 camera is a 3.2g camera of similar dimensions to the BetaFPV drone camera. It has a resolution of 976 x 582 which also exceeds the requirement of 480p. The device transfers with either a signal system of NTSC (National Television System Committee) or PAL (Phase Alternating Line). The device draws 120mA of current at 3.3V and 110mA of current at 5V. It has a field of view of 170°. This might be a better option because of the low resolution, but it is heavier.

3.1.8.3. NewBeeDrone BeeEye FPV Camera

This NewBeeDrone $13 camera weighs a low 1.7g. The resolution of the camera is 728 x 492 which slightly exceeds the resolution. This low resolution would help out because the resolution would not need to be downscaled before transmitting the video. The device has a 120° field of view. The product page does not have any more information on the camera, which means compatibility is not guaranteed.

3.1.8.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Camera Name	**Weight**	**Resolution**	**Field of View**	**Power Consumption**	**Signal System**	**Cost**
BetaFPV	1.4g	1280 x 1024, 30fps	160	120mA at 3.3V, 110mA at 5V	NTSC	$15
RunCam Nano2	3.2g	976 x 582, 30fps	170	120mA at 3.3V, 110mA at 5V	NTSC, PAL	$20
NewBeeDrone BeeEye	1.7g	728 x 492, 30fps	120	N/A	N/A	$13

Table 9: Comparison of Camera Options

All things considered in the comparison in the table above, it is best to go with the RunCam Nano2 FPV camera shown below. This camera is the most expensive, but has a good compromise of resolution and field of view. The lower resolution means less processing used for video downscaling. The selected camera also weighs the most out of the selection but it still weighs less than .08% of the total payload weight allotted. The extra $5 over the BetaFPV camera seems to be reasonable for the resolution reduction in this scenario. The NewBeeDrone, while a seemingly good option, had to be ignored for its lack of specifications.

3.1.9. Video Display

The video display for this project will be used to display the live video stream that the rover will transmit during its mission. The display chosen needs to be both high enough resolution and large enough to view easily.

The chosen minimum resolution for the project is 480p (480 pixels screen height). Displays with resolutions less than 480p would be cheaper, but it would be harder to view details in the rover livestream. The chosen display will also need to work with battery power. Working with battery power means a higher resolution can't be chosen because of the limited power supply from the battery.

Displays are also expensive, so cost is a major consideration in the choice. Also in consideration is picking a display that works more easily with the video receiver than others. The video receiver gives a video out pin to be used as video input for an RCA cable monitor. Leveraging the exact output from the video receiver would be best so there isn't energy wasted on conversions. The displays considered for this choice will be evaluated below.

3.1.9.1. Lychee 7" Digital HD Car TFT LCD Color Screen Display

This $40 600p monitor surpasses the minimum requirements for the display needed. The 600p resolution surpasses the 480p requirement agreed upon. The display also is the largest out of the three options considered, at 7 inches diagonally. Unfortunately, it is one of the more expensive options being evaluated. It comes with a remote control that allows you to flip the image if necessary, but this feature doesn't help for this use case. It also cannot be ignored that a higher resolution will consume more power, so the ideal situation would be to pick a display that is close to, or exactly, 480p resolution.

3.1.9.2. Laipi Camera Monitor, 12V 5" Car TFT LCD Display

This $23 800x480 pixel monitor meets the minimum requirement of 640x480 pixels. This display comes in the same 5 inch size as the GreenYi display but for less cost than the GreenYi display does. It requires 12 volts which it has in common with the other display. One concern with this Laipi display is that it has 2 reviews on Amazon, one good one bad. The other concern is the lack of documentation on the product page.

3.1.9.3. GreenYi-08 TFT LCD Color Screen

This $40 800x480 pixel monitor has the exact same specifications as the Laipi display. This display has a 5 inch screen size, required Voltage of 12V, and can take in the same video formats as the other 2 displays. This display also has 188 reviews with a 4 star rating on Amazon compared to the 2 reviews and 3 star rating the Laipi camera has. The amount of successful reviews on the product matters because there is not enough time or money to test all of the options. Therefore, if this camera is known to be more reliable than the Laipi camera it might be worth paying the extra cost to be more confident that it will work.

3.1.9.4. Comparison

Display Name	Screen Size	Resolution	Required voltage	Video format(s)	Cost
Lychee 7" Digital LCD Display	7 in	1024 x 600	12V	PAL, NTSC	$40
Laipi Camera Monitor	5 in	800 x 480	12V	PAL, NTSC	$23
GreenYi-08 TFT LCD	5 in	800 x 480	12V	PAL, NTSC	$40

Table 10: Comparison of Display Options

Based on the comparison, it was determined that the GreenYi LCD monitor is the best monitor for the Rover Control Station. The Laipi 5 inch display would be too much of a risk considering the bad reviews. The Laipi display raises some red flags because the price of the display independent of the housing seems to be more than the cost of the Laipi display. The GreenYi display is closer to the price of the cost of a 800x480 pixel display and has better reviews, so it seems this choice has a higher likelihood of working. The Lychee 7 inch would be a great option, but displays draw more power based on the amount of pixels they contain. Even if the Lychee display has approximately 60% more pixels than the GreenYi LCD monitor, it still consumes marginally more power which is detrimental because of the battery power supply.

3.1.10. Radio Frequency Transceiver

A radio frequency (RF) transceiver is the combination of a transmitter and receiver. It allows for two-way communication or singular use as either a transmitter or receiver. For this project RF communication will be used to control the rover, so only one-way communication is necessary.

The radio frequency (RF) transmitter will be used to send data from the controller to the RF receiver located on the rover. The main flight computer will be transmitting telemetry in 70cm and ultra-high frequency bands (420 MHz - 450 MHz and 1 GHz - 2 GHz). The rover must avoid using 420 MHz - 450 MHz.

The maximum altitude (apogee) of the Arcturus rocket is expected to be 3200 meters and the tentative simulated longitudinal distance that will be travelled is roughly 1.61 km. This will depend on the wind speed, wind direction, rocket launch direction and rocket angle of attack. These variables cannot be fully estimated until the second Arcturus Rocket Design team finalizes design plans. Then OpenRocket will be used to simulate the rocket and payload trajectory to provide an accurate and final estimate for longitudinal distance. Until then, The assumption is that the larger the range, the better.

The range of radio frequency is affected by frequency, antenna and cable selection, and antenna height. Lower frequencies help radio waves reach further than higher frequencies. In free space, a 900 MHz radio will transmit more than half as far as a 2.4 GHz radio with the same modulation and output power because a smaller frequency means the wavelength is longer. Longer wavelengths also require a larger antenna. Some cases require the use of a higher frequency like 2.4 GHz. These cases include the need for a smaller antenna and more bandwidth.

For this project, a large range is required and all components are constricted by size, so the best fit would be a transmitter with a very high frequency like 2 GHz. All proposed options will be evaluated below.

3.1.10.1. SX1276 LoRa Transceiver

This $19.50 transceiver uses a default working frequency of 170 MHz. In open and clear air using a 2m antenna with gain 5dBi, it can reach up to 8km in range. The data rate for this transceiver can be set from 0.3 - 9.6 kbps and has a receiving sensitivity of -147 dBm. The main communication interface is UART with a baud rate ranging from 1200 to 115200. When used as a transmitter, the module will draw a minimum of 630 mA current with a power supply of 3.3V. As a receiver, the module will draw a minimum of 21 mA current with a power supply of 3.3V.

3.1.10.2. SX1278 LoRa RF Transceiver

This $27 transceiver uses a working frequency of 915 MHz. Similarly to the SX1276 module above, the range of this transceiver is 8km under the same testing conditions and antenna parameters. The data rate for this transceiver can be set from 0.3 - 19.2 kbps and has a receiving sensitivity of -147 dBm. The main communication interface is UART with a baud rate ranging from 1200 to 115200. When used as a transmitter, the module will draw a minimum of 560 mA current with a power supply of 3.3V. As a receiver, the module will draw a minimum of 20 mA current with a power supply of 3.3V.

3.1.10.3. SX1262 LoRa RF Transceiver

This $13.25 transceiver uses a default working frequency of 868 MHz. In open and clear air using a 2.5m antenna with gain 5dBi, it can reach up to 10km in range. The data rate for this transceiver can be set from 0.3 - 62.5 kbps and has a receiving sensitivity of -148 dBm. The main communication interface is UART. When used as a transmitter, the module will typically draw 43mA current with a power supply of 5.0 V. As a receiver, the module will draw a typical amount of 17 mA current with a power supply of 5.0 V.

3.1.10.4. Comparison of Parts

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	**Frequency**	**Max Data Rate**	**Range**	**Cost**
SX1276	170 MHz	9.6 kbps	8km	$19.50
SX1278	915 MHz	19.2 kbps	8km	$26.99
SX1262	868 MHz	62.5 kbps	10km	$13.25

Table 11: Comparison of Radio Frequency Transceiver Options

There is still more research to be done to finalize the choice for this part. Antenna choices will impact the choice of which RF transceiver to use as well as additional input from the Arcturus Rocket Team on maximum range required.

The RF transceiver that has been chosen is the REYAX RYLR896 SX1276. It has a UART Interface and operates at 868/915 MHz frequency. This module was designed to include a PCB integrated antenna. It can operate to a maximum range of 8km using the LoRa long range modem which provides ultra-long range spread spectrum communication while minimising current consumption. Following is an image of the chosen transceiver component.

3.1.11. Video Transmission Methods

The RC rover's main requirements are to be able to be controlled through Radio Frequency, and to send a live video feed to the control station from the rover. Video transmission is one of the most difficult tasks to implement in this project. Since this rover is meant to operate in desert-like terrain with no communication towers nearby, internet and bluetooth cannot transmit the video. The first thought for video transmission was to use the same RF transceivers used for radio control and transmit video through one of the channels available through the module.

The goal for video transmission through RF is to capture the data perceived by the camera, encode the data, transmit the encoded data through RF, receive the signal at the control station side, decode the data and display it on the control station screen. Assuming the minimum resolution requirement of 640 x 480 pixels and assuming a single frame per second, the data rate would be 2.5Mbps. The maximum data rate of the

RF module is around 62.6 kbps and will not be able to transmit video data even for a single frame per second.

To overcome this obstacle methods on how to compress the video data to a size that can be transmitted over RF were researched. There are chips available that can compress video using H.264 video format. H.264, also known as MPEG-4 is a commonly used compressor and decompressor (codec) technology that is used in .mp4, .mov, and .f4v container formats. It is also used for recording and distributing video. The H.264 project was implemented to create a standard that could provide good video quality at much smaller bit rates than previous without making the design so complex that it would be impractical.

Multiple video codec chips, including the VoIP-X-4K board created by System-On-Chip Technologies were found. Unfortunately, these chips cost over $3000. While it would be useful to this project the cost is too much to justify the need when there are other methods to video transmission available. A video compressor chip manufactured by Analog Devices called ADV212 which is much cheaper at $40 was also found. The issue with this chip is that it requires the use of a multi-layered PCB.

Searching for more video compression methods, it was found that it could be accomplished by using a more powerful microcontroller. Using an FPGA (Field-Programmable Gate Array) chip, a program to encode and decode video data to compress it could be written. This method seems simple, but is a large project in itself and would not be doable in the time given to complete this project.

Another method found for video compression was to use a RISC-V (Reduced Instruction Set Chip) processor. RISC-V is an instruction set architecture developed at UC Berkeley and is completely open source. The issue with using a RISC-V processor was that the chip only came in breakout boards and a standalone chip could not be obtained. Even then, the chip would have required multi-layered PCBs for soldering. The team opted not to get the RISC-V breakout boards because to allow the team to meet the requirement for significant PCB design.

Finally, researching FPV (Flying First Person View) systems commonly used for drones showed what kind of hardware they use for video transmission. It was found that there are transmitters and receivers specifically designed for wireless video transmission. In an FPV system, the video data obtained by the onboard camera is also transmitted over radio to the video receiver to be displayed on the screen. Commonly, a VTx (Video Transmitter) chip is obtained and set up with a camera, antenna, and power supply to be connected to the rover or drone, and a pre-built video receiver is used. It was identified what VTx (Video Transmitter) chip would work best for the project and that information allowed the part research in the following section to continue.

3.1.12. Video Transmitter and Receiver

The video transmitter and receiver are two separate parts that will work in tandem to send a video signal from the rover to the Rover Control Station. The biggest constraints for these parts are their compatibility with each other, the range they can support, and the data transmission rate.

To confirm compatibility between a video transmitter and receiver it was necessary to check the frequency ranges and check if they matched. Fortunately there are a multitude of 5.8Ghz receivers and transmitters and most of them have ranges that work with each other.

The range the video transmitters and receivers need to work at a range of approximately 1.61km. Typically transmitters and receivers for a 5.8GHz signal are not used for longer distances than 500 meters, but with the proper antenna it is possible to get extra range out of the same transmitter. The antenna chosen is a Cloverleaf antenna which allows for a circular polarization so the signal is spread in all directions. There might be issues with the video if line of sight is lost for too long, but it was determined that this will not be a detrimental issue.

The last important metric for the video transmitter is the data transmission rate. To move forward with a transmitter receiver combo, the data rate needs to support the requirement of 480p video. For making sure of the proper data rate, the component that matters is the frequency of the transmitter. From extensive research it seems there are too many factors to calculate whether the 5.8GHz can support the video requirements. However, there is extensive footage of drones using the 5.8GHz frequency for video quality higher than the minimum requirements. With this information it was concluded that any 5.8GHz video transmitter should work for this use case. The transmitter and receivers that were evaluated for this part selection are shown below.

3.1.12.1. Boscam FPV 5.8G Audio Video Transmitter Module

This 5.8GHz transmitter module comes at a relatively cheap $19.99. The transmitter power is 200mW so it is better for longer range transmission than other models. This transmitter is capable of transmitting amongst 8 different channels, which seems to be the minimum for a 5.8GHz transmitter. The transmitter module does not come with an antenna, but the Cloverleaf antenna that was chosen is a more unique antenna that transmitters and receivers do not typically come with. This module is also compatible with the entire selection of cameras evaluated in section 3.1.8.

3.1.12.2. RX5808 Receiving Module FPV 5.8G Audio Video

This $19.99 5.8GHz receiving module comes with support for 8 channels. Conveniently it is the same 8 channels that the transmitter module supports. The video output from this chip is composite video which makes it easy to find a monitor to work with it. The receiver here has a pin for an antenna which is going to be used for the Cloverleaf antenna (for more details visit section 3.1.15).

3.1.12.3. TS832 48Ch 5.8G FPV Transmitter 600mw

This $18.88 video transmitter comes in a form factor with a pre-installed antenna, a screen to show the current channel, a connector for camera input and a connector for power all built in. The transmitter boasts a 5km range for its AV transmission which is well within the required specifications. At a lower price than the boscam module, and with the prebuilt features that will save valuable money and allow the team to commit more time to other aspects of the project, this is a good value part.

3.1.12.4. Wolfwhoop WR832 5.8GHz 40CH Wireless FPV Receiver

This receiver unit is designed to work with any 5.8GHz transmitter that shares a channel with this receiver. It comes in a package with a screen and channel selector to edit this channel. It has a DC power in plug and a pair of AV out RCA connectors that will easily connect to the screen being used for this project. It also has an included antenna all for the price of $16.66. This part provides extreme cost and time efficiency over the RX5805 module.

3.1.12.5. Parts Choice

In the table below, all options researched and considered for this part of the system are listed as the final choice that was made.

Name	**Frequency**	**Channels**	**Dimensions**	**Power Usage**	**Cost**
Boscam FPV 5.8G Video Transmitter	5.8 GHz	8	28 x 23 x 3 mm	3.5V 200mA	$19.99
RX5808 FPV 5.8G Video Receiver	5.8 GHz	8	28 x 23 x 3 mm	3.5V 200mA	$19.99
TS832 48Ch 5.8G FPV Transmitter	5.8 GHz	48	54 x 32 x 10 mm	7 - 16V 220mA	$18.99
WR832 5.8GHz FPV Receiver	5.8 GHz	40	80 x 65 x 15 mm	12V 200mA	$16.66

Table 12: Video Tx and Rx Parts Selection

The four transmitters and receivers listed in this section all share the same theoretical range and share the same transmission/reception frequency. The main drive behind the decision for this pair of parts was cost. With the TS832 and the WR832 both coming in at a lower price than the other pair of parts while providing more channels and being set up for immediate and convenient use with the design of the system these are the best options and will be used.

The size differences between the options however must be addressed and were considered in the choice. The receiver chosen is much larger than the other option, but this is acceptable due to the fact that the control station that this receiver will be a part of does not have a size limitation. The rover however does have a size limitation and the transmitter chosen is marginally larger than the other option. This was found to be within specification for multiple reasons. First, the total PCB size needed to implement the unchosen option would be very similar to the size of the chosen Tx unit. Second, the rover can still accommodate this size of transmitter, and therefore the benefits that this transmitter presents makes the increased use of space acceptable.

3.1.13. Encoder/Decoder

An encoder is a device that converts information from one form to another. It is mainly used to compress the information needing to be transmitted so that transmission speed is decreased. The decoder is located on the other end of the transmission. After a receiver gathers the encoded information sent from the transmitter, the decoder will convert this input into a different output form.

Here, the encoder will be located in the remote control and will convert the information from the control switches into a form easily transmitted through the RF transmission system. Then the decoder located on the rover will decode the information from the RF receiver into a form understood by the motor drivers. An encoder and decoder will also be used to transmit and display the video data captured by the rover. All encoder and decoders in this system are not free standing and are part of the transmitters, receivers, and transceivers used for this system. Currently, the RF transceiver chips selected do not require the encoding or decoding of data.

3.1.14. Analog Joystick

The joystick will be used to control the RC rover from the control station. The goal is to get the rover to move in all four directions. A single 2-axis analog joystick that will allow the rover to move forward and backward by pushing the joystick in the positive or negative direction of the y-axis will be used. Pushing the joystick along the x-axis in the positive (right) direction will make the rover turn in place to the right and moving the joystick to the left will turn the rover to the left. There is no requirement for the robot to be able to rotate and move at the same time.

The 2 axis analog joystick works as the combination of 2 potentiometers which represent the X and Y axis. It works by reading the voltage values through the potentiometer and sends analog values that represent these voltage values. the end of values change as the joystick shaft is manipulated. This data must be able to be transmitted through the transmitter module used in this project. Normally an encoder would be used between the analog joystick and transmitter module to convert the analog joystick's data into a format transmittable over the transmitter module.

3.1.14.1. Adafruit Analog 2-axis Thumb Joystick

One possible method of controlling the rover is through an analog joystick. This can be programmed to be sensitive to the amount the joystick is pushed forward or backward to move faster or slower.

3.1.14.2. Adafruit Push-Button

Another possible method of controlling the rover is through four push buttons to replicate a gaming controller. Each button will represent a direction. The top and bottom buttons will be for moving forward or backward. The left and right button will work to turn left or right. It can be possible to program the buttons to turn and move at the same time if necessary.

3.1.14.3. Comparison

Due to the more precise control provided by an analog joystick, and the fact that members of the team already possess an analog joystick unit for testing, the analog joystick will be the best method of control for the rover. The following is an image of the analog joystick chosen for this project.

3.1.15. Antenna

An antenna is used to capture radio waves. Typically it is just a long wire that is placed such that it is exposed to RF waves. The waves create a small alternating current in the wire that captures the signal.

Due to the long distance between the control station and the rover, an antenna is required to make sure the RF transmission is received. The RF transceiver modules that were researched include the antenna size and gain used when testing the module's transmission range. Ideally, an antenna that matches the test condition specs will be found and used. The RF transceiver module also specifies the type of antenna that is compatible.

The test conditions for the RF transceiver modules show that an antenna with a gain of 5dBi and height of 2 - 2.5 m was used. Two of the modules use an SMA-K antenna while one uses an IPEX or stamp hole antenna.

A cloverleaf antenna will be used for the video transmitter and receiver. This antenna has a radiation pattern similar to a dipole antenna which can transmit and receive from all directions (Flite Test)[31]. The RF transmitter and receiver come with a coiled wire antenna.

3.1.16. CLASS Microcontroller

The MCU used on the capsule PCB has multiple responsibilities that influence the choice for the part. The capsule PCB MCU will poll data from the main PCB via wireless transmitter, and be responsible for keeping the electromagnet holding the rover in place active while descending, and responsible for releasing this magnet and opening the capsule door once landed.

With these responsibilities in mind, the choices for the microcontroller were based on: available GPIO, I2C and UART pins. Multiple ADCs may also be needed for processing data that is sent and received through the transmitter. With the parts so far chosen, there are a maximum of one I2C and UART devices, 4-5 GPIO pins and a maximum of 5 ADCs needed for the capsule electronics.

3.1.16.1. Texas Instruments MSP430FR6989

The MSP430 line of microcontrollers presents many benefits as a choice for this system. While it may have a higher price than the other components, the team already possesses a familiarity with the operation of the MSP430FR6989 and own breakout boards for this MCU that would be used for prototyping at no extra total cost. The other two options however are unfamiliar to the members of the team and breakout boards would need to be purchased for prototyping.

The MSP430FR6989 may have the lowest clock speed, but it uses 16-bit architecture, making it marginally faster than the other two options; this is always a benefit as faster processing gives quicker system response times. This processor has more than enough pins for what the project needs and having two I2C lines allows easier setup compared to the one line of the other devices.

3.1.16.2. Atmel ATmega328 - TQFP

The ATmega328 is a more cost effective option than the MSP430, but it is inferior to the MC9S08PB8 and is easily outweighed by the cost difference. The ATmega328 would be a suitable MCU for this system, as it has all of the necessary components, but in comparison to the MC9S08PB8, where more in almost every category can be had for less money, it loses its ground in the comparison. The only benefit it has is it’s gpio count, but since not all of the GPIO pins would be utilized on either device the other options wins over this device.

3.1.16.3. NXP Semiconductors MC9S08PB8MTG

The MC9S08PB8 is a very cost effective MCU with a large amount of I/O for the price and would be well suited to use for the capsule PCB. At twenty percent of the cost of the MSP430, this MCU shows much promise with the main two hardware downsides being a single I2C line and effectively half the speed of the MSP430. Both of these are of low concern due to the low number of components this MCU will be responsible for and the properties of I2C.

3.1.16.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

MCU	Speed	ADCs	I2Cs	PWM	GPIO	Cost
MSP430FR6989	16-bit, 16 MHz	12, 12-bit	2	19	63	$7.66
ATmega328 - TQFP	8-bit, 20 MHz	8, 10-bit	1	2	23	$3.00
MC9S08PB8MTG	8-bit, 20 MHz	12, 12-bit	1	8	18	$2.05

Table 13: Comparison of Capsule System Microcontroller Options

While the MC9S08 is a contender, the lack of familiarity with the part adds another variable to the system design that the team members wish to avoid and it will be excluded from this choice. The main decision between the ATmega328 and the MSP430 is the cost since both meet the requirements needed to manage the CLASS system. The ATmega328 is ultimately the best choice for the capsule PCB due to being half the price of the MSP430 and having suitable I/O that will be enough for its application.

3.1.17. Rover Microcontroller

The MCU used on the rover PCB has multiple responsibilities that influence the choice for the part. The main PCB MCU will poll data from the wireless transmitter, poll and process data from the integrated sensors over I2C, send signals to control the motors on the rover as well as IC switches on the board that will be used to limit power to different subsystems.

With these responsibilities in mind, the choices for the microcontroller were based on: available GPIO pins, processor speed, available I2C pins, and the availability of PWM compatible pins. Multiple ADCs may also be needed for processing data that is sent and received through the transceiver. With the parts so far chosen, there are 2 I2C devices, 8-12 GPIO pins needed, 2 PWM capable pins needed, and a maximum of 5 ADCs needed on the rover PCB.

The MCUs that were considered for the rover are exactly the same as those considered for the capsule. They will not be individually listed again to avoid redundancy but the comparison table below is shown again in the same form as the previous MCU comparison table for the convenience of the reader.

3.1.17.1. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

MCU	Speed	ADCs	I2Cs	PWM	GPIO	Cost
MSP430FR6989	16-bit, 16 MHz	12, 12-bit	2	19	63	$7.66
ATmega328 - TQFP	8-bit, 20 MHz	8, 10-bit	1	2	23	$3.00
MC9S08PB8MTG	8-bit, 20 MHz	12, 12-bit	1	8	18	$2.05

Table 14: Comparison of Rover Microcontroller Options

The ATmega328 has been essentially disqualified from selection due to its complete disadvantage to the MC9S08PB8. The main decision is between the ladder and the MSP430. The MSP430 is ultimately the best choice for the rover PCB due to it's high compute speed that will be useful in having fast system response times enabling quicker choices and potentially a higher success rate for the rover mission.

3.1.18. Rover Control Station Microcontroller

To handle receiving a video signal there needs to be a device capable of handling video reception and RC transmission from the rover. To be able to handle video reception, a chip that can decode the received video signal would be needed. The video signal that is intended on being sent is a 480p 30 frame per second signal. According to SmoothComp support, between a 500 and 2000Kbps bitrate is needed to achieve the desired video quality. However, the best way to check if a chip meets the requirements for a certain video quality is to check if the product description explicitly states it. There are a multitude of factors that go into the ability of a chip being able to handle a certain video quality, so much that it's not feasible to evaluate this for all of the microcontroller options. The choices for RCS are based on what the product description explicitly states it can handle.

Initially the idea was to find a transceiver compatible with a laptop so the signal could be sent and received there, but the team concluded it would not be a fully encompassing solution for the rover. It was concluded that it is not fair to assume the parties using this system will have other devices on hand they can use with the rover. So it was decided that a microcontroller would be used for the Rover Control Station (RCS). All microcontrollers considered for the duties of the RCS are listed below.

3.1.18.1. Raspberry Pi 4b 4GB RAM

This $40 Raspberry Pi Microcontroller Unit is a simple solution for the Rover Control Station. This is a microcontroller that the group is familiar with and have previously worked with for these same exact tasks. The Raspberry Pi 4b is great with video decoding as it is capable of displaying 4k output to 2 monitors. The Raspberry Pi would have enough pins to handle video reception and remote control transmission.

The part where this option falls apart is the amount of power needed to run the Pi, as well the oversimplification of the scope of the project. The recommended power to run a

Raspberry Pi 4b is 3A and 5V, which is more power than the team could supply for a meaningful amount of time with the space restrictions of the project. This application of the pi wouldn't require so much power, so power consumption could possibly be reduced. The other problem with the Raspberry Pi 4b, is that it simplifies this project to the point where it becomes more about learning to program the raspberry pi than learning about the individual electronic R&D required for this project. It has this issue in common with the Raspberry Pi Zero W.

3.1.18.2. Raspberry Pi Zero W

This $10 Raspberry Pi Microcontroller is a great low cost alternative to the Raspberry Pi 4b. This microcontroller also has all of the same functionality as the Raspberry Pi 4b but in a smaller form factor with a slower cpu. The idea was that it would complete the tasks needed, but with less power draw. The Raspberry Pi Zero W requires a similar, but slightly less 5V and 2.5A to run. This pi would handle what is required for less money and power than the Raspberry Pi 4b. However, using a Raspberry Pi still reduces the scope of the project too much for it to be a valid solution for the Remote Control Station.

3.1.18.3. ATmega328 - TQFP

This $2.18 microcontroller is the lowest costing out of the microcontroller options for the Rover Control Station. This microcontroller has much more limited functionality than a Raspberry Pi, but will allow the team to learn more about the process of using embedded electronics than a Raspberry Pi would. This ATmega328 chip has ADC capability which will allow the input from the joystick on the Remote Control Station to be read. This new board also does not have the ability to decode a video signal, but it was decided that a dedicated module to decode a received video signal could be used. This way the video signal won't pass through the microcontroller at all, eliminating the need for the microcontroller to have a processor powerful enough to decode a video signal.

3.1.18.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

MCU	**Speed**	**ADCs**	**I2Cs**	**PWM**	**GPIO**	**Cost**
Raspberry Pi 4b 4GB	32-bit, 1.5 GHz	0	4	2	21	$40.00
Raspberry Pi Zero W	32-bit, 1 GHz	0	4	2	21	$10.00
MSP430FR6989	16-bit, 16 MHz	12, 12-bit	2	19	63	$7.66
ATmega328 - TQFP	8-bit, 20 MHz	8, 10-bit	1	2	23	$3.00

Table 15: Comparison of RCS Microcontroller options

Based on the evaluated options, the ATmega328 will be used for the Rover Control Station. Although the other microcontrollers are more than capable of accomplishing the task, they are significantly more expensive and don't allow the team to explore the more intricate compatibility issues in this project. The chosen solution is to use the less expensive ATmega328 chip in a custom made printed circuit board along with transmitter and receiver modules. This choice allows the team to complete the sufficient pcb design requirement placed by the Senior Design class.

3.1.19. Rover Battery

The rover will use a rechargeable battery power supply to reduce waste, recurring costs, and allow it to have independent operation of an external power source. The criteria for battery selection were battery dimensions, battery capacity, weight, and price. The battery types considered were lithium batteries due to their popularity in electronics, their ability to be recharged, and their electronics friendly voltages.

The rover is expected to use roughly 3150mA max with all subsystems at full power. This means the battery must be suitable for at least this much current draw at any time to avoid overheating.

This max current draw number can also be used to calculate the size of the battery needed. However, with the use of the load switches explored earlier, power towards the motors can be completely disabled until the rover is ready for deployment, allowing it to sit idle pre takeoff and in flight consuming a maximum of only 350mA at any time. Using this can prolong the system battery life greatly and reduce the cost of the system.

For safety, a battery size was calculated to allow the rover to sit idle for an extremely conservative 7 hours and run at full power for 1 hour. The equation to determine the battery size follows:

$$350mA * 7hr + 3150mA * 1hr = 5700mAh$$

Equation 6: Minimum Rover Battery Capacity

The minimum battery capacity above will be used to choose the battery since it represents the motors max current draw, but the motors are expected to run at a rate that consumes 330mA each, making the theoretical maximum power consumption to be 1750mA. With a 6000mAh battery, the following equation shows the expected length of the rover's moving lifespan after a 7 hour pre-deployment timeline is slightly over 2 hours.

$$\frac{6000mAh - 350mAh * 7hr}{1750mAh} = 2.03hr$$

Equation 7: Theoretical Deployed Rover Lifespan at Estimated Power

It was decided that all battery options should be under 150g, and less than 100mm x 80mm x 20mm. The batteries that were explored will be listed below.

3.1.19.1. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	Capacity	Voltage	Standard/Max Discharge Rate	Dimensions	Weight	Cost
LP906090 JH	6000mAh	3.7 V	1200/6000 mA	2.0 x 60.5 x 9.9mm	102g	$32.72
MIKROE-4475	6000mAh	3.7 V	3000/6000 mA	99.0 x 67.0 x 8.1mm	115g	$21.90

Table 16: Rover Battery Comparison

The two types of batteries explored were the typical electronics single-cell flat lithium polymer battery that provides high capacities in small and light form factors at 3.7V. These were chosen because they are rechargeable, low profile to easily fit against the rover frame, and easy to find.

The two options found were the only ones that were found on both mouser and digikey that suit the discharge rate and size requirements listed above which is the reason they have marginally more capacity than needed. Due to its higher standard discharge rate (the rate that is the safest for long term continuous current draw) and price that is $10 less than that of the competitor, the MIKROE-4475 LiPo battery was the obvious choice to power the rover electronics.

3.1.20. Capsule System Battery

This system will use a LiPo Battery for the same reason as the previous. The capsule is expected to use roughly 700mA max with all subsystems at full power. This means the battery must be suitable for at least this much current draw at any time to avoid overheating.

This max current draw number can also be used to calculate the size of the battery needed. In this system there will be one electromagnet powered on from the moment the system is powered on until the rover is ready to leave the capsule. When it is ready to leave this electromagnet loses power and a solenoid briefly receives power to allow the capsule door to open.

For safety, a battery size was calculated to allow the electromagnet to run for an extremely conservative 8 hours and to have the solenoid be activated for 30 seconds total during the duration of the mission. The calculation to determine the battery size follows:

$$100mA * 8hr + 600mA * .00833hr = 805mAh$$

Equation 8: Calculated Minimum Capsule Battery Capacity

The batteries that were explored will be listed below.

3.1.20.1. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	Capacity	Voltage	Standard/Max Discharge Rate	Dimensions	Weight	Cost
MIKROE-698	1000mAh	3.7 V	500/1000 mA	53.0 x 35.0 x 5.9mm	23g	$8.90
MIKROE-4473	1500mAh	3.7 V	750/1500 mA	63.0 x 39.5 x 6.1mm	23g	$10.90

Table 17: Capsule Battery Comparison

The 1500mAh battery was considered due to its standard discharge rate that exceeds the max discharge of the capsule system, but it ultimately is not necessary. The 1000mAh battery will be used in this system since the maximum current draw is within specification for this battery and it has ample capacity to power the system for the target amount of time.

3.1.21. Rover Control Station Battery

The system will use a LiPo Battery for the same reason as the others. This PCB is expected to draw roughly 455mA max with all subsystems at full power. This means the battery must be suitable for at least this much current draw at any time to avoid overheating.

This max current draw number can also be used to calculate the size of the battery needed. In this system the main power consumers will be an LED screen and its driver, a radio transceiver, a video transmitter, and an MCU.

For safety, a battery size was calculated to allow the entire system to run for an extremely conservative 8 hours. The batteries that were explored will be listed and compared in the following table. The calculation to determine the battery size follows:

$$505mA \ * \ 8\,hr \ = \ 4040mAh$$

Equation 9: Calculated Minimum Video Display and Remote Controller Battery Capacity

The batteries that were explored will be listed below.

3.1.21.1. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	**Capacity**	**Voltage**	**Standard/Max Discharge Rate**	**Dimensions**	**Weight**	**Cost**
Adafruit 354	4400mAh	3.7 V	2200/8800mA	69.0 x 37.0 x 18.0mm	95 g	$19.95
MIKROE-4475	6000mAh	3.7 V	3000/6000mA	99.0 x 67.0 x 8.1mm	115g	$21.90

Table 18: Video Display and Remote Controller System Battery Comparison

Both batteries considered in the system met the requirements for maximum discharge current and expected required battery life. The first battery is a Lithium Ion battery, and the second is a Lithium Polymer battery. Due to the minimal $2 price difference with a marginal gain in capacity, the deciding factor was the form factor and dimensions of the battery. It was decided that the thin rectangular form provided by the 6000mAh battery would be more suitable for the portable design that is planned for the video receiver and remote controller unit therefore the $2 price increase was justified by the increased battery capacity and more suitable dimensions.

3.1.22. Linear Charging Management IC

Since a rechargeable battery power source was chosen to reduce waste and recurring costs in the system, a battery charging IC must be used to safely return the battery to full capacity after use. The two types of battery chargers that will be considered are a simple stand-alone linear li-ion / li-polymer charge management controller, and a USB power controller and li-ion charger IC.

The criteria for charging a battery is given in the battery datasheet where the listed common maximum charge rate is .5C which is half of the capacity of a battery. The recommended charge rate for many LiPo/Ion batteries is 500mA because a USB port can easily supply that amount of current. The 500mA rate will be targeted during the part selection to be implemented for all three of the battery charging circuits needed. The options considered are listed below.

3.1.22.1. Microchip Technology MCP73833-CNI/UN

The first option fits in the stand-alone linear charge management controller category. This charger supplies a maximum of 1.1A and is compatible with the battery type being used. This maximum rate can be adjusted to the target 500mA when biasing the circuit as written in the datasheet for the part.

This part is USB compatible, meaning it accepts the 5V input that a usb port provides. This would allow the rover to be charged using a usb wall adapter from any outlet, a computer with a suitable USB port, or a portable battery bank. This prevents the use of a less common charging connector and standard being used and is convenient to the users.

3.1.22.2. Analog Devices LTC4055EUF#PBF

This option is a USB power controller and li-ion IC charger. It has a maximum charge rate of 500mA which is the target charging rate for the system battery. This option differs from the last and justifies its higher price with its incorporation of the USB power controller function. This device not only allows the battery to be charged via USB but will allow the entire circuit to be powered by the USB port. This benefit can be used to power the circuit using the USB options stated in 3.1.22.1. It can also be used to effectively extend the power supply of the rover by using a USB power bank to power the rover while charging the battery while having the battery capacity available. The power expansion will likely not be used in this application due to the space constraints of the capsule, but in solo rover operation this could be beneficial to the product owners.

3.1.22.3. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Name	**USB Power Passthrough**	**USB Charging**	**Max Charge Rate**	**Cost**
MCP73833	no	yes	1.1A	$1.12
LTC4055	yes	yes	.5A	$5.87

Table 19: Comparison of Battery Charging Management ICs

The MCP73833 was determined to be the best fit for this application due to it’s suitable charge rate, and the reduced cost compared to the LTC4055. The ability to power the rover via USB and charge instead of simply charging the battery via usb was decided to not be worth the price difference, so the cheaper option was chosen.

3.1.23. Software Selections

This section will cover the software that was chosen for use in this project and the reasons for each choice. It will cover two programming softwares, and three electronic circuit design softwares.

3.1.23.1. Texas Instruments Code Composer Studio

Texas Instruments Code Composer Studio is a free embedded systems IDE designed for use with the embedded C language. This IDE was chosen for a few reasons: familiarity, compatibility with the MSP430s used, and the ease of programming provided by using this solution.

Code Composer Studio is the standard IDE used at UCF for all embedded systems classes, this means that the three ECE team members are very familiar with the use of this IDE. Choosing a software with which one is familiar is always ideal to allow large savings in time. This time savings will allow team members to jump straight into development giving them more time to commit to development, and producing better results.

Code Composer Studio can be used with a multitude of CPUs but it directly supports the MSP430 due to both the software and hardware being created by Texas Instruments. Since the team will be using at least one MSP430 chip this also made this IDE an obvious choice.

Finally, Code Composer Studio (CCS) - in combination with the MSP430 launchpad that the three ECE members already own - makes the programming of an MSP430 MCU extremely easy. As long as 3 pins are wired to the MCU - reset, spi-bi-wire, and power, the MSP430 launchpad can be wired up to the developed MSP430 device for programming. This means all that is needed to program the developed MSP430 boards is a computer with CCS, usb cable, the launchpad, and the development board. No proprietary programming pin interfaces will be needed, which saves board space as a bonus.

3.1.23.2. Texas Instruments WEBENCH Power Designer

Texas Instruments created a free, online software called WEBENCH Power Designer for use by anyone creating embedded systems applications. This software is very powerful and allows users to create voltage regulation circuits with only a few inputs. The user gives the range of input voltages, the desired output voltage and max output current, and then they are supplied with many options to choose from that show cost, efficiency, topology, board space, and other deciding factors. This allows the user to make an informed decision regarding which option they want to favor in their designs to save money, space, or lost power.

This software was chosen mainly due to the guaranteed performance it provides as well as the large amount of time it saves a designer. This software was used to design all of the voltage regulators used in this project that will be discussed in chapter 5 of this document. The time this software saves allows the team members to dedicate more time to the rest of the circuit designs in this project that contain mission-critical sensors and operations.

3.1.23.3. Arduino IDE

Arduino IDE is a free IDE used in many hobbyist electronics projects due to its large number of open-source libraries, its ease of use, and its large amount of community support and existing knowledge.

This IDE will be used to program the Atmel MCUs used in this project. Due to their ability to be easily set up to accept Arduino code, and the group member's familiarity with Arduino code, choosing this IDE for these MCUs was an easy choice, and will allow for easier code development on these platforms.

3.1.23.4. AutoDesk EAGLE

AutoDesk EAGLE is a CAD software that is used for PCB design. It provides the ability to create schematics and full PCB layouts, and provides these services free of cost as long as a design is simple enough (2-layer PCB). This software was chosen over other software for a few reasons: familiarity, and ease of use.

Besides being an industry standard software, EAGLE is also UCFs standard PCB CAD software taught in UCF classes. This means that all of the ECE team members have used and are familiar with this software, and its uses. This once again, allows for the learning curve of new software to be skipped, and development to be started immediately, allowing the team to create better designs.

EAGLE also provides many benefits that online or simpler PCB CAD software does not provide. It is supported by UltraLibrarian - which will be discussed in the following section- to make creating new designs with parts directly chosen from suppliers a very easy and painless process. It also has an excellent time-saving feature that allows a developer to directly select - from parts suppliers - the parts that were used in a design inside of EAGLEs interface, and add those items to a bill of materials. This can save hours of work scouring parts supplier inventory for the parts used in a design, and provide assurance that the right parts are being selected.

3.1.23.5. SOLIDWORKS

SOLIDWORKS is a 3D modeling CAD software used to create engineering designs and models. This program is free for UCF students to use and was used by the team's mechanical engineer. This program was chosen due to the familiarity of the program to the team and due to its features.

SOLIDWORKS, like many of the softwares spoken of thus far, is a standard at UCF as well as in the industry, and therefore is very familiar to the team. Once again this familiarity leads to large time savings in the lack of a learning curve, and increased design quality.

SOLIDWORKS also has the ability to perform simulations on generated designs. Both the capsule and rover CAD models were created via SOLIDWORKS and this allowed multiple force simulations to be run on both models. This provides insight into the quality of the designs, and allows the function of the designs to be evaluated without manufacturing. This saves large amounts of sponsor money and team member time.

3.1.23.6. UltraLibrian

The last software used is UltraLibrarian. This is an online and free software that allows users to search specific electrical components and download pin layouts, footprints, and 3D models for their electronic designs. These designs are supported for export in many CAD softwares, but especially EAGLE, and the software was used for every non-trivial circuit component used in the designs of this project.

This software saves users hours of time that would be spent reading datasheets and creating their own custom components in their CAD software. This time savings is invaluable with the extreme speed of this project and the limited time provided for development.

3.2. Final Parts Selection

All of the parts chosen in section 3.2 are listed below for convenience and ease of viewing. The expected number of each part can be seen in chapter 7 which covers the costs of the systems. Both estimated and true values of the number of parts that will be ordered can be found there.

3.2.1. Table of Parts

This section orders all of the chosen parts in a table by the order of their appearance in the document. It includes the name of the part and what function it fills as well as its cost.

Part	**Name**	**Cost**
Motor and Motor Driver	DFRobot FIT0441	$19.90 each
Capsule Door Lock	Driak Electric Lock	$4.88 each
Coupling Mechanism	MATEE Metal Electric Cabinet Lock	$30.06 each
Altimeter	TE Connectivity MS560702BA03-50	$4.05 each
Accelerometer	Analog Devices ADXL343	$3.10 each
IC Load Switch	Vishay SI1869DH-T1-E3	$0.48 each
Camera	RunCam Nano2 FPV Camera	$20 each
Video Display	GreenYi-08 TFT LCD Color Screen	$40 each
Radio Frequency Transceiver	REYAX RYLR896 SX1276	$19.50 each
Video Transmitter	TS832 48Ch 5.8G FPV Transmitter	$13 each
Video Receiver	WR832 5.8GHz FPV Receiver	$13 each

Table 20.a: Collection of all Parts Selected

Part	Name	Cost
Analog Joystick	Adafruit Analog 2-axis Thumb Joystick	$4 each
Capsule MCU	Atmel ATmega3209	$4.25 each
Rover MCU	Texas Instruments MSP430FR6989	$7.66 each
RCS MCU	Atmel ATmega3209	$4.25 each
Rover Battery	MIKROE-4475 LiPo 6000mAh	$21.90 each
Capsule Battery	MIKROE-4473 LiPo 1500mAh	$10.90 each
RCS Battery	MIKROE-4475 LiPo 6000mAh	$21.90 each
Battery Charger IC	Microchip Technology MCP73833	$1.12 each

Table 20.b: Collection of all Parts Selected Continued

3.2.2. Images of Parts

This section presents images of all of the non-trivial parts used in this system. All parts that are surface mounted connectors or batteries are not shown due to their simple nature. Also excluded are the chosen IC circuit board parts due to their inconsequential size in the scope of the system design. All parts shown below are presented in the order of their appearance in this document from left to right and top to bottom, labeled in order from 4.a - 4.i.

Figure 4.a: Selected Motor (Digikey)[8]

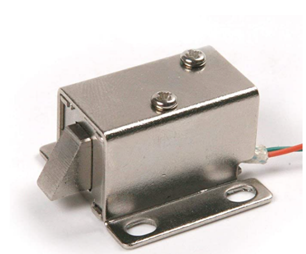


Figure 4.b: Selected Capsule Door Lock (Amazon)[9]

Figure 4.c: Selected Coupling Mechanism (Amazon)[10]

Figure 4.d: Selected Video Camera (Amazon)[11]

Figure 4.e: Selected RCS Display (Amazon)[12]

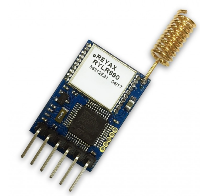


Figure 4.f: Selected Radio Transceiver (Amazon)[13]

Figure 4.g: Selected Video Transmitter (Amazon)[14]

Figure 4.h: Selected RCS Receiver (Amazon)[15]

Figure 4.i: Selected Joystick (Mouser)[16]

4. Constraints and Standards

This chapter discusses the many constraints and standards the remote controlled rover and deployment system is subject to. The majority of the constraints are created from the FAR competition rules, and the rocket design provided by the FAR rocket senior design teams. This system and its components are all reliant on the standards that support their function which must be considered and respected. First the constraints will be explained, and then the standards will finish this chapter.

4.1. Constraints

This section will cover any constraints that the system was designed around and abides by. Constraints that fit into the categories of engineering constraints, environmental constraints, manufacturing constraints, ethical constraints, and safety constraints were considered and will be explored in the following subsections.

4.1.1. Engineering Constraints

Engineering constraints were derived from the team's requirements, the operating environment of the project, the FAR competition rules, and the FAR rocket team. All considered engineering constraints are shown in the following table.

Constraint Number	Constraint Description
1	Payload mass must be at least 1 kg or greater
2	Payload capsule and payload must be able to handle impact speed of 3 m/s
3	The payload must be able to traverse desert train including sand and rocks
4	The radio band of 420 MHz - 450 MHz is reserved for the rocket avionics
5	Payload capsule and payload must be able to withstand up to 8 g when the drogue parachute deploys and during launch acceleration
6	The payload capsule and payload must withstand the heat, pressure, and force of the ejection charges used for deployment of the payload capsule
7	The payload, sled, and capsule assembly must weigh less than or equal to 4.31 kg

Table 21.a: Engineering Constraints Table

Constraint Number	Constraint Description
8	Payload sled must take up no more than 1.27 cm on either side of the payload
9	Payload and capsule assembly cannot be more than 12.7 cm in diameter
10	The length of the sled and capsule cannot be more than 40.64 cm
11	The payload must be unaffected by operation in the radio frequency ranges of 420 MHz - 450 MHz and 1 GHz - 2 GHz
12	The payload capsule deployment system must be reusable, and no parts should be destroyed or wasted during operation

Table 21.b: Engineering Constraints Table Continued

4.1.2. Environmental Constraints

The protection of the environment and the characteristics and quality of the operating environment have been considered as constraints, and respected in this project. This section will explain the need for both the consideration of the waste and litter produced by the operation of this design as well as the constraints the makeup of the environment places on the system and how these constraints are addressed.

4.1.2.1. Waste and Litter Constraints

To prevent unnecessary contribution to the waste created from launching a rocket, it was decided that all parts of the deployment system, and rover mission that this team is in control of would be waste free. The main target of the waste reduction was opting for rechargeable batteries, a capsule door system that uses solenoids instead of detonation charges, and avoiding the implementation of any one time use technologies.

Managing litter can be challenging during a rocket launch with explosives and other destructive techniques in use that can separate parts of a design unintentionally causing litter in the process. This side effect has been acknowledged and avoided in the design of this project. All items designed for deployment and the rover mission will be harvested after use and shall be ready for reuse without waste,

4.1.2.2. Expected Environment Constraints

The FAR rocket competition takes place in a desert which presents multiple challenging environmental constraints that have been considered in the design and implementation of this project. The number one issue that quickly presents itself is the terrain of the operating environment. It is expected that sand, rocks, boulders, and varying slopes typical of the Mojave desert will be encountered by the rover while in operation, and by the capsule on landing.

The first choice made to work with this constraint was adopting both tank tracks instead of wheels, and differential steering instead of a rack and pinion setup as discussed in section 3.1.1. Considerations were also made to the structural integrity of the capsule and the rover chassis to accommodate the rough terrain and the challenges that could be experienced during landing.

4.1.3. Manufacturing Constraints

Manufacturing constraints can be created by resource availability, manufacturing price, and design size and complexity. When designing for manufacturing all of these factors must be considered. This section will explore constraints that the project team has identified will impose on the project and how they are addressed.

4.1.3.1. Rover Manufacturing

There are numerous methods and materials to be considered for the design of the rover chassis and capsule. In the 3D-printing process, which was chosen as the manufacturing method for the rover chassis, there are materials that when being printed produce harmful particles into the air. Fumes from the 3D-printing process were shown to have a profound negative effect on human health when inhaled (Illinois Tech)[17]. These hazardous vaporized chemicals can be mitigated by working in a well ventilated space and by using the appropriate PPE. However there are varying levels of toxicity depending on the temperature required to use the material for manufacturing purposes as well as the composition of the material itself (m3Dzone)[18]. In an effort to best protect the health of the group behind this project, all 3D-printing will be done in a well ventilated room approved for such manufacturing techniques, appropriate PPE will be used when in contact with the material during manufacture, and materials for the rover chassis will be heavily scrutinized for their printing temperature and chemical compositions.

4.1.3.2. Silicon Shortage Effects

With the occurrence of COVID-19 and limited production and manufacturing of silicon products as a result, the effects of the silicon shortage have been felt by every member of the chain since early 2020. This shortage affects consumer electronics availability, pricing, and technology advancements as well as the ability for all manufacturers of silicon products to produce enough to suit the market.

This shortage placed limitations on this project in a handful of ways. The increased lead times for many IC components and non-linear circuit components have led to large numbers of out of stock components which greatly limited the search space for parts selection. Parts were still sourced to suit the needs of the project but greater effort was used since the search space was greatly widened and many popular components were out of stock until the middle of 2022.

Another effect is increased prices of silicon components. It has been noted that over the last year silicon has risen in price more than ever before. The average electronic component is stated to have risen in price by 15% with some components having risen up to 40% (z2data)[19]. This effect is likely present in the final cost of this project, which is not a cost felt by the members of the team, but there was an aim to reduce cost as much as possible while meeting the project requirements.

4.1.4. Ethical Constraints

Ethical decision making must be employed when designing any product that will be used by the public or in public. The team explored the ethical considerations that impact the design of this system and came to a few conclusions. It was decided that due to the nature of this project that will only be operated by the team members and not available to the public there could be a wider disregard for the typical ethical considerations of other products such as consumer electronics or applications.

With this knowledge the team decided to forgo any considerations regarding the direct impact on humans that this project may have since there will be no consumer use of the project. However, the team still maintained the ethical considerations regarding the environment listed in section 4.1.2 which has an impact on all life on earth.

4.1.5. Safety Constraints

When operating rocketry, safety is of high concern due to the volatility that a poorly designed rocket can have. While this team is not responsible for the rocket in this project, considerations were made to avoid causing any interference with the rocket that would cause it to be a danger to others.

At any launch of the rocket - and therefore the payload - that this project entails, safety precautions will be taken to guarantee safe distances from the launch location are in place. However, this team ensured through coordination with the rocket teams that the design presented in this paper would not be a danger to the operation of the rocket in any way. The main interferences considered were: interference with the rocket electronics, interference with the rocket communication systems, and dangers to the rocket structure.

The first two interferences are managed by the frequency operation constraints listed in section 4.1.1, and by maintaining separate electrical systems for the rocket and payload. However, due to the payload's use of LiPo batteries, which can be volatile, considerations were made to determine if this could be detrimental to the rocket. It was determined through discussions with the rocket team, that even during the use of the explosive deployment charges, the batteries will not be placed at risk, and therefore will not endanger the integrity of the rocket and safe operation will be maintained.

4.2. Standards

This section will consider all of the standards that influence the project and the design of the system. Standards will be gathered from the categorization of the parts and technologies that have been selected to implement this project. These standards will be reviewed in the following subsections.

4.2.1. Code of Federal Regulations - Title 14

This section addresses the standards listed in Title 14—Aeronautics and Space from the Code of Federal Regulations related to the use of instruments in aeronautics and space that the group found relevant to this project. While many of the standards addressed in this federal regulations document are for commercial spaceflight, they are a few useful considerations for the scope of this project. The standards contained in this document that were found to be relevant will be listed and explained below.

4.2.1.1. § 29.1303 Flight and Navigation Instruments

The document lists the required flight and navigational instruments to be an airspeed indicator, a sensitive altimeter, a direction indicator, a clock for hours, minutes, and seconds, an air temperature sensor, and a gyroscopic rate of turn indicator for pilot viewing.

This document lists these instruments for aircraft that are human piloted allowing the team to disregard the requirement for an airspeed indicator, clock, gyroscopic rate of turn indicator, and direction indicator (Federal Aviation Administration, 821)[20]. Since the capsule will be unmanned, the project will not require these pilot serving instruments. The capsule will however contain a pressure altimeter that is capable of also measuring temperature, as well as an accelerometer capable of measuring acceleration, tilt, velocity, and direction of descent for the capsule. These instruments will be continuously monitored by the rover's microcontroller while it is in descent to determine when the capsule is on the ground and the rover is ready for deployment.

The requirement of a sensitive altimeter is not well defined in the document, however the altimeter chosen for this project was picked with respect to the sensitivity needed for the capsule's safe operation. With an accuracy of +/- 10cm, the altimeter used in this project will be sufficient for detecting the movement and height of the capsule between deployment and landing.

4.2.1.2. § 29.1325 Static Pressure and Pressure Altimeter Systems

This standard requires that "each instrument with static air case connections must be vented to the outside atmosphere through an appropriate piping system, [and] each vent must be located where its orifices are least affected by airflow variation, moisture, or foreign matter" which will be met in the design (Federal Aviation Administration, 826)[20].

Considerations will be made for having a non-sealed capsule in the design to allow an accurate reading from the altimeter. The rocket itself may or may not be pressurized, but since the altitude of the capsule is only of importance after deployment from the rocket, there is no impactful interest in the rocket's pressurization for meeting this standard.

4.2.2. ASTM F811

The ASTM F811 Standard Practice for Accelerometer Use in Vehicles for Tire Testing is aimed at the use of accelerometers in tire testing, which will not be done for this project, but it does provide useful information about expectations of accelerometer mounting, placement, and testing that will be studied and implemented for this project.

This standard requires that for accurate measurement, an accelerometer must be firmly attached to the chassis of the vehicle or stabilized to the earth, mounted near the center of gravity of the vehicle, and must be mounted with +/- 2 degrees of the vehicle axis (ASTM F811, 2)[21].

All of these requirements listed are expected to be followed while opting for the solid mounted option for the first requirement. These requirements can be met by solid mounting the circuit board to the rover chassis with the accelerometer placed towards the center of mass of the fully assembled rover. Following this procedure should verify the requirements of this standard and give more accurate readings as the standard implies.

4.2.3. ASTM F3153

The ASTM F3153 Standard Specification for Verification of Avionics Systems document provides a solution for developing and performing system testing for avionics systems that will be followed for the testing of the avionics sensors and other operations in this system. An abbreviated version of the specified procedure is as follows (ASTM F3153, 1 - 2)[22]:

1. Document every function to be tested in the system.
2. Create a description of the function, including the explanation for its intended use, and its operating parameters and limitations.
3. For every function to be tested, create pass/fail criteria and create feasible scenarios to test the pass/fail criteria.
4. Run the tests and verify the accuracy of the expected behavior.
5. Document pass/fail outcome and scenarios that caused the outcome, and fix the issue if it exists (or the issue can be deferred for a future update with reasoning).
6. Perform regression testing with every change of the system that could affect the functions.
7. Create a verification document that tracks the name of the system, revision indicators, functions that have been verified and by what means, and the date of verification.

The test procedures defined for the avionics systems specifically and other electromechanical systems will be evaluated using this methodology to ensure proper function is occurring with registered and tracked results.

4.2.4. FCC 03-110A1

The FCC 03-110 Part 15 Specification document outlines the acceptable uses for the 5GHz frequency band. In the document it states that the 5.725-5.825 GHz band is allowed for individual use if operating in a total of 300 MHz of spectrum(FCC parts 2 and 15)[23]. The video transmitter and receiver are the only parts operating in the 5.8GHz band so these are the parts subject to these FCC regulations. The video transmitter will be tested to make sure it complies with these regulations.

In the same FCC Part 15 document, it specifies that devices operating within the 5.47-5.725 GHz band cannot have a higher transmit power than 250 mW(FCC parts 2 and 15)[23]. Although stated as 5.8 GHz receivers, many of the FPV drones can operate at a slightly lower frequency band which falls within the aforementioned range. When using the transmitter for the rover, the group will double check to make sure the transmitter is compliant with FCC regulation.

4.2.5. Programming Language Standards

This section will cover any resources used to standardize any code produced during this project. Standardized code ensures code uniformity and the ability for multiple members to work on the same code without readability and formatting issues. Failing to follow an agreed upon coding standard can lead to large issues in product development, and this will be used to prevent this issue.

4.2.5.1. Embedded C

For any microcontrollers used for this project, embedded C, or embedded C based languages will be used to program the functionality the microcontroller implements. To create efficient, clean, powerful code, the book *Embedded C Coding Standard* will be used. This work is presented online for free by the BARR group and is written by Michael Barr. This book presents simple conventions for creating clean and efficient embedded C and it will be utilized for such purposes.

4.2.6. Display Standards

This section will cover the display standards being used for the display of the wirelessly transmitted rover video. It will cover the standards related to the screen being used, the encoding/decoding being used, and the transmission medium/ports in use.

4.2.6.1. Resolution

For the rover livestream many different resolutions were considered. Each resolution had to be manually evaluated based on existing footage on the internet. What was found is that the most effective resolution would be 480p for the livestream. 1080p was the first option evaluated, but it couldn't be reasoned because the amount of power, the cost of the camera, and the cost of the display increased drastically with this premium resolution. It couldn't be reasoned that using a higher resolution would provide a useful amount of more visual information than 480p could grant us. 720p resolution was similarly eliminated from the list because the price of a display with enough pixels to display 720p would be more expensive than could be reasoned. All that was left were 480p and below, with resolutions below 480p not giving good enough quality and cost reduction. 30 frames per second would take slightly more power to display on a 480p screen, but the difference was found to be insignificant. Therefore the best option was 480p.

4.2.6.2. Video Encoding and Decoding

For video encoding and decoding, the two common formats that video transmitters and receivers use are NTSC and PAL.

NTSC is the format used by older TVs in the U.S. before HDMI started being used as the most popular format. NTSC stands for National Television System Committee who introduced this format to all of North America and some parts of South America. NTSC video is a composite video format because luminance and chrominance were transmitted in one signal. NTSC was used most commonly for transmitting 480p video.

On the other hand PAL was the format used by most of the rest of the globe as the primary analog television encoding system. PAL stands for Phase Alternating Line which describes the way the color information in the signal is reversed at each line. While PAL does transfer a higher resolution, there can be issues if there are phase errors.

The transmitters and receivers evaluated function with either one of these video formats. The choice was made to use the NTSC format, but the difference is anticipated to be insignificant in the quality of the livestream. PAL could have been used but the video quality can immensely degrade if there is a phase error.

4.2.6.3. RCA Phono Display Connection

An RCA (Radio Corporation of America) phono display is a connection commonly used for Composite Audio Video connection. This connector is important because the input to the display is a composite video connection. The camera being used does not have any audio so the only connection being used will be the composite video. This RCA Phono Display connector will allow the connection to any of the displays evaluated because they all support RCA connections.

4.2.7. Electronic Communication and Control Standards

This section of standards will list and explain the communication and control standards being used to control the electronics and electromechanical systems used in this project. It will explain the use of the standard in the project and how the technology works.

4.2.7.1. I2C or TWI

Phillips Inter-Integrated Circuit (I2C) is a synchronous serial communication protocol that allows multiple devices to communicate with each other when organized by a controller. Two Wire Interface (TWI) is the non-standardized version of this communication protocol that is also commonly used in circuits. From this point forward, since TWI may be used in this project, TWI and I2C will both be referred to as I2C for the reader's convenience and for clarity. I2C uses two wires for connections: serial data (SDA) and serial clock (SCL).

Between two devices, the controller provides the clock via the SCL wire and sends data over the SDA wire which the peripheral device will read to know if it needs to send data or accept data (read or write). Multiple peripheral devices can also be set up in I2C due to the devices having addresses. As long as the addresses are not the same, any amount of I2C devices may share the same wires. The devices all share the same SCL and SDA lines and use the data sent from the controller to check if the target address matches theirs to know if they are being chosen for communication. I2C also has the benefit of being able to have multiple controller chips at once, but they must take turns using the wires and this must be planned by the programmer since they cannot communicate directly over I2C.

I2C will be used in the system to facilitate data capture from the altimeter and accelerometer on the rover and in the CLASS system for use in determining when the rover/capsule has landed. They may also be used for speed monitoring during the mission lifecycle.

4.2.7.2. SPI

Serial Peripheral Interface (SPI) is a synchronous serial communication protocol. It facilitates full duplex communication between a controller device and multiple peripheral devices at once. SPI uses 4 wires on all peripheral devices: clock, data in, data out, and chip select, SCLK, MOSI, MISO, and CS respectively. The controller device will have a minimum of 4 wires: clock data out, data in, and chip select (more than one can be used when peripheral devices are not daisy chained), SCLK, MOSI, MISO, CS respectively.

SPI functions with the controller device providing a clock to all of the peripheral devices and using the chip select wire to tell the devices which one is supposed to be ready for transmission. It then sends a signal to choose to write or read data from the selected device.

In this system, SPI will be used for sending and pulling data from the video transmitters and receivers as well as sending the received data to the display. These controllers will be a MCU on the rover handling the transmission and another MCU at the receiver polling and displaying video data.

4.2.7.3. PWM

Pulse width modulation (PWM) is a type of electric signal modulation that is often used to have variable control over the intensity of devices that are being controlled by this signal. PWM uses the concept of duty cycle to set a frequency and duration of the modulation that can control a connected device.

The duty cycle of a PWM signal is the amount of time in a period that the signal is on i.e. 30% duty cycle means the signal is high for 30% of the period and low for the other 70%. However this does not entail leaving the signal low for multiple seconds and turning it high for a proportionate amount of time. Instead this period of on/off is one clock cycle of the driving signal.

PWM is often used to control the speed of DC motors, the brightness of LEDs, control servos, or generating audio. In this system it will be used to drive the four brushless DC motors of the rover to control both speed and direction as signals are sent from the joystick on the controller PCB system.

4.2.7.4. UART*

A Universal Asynchronous Receiver/Transmitter (UART) is a device that uses two wires and no clock to allow serial communication in both directions between itself and the other UART device it is connected to. These devices use two pins, Tx and Rx, to transmit and receive data respectively. The devices transmit with start and stop bits to replace the need for a clock to drive their communication. The devices are able to communicate when they both share the same transmission rate - baud rate - configuration, which is usually set at 9600 baud.

UART will be used in this system to transmit remote control data over wireless radio signals. The radio frequency transceivers chosen in the parts selection use UART to receive the data to be sent and to pass on the data they received. Both transceivers will be connected to microcontrollers that will give and take the data via UART.

*UARTs do not fit under communication protocols or control standards but are being included in this section as a recognized common hardware standard that uses a special form of electronic communication unlike the other protocols.

4.2.8. Connection/Interface Standards

This section will cover the standard connectors that will be used on the system PCBs and components. The connection standards listed below are common to many embedded systems electrical designs and should be understood and evaluated before their use is determined in a production circuit.

4.2.8.1. USB 2.0

Universal Serial Bus (USB) is a standard connector type used in all computers and many electronics for both power and data. USB micro B will be used in this system and it provides 5V of power and up to 10 Gbps data transfer. USB micro B was chosen due to it’s high data rates, common availability, convenient form factor, and the strength of the socket when compared to USB mini.

USB micro B will be used as the charging port on all three PCBs that will be used in the system. Due to its standard 5V input it compliments the battery charging management ICs chosen for this system and will allow for convenient charging via wall, or computer.

It can also be used for programming for the MCUs on each of the three PCBs if this is decided to be the best course of action.

4.2.8.2. JST

Japan Solderless Terminal (JST) is a standard electrical connector developed for use in circuit boards. They are used to interface multiple electrical components to the same system. They will be used in this project, for the motor connections, battery connections, and potentially other uses.

JST headers come in multiple forms with varying pin spacing, structure, and voltage/current limits. These connectors are useful due to their solderless nature and the fact that they provide a sturdy connection that is much more reliable than the insecurity of putting a solderless female jumper connection on a male pin header that is soldered to a PCB. The likely candidates of JST pin layouts will be 1x2, 1x3, and 1x5 formats.

4.2.8.3. Standard Pin Headers

Standard pin headers will also be used on the PCB to provide connections for such things as programming the microcontrollers and connecting external components. Since components for video and radio transmission are cheaper to buy than design, they will be external components and must be connected to the board via wire. This will be done using standard pin headers and soldered connections when JST is not an option. It will also be used especially for the programming of PCBs with an MSP430 chip that will use spi-bi-wire powered by an MSP430 breakout board for easy programming.

4.2.9. ASTM E2854/E2854M

This standard is titled *Standard Test Method for Evaluating Response Robot Radio Communication Line-of-Sight Range*. It supplies information regarding deriving and completing testing criteria for radio controlled robots which directly suits the goals of this project (ASTM F2854/E2854M-21)[24]. The standard defines intensive testing criteria to determine if at certain operation distances the robot is still effective in its responsiveness and control accuracy. The document gives a full outline of the testing criteria. The team intends to follow this criteria either with their own testing methodology derived from this standard or exactly the one listed in this standard. This criteria can be seen in chapter 6 where test procedures are outlined.

5. Design

This chapter will cover the details of the design of each major subsystem in this project. In order these subsystems are: the rover chassis, capsule structure, power systems, rover propulsion and auto-start, CLASS system, video transmission, video display, remote control, radio transmission, and rover RC movement. Each subsystem will explain the design approach and give an explanation and view (if applicable) of the design that was finalized in this semester.

5.1. Rover Chassis Design

This section will cover the considerations and choices made when designing the frame/chassis of the rover. This encompasses the 3D CAD design as well as the material choices and structure considerations. This section will approach this by first describing the approach to material selection, then explaining the design decisions for the structure of the rover chassis.

5.1.1. Overview

The material composition of the rover chassis is a very important design consideration as the rover must be able to withstand shock and vibrations of varying frequencies throughout its mission. The material must be strong and rigid yet flexible enough to successfully transmit vibrations without causing damage to the rover chassis itself or the electronics stored on board. The material must also be 3D-printable to reduce the complexity of the manufacturing process and to reduce the amount of screws and joints that would be used with other manufacturing methods. The chassis will hold the motors and all of the electronics that allow the rover to operate, and it therefore must also accommodate and provide protections for these components.

5.1.2. Material Design Approach

Materials will be judged based on their tensile strength, toughness, and Young's Modulus values, as well as other factors such as cost.

Impact toughness* measures a material's ability to absorb energy and deform plastically rather than fracture when a sudden load is applied. Tensile strength measures the maximum pulling stress a material can withstand before fracture and is a common metric when comparing the general strengths of materials under numerous loading conditions. Young's Modulus, also known as the modulus of elasticity, gives insight into how a material behaves when undergoing elastic deformation. More specifically, Young's Modulus measures the stress experienced by the material per unit of strain (micrometer per meter). The materials considered will be compared with these considerations in the table in 5.1.1.4. All mechanical properties obtained from matweb.com.

*Charpy Impact at room temperature

5.1.2.1. Acrylonitrile Butadiene Styrene (ABS) Plastic

ABS is a thermoplastic and is the most commonly used plastic for 3D-printing. It is known for its high rigidity and impact resistance. It can maintain its normal mechanical properties within a wide temperature range of -20ºC to 80ºC. ABS is readily printable and compatible with post-printing manufacturing such as sanding, machining, and painting. ABS is the least expensive material examined in this comparison.

5.1.2.2. Alumide

Alumide plastic is manufactured from the combination of aluminum powder and polyamides using a Selective Laser Sintering process. Alumide boasts a high tensile strength and rigidity. Alumide requires post-printing refinement such as sanding and grinding. This material has a very high temperature resistance of up to 172°C. Since the printing process required for this material is not the same as that of a traditional plastic, the process and material are more expensive.

5.1.2.3. Nylon (PA 6)

Nylon can be found in filament form and used in fused deposition modeling. Nylon offers good rigidity and shock resistance as well as a moderate degree of flexibility. It is notably impact resistant and is resistant to surface wear. Nylon quickly absorbs moisture from the air during manufacturing so is susceptible to deformation during that process. Nylon has a maximum operating temperature of 95°C. Nylon is slightly more expensive than ABS. Additionally, Nylon emits toxic particles during printing and must be printed inside of an enclosed 3D printer placed in a well ventilated room (m3Dzone)[18].

5.1.2.4. Comparison

In the table below, all options researched and considered for this part of the system are compared for the final choice to be made.

Material:	**Tensile Strength (MPa):**	**Impact Toughness (kJ/m^2):**	**Young's Modulus (GPa):**
ABS	29.6 - 48	16.5	1.79 - 3.2
Alumide	48	29	1.32 - 1.4
Nylon (PA 6)	50 - 90	45	1.3 - 4.2

Table 22: Comparison of Rover Chassis Material

As the above table shows, Nylon has superior mechanical properties. However, due to safety reasons surrounding the potentially hazardous nature of manufacturing a Nylon design, Nylon will not be considered as a viable chassis material. Alumide has a higher impact resistance and around the same tensile strength as ABS, but has a lower modulus of elasticity. This means that Alumide will tend to strain more under stress. ABS offers a balanced modulus of elasticity and tensile strength with the lowest impact toughness. However, ABS is the cheapest and simplest manufacturing option and its impact toughness, while the lowest, should be sufficient given the anticipated impact the rover is expected to experience during the mission. It should be noted that the impact at landing will be absorbed by not only the rover, but the payload capsule as well, limiting the need for a high impact toughness. It is for these reasons that this project shall proceed with using ABS plastic for the manufacturing of the rover chassis.

5.1.3. Structural Design Approach

The rover chassis shall be made to fit securely inside the payload capsule throughout the flight and subsequent descent and landing of the payload assembly. There shall be enough clearance to allow for the rover to drive forward and exit the capsule after landing. This clearance must also allow for the capsule locking mechanism which is to be placed on the upper inside surface of the capsule. The bottom area of the rover chassis must be large enough to accommodate four housings that will be used to secure and mount the motors. Furthermore, the main body of the rover responsible for holding and securing the on-board electronics and communication equipment must be sufficiently large enough to hold the largest item. The rover chassis must feature an extruded cut on the front face of the chassis that will act as a mounting surface for the video camera. This extruded cut must have a passthrough for wires to be sent through. The chassis frame itself must be rigid yet flexible while having ample room to access the electronics bay.

The chassis dimensions are bound by the dimensions of the payload capsule. These constraints are as follows: The chassis may be no more than 250 mm long to account for the space taken up by electromagnetic coupler. The chassis cannot be more than 130 mm wide in order to fit inside the capsule with at least 5 mm clearance on each side. The rover chassis must be less than 90 mm tall from the track to the top center point. The electronics bay of the rover must be at least as large as the battery which is the largest component. This means the electronics bay must be at minimum 99 x 67 mm in area. The next section will provide a CAD model of the rover chassis based off of these dimensional criteria.

5.1.4. CAD Model

This section provides a view of the rover CAD model used to design the structure of the rover and plan the sizing of other system parts. This model will help the reader visualize the design aspects previously discussed.

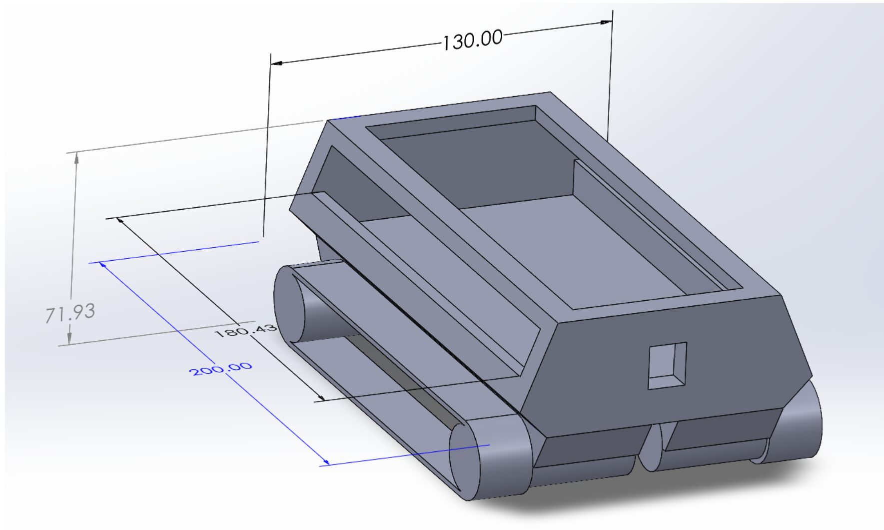


Figure 5: Rover Chassis SolidWorks Model with Dimensions in Millimeters

In the above SolidWorks model, the rover chassis design can be seen with a simulated motor and tank tread assembly attached. The rover is 200 mm long, 130 mm wide, and approximately 72 mm tall. The electronics bay is approximately 180 mm long by 95 mm wide. Also shown is the cutout for the camera on the front face of the rover.

5.2. Capsule Structure Design

This section will go over the design considerations behind the capsule structure design and shall justify all major design decisions. This includes all relevant calculations, figures, and CAD modeling. Dimensional requirements will also be covered as well as the actual dimensions of the final draft of the capsule design. This section will first begin by covering potential capsule structural materials and the selection of a material to be used in the final product.

5.2.1. Capsule Materials

The selected material for the capsule must be very light to keep the overall payload mass down. This is of key importance for the overall performance of the rocket. The selected material must also be durable and impact resistant. The capsule should not significantly deform during the landing event or key features may be compromised and put the mission in jeopardy. Having a durable material is also important for other events leading up to launch such as testing and alterations that may need to be made after the initial manufacture of the capsule. Advantages for certain materials beyond material properties must also be examined. Workability and ease of use must also be considered when looking for a material. This material must be able to bend in a circular shape of approximately 15 cm in diameter. Furthermore small holes and cutaways must be made in this material in order to manufacture the capsule as designed. One material that has the ability to satisfy all of these parameters and more is aluminum. Aluminum is a very light, inexpensive, and in the right form a very workable material. Aluminum is a commonly used material for the construction of airplanes which is a comparable application to this project. Other useful properties of aluminum include a high rate of thermal conductivity, ductility, strength, and toughness (Kloeckner Metals Corporation)[25]. In sheet form, aluminum is very flexible and can be manipulated with ease if provided the correct equipment. The performance of aluminum as a building material varies with the type of aluminum alloy and treating methods used in its creation.

Aluminum has seven different alloys each with characteristic properties, three of which will be discussed as potential material selections for the payload capsule. 2000 Series aluminum is a copper-aluminum alloy commonly used for aircraft (All Metals Fabrication)[26]. 5000 Series aluminum is an aluminum-magnesium alloy that is known for its high tensile strength and ability to manipulate (All Metals Fabrication)[26]. Finally, 7000 Series aluminum has a very high strength and is used in aerospace applications as well (All Metals Fabrication)[26]. Mechanical properties do not only differ between the alloy series but also with the temper of each alloy within a series. For example, aluminum 2024-T3 has a different ultimate tensile strength compared to aluminum 2024-T5 (MatWeb)[27]. In this section, one aluminum variety from each series will be compared by their mechanical, chemical, and manufacturing properties.

5.2.1.1. 2024 Aluminum Sheet

Aluminum 2024 is an aluminum alloy primarily consisting of aluminum and copper. This aluminum alloy, like other alloys in the 2000 series, offers high strength and good machining performance. Aluminum 2024 has excellent performance over a wide range of temperatures. This alloy is commonly available in sheet form and could easily be machined and worked for this application.

5.2.1.2. 5083 Aluminum Sheet

Aluminum 5083 is an aluminum-magnesium alloy and is commonly used in the automotive and shipbuilding industries for its high strength and lightweight nature. It is also known for its corrosion resistance and weldability.

5.2.1.3. 7075 Aluminum Sheet

This alloy is composed of Aluminum and Zinc and sees extensive use in the aerospace industry. It is known for its multitude of impressive mechanical properties such as its high strength, toughness, and ductility. Aluminum 7075 is susceptible to embrittlement and mechanical failure under certain conditions such as very low temperatures, radiation exposure, and material impurities.

5.2.1.4. Comparison

The table below compares the mechanical properties of the above alloys. The modulus of elasticity and ultimate tensile strength are compared as well as the elongation at break percentage which is the percentage of elongation the material experienced during a tensile test before the material failed. Elongation at break gives insight to the ductility of the material. Machinability is a metric based on the cutting speed of a tool when machining a given material. This time is compared to materials of similar makeup or, in this case, other aluminum alloys. All values obtained through matweb.com.

Material	Modulus of Elasticity (GPa)	Ultimate Tensile Strength (MPa)	Elongation at Break	Machinability
Aluminum 2024-T3	73.1	137	10%	70%
Aluminum 5083-O	71.0	290	25%	30%
Aluminum 7075-T6	71.7	572	9%	70%

Table 23: Comparison of Payload Capsule Material

According to the above table, Aluminum 5083-O holds no advantages over the other two alloys. Aluminum 7075-T6 and Aluminum 2024-T3 offer similar machinability, modulus of elasticity, and elongation at break percentages, however Aluminum 7075-T6 has a considerably higher strength than the 2000 Series alloy. Due to the overwhelming performance advantages offered by Aluminum 7075-T6, this project will proceed with this option as the structural material for the payload capsule.

5.2.2. Capsule Structure and Expected Operation

The payload capsule is to be designed to contain the rover throughout flight and landing. It is to be a semi-cylindrical shape with a curved end to aid in landing. Key features in the payload capsule design include an eyelet anchor point to attach to a parachute, side rails on the exterior of the capsule, an overall geometry that will ensure the capsule lands upright, an electromagnetic coupler, a door, and finally the CLASS feature for landing procedures. The overall dimensions of the capsule must not exceed the inner diameter of the rocket body (15.24 cm) and the length of the rocket's payload bay (40.64 cm). Additionally, the side rails must not take up more than 1.27 cm on either side of the payload capsule.

Once the rocket has reached its apogee, the payload parachute will be ejected and create a drag force which will extract the capsule from the rocket's body. This deployment process will be aided by the inclusion of rails on the outside of the payload capsule. The parachute is to be attached to an eyelet anchoring point at the rear of the capsule. As these events are taking place, the rover will be held in place within the payload capsule by an electromagnetic coupling device. The capsule will then descend toward the ground with the capsule oriented at an angle less than 90 degrees with respect to the horizon. When the capsule makes contact with the ground at the end of its descent, the curved geometry of the capsule entry point coupled with the negative angle of attack will guide the capsule to come to a complete rest in its intended upright position. To further increase stability during landing, fixed landing gear will grab hold of the ground and support the weight of the payload. At this time the capsule's onboard control system, CLASS, will detect that the capsule has come to a rest and will automatically initiate landing protocol. The electromagnetic coupler will switch off and decouple from the rover inside, and the solenoid locking mechanism which keeps the capsule's door closed will retract and allow the door to open. Once these events have taken place the capsule will have served its purpose and the rover will exit and begin its mission.

The payload capsule's exterior railings are intended to keep the capsule secured during flight by mating with a complimentary track mounted on the inner surface of the rocket's body. This rail and track system will also ensure smooth operation when the capsule separates with the rocket.

The parachute anchoring point is an eyelet designed as an attachment point for the parachute. The location of this eyelet is the key component in producing an angle of attack suitable for a stable landing. Once the object has reached terminal velocity, and neglecting shocks due to changing air pressure or wind gusts, the object will find itself oriented so that the forces and moments which occur due to buoyancy, drag, and the weight of the object are balanced in dynamic equilibrium. In short, the eyelet, which acts as a hinge support with the force being the drag force exerted by the parachute, will find itself oriented directly above the center of mass of the payload. If the eyelet and support is placed off center from the center of mass during normal horizontal orientation, the force balancing will result in the capsule having an angle of attack during its descent. Having an angle of attack when landing is important as it can be used to control the side the payload lands on. Figure 5.2.1 and the subsequent calculation provides a visual depiction of the balanced forces and how the angle of attack can be found. Note, the drag force generated by the capsule itself is insignificant compared to the attached parachute and is therefore neglected.

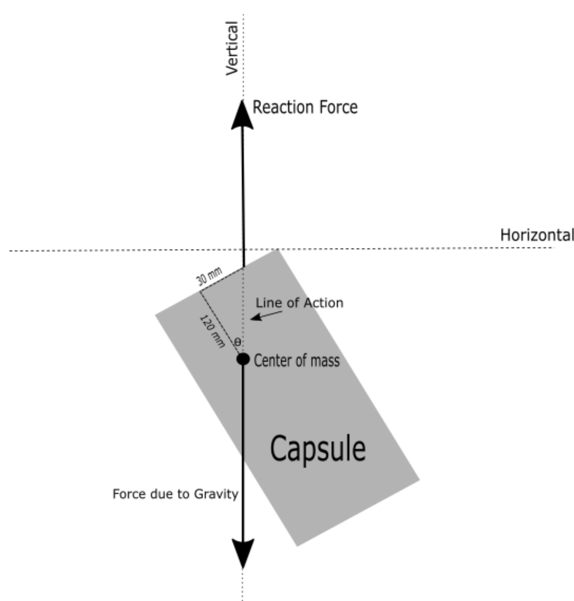


Figure 6: Force Diagram for Descending Capsule* **

*Not to Scale
**Center of mass location relative to eyelet derived using SolidWorks simulation.

To find θ, the angle of the capsule and the vertical datum, and subsequently the angle of attack (AoA), take:

$$\theta = tan^{-1}(30mm/120mm) = 14.04\, degrees$$
$$AoA = 90 - 14.04 = 75.96\, degrees$$

Equation 10: Angle of Attack of the Descending Capsule

Thus the expected angle of attack is approximately 76 degrees for the given center of mass location.

The secondary feature intended to ensure upright landing is the curved end of the capsule opposite the end that attaches to the parachute. This feature aids the landing process by guiding the capsule toward its fixed landing gear after making contact with the ground. This design works in tandem with the capsule landing at an angle. After the curved end contacts the ground capsule will fall directly onto the landing gear which will dig into the soil, providing even further stability.

The components of the CLASS (explained in section 5.5) are also contained inside of the capsule. The CLASS is composed of a PCB and battery pack located underneath the bottom exterior of the capsule.

5.2.3. CAD Model

This section will show and explain two different views of the capsule CAD model. These two model views will show the main features of the capsule to help with the understanding of the referenced design choices.

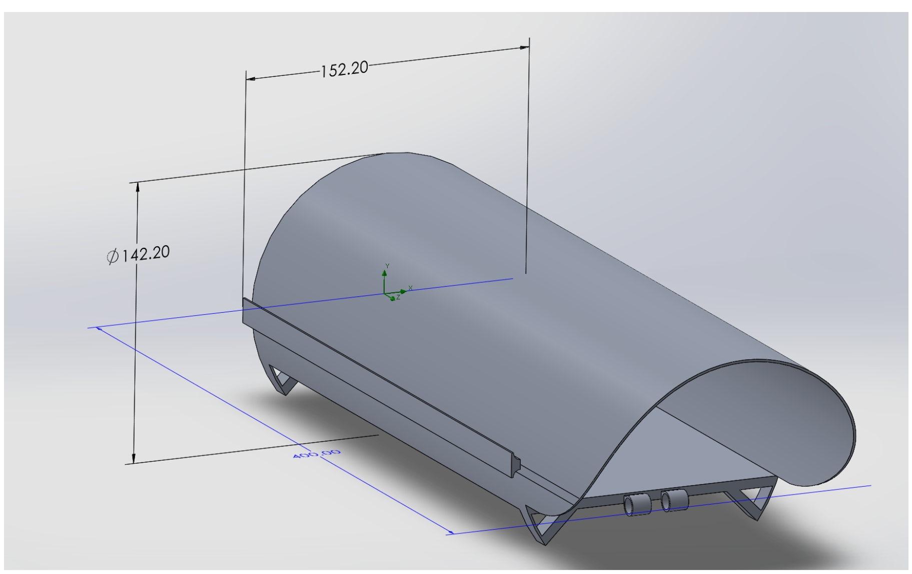


Figure 7: Capsule SolidWorks Model with Dimensions in Millimeters

The above SolidWorks model shows the finalized design for the payload capsule. Note that this figure does not include the door and opening mechanism. The maximum width of this model is 15.22 cm which is less than the maximum inner diameter of the rocket. This maximum width measures the span between the outermost points of each railing and can be flush with the inside surface of the rocket body. Also seen in the above CAD model is the curved end of the capsule designed to tip the capsule toward the landing gear (also shown at the bottom of the model). Near the opening of the capsule brackets for the capsule door are shown.

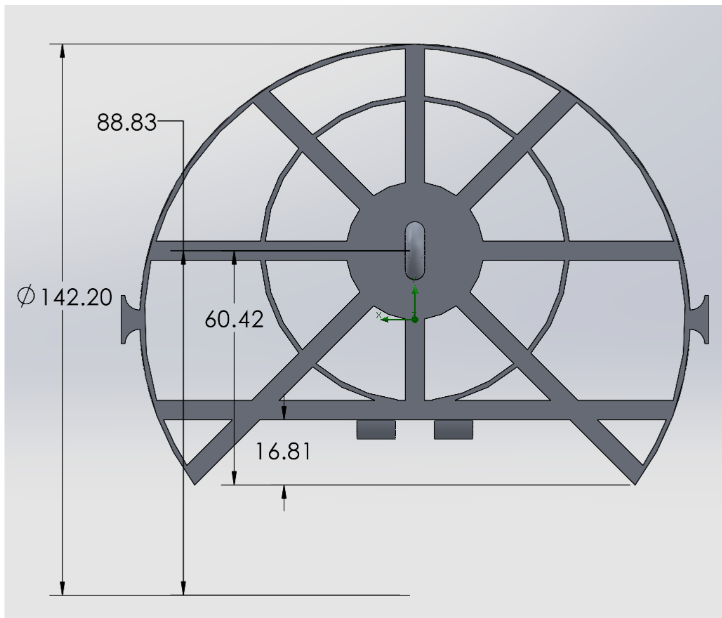


Figure 8: Rear Perspective of Capsule SolidWorks Model with Dimensions in Millimeters

This view of the capsule model shows the offset location for the parachute eyelet. As discussed above, this offset helps generate an angle of attack that will be integral to upright landings. The concentric ring design is useful for distributing tensile forces to the main cylindrical body of the capsule when descending via parachute. Seen in the center of the innermost ring is the eyelet which acts as an attachment point for the parachute.

5.3. Power Systems Design

This section will explain the approach to the design of the power systems of the project. The rover, the capsule, and the radio control station all have individual power sources and require their own designs. The way that the challenges presented in these power systems were solved will be shown in this section along with a description of the final design, and schematics.

5.3.1. Overview

Due to both the weight limitations of the capsule, rover, they can only realistically have a power supply that is in a standard flat, single cell lithium battery form factor. This form factor does however come with two main limitations. First, batteries of this form factor are almost entirely available with a nominal output voltage of 3.7V. Secondly, they have capacity maximums, with the maximum dimension battery that was found to be within the specifications of this project having a capacity of 6000mAh.

These limitations required a smart approach to the design of the power systems of this project so that one singular battery could supply each individual system with the power needed to last the lifetime of the mission. The approach taken to solve these issues will be explained below.

5.3.2. Voltage Regulation Design Approach

Voltage regulation is a common design process for all embedded system designs and many other electronics. It is often the case that the input voltage is a standard voltage value, but is not used by all or any of the circuit components, and thus regulation is needed. Thankfully, voltage regulation design for this project was made to be much easier by the use of Texas Instruments' WEBENCH power designer software.

This approach was chosen for a few reasons. The ease of design allowed more attention to be directed towards other mission critical parts of this project. The reliability of the software provides designs that can be trusted. The software's ability to provide links to all of the parts used in the design provide even further time savings and reliability that is invaluable to the system.

Both voltage boosting and voltage reducing circuits will be needed for the design of this system. With parts operating in the 3.3V to 12V range, and with all power supplies being 3.7V, regulators are essential to the function of the system. The designs presented by TI's solution will be evaluated and compared in the following subsections for each target output voltage. The considerations for the designs will be efficiency, footprint, number of parts, and IC cost as well as estimated BOM cost.

All designs in the following section will use the criteria of a supply voltage ranging from 3.0 - 4.2V which is the standard operating range for LiPo batteries, and the batteries used in this system. Each design will have its own current considerations, and to reduce system complexity, the circuit that requires the highest current draw at each voltage will set the criteria for max current out since this cannot damage circuits which will not draw this much current, but the regulators need to handle the current drawn from them.

The designs will use the balanced design criteria inside of WEBENCH, and the most efficient, smallest area, and lowest cost designs will be compared. The decision will be made based on the most valuable design that retains efficiency > 90%. All designs are compared in the tables in the following sections.

5.3.2.1. 3.3V Buck-Boost Circuit

The highest current draw from this 3.3V circuit will be the video receiver and remote controller circuit expected to use a maximum of 500mA. This circuit will be designed for a minimum 1A output for safety. This circuit needs a buck-boost topology due to the fact that the batteries minimum and maximum voltage are below and above the needed output voltage respectively.

Regulator	Efficiency	Footprint	BOM Count	IC Cost	BOM Cost
TPS63024YFFR	94.4%	102mm^2	7	\$0.84	\$1.42
TPS630250YFFR	95.3%	102mm^2	7	\$0.78	\$1.60
TPS63810YFFR	92.4%	52mm^2	5	\$1.08	\$1.81

Table 24: Comparison of 3.3V Buck-Boost Circuits

All other things being equal, option two seems to be the best choice for this voltage regulator circuit. This circuit provides the second lowest cost and a relatively average footprint in comparison to the other two options. With an efficiency of 1.1% greater than the second highest performing circuit, and with the same required footprint than the lower efficiency option, this is the best option. The TPS630250YFFR circuit as designed by TI's WEBENCH will be used for all 3.3V regulator circuits.

5.3.2.2. 5V Boost Circuit

This battery to 5V circuit serves as an intermediary circuit in boosting the battery to 12V. This circuit will take the battery range of 3.0 - 4.2V as an input, and boost to 5V as the output. Since this is feeding the 12V boost circuit, it needs to have the same maximum current draw which is 1.75mA as described in the 12V section following. The following table compares the options generated for this design.

Regulator	Efficiency	Footprint	BOM Count	IC Cost	BOM Cost
TPS61022	94.9%	149mm^2	7	\$0.60	\$1.13
TPS61032	92.2%	679mm^2	12	\$1.11	\$2.36

Table 25: Comparison of 5V Boost Circuits

While the first option beats the second in every category, it, like all designs that were created with a higher efficiency than the second, could not be purchased. Therefore the second option must be chosen since it is the only option available for purchase due to the chip shortage. While this item does not boast the best efficiency, it does meet the minimum efficiency requirement. This makes the TPS61032 regulator circuit designed by TI's WEBENCH the clear choice for all 5V circuit implementations.

5.3.2.3. 12V Boost Circuit

This circuit will be designed as a 5V to 12V boost. This was done to avoid the use of very large through hole capacitors that are needed for a 3.3V to 12V design. It was also found that the regulators recommended for a 3.3V to 12V design were all out of stock due to the chip shortage. The highest total current drawn from this 12V circuit will be needed to drive the motors and video transmitter. The max current draw needed wil be to power these parts on the rover circuit. The current adds up to 1540mA, so the circuit will be designed for 1.75A max.

Regulator	**Efficiency**	**Footprint**	**BOM Count**	**IC Cost**	**BOM Cost**
TPS61288	96.2%	302mm^2	13	$1.48	$2.81
TPS611781	95.3%	409mm^2	20	$1.74	$4.71
LM5156HQ PWPRQ1	93.7%	568mm^2	18	$0.92	$3.35

Table 26: Comparison of 12V Boost Circuits

While the first option has the second lowest cost, and footprint, and the highest efficiency of all of the generated options, and the second presents a good choice, the third must be chosen. Ideally, the first option would be the best due to its high efficiency and lack of downsides. However, the third option must be chosen since both of the first two options are unavailable for purchase due to the chip shortage. This makes the LM51561DSSR regulator circuit designed by TI's WEBENCH the best choice for all 12V circuit implementations.

5.3.3. Power Management Design Approach

The choices made for the battery power supplies chosen in chapter 3, were made in tandem with the design of the system power management. The battery choices were made based on target operation time lengths and maximum current draw.

The task of designing the power management for the RCS was more trivial than that of the rover and CLASS. The RCS only requires a small maximum current draw that can always be active during the mission lifetime. This made power management as simple as choosing target operation durations and multiplying those durations by the maximum current draw of the system to find a suitable battery. However, the rover and CLASS power systems were more complicated and needed similar but individual solutions explained in the following sections. The full operation plan for the CLASS and rover automatic power systems will be explained in individual subsections 5.4 and 5.5 respectively.

5.3.3.1. Rover Power System

The rover system took more effort due to the high current draw required for the four DC motors that will propel the rover. With a maximum current draw of 3150mAh, the rover would be able to run at full power for 2 hours from a full charge without running out of power. However, the motors are not suitable to be held at idle due to the extreme current draw of forcing the motor to idle as well as this current draw being greater than the rated current draw. Therefore while the rover is in flight in the capsule the motors must not receive any power so that they do not need to be held at idle, wasting a large amount of the battery, and causing potential damage to the motors.

Due to the need of the motors to be unpowered before takeoff and during the flying portion of the mission, but powered automatically when the capsule has landed, an autonomous solution was needed. The idea to solve this problem is to use a microcontroller operated power switch as well as sensors that would detect when the capsule has landed to only power the motors when they are ready to move. This will be done using an accelerometer and altimeter combination that will be able to detect when the rover is not facing any movement or acceleration greater than gravity and is therefore ready to move and be powered.

5.3.3.2. CLASS Power System

The CLASS faces a unique issue where the electromagnet that keeps the rover connected to the capsule needs power to stay locked, but the door lock solenoid needs to be powerless to hold the door shut. Therefore the capsule will employ autonomous power cutoff and connection systems in the same way the rover will. It will use an accelerometer and altimeter in conjunction to determine when it has landed and then use MCU controlled load switches to control the locks in the capsule.

5.3.4. Battery Charging Design Approach

Charging Li-Po batteries has become quite simple with the use of battery charging ICs. The IC being used was chosen in chapter 3 and is the MCP73833. A battery charger is needed to recharge a lithium battery without burning out the cells due to overcharging or overvoltage.

This design was created with user convenience in mind. Due to the properties of USB and the fact that 5V USB wall plugs are so common, the charger was designed to be powered by USB so that any user can recharge the battery via a computer USB port or a common wall wart.

One downside of the design that is due to the nature of the charger chosen is that the battery must be moved to a separate port than the power port of each individual system to be recharged. The battery will be secured via JST connector so that the moving process is simple, but it is recognized that this is more work for the user. The schematic for this charging system can be seen in the following section.

5.3.5. Schematics

This section will show the schematics used for the voltage regulators in the following three figures and a schematic for battery charging in the fourth figure. These voltage regulator schematics were designed by Texas Instruments but the designs shown are screenshots from the team's work environment and the team's direct implementation of Texas Instrument's design.

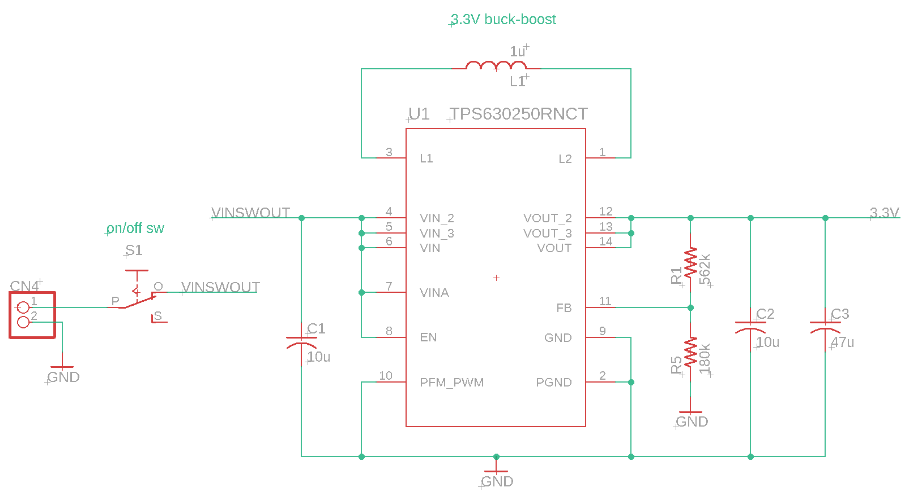


Figure 9: 3.3V Buck-Boost Regulator Design (Courtesy Texas Instruments)[28]

The 3.3V circuit takes the input of the battery voltage and outputs 3.3V for the sensors and MCUs on the boards. To the left of the circuit is the two pole, two throw switch that blocks the battery connection to the entire circuit with output VINSWOUT that connects to the 3.3V converter and also the 5V converter.

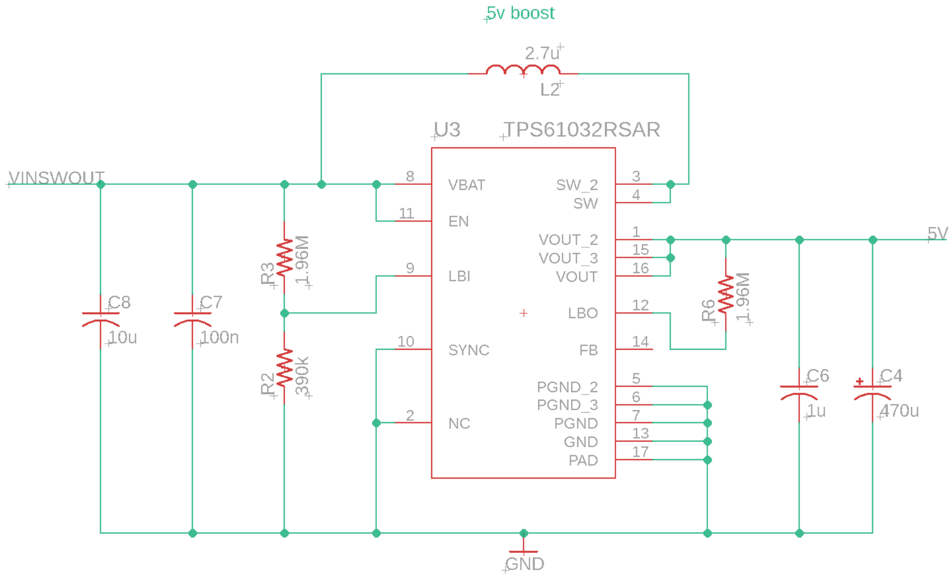


Figure 10: 5V Boost Regulator Design (Courtesy Texas Instruments)[28]

The right side 5V regulator also takes the battery voltage as input but supplies 5V that will go straight into the 12V regulator as discussed prior. Note that the input of this circuit is also VINSWOUT as shown in the 3.3V figure.

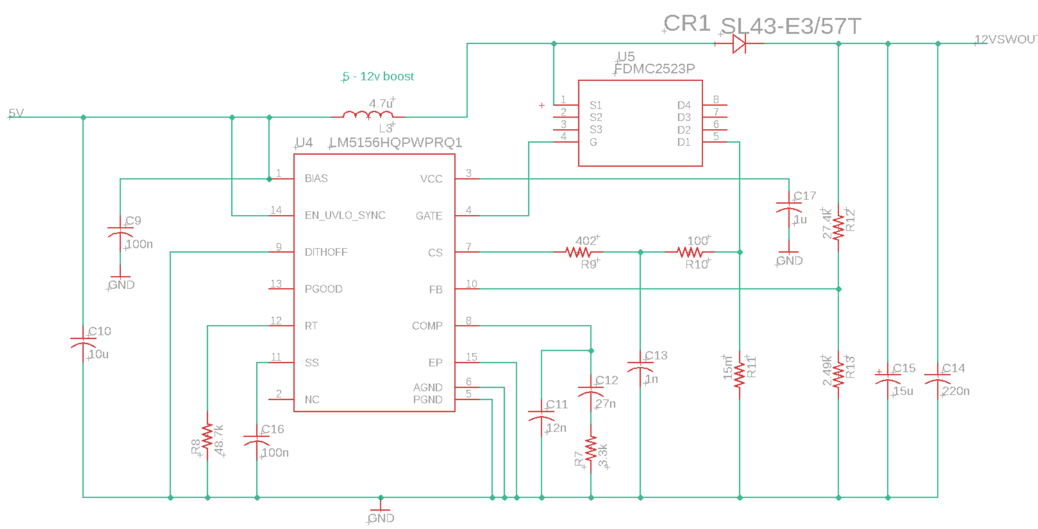


Figure 11: 12V Boost Regulator Design (Courtesy Texas Instruments)[28]

It should be noted that the 12V schematic uses the 5V schematic as its input to implement the 3.3 - 12V boosting. Again, this was due to the lack of parts that can directly implement 3.3 - 12V and was done to reduce capacitor sizes that take up large amounts of vertical board space and weight.

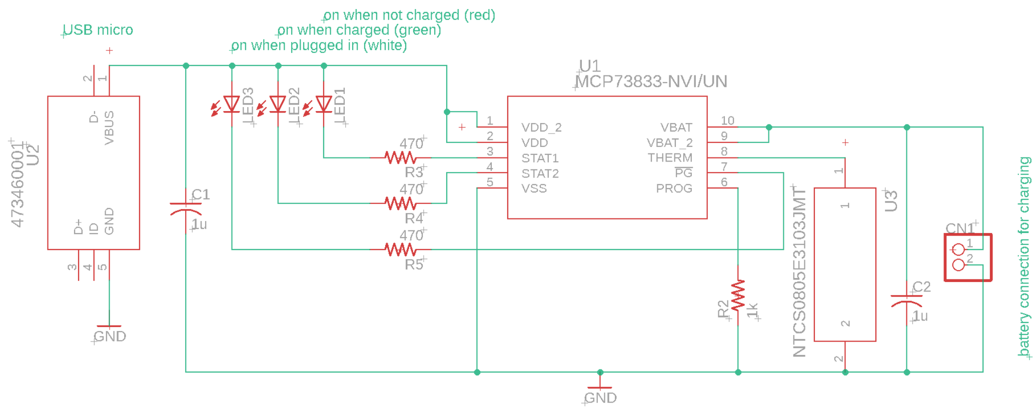


Figure 12: Battery Charger Schematic

From left to right the components are: a USB micro port, the charging IC, and a JST-2 pin connector for the battery. The USB port will provide the charging power for the battery when the battery is plugged into this JST plug instead of the plug that provides power to the board(s) it is used on.

5.4. Rover Propulsion and Auto-Start Design

In order to complete its mission, the payload must be able to propel itself in response to radio control. Generally, this can be accomplished by a system of motors, wheels, and a method of steering. This section will cover the design of the movement system of the rover, and explain its auto-start system that was briefly mentioned in the power system section.

5.4.1. Overview

For a land propulsion method to be chosen for this mission, the system must be able to navigate sandy and rocky conditions commonly found in a desert without getting stuck or damaged. The chosen wheel configuration must be able to adequately balance and support the weight of the rover over the previously described terrain as well. The propulsion systems also have to be robust and not prone to malfunction. Additionally, the system must be simple to steer and easily respond to vehicle control inputs. Steering mechanisms must be simple in order to reduce the size and complexity of the vehicle in the interest of saving weight. The traditional wheel and continuous track configurations will be compared along with different steering methods based on these criteria.

5.4.2. Propulsion Design Approach

When designing the propulsion system, two different configurations were considered. The first option is a traditional wheel and tire system, where four separate treaded tires spin to move the vehicle forward or backward. The second option is the continuous track configuration which features two or more wheels bound by a track. The track moves as the wheels rotate which propels the vehicle in the direction of the track's motion. Each of these configurations may be controlled or steered via several different methods. Numerous steering methods exist to control the direction of the traditional wheel and tire vehicles by either changing the angle the tires make with respect to the body, otherwise known as rack and pinion steering, or by utilizing a differential power input, or differential steering. In order to reduce mechanical complexity and save weight, two relatively simple methods will be proposed and compared. The goal is to select the most appropriate propulsion and steering methods in order to ensure successful completion of the mission. The options considered are listed below.

5.4.2.1. Traditional Wheel

The traditional wheel configuration is versatile as it can operate by powering only two wheels. Two wheel drive performs poorly in sand and gravel as the two unpowered wheels can become stuck easily. This contrasts with the four wheel drive option which performs better in such conditions as it has more tractive force. However, due to the nature of the vehicle only having four smaller points of contact with the ground under this configuration, becoming stuck in sand or other terrain hazards is still possible. To limit this possibility, large tires with aggressive or advanced tread designs must be implemented. Traditional wheels and tires are well suited at maintaining stability and control at most speeds on favorable terrain.

5.4.2.2. Continuous Track

This traction system is characterized by its use of drive wheels that work together on either side of the vehicle to turn a large, continuous track which propels the vehicle forward. This system performs exceptionally well at traversing the rocky and sandy terrain typically found in a desert. This is due to how the large tracks that span the length of the vehicle distribute weight over a wider area. The larger tracks also increase the area in which the treads can transmit force to the ground. All of these attributes allow continuously tracked vehicles to perform well in challenging and unpredictable terrain. Additionally, because of the larger area of support, such vehicles are sturdy and resistant to tipping over. The track itself is thin and light to allow for constant deformation when in motion. These systems typically are harder to control at high speeds unlike the traditional wheel configuration. This is due to the fact that continuous tracked vehicles can only be steered by differential power input, or differential steering.

5.4.2.3. Rack and Pinion

A simple rack and pinion steering system uses a circular gear, the pinion, to drive a linear gear, the rack, left and right in order to change the direction of the attached wheels. Such a system is incompatible with the continuous track wheel system due to the nature of two wheels on either side being connected by a single track. Therefore this steering system can only be used with the traditional wheel setup. This system is mechanically very simple and reliably reorients vehicles at all speeds.

5.4.2.4. Differential Steering

This method of steering is simple as it only involves manipulating power inputs to either side of the vehicle. Differential steering also involves as little moving parts as possible as it works by directly inputting torque from the motors directly into each wheel. Turning left or right works by rotating the wheels on one side of the vehicle in the opposite direction of the other side. Due to this, the vehicle cannot move forward and turn at the same time as the rack and pinion steering is able to do.

5.4.2.5. Conclusion

The decision was made to utilize differential steering in the design of the rover for this mission. The chief advantage to this style of steering is its simplicity. This steering option uses few moving parts which, if utilized, would add to the overall weight of the payload and also possibly be subject to mechanical failure as well. A secondary advantage of this configuration is ease of control for the user in command of the rover. Simple power inputs can be made to control the rover and spin it in place to record its surroundings. As for the wheel setup, the decision was made to go with the continuous track configuration which is compatible with the differential steering system. This decision was made due to the overwhelming performance advantages held by continuous track vehicles in sandy or desertlike environments. The rover also does not need to be able to achieve high speeds or turn at speed, therefore this design will move forward with a continuous track wheel system.

5.4.3. Rover Auto-Start Description and Expected Operation

Everytime the rover's main power switch is turned on, the microcontroller on the rovery PC will set the load switches connected to each motor to be "open" and will cause the rover motors to be unpowered and therefore unmoving. Again, this is done via power removal and not forced idling because of the detriments described in the power system section. This initial behavior will remain at all times until a series of events happens that verify the rover's landing as follows.

The first event in the series is the detection of flight criteria. This is triggered when a vertical acceleration greater than 4g is detected by the accelerometer and when the altimeter detects an altitude that is 1800m greater than the rover's altitude when it was first powered on. These events do not need to happen at the same time, but will be individually logged. When they are both found to have happened, the first event in the series is completed. The measurement of 4g of vertical acceleration is a force that is highly unlikely to be experienced by the rover until the rocket has taken off. If the rocket fails to produce this acceleration, this event will be triggered when the rocket drogue shoot deploys which is expected to cause 8g of force. This metric checked against an altitude of 1800m (~6000ft) gives the rover no doubt that it is in flight.

The second event is the detection of zero motion from both the accelerometer and the altimeter. Vertical velocity measurements can be obtained from the accelerometer and can be used to ensure the rover is no longer falling. This can be compared to the readings of the altimeter as a sanity check. If the altimeter's readings are viewed as a rate of change, and no change is found it can be determined that there is no relative movement at that moment if both sensors register zero movement. The altimeter is being used this way since it cannot reliably detect a lack of motion based on elevation numbers. There are two reasons for this: the starting altitude of the rover inside of the rocket is very likely to be different than that of its landing altitude due to the elevated position in the rocket, and the altimeter's slight +/20cm inaccuracy could lead to the starting elevation never being met if the capsule landed at the starting elevation.

The third event is the verification of landing. A timer will start that will verify that no movement is detected for 5 seconds before the rover motors are allowed to receive power. This timer will run and monitor the measurements presented in event two to verify no change has happened. This timing action is needed because there are other events in the mission lifetime where zero movement has a chance to be detected. These events are at the rocket apogee when acceleration, velocity, and rate of change of altitude briefly are zero before the rocket descends, and the same behavior can happen with every parachute deployment that affects the canister.

Once all of these events have been triggered in this order, the rover motors will be allowed to receive power. The microcontroller will save in the code an enable variable that will allow the remote control signals received from the RCS to move the rover. It will therefore not have permanently unpowered motors and will be able to be controlled from the observation location using the RCS. The operators will then pilot the rover out of the capsule using the systems discussed in sections 5.8 - 5.10 after the capsule has opened and released the rover as described in the next section.

5.4.4. Landing Detection Logic Illustration

The following figure is a general finite state diagram that covers the landing detection system employed for the rover auto-start system and the CLASS. This logic will be used in the code. The electrical schematic that shows the sensors and connections used to realize the hardware for this design will be shown in section 5.5.4 to reduce redundancy. The design shown there will be used the same way for the rover landing detection system. In the same vein, this logic shown below for landing detection represents the same logic that will be used in the CLASS system and will only be shown here to prevent redundancy.

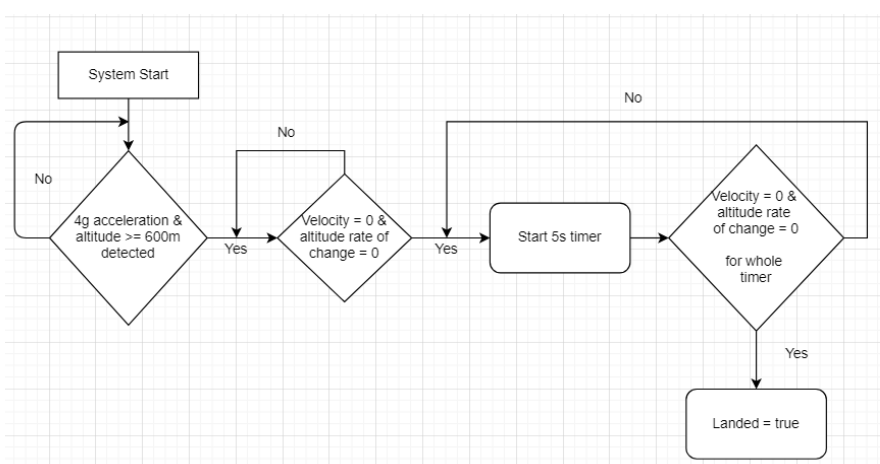


Figure 13: Landing Detection System State Diagram

5.5. CLASS Design

This section will cover the Capsule Landing Automated Sequence System purpose, design process, intended function and schematic. Due to the shared characteristics with the rover auto-start system as previously mentioned, that system will be continuously referenced and substitutes in each section will be explained.

5.5.1. Overview

This system was designed to provide a safe environment for the rover that physically joins the rover to the capsule and locks the capsule door until the capsule has landed and it is safe for the rover to exit. The Capsule Landing Automated Sequence System has the responsibility of maintaining capsule and rover security during flight time, tracking the real-time capsule elevation and acceleration conditions, and managing the safe release of the rover so that it may complete its mission.

5.5.2. Design Approach

This system was designed with the sole purpose of providing a secure environment for the rover until the capsule has landed and the rover can safely begin its mission. The two most important aspects of this design were keeping the rover safe during flight and approaching the design with failsafe operation in mind.

5.5.2.1. Rover Security

Two locks were decided upon to ensure the rover has a secure environment. The first is a lock to secure the door of the capsule while in flight, and the second is a lock to secure the rover to the capsule by its chassis. The favorable final design would be to have a lock for the rover and a lock for the door that releases under different electrical conditions. This would allow for the rover to maintain security in the case that one lock loses or gains power during flight when it was not supposed to. But, options that oppose this favorable design were still considered to allow multiple parts of varying sizes, performance, and cost to be compared.

The door lock - as seen in section 3.1.3 - was chosen to be a small electric solenoid lock. This lock will hold the door shut when it is not powered, and will need autonomous control to receive power to open which will be discussed later.

The rover lock - as seen in section 3.1.4 - was then chosen to be an electromagnetic coupling device. This device was chosen for multiple reasons, but it had the added benefit of meeting the favorable design requirement mentioned earlier. This lock holds shut when it is consistently powered.

The dichotomy between the rover lock and the door lock allows the power system in the capsule to either shut off completely or power both locks at once and allow the rover to remain secure. This better suits the failsafe operation of the CLASS system.

5.5.2.2. Failsafe Operation

The automated function of this system must have confidence in its decisions and be designed in a way that prohibits failure. Almost entirely similar to the way the rover auto-start functionality will work, the CLASS will use sensors mounted to the capsule PCB to determine when it is safe to release the rover for its mission. The altimeter and accelerometer sensors will work in combination with MCU controlled load switches to toggle the operation of the capsule locks when necessary. The requirement for this sensor system is explained in the following section.

5.5.2.3. Duplicate System Reasoning

After reading this previous section on the CLASS design, it is reasonable to wonder why the rover and capsule both have the same sensor configuration to detect landing when one of the systems is already detecting this event. There are a few reasons for this choice.

The first reason for this copied system is that the rover could not have any electrical connection to the capsule. This is due to the fact that a hard-wired communication line could not be set up that would prove to be stable for the duration of the flight as well as be easily separable when the rover must leave the capsule. This issue initially led the team to consider establishing a radio signal between the two PCBs (rover and capsule), but this led to the second issue.

Allowing the capsule to have its own radio transceiver like those used to allow the RCS and rover to communicate not only takes up a marginal amount of space but could add unnecessary interference complications to the communication between the RCS and rover. With the transceiver measuring at 42.5 x 18.36 x 5.5 mm, it would take up more space alone than the PCB to which it was attached. It also carries the price of $19.50 compared to the total cost of $7.15 for an altimeter and accelerometer implementation.

The final issue with using a connection to transmit the already calculated event data is it adds another point of failure to the system. If the connection between the rover and capsule failed the capsule would never release the rover, resulting in system failure. Contrarily, if the capsule has its own sensors it can make an independent decision based on the same code that was used for the rover allowing the two systems to be individual but working synchronously.

5.5.3. Design Description and Expected Operation

This section functions in a way almost completely similar to that of the rover auto-start system explained in section 5.4.3. The moment the capsule PCB is powered, the microcontroller will direct power to the electromagnet via the load switch, and it will cut off the solenoid from power using the load switch, therefore locking the door. This behavior remains until the landing criteria has been met and the diagram of this logic can be seen in section 5.4.4.

This system requires the same criteria to verify landing and allow the capsule locks to open and the rover to leave. The same series of events that are described in detail in 5.4.3 are used in this system. To recap, the events are: acknowledgement of the criteria that the rocket has launched, the detection that the payload is still by measurement of both an altimeter and accelerometer, and the verification that the capsule remains still for 5 seconds after this event.

After these three events are met, it can be safely assumed that the capsule containing the payload has experienced touchdown, and the payload can safely exit. This will be handled by the microcontroller on board of the capsule PCB. The microcontroller will be connected to two load switches that provide the link to power to both the electromagnetic rover lock and the electric solenoid capsule door lock.

It will first send a signal to disconnect the electromagnet from power and keep it disconnected for the remaining mission. It will then trigger the load switch connected to the door solenoid for a very brief amount of time to allow the door to fall past the lock, and then it will remove power from the solenoid. This is a two step process due to the nature of the solenoids function. The solenoid cannot receive power for a long period of time or else it will burn out due to its design. Therefore it will be triggered long enough to allow the door to open and then return to its locked position.

These triggers in combination will leave the door opened and the rover unburdened, and control will be transferred to the RCS operator to move the rover out of the capsule, and complete its mission with its live video transmission discussed in the next section.

5.5.4. Schematic

This section will show the schematic for the CLASS system MCU, sensors, and load switch connections that power the function of this design. The first image shows the sensors used to detect the landing of the capsule. This is also very similar to the configuration used on the rover sans the same MCU choice.

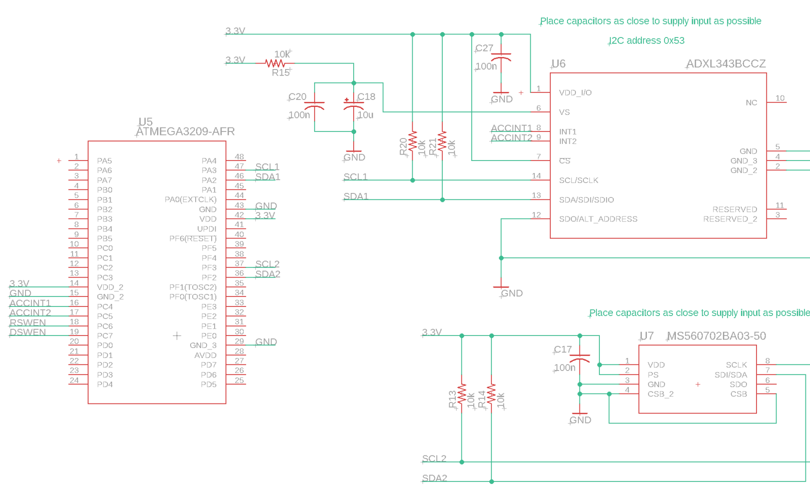


Figure 14: Landing Detection System Sensors Schematic

Both sensors on the right are connected to the MCU on the left via I2C. They are on different I2C lines entirely to allow both sensors to be read with less I2C addressing management on the MCU's part. The top sensor is the accelerometer and the bottom sensor is the altimeter for the system. This system will be duplicated for the rover and its respective MCU.

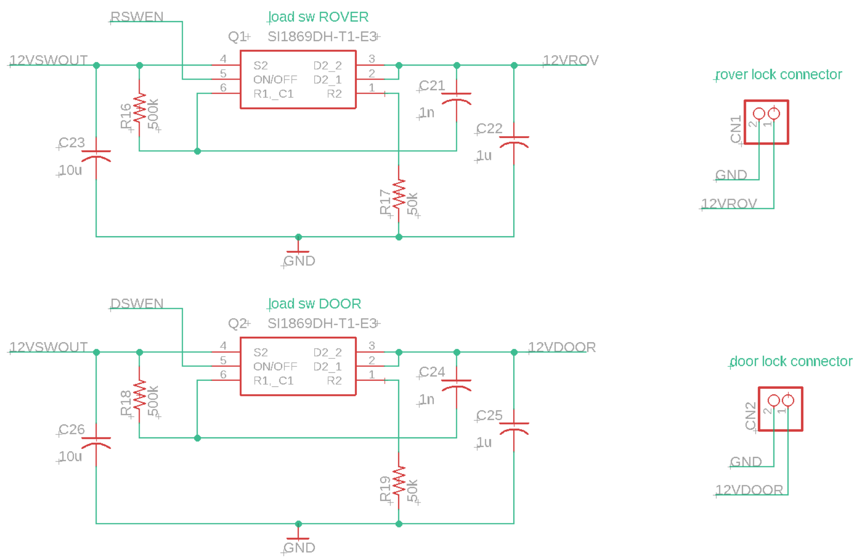


Figure 15: Capsule Door and Rover Lock Control Schematic

In the above schematic, two load switches that take the 12V input are shown on the left, and two 2-pin JST connectors are shown on the right. It should be noted that the JST connectors that give power to their respective locks take input from their independent load switches. As discussed before this is to allow the switches to control the locks individually. The switch enable of each switch is connected to the same MCU shown in the CLASS sensors schematic at MCU pins 18 and 19 for the rover and door switch respectively.

5.6. Video Transmission System Design

This section will cover design considerations and expectations for the video transmission system.

5.6.1. Overview

The Video Transmission System needs to ultimately be able to transmit a signal that can support the rover video specifications. The requirements placed on the video by the group were: 480p resolution and 30 frames per second. As long as the Video Transmission System can support these requirements, it was considered a viable option.

5.6.2. Design Approach

When initially looking at which components to choose for the video transmission system, several different factors needed to be considered. The factors important to transmission were the: camera module, transmitter frequency, transmitter signal format, and video output format. When deciding on components, pricing was the determining factor in the selection. Since the resolution requirement was the most flexible, it was the price that drove our resolution requirement and in turn our component selection. Prices vary drastically depending on the target resolution and frame rate. It was simple to find cheap cameras that support the highest current resolutions, but these options weren't viable because of the transmitters, receivers, and displays necessary to support it. For example, it was simple to find a camera, transmitter, receiver combination for 4k resolution, but a 4k display was well beyond the budget allotted. It would be irrational to transmit a higher fidelity video signal than can even be displayed. Also the rover and RCS are working on battery power so it wouldn't make sense to consume more power for no significant gain in visual information. With higher resolution displays being the most expensive aspect of the livestream process, all of the Video Transmission System components were chosen according to the display.

5.6.2.1. Camera Module

The camera module is ultimately what drives the quality of the video, but in this situation all that was needed is a camera that could capture the amount of pixels the display has. Fortunately it was simple to find cameras with enough pixels to exceed the resolution of the display. It was more difficult to find cameras with resolutions below our chosen display's resolution.

Equally important to the resolution is the format which the camera outputs. Most cameras today take and output them in a digital format, but most FPV drones take advantage of analog video output. Similarly the FPV video transmitters and receivers typically take in analog input and give analog output. For the most part, considering which camera to use was simple, pair an FPV camera with FPV transmitters and receivers.

Another consideration for the camera was the field of view it allowed for. While resolution was not a large consideration for the RCS, visual information was. Being able to see a wider field of view definitely allows the rover operator to make more informed decisions about navigation. When choosing a camera, field of view was another one of the major considerations that drove our camera choice.

5.6.2.2. Transmission Frequency

When it came to finding a compatible video transmitter, one of the most important considerations was guaranteeing the transmitter could transmit video at our desired quality. The biggest concern was whether the transmission frequency chosen would be able to transmit signal at the required quality. Prior to researching the frequency necessary for video transmission it was planned to use the same transmitter and receivers for the rc controls and the video. However, video transmission was found to require a higher frequency than rc transmission so the idea quickly fell apart. It was also not feasible because there seemed to be no simple way to transmit both sources of data on the same signal. Therefore the choice was made to use two separate pairs of transmitters and receivers.

The most cumbersome hurdle faced with the video transmission was finding a transmitter that could work across the expected rover to RCS distance. Most commonly used for fpv drones are 5.8GHz and 2.4GHz transmitters and receivers. In making the choice between the two frequencies the most important factor was the transmitter being able to keep a connection. It is known that the lower the frequency, the better the distance of the transmission. It seemed that 2.4GHz was the better option but it seems there were no combination of compatible 2.4GHz transmitters and receivers in the United States. With this obstacle, it was decided to use the 5.8GHz frequency transmitters for the video transmission.

The two biggest concerns with the choice of 5.8GHz is the shorter distance the signal can traverse and the inability of the signal to penetrate surfaces. 5.8GHz transmission is often used for high quality transmission but is known to instantly lose signal when line of sight is lost. This might not be a big problem for FPV drones because they are airborne, but the issue does pertain to the rover. It is expected there might be some partial obscuration which could possibly cut off our video feed. Obscuration is a much larger issue with a land vehicle than it would be with a drone.

5.6.2.3. Transmission Power

To increase the transmission distance a transmitter can be given more power. To be able to use a 5.8GHz transmitter for the rover, it would only be possible with a higher power transmitter. As higher frequencies have diminishing ranges, the only way to meet our distance requirement would be to choose a transmitter rated for a certain wattage. If using a 2.4GHz signal, wattage is still an important factor to consider but this frequency can span longer distances with less power consumption.

Also noted is the antenna choice that gets paired with the transmitter and receiver. Antennas are important because they can give signal extra range and prevent signal loss when not properly aligned. There are a wide variety of antenna choices with some of the most common formats being dipole, circular, and helical. The most common are dipole antennas which allow for increased transmission distance, but lose signal when not aligned with each other. The circular antenna works well to combat the issue of signal loss when misaligned, but costs more. Helical is different entirely, it allows for a further range but only if facing in the direction of the receiver. The antenna that came with the chosen transmitter is a dipole antenna and the rover will make use of it to save on the given budget.

5.6.2.4. Transmission format

Initially there was a strong consideration between digital and analog video transmission. Knowing that current technology uses digital video transmission to achieve higher quality, the digital signal format was the first consideration. Digital signal transmission is done by having an analog to digital converter in the camera module or on a separate board. Next the signal is encoded to be sent across to the receiver where it is decoded and output to the input of a display. This process is more power consuming than using analog transmission.

Analog transmission has a similar format but the data is not encoded, the transmitter is only used to send the signal across the air. The received signal is not decoded either and rather output straight to the input of the display. The problem with analog signals are their susceptibility to interference. Along a wire or across the air, interference greatly impacts the resulting video quality. As stated before, the quality of the livestream is not the biggest priority so it is a reduction that can be taken for its simplicity of use.

Upon researching it also looked as though the digital video transmitters could be up to 3x the cost of an analog video transmitter. Not only that, the display station would need a more expensive display to take in a digital signal for input. This price hike for digital signal transmission couldn't be reasoned, so the choice was to use analog signal for the video transmission.

5.6.2.5. Video Input/Output Format

Another important consideration was the camera input to the video transmitter. Fortunately, with the camera being made for FPV drones compatibility wasn't an issue. The cables for most FPV cameras all had video outputs in the same format that most FPV video transmitters receive. The two video outputs most common in FPV drones are NTSC and PAL.

The NTSC format is the signal that most Televisions used before HDMI was invented. NTSC stands for National Television System Committee, the organization that invented the standard in format in 1954. This format was used for analog video transmission, most commonly with a display format of 480i 30 frames per second. The "i" next to the resolution denoted that the lines on the display were interlaced horizontally, but the resolution is the same as the 480p resolution more commonly used today. This transmission standard is no longer used commercially for tv, as they switched to digital signal transmission for its capability of higher resolution output. However, this analog signal format remains commonly used in FPV drones because of its simplicity to decode. A drawback of NTSC would be that the analog signal is more susceptible to interference than a digital signal, but the trade off for ease of decoding is very much worth it in these scenarios. In the scenario of the rover, changes in the quality of the livestream are important, but not more important than the drastic increase that would be incurred if we switched to digital signal transmission.

PAL is similar to NTSC in how it was a common signal format for television prior to digital signal transmission. PAL stands for Phase Alternating Line and was used for a typical video quality of 576i at 50Hz. It being another analog signal format, it is susceptible to the same interference an NTSC signal would be. With the necessity of analog signal transmission for fpv drones, this is another readily available signal format on most FPV drone hardware.

The camera chosen for this rover outputs either NTSC or PAL format. The transmitter and receiver both work with composite video input and output so either of these formats will serve our purpose.

5.6.3. Design Description and Expected Operation

The decided upon transmitter and receiver are both for 5.8GHz frequencies. The power used by the transmitter is an advertised 600mW. A sizable number of 5.8GHz video transmitters had a high power rating, seemingly to combat the short distances that the frequency can reach. Blatantly advertised on the transmitter is the ability to transmit across 5km which is over 3x as much as the required distance of 1.61km. The camera output is composite video of which there is a corresponding input for on the video transmitter. On the receiving end there is a composite video output cable which will feed directly into the female AV cable on the display. Our display does not have a resolution higher than 480p, so NTSC was chosen to not exceed the display pixel count.

With this design it is expected to achieve the desired livestream quality of 480p, 30fps. The components selected have been successfully used for higher fidelity video transmission at 1080p, 60fps. Therefore the lower fidelity specifications being used for this rover are expected to be met by this hardware which can support much higher video fidelity than it is being used for.

5.6.3.1. Analog camera recording

The analog camera is expected to operate by reading voltages from each of its photosites. After the values are read they are combined into a waveform, which is the desired composite video signal. This signal is transmitted along the “video out” wire from the camera and fed to the transmitter to send from the rover to the RCS.

5.6.3.2. Video Transmitter

Upon receiving the composite video signal from the camera, the only job of the transmitter is to send the signal input to the receiver. To accomplish this, the signal is passed through the antenna and out across the air to the receiving antenna.

5.6.3.3. Video Receiver

The video receiver will take in the received composite signal through its own antenna and pass it through a wire for video input to the display. The orientation of the transmitter antenna must match the orientation of the receiver antenna or there will be loss of signal. No video encoding was required in this process because the display is expecting the analog video signal.

5.6.4. Diagram

Below is a diagram explaining the process of converting, sending, and displaying visual information with the rover video transmission system. Due to the fact that no microcontroller intervention in this system is needed, and the system only receives power from it's respective PCBs, no traditional electronic schematics are included.

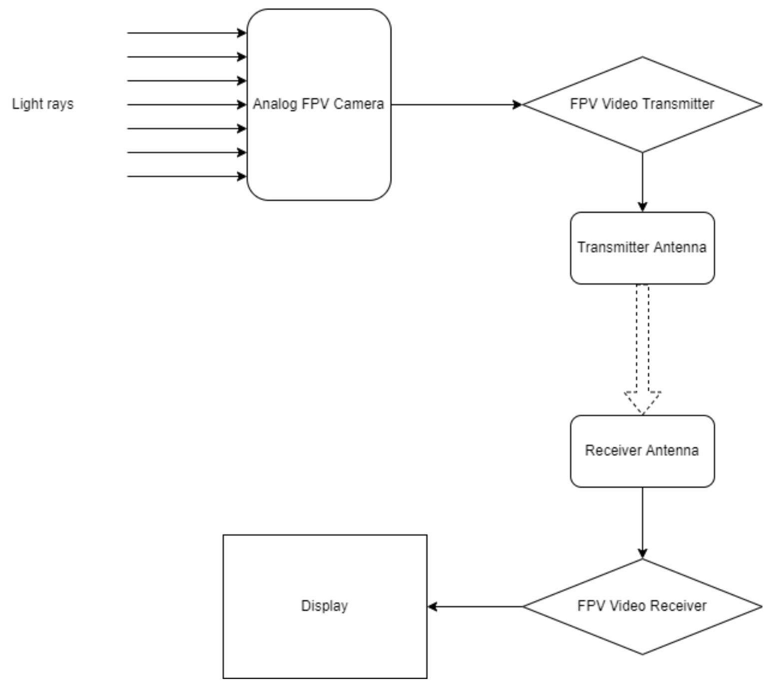


Figure 16: Video Transmission Diagram

This diagram shows the travel of data through the video transmission system. The solid arrows between the devices represent electrical connections, and the dashed arrow represents wireless communication. This diagram will be used to connect the flow of the wireless video capture, transmission, and display devices.

5.7. Video Display System Design

This section will outline the design and expectation of the video display system integrated into the RCS.

5.7.1. Overview

The Video Display System has the sole function of displaying the live video signal being sent from the rover. The system is expected to display the video signal well enough that the surrounding area can be easily seen in real time.

5.7.2. Design Approach

The Video Display System needed to be chosen to work with the video signal output from the video receiver. The video receiver outputs an AV composite video signal, so our options were to convert that signal into another format or find a display that takes in composite video natively. The latter option was chosen to not complicate the design, save the power that would be lost in conversion, and because there are a variety of low cost displays which natively display composite video.

The size of the display was the most subjective point of the Video Display System. The display needed a size big enough to display the area surrounding the rover without any crucial video information lost. The size of display would be one of the biggest dimensions in the RCS, so the ideal display would be a compact, medium size display. Too big of a display would make the RCS more heavy than desired, and draw more current from the battery. The compromise between resolution, screen size, and power draw is subjective because “informational enough” video quality from the display can vary from person to person. With no clear way to quantify how much a certain video quality is objectively worth, an agreement was made between group members to get a lower quality display because of the cost savings.

5.7.3. Design Description and Expected Operation

The final expectations agreed upon for the display were: 480p resolution, 30 frames per second, 5 inch display. It was determined these specifications would meet the requirement of “informational enough”. The display decided upon is a monitor display that comes with a female composite video cable for video input. This input can be made to work by connecting the male AV composite cable from the video signal receiver to the female composite AV cable on the display.

The expected use for the screen is for integration into the RCS. With the RCS being a custom housing being created for the display, the chosen display will need to be removed from the case it comes in. The product description states the monitor with the housing to be 6 ounces, so there are no expected issues with its weight contribution to the RCS. The weight of the RCS would be a bigger consideration if given a larger budget. Also, the wiring inside of the display housing is not included in the product description so it is possible that connections for the display pcb might have to be unsoldered and resoldered.

5.8. Remote Control System Design

This section will cover the design of the remote control system that will be used to operate the RC Rover from afar.

5.8.1. Overview

The remote control system will be used to control the RC Rover from the main control station. The main components of the system are a two-axis analog joystick and a radio frequency transmitter module.The joystick must be compatible with the transmitter and be able to send movement control signals accurately. The following passages will explain how the analog joystick will communicate with a transmitter module and how this connection will be designed and tested.

5.8.2. Design Approach

The remote control system is used to control the RC Rover from the main control station. The goal is to get the remote control system to work over a distance of 4 km or more. It should be able to control the RC Rover to turn left or right forward or backwards. Based on our design and requirements it is not necessary for the RC Rover to be able to turn and move at the same time. Remote control system will contain only one two-axis analog joystick that will be connected to the radio transmission module on the control station side.

The two-axis analog joystick works as the combination of 2 potentiometers which represent the X and Y axis. It works by reading the voltage values through the potentiometer and sends analog values that represent these voltage values. the end of values change as the joystick shaft is manipulated. This data must be able to be transmitted through the transmitter module used in this project. Normally an encoder would be used between the analog joystick and transmitter module to convert the analog joystick's data into a format transmittable over the transmitter module.

The analog joystick consists of 5 pins total labeled as GND, +5V, VRx, VRy, and SW. It also has the option to be used as a push button if the capability becomes of use for the remote control system. Only the GND, +5V, VRx, and VRy pins will be necessary to control the RC Rover.

The remote control system will consist of the two axis analog joystick, the transmitter module that will be used, which is the Reyax LoRa transceiver module. The chosen microcontroller for the remote control system, a video display screen, and a video signal receiver. The microcontroller has the capability to encode the analog joystick's data then communicate with the LoRa transceiver module to transmit the encoded data.

The program written to connect the analog joystick to the LoRa transceiver module must first be able to read the analog data provided when moving the joystick shaft. Based on the input data from the analog joystick, the program should be able to classify the data as whether it is to control the RC Rover to move forward, backward, turn left, or turn right. Based on how much the joystick shaft is pushed in either of the four directions up, down, left, right, the program should interpret the reading as speed. When the joystick shaft is pushed all the way in one direction the speed will be faster compared to pushing the joystick shaft halfway in one of the directions.

At the end of this program that interprets the analog readings of the analog joystick, the data, all the data interpretations must be compiled into one string. The data's length needs to be found as well then the compiled data can be sent using the AT commands that the LoRa transceiver module responds to.

5.8.3. Design Description and Expected Operation

The main operation required of the remote control system is to be able to control the RC Rover to move forward, backward, turn left, or turn right. This necessary movement will be controlled by the 2 axis analog joystick located on the remote control system. This analog joystick's position needs to be translated into electronic information that can be processed by the microcontroller. This is possible by the analog joystick's design consisting of two potentiometers and a gimbal mechanism.

The gimbal mechanism is made up of a narrow rod and two rotatable slotted shafts. One shaft allows the rod to move in the X axis while the other allows the rod to move in the Y axis. When moving the joystick up and down the Y axis shaft will be moved. When moving the joystick left and right the X axis shaft will be moved. Moving the joystick diagonally will move both slotted shafts.

A potentiometer is connected to each joystick shaft. The potentiometer helps to interpret the joystick's position as analog readings. To read the analog joystick's physical position when the position is manipulated, the change in resistance by the potentiometer needs to be measured. The values can vary from 0 to 1023 because the joystick's resolution is 10 bits. The joystick's neutral value will read around 512 for both the X axis potentiometer and the Y axis potentiometer.

In order to get the readings of the analog data from the joystick and determine the X and Y coordinates of the analog joystick's position, both analog outputs from the analog joystick need to be connected to analog pins on the final PCB design. To test the analog joystick an Arduino UNO microcontroller board will be utilized. The Arduino Uno microcontroller board is based on the ATmega328P microcontroller. This is the same microcontroller that has been chosen to be used for the final remote control station design and to be used on top of the RC Rover.

The analog joystick board has a total of 5 pins labeled as GND, +5V, VRx, VRy, and SW. Out of these five pins, only four are necessary for the analog joystick to be used as a remote control for the RC Rover. The necessary pins are GND, +5V, VRx, VRy. These pins represent ground, 5V power supply, variable resistance output along the X axis, then variable resistance output along the Y axis.

The VRx and VRy pins of the analog joystick module board will be connected to analog pins A0 and A1 on the Arduino UNO microcontroller board (Arduino Project Hub)[30]. The +5V pin will be connected to the 5V terminal on the Arduino UNO and the GND pin will be connected to the GND terminal of the Arduino UNO.

To first test that the analog joystick component is working properly, a simple program can be written. The program will read the measurement from the analog inputs VRx and VRy and display the measured values onto the computer screen. Next this first program can be modified to classify different analog joystick measurement readings as moving up, moving down, turning left, or turning right. Instead of displaying the measured values of the analog joystick, the computer screen will display the words forward, backward, left, or right depending on how the analog joystick is manipulated.

After the first two programs show that the analog joystick is working as expected and that the program can accurately determine in which direction the RC Rover should move the data can be compiled to be encoded and transmitted through the LoRa transceiver module. To test whether the analog joystick's data gets correctly transmitted through the RF signal transmission system, first the RF signal transmission system must be designed, built, and tested. This design process is explained in section 5.9.

5.8.4. Schematic

The following design schematic will show the pin connections of the analog joystick and LoRa transceiver module to the Arduino UNO.

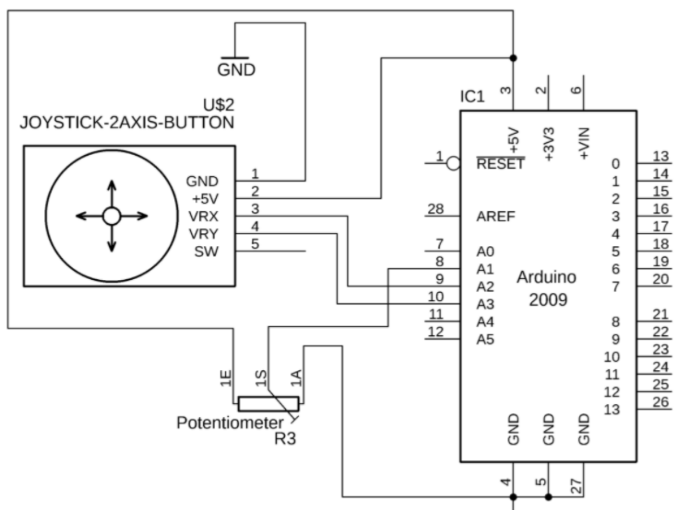


Figure 17: Schematic of Joystick Connection to RCS MCU(Electronic Clinic)[29]

This diagram shows how the joystick will be connected to the MCU on the RCS. The joystick communicates using the MCUs ADC pins for both the x and y direction of the joystick.

5.9. Radio Signal Transmission Design

In this section, the design and testing of data transmission over radio frequency will be explained.

5.9.1. Overview

Data transmission over RF (Radio Frequency) is one of the most important requirements of this project. The name of the project itself is RC (Radio Controlled) Rover, showing that the rover designed in this project will be controlled through a remote control system that will transfer the data containing movement directions over RF. The data must also be able to be transmitted over a long distance from the main control station area to the landing location of the ejected payload from the rocket, around 2 kilometers.

The RF transmitter and receiver module used will be the LoRa REYAX RYLR896 transceiver module. Transceivers can be used as either transmitters or receivers or both at the same time. In this project a two way radio signal transmission system is required. This is because while directional movement data will be transmitted from the main control station to the RC Rover, the RC Rover needs to send various sensor data back to the control station.

The following sections will describe how a two-way radio transmission system will be designed and tested to accomplish the requirements and necessities of this project.

5.9.2. Design Approach

The main requirements that need to be met by the RF signal transmission system is that it must be a two-way connection and be able to transfer data for over 2 km in distance. The transceiver module that was chosen, LoRa REYAX RYLR896, is advertised to feature the LoRa long range modem which provides an ultra-long range of communication over various frequencies. It should be able to reach 4 km transmission range normally but can be programmed or modified to reach a maximum of 15 km range.

When designing the RF signal transmission system the main complexity and hesitation came to choosing which RF transmitter and receiver module should be used to accomplish this task. The Rocket Team informed the group that the rocket will be using two frequency ranges to accomplish its requirements. The rocket would be using 420MHz - 450 MHz and 1 GHz - 2 GHz. The team was instructed to avoid using any components in the 420 MHz - 450 MHz range as this would interfere with the rocket's functionality. 1 GHz - 2 GHz was still safe for the team to use for this RC Rover. The RYLR896 transceiver module uses 868 MHz or 915 MHz.

The chosen RF transmitter and receiver module is actually considered a transceiver, which means it can be used as either a transmitter or receiver or both based on how the pins are configured. Two of these transceiver modules were bought to use one on the RC Rover to receive data on how and where the RC Rover should move. This movement data would be transmitted to the transceiver on the RC Rover by another transceiver that is located on the remote control system.

The LoRa transceiver module consists of a total of 6 pins labeled as VDD, NRST, RXD, TXD, NC, and GND. The VDD pin is used for power supply, NRST is used for an active-low reset, RXD works as the UART data input pin, and TXD is the UART data output pin. Finally, GND is the ground pin. This pin layout shows exactly how this module can receive input or give a data output.

To test the connection between these two transceiver modules, two methods were found. One method used USB to TTL serial cable adapters. TTL stands for transistor-transistor logic. TTL serial is a method of serial communication where data is transmitted between the limits of 0 and 3.3 or 5 volts based on the transceiver's power supply. This is also how UART serial communication is performed.

The USB to TTL adapter would be used to establish a connection between the computer and the transceiver module. To connect the transceiver to the adapter, jumper wires are utilized. The pins available on the TTL side of the adapter are labeled as 5V, VCC, 3V3, TXD, RXD, and GND. To connect the transceiver module to the USB to TTL adapter, the transceiver's RXD pin is connected to the adapter's TXD pin and the transceiver's TXD pin will be connected to the adapter's RXD pin. GND will be connected to GND, then VDD is connected to the 3V3 pin as the power supply.

Now to establish the connection between the computer and the transceiver, any terminal program could be used. The transceiver module can be programmed using "AT" commands. AT commands are a group of instructions that are used to control a modem. AT is the abbreviated form for ATtention and every command line would start with "AT" or "at" which is why it is called AT commands. AT commands can be used to test the communication with the transceiver module or program the settings of the transceiver module to use different frequencies.

To establish a connection between two transceiver modules, they must be able to find each other by an address. The addressing scheme will depend on the module and implementation. Using AT commands we can set a network id and address for two transceiver modules. Then modules on the same network will be able to communicate with each other.

To test the connection between two transceiver modules using USB to TTL adapters, the user can simply connect both USB to TTL serial cable adapters to the same computer and configure the pins to the adapter as necessary. Sending a message from one transceiver to the other is as simple as using the AT command "AT+SEND" followed by the address of the second module, the number of bytes in the message, then the message that is needed to be sent.

The issue with using the USB to TTL serial adapters to test the transceiver modules is that it is difficult to see how to integrate the modules into the PCB layouts of the RC Rover and remote control system. This is because testing the modules by connecting them directly to the computer does not help to see how the modules can be connected and controlled by microcontrollers separate from the computer.

Another method to test the RYLR896 transceiver modules is to use Arduino UNO microcontroller boards. This method will work best for the purposes of this project as the Arduino UNO microcontroller board is based on the ATmega328P microcontroller, which is the chosen component for the radio control system as well as the RC Rover.

5.9.3. Design Description and Expected Operation

The LoRa REYAX RYLR896 transceiver module is an Arduino component that can be interfaced with any microcontroller using UART. By using the Arduino UNO to test the RF signal transmission system, the final design can easily be converted to be compatible with the microcontroller on the RC Rover and remote control station.

To first build the RF signal transmission system, both LoRa transceiver modules must be connected to an Arduino UNO microcontroller board. Arduino is based on a 5V controller while the REYAX transceiver modules can only handle voltages from 2.8 to a maximum of 3.6V. The typical voltage for the LoRa transceiver module is 3.3V, so a converter would need to be used to convert the 5V from the Arduino UNO to 3.3V.

Instead of using a converter, a voltage divider circuit can be built to reduce the voltage that theArduino UNO will send to the LoRa transceiver module. By connecting a 4.7k and 10k resistor in series the 5V voltage supply would be reduced to 3.4V, which is an acceptable voltage level for the LoRa transceiver modules. This voltage divider is not for the 3.3V power supply for the LoRa transceiver module, but rather to control the operating voltage that the Arduino UNO uses from damaging the REYAX transceiver modules.

While prototyping and building this design on a breadboard, jumper wires will be used to complete the connections necessary. In the final design implementation these connections will be integrated into the final PCB layout of the RC Rover and the remote control system. A wire from the middle of the resistors should be connected to the RXD pin on the LoRa transceiver module, then from the then of the 10k resistor a wire must be connected to the ground while from the other side of the 4.7k resistor should be connected to the pin labeled as TX on the Arduino UNO.

The LoRa transceiver module consists of six pins. These are labeled as VDD, NRST, RXD, TXD, NC, and GND. The VDD pin is for the power supply, NRST is used for active low reset when necessary, RXD is for the UART data input received by the module, and TXD is for the UART output data that the module wants to transmit to another module. Finally GND is to ground the LoRa transceiver module.

To complete the pin connections to the Arduino UNO, first the GND pin of the LoRa transceiver module should be connected to the GND pin on the Arduino UNO. To supply power to the LoRa transceiver module a wire must connect the VDD pin on the transceiver module to the 3.3V power supply pin on the Arduino Uno. Next the TXD pin of the LoRa transceiver module should be connected to the RX pin of the Arduino UNO. The RXD pin is already connected to the TX pin of the Arduino UNO through the 4.7k resistor.

This pin connection design between the Arduino UNO and LoRa transceiver module was first designed to represent the transmitting side of the RF signal transmission system. Since the LoRA modules are transceivers and can transmit and receive data the connections remain the same on the receiving side of the RF signal transmission system. So the second LoRa transceiver module can be connected to the second Arduino UNO and set up using the same steps as above used for the transmitter side.

To first test the connection between the two LoRa transceiver modules, the AT commands can be used to send various messages from either the transmitter or receiver side. The USB to TTL serial cable adapter may still come in use to directly interface with the LoRa transceiver modules to check that they are on the same network and have unique addresses that can be used to identify each transceiver module.

When programming the transmission of data over the RF signal transmission system, an important line to include is to declare the baud rate for serial communication necessary for the timely communication between the RC Rover and remote control system. REYAX provides a LoRa AT Command Guide which can be applied for programming the specific REYAX RYLR896 transceiver module that is used in this project.

The LoRa AT Command Guide explains how to use AT commands and the sequence in which they should be used from setting up characteristics of the LoRa transceiver modules like the address, network id, frequency for transmission, and other RF wireless parameters.

After configuring the settings for the LoRa transceiver modules and testing simple data transmission works through AT commands, the analog joystick can be interfaced with one of the LoRa transceiver modules and Arduino UNO set ups to test whether the analog joystick position is transmitted correctly. Following the testing of the analog joystick in section 5.8, similar steps can be taken to test the analog joystick along with data transmission over the RF signal transmission system.

First the raw coordinate data can be transmitted over the RF signal transmission system. The coordinates of an idle analog joystick would read around (512, 512) representing the X and Y axis as the positional data along each axis ranges from 0 to 1023. Similar to the program written to test the analog joystick, two programs would need to be written to configure the transmission of the analog joystick's positional data.

On the side where the analog joystick is connected to the Arduino UNO and LoRa transceiver module, the program must first be able to read the positional data from the analog joystick. This process is explained in section 5.8. After the analog joystick's positional data is read, the program must encode this data to be transmitted over the LoRa transceiver module. This is simply done through the AT commands provided in the LoRa AT Command Guide. The positional data can be sent through serial communication using the command AT+SEND, followed by the number of bytes, then the data that needs to be transmitted.

On the receiving end which consists of only the LoRa transceiver module and the Arduino UNO, a program needs to be written to interpret the data received by the LoRa transceiver module. Since the data is transmitted in the form of a string, a variable can be declared in the form of a string labeled as Incoming. After identifying the variables necessary to receive the transmitted data, a loop can be created to identify whether the variable contains data, display the data, then clear the data from the variable to make it available for the next transmission. This is just a possible method for reading the data transmitted from the analog joystick through the LoRa transceiver module. A more convenient or correct method of reading and decoding the data received may be developed during the testing stage.

After testing and determining that the analog joystick's data is transmitted through the RF signal transmission system, testing can begin to configure the LoRa transceiver modules to set up a two-way transmission system. In the final stage, this will allow the RC Rover to send various sensory information to the control station in addition to receiving the analog joystick data from the remote control system telling the RC Rover how and where to move.

To test a two-way connection, one of the sensors can be connected to the LoRa transceiver module and Arduino UNO setup without the analog joystick. The programs written to perform the data transmission of the analog joystick can be modified to create a loop where both sides will check if there is received data, read it, then send data to the other LoRa transceiver module.

To avoid accidentally damaging the sensors, a two-way transmission system can be designed using LEDs. Along with the pin connections of the LoRa transceiver module to the Arduino UNO, an LED light should be connected to the Arduino UNO board. The anode of the LED light should be connected to a digital pin on the Arduino UNO, then the cathode of the LED should be connected to ground. This should be done on both LoRa transceiver modules and Arduino UNO setups.

Next a program should be written using the AT commands. Both sides will contain similar programs. After declaring the baud rate and completing the setup of the LoRa transceiver module's characteristics, a loop should be created to determine when data is being received and when data is being transmitted. Simply, either side of the RF signal transmission system will send a transmission using AT commands saying "AT+SEND = 0, 8, Testing!", turn the LED on for 0.01 seconds, turn the LED off then start a timer at the end of the transmission. At the beginning of the loop, a timer will start counting, then a variable will determine if the time passed from the beginning of the loop starting is larger than the time of the final transmission plus the blink of the LED light. If this is true, the loop will begin again.

In the receiving section of the program, the code will have an empty variable waiting to be filled by the data transmitted from the other LoRa transceiver module set up. When the program determines that there has been data received, the statement received will be displayed, then the LED on the setup which received the transmission will blink for 0.01 seconds.

To make this testing of the two-way RF signal transmission system easier and more noticeable that the connection works both ways, two LED lights can be used at each LoRa transceiver module and Arduino UNO setup. A flashing red LED will mean data is being transmitted, and a flashing green LED will represent data being received.

After this two-way system is determined to be working, the sensor boards that will be used on the RC Rover can be connected to the Arduino UNO to modify the program to fit the type of data that needs to be transmitted from the sensors. The other side of the RF transmission system will still contain the analog joystick to begin interfacing all the final components together.

5.9.4. Schematic

The following schematic is just a placeholder for the final schematic design that will be implemented for the RF signal transmission system. This image shows how the transmitter will be connected to the arduino via UART.

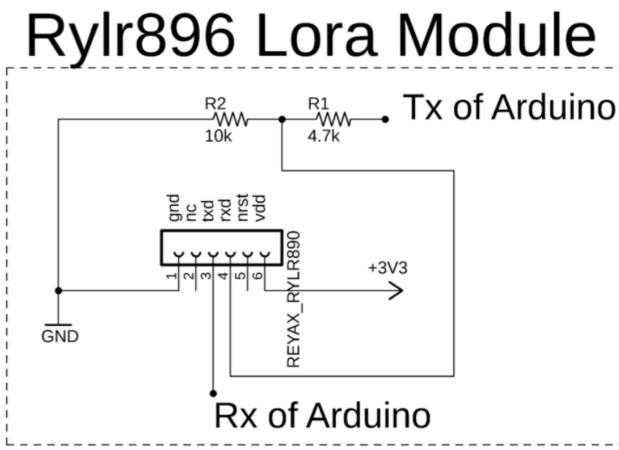


Figure 18: Schematic for the Connection of the Lora Module to the Arduino (Electronic Clinic)[29]

The radio transceiver being used as a transmitter in this diagram is connected to the MCU in the RCS via UART. This will allow the MCU to send the data that will be transmitted to the transceiver.

5.10. Rover RC Movement Design

This section will describe the design process for the rover response to the remote control signals sent from the RCS. It will include the design responsibilities, approach, and a description of the design's function and logic. This section will not include a schematic due to the design that the motors will mount to the board via JST connectors that bridge the motors to the MCU. Therefore showing a schematic would be redundant.

5.10.1. Overview

The rover is required to move a minimum of 3.05m (10ft) after the capsule has landed via remote control. As stated prior, the rover will be piloted from the observation location at the launch site via radio transmission using a 2-axis joystick. The rover will need to receive the signals sent from the RCS and process them to be used to control the speed and direction of its motors.

5.10.2. Design Approach

As discussed in prior sections the rover is using a 2-axis joystick controller and 4 motors driving a set of tank tracks to control and power its locomotion. The radio control signals will be received via the lora module previously covered. This module will provide an output via UART for the rover microcontroller to process.

The microcontroller will be responsible for polling the data from this transceiver and converting its data to a usable signal for the motor control. The microcontroller will not need to poll the data from the device until the rover has landed and the auto start process has finished as described in section 5.4. After this process has occurred the MCU will poll the transceiver and receive the joystick positional data sent by the RCS. This data will then be used to determine the direction and speed of the four rover motors connected to the MCU.

The positional data sent by the RCS will be digital data representing the direction and magnitude of push that the joystick is receiving. This data can easily be interpreted into a vector to control the speed and direction of the rovers motors. The 2-axis joystick used in this project has individual pins for x and y outputs. Therefore numbers from the y pin will drive linear rover motion (back and forward motion) and numbers from the x pin will drive rotational motion for the rover (spinning clockwise or counterclockwise).

Once again the issue of forcing the motors to stop being potentially damaging impedes this design. Therefore the load switches will remain in use for the remote control portion of the rover mission. When the MCU is receiving signals that the joystick is not sitting at the neutral position it will allow the load switches to be “closed” so that the motors can be driven according to the joystick position. However when the joystick is detected to be in the neutral position, the MCU shall “open” the load switches so the rover will be stopped but the motors will not be forced to idle.

The motor speeds will be controlled by a PWM signal sent from the rover MCU gpio pins that are PWM compatible. The speed will be proportional to the amount that the joystick is pushed to allow the rover operator to have fine motor control of the rover to allow not only small movements, but higher accuracy terrain avoidance when necessary. The MCU will also be connected to the direction pin of the motors. This will again be determined by the position of the joystick but instead relative to the +/- x and y directions rather than an absolute position like the motor speed. The expected behavior of this design will be detailed in the next section which will cover the experience and inner workings of using this design.

5.10.3. Detailed Design Description and Expected Operation

This section will explain the expected behavior and describe how both the interpretation of remote control signals and the rover controlled movement will operate. While these systems work in tandem, and the first feeds the second, they will be explained separately since they are separated and mediated by the microcontroller.

5.10.3.1. Interpreting Remote Control Signals

As discussed previously, the remote control signals will be read through the radio transceiver connected to the rover PCB. THe transceiver is read through UART and the raw joystick data will be received through the transceiver.

The remote control signals will be polled from the transceiver by the microcontroller when rover operation begins. This means that the microcontroller will not poll the transceiver for information until it has verified that the rover has landed as described in section 5.4. When the rover verifies this process has completed, the transceiver polling will begin.

The rover will constantly sample the transceiver via UART using the standard rate of 9600 baud. Since the data will be raw joystick data it must be converted to be usable motor control. The rover microcontroller will be aware of the joystick maximum and minimum values which will be referred to as Y_MIN, Y_MAX, X_MIN, and X_MAX for the purposes of this section. These values come from the x and y outputs of the joystick module.

Although a two-axis joystick is being used, the module itself is able to move a full 360 degree circle, which means that both the x and y components can send a signal at the same time. To avoid conflicts in signaling, the component with a higher relative value will be used as the input for the motors. Since each component generally ranges from 0 - 1023, with 511 representing the neutral position, a simple conditional logic branch can be used to find which component will take precedence. If the components are tied, the y component will default to having precedence.

Once the dominating component has been determined, it's value will be processed by another branch of logic to determine the direction and the absolute value from 0 to 1. This will be done as follows:

1. Retrieve dominate component value in range 0 - 1023
    a. If less than 511 (negative direction on joystick)
        i. Set direction as backward or CCW (based on input component)
    b. If greater than 511 (positive direction on joystick)
        i. Set direction as forward or CW (based on input component)
        ii. Subtract 511 from component
    c. If 511 (joystick is in neutral position)
        i. Set direction as no direction
        ii. Set speed value as 0
2. Evaluate the resulting component value to translate the value to an integer between 0 and 10 and save that as the speed value.

This logic will set an integer direction variable and an integer speed variable to be used to control the rover motors as explained in the next section.

5.10.3.2. RC Movement Design

The microcontroller will use the data calculated in the previous section to set the direction of rotation and the speed of the four motors on the rover. The motors have pins for direction and speed control. The speed control is handled by a simple PWM signal. This PWM signal will be determined by the speed value set between 0 and 10 where each integer represents the PWM duty cycle value divided by 10. The PWM signal does not need any higher precision due to the difficulty of consistently moving a joystick less than a tenth of its actuation range.

Five total movements will be supported from the two-axis joystick and their criteria and behavior will be as follows.

1. If the direction value is set to backward, turn on the motors via the load switches, set the PWM of all four motors to the same duty cycle and set each side of motors to opposite directions so that they will move the wheels in the same relative motion
2. If the direction value is set to backward, repeat the same process as above, but the directions of each side will be reversed
3. If the direction value is set to rotate clockwise, turn on the motors via the load switches, set all four motor PWMs to the same duty cycle, and rotate all motors in the same direction to allow the rover to rotate in place
4. If the direction is set to counterclockwise, repeat the above behavior, but reverse the directions of all the motors
5. If the direction is set to unmoving, turn off the motors via the load switches to prevent motor movement

These five supported movements allow the joystick user to have full and accurate control of the rover for the duration of the mission once the rover has safely landed and been released from the capsule.

5.10.4. Schematic

The following schematics will show the MCU setup for the rover as well as the connection of the motors that were discussed in this section. The following parts will be excluded from this section due to their prior discussion: the altimeter and accelerometer, the battery charger, and all voltage regulators.

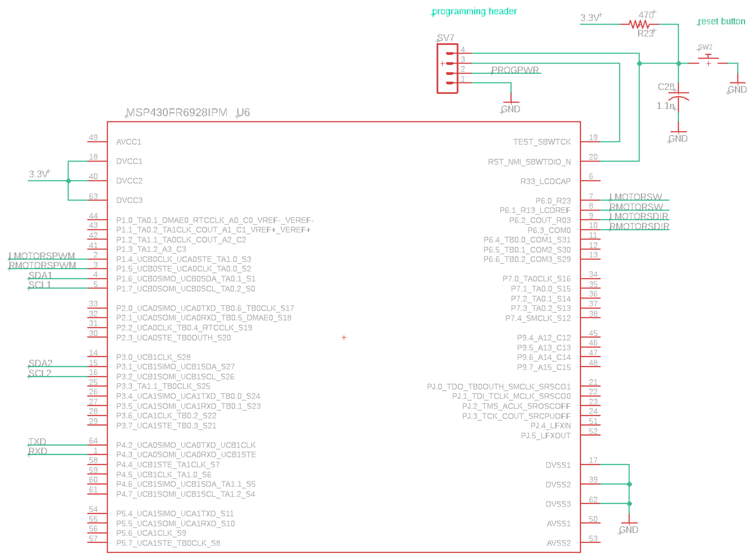


Figure 19: Rover MCU connections

This figure shows all of the connections that allow the MCU to control the following components: altimeter and accelerometer (as discussed in the CLASS schematic) via I2C, the RC signal receiver via UART, and the left and right banks of motors via PWM, GPIO powered direction control, and GPIO load switch control. These connections will be explained in the following schematics.

On the top right the MCU programming header pins and reset button can also be seen. The MCU will be programmed via spi-bi-wire using the MSP430 launchpad. This is done by directly connecting the MSP430 launchpads programming bypass pins to these pins on the designed PCB and then using Code Composer Studio to program the target MSP430 MCU.

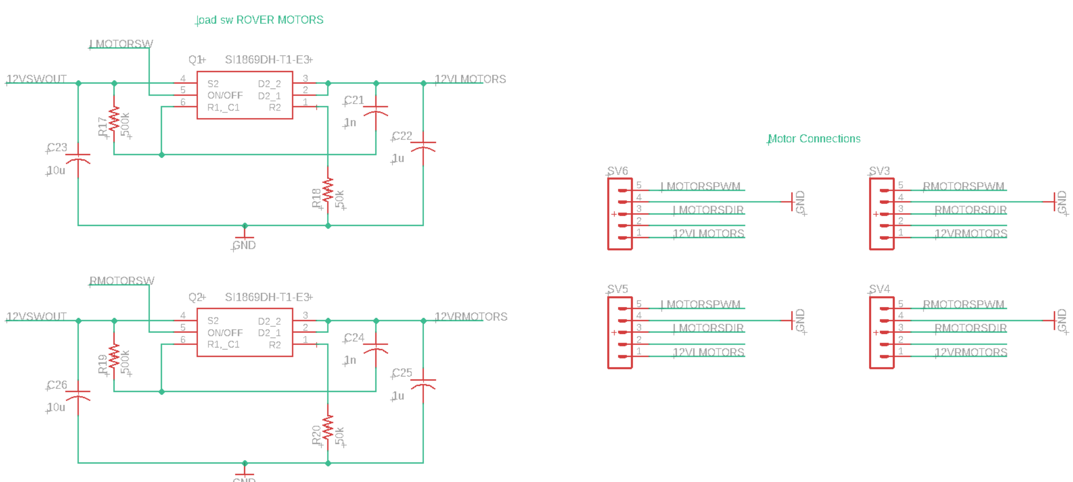


Figure 20: Rover Motor Connections Schematic

This figure shows the pin headers that the motors will be wired to and the power control of the motors. On the left, load switches can once again be seen that bridge the 12V power supply to the motors and allow precise on/off control of the motors via the MCUs GPIO pins (1 per load switch). The right side of the schematic shows the 5-pin headers that the four motors are connected to. It should be noted that the two left motors and two right motors share the same load switch input, and the same signals for their PWM controls. This is because each side of motors will always be moving in the same direction, at the same speed, at the same time. This allows data lines to be reused between the two motors. This saves MCU pins, board space, and reduces MCU computing load and therefore, potentially some power.

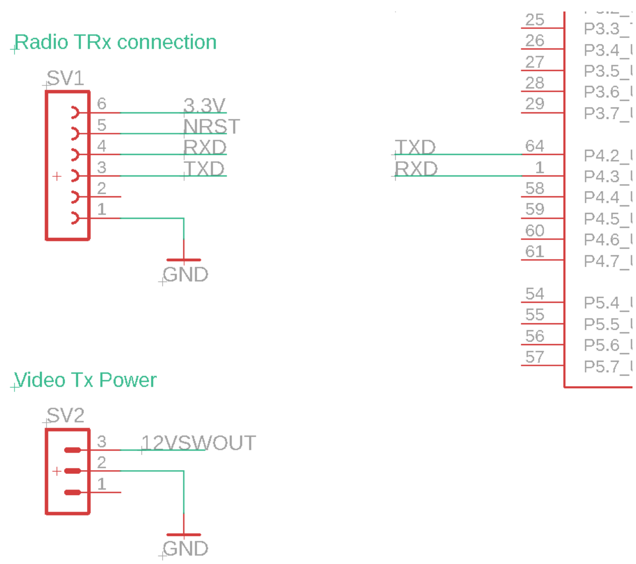


Figure 21: RC Transceiver and Video Transmitter Connections

The last part of the rover schematic that has not been covered in this section or previous sections is the connection of the transceiver that will get the RC signals from the RCS, and the video transmitter that will transfer the camera (not pictured) signals to the RCS .

The radio transceiver communicates with the MCU via UART which will allow the MCU to turn the incoming signals into PWM signals for the motors. This process was discussed in the previous section on remote control. The transceiver may be used to send back diagnostic data to the RCS but that has not been decided. However it will be wired to enable this to allow the decision to be made if desired.

The video transmitter does not require MCU interaction and is only powered by the rover battery. It also has passthrough power for the video camera that will be used and therefore no connection in the schematic is needed for the camera. The camera's data lines and power connect to the video transmitter which receives 12V power from the PCB, and handles its own transmission to its video receiver.

6. System Integration Testing

This chapter will cover the cohesive high-level testing procedures for all of the subsystems designed in chapter 5. It will present the testing for the rover, capsule, and remote control station, and explain the procedures and results of the tests employed in each subsystem. At the end of this chapter, the facilities and equipment used to prototype/test will be acknowledged and explained.

6.1. Rover Systems Testing

This section will cover the subsystems of the rover. The main rover subsystems are locomotion, landing sensing, auto-start, video transmission, and remote control reception. Each section will present the test procedure and the results. A picture will be included of the testing when applicable.

6.1.1. Landing Sensing

This section will cover the landing sensing detection logic that is also used for the CLASS system. It will use very similar hardware to the final implementation of the system.

A breakout board for both an accelerometer and an altimeter were purchased for testing this section. These two boards will both be connected to an MSP430 launchpad to read their output values via I2C. Due to the inability for the team to simulate high G and high altitude environments, the codes will be edited for what can be done in the lab.

6.1.1.1. Accelerometer Test Procedure

The accelerometer will be tested for its ability to both register and save a state in the mode that a certain G force has been measured, and it will also be tested for its ability to detect zero rate of change in acceleration over the length of 5 seconds or more.

Since the real system will initialize the beginning of landing detection after 4g of force is detected, and this is not possible for the team members to simulate, they will test for 2g of force recognition. The team members believed 2G of force can be simulated by a swinging human arm and will attempt to produce this force for testing.

If the creation of 2g of force is possible, the MCU should detect the 2g force and then begin to check when the rate of acceleration change is 0 for 5 seconds as discussed in the design section which should light an LED on the MCU breakout board.

To test the device, the initial force will be induced on the device, and then the device will continuously be accelerated in different directions, for 10 seconds, briefly held still for 3 seconds, accelerated for another 10 seconds, and then set to rest and after 5 seconds the LED should light up indicated the landing state has been detected. This is the success criteria for this part.

6.1.1.2. Altimeter Test Procedure

Due to the group's inability to take the altimeter to high altitudes before a test launch of the rocket is done, it will be tested under normal, daily conditions. It will be tested for two things like the altimeter: the ability to detect a set height in the code, and the ability to detect a lack of change in its current height.

The code for this test will be nearly identical to that of the accelerometer. The height set for the altimeter to begin its landing checking will be a few meters lower than the height of UCF parking garage D which will be determined by the altimeter. When it detects this height it should begin to check if the height has not changed for 5 seconds and then light an led on the breakout board to signify it has detected the landing. This behavior mimics that of the accelerometer and more detail can be found in the previous section.

The test will be carried out by ascending from ground level to the top of UCF parking garage D where the altimeter will detect the target height. The altimeter will then be moved around by hand from the tester’s feet to over their head by full arm extension for 10 seconds. It will then be allowed to rest for 3 seconds, and will once again be moved around from feet to full arm extension above the head for 10 seconds without rest. After this it will be out on the floor, and after 5 seconds it shall light the LED signifying it has detected landing.

If both this test and the previous accelerometer tests are successful the landing detection system can be assumed to be functional.

6.1.2. Rover Locomotion

This section covers the tests that will determine if the movement of the motors as intended is possible. It will test motor control of speed and direction via PWM controlled by a microcontroller board.

6.1.2.1. Test Procedure

This test will be done by connecting a motor to an MSP430 breakout board to be controlled by the board. The motor comes with the following pins: power, ground, direction, speed, and FG (a pin that can tell the microcontroller the exact speed of the motor). All pins will be connected except the FG pin which is not necessary and will not be used in the final design. The motor can have leads straight to the microcontroller since it has an integrated motor driver and therefore no extra circuitry is needed.

Code will be developed on the MCU to run the motor via PWM as it will be in the rover implementation. The motor will receive power from a voltage generator at 12V and will receive direction and speed control from the MCUs GPIO and PWM pins respectively. The code will have two operations that will be explained below.

The first operation of the code will be to adjust the motor speed. One button on the MCU development board will be responsible for adjusting the PWM duty cycle that controls the motor in increments of 10% starting from 10% going to 100% and rolling over to

10%. A piece of tape will be attached to the motor output shaft to make the changes in speed observable.

The second operation of the code will be to invert motor direction. The second button on the MCU launchpad will be used to control the motor direction. Each time the button is pressed the motor will change to a different direction. This will once again be observed via the piece of tape on the motor output shaft.

If both the change of direction and changes in speed can be observed and are consistent, the motor will be verified to work for its intended uses. The test will be successful and provide confidence that the four motors that will be used will be sufficient to power the rovers locomotion.

6.1.3. Auto-Start

This section covers the testing that will determine if the logical design of the auto-start system is possible. That is determining if the rover motors can indeed be turned off by removing their power source via load switch.

6.1.3.1. Test Procedure

This will be a simple test of the ability to cut off motor control via load switch. A motor can be attached to an MCU via breadboard in a way that allows it to be speed controlled by an MCU generated PWM signal. This will allow the motor function to be observed when the load switch is activated. Between the voltage generator and the motor a load switch will be wired that is controlled by the MCU.

The motor will first be powered on with the load switch “closed”. The code running on the MCU will be the same code discussed in the last section, where there is a button to control motor speed, but the other button that was used for direction will instead be used to control the load switch. The motor should be spinning and the speed should be controllable via the button.

Next the button will be pressed that will “open” the load switch via MCU control. When this happens, the motor is expected to lose all power and stop moving. The code running on the MCU that should allow the variance of the motor speed with the button press will continue to run, but the motor should not move no matter what speed is selected. After this, the load switch should be “closed” once again via another button press on the MCU board and the motor should be observed to turn back on and be fully functional, once again moving with varying speeds as controlled by the tester.

If the behavior described above is successful and the load switch can stop the motor from moving and redeliver power without damaging the motor, the test will be successful. This behavior will be used to force the rover to idle before the canister has landed and also force the rover to idle when there is no joystick input.

6.1.4. Video Transmission and Reception

This section will cover the testing that will determine if the video data can be sent from the rover to the remote control station. This will be done using the same transceiver and receiver combination that will be used in the final implementation. This section works in tandem with section 6.3.3 as this testing must be successful for that testing to be completed.

6.1.4.1. Test Procedure

This system will use an FPV video transmitter, FPV video receiver, and an FPV camera. Each of the parts mentioned will all be tested with an oscilloscope to make sure signal is being produced, transmitted, and received without any issue.

To make sure that the camera is working it will be tested out on an oscilloscope to make sure it produces a signal when plugged into power. The other way to check if the camera is producing a useful signal will be to plug in the camera into the display and make sure it produces an image without significant noise. If the image from the camera straight into the display contains too much noise, then it’s likely the image won’t be good enough for the competition when it’s being transmitted. If the image produced is noisy, the things to check will be any surrounding wires, then any surrounding devices, lastly checking connections to make sure everything was wired properly. If fixing the aforementioned issues do not solve an unusable noisy image, then the problem is the camera and another one would need to be ordered.

To check that the FPV video transmitter is working the camera will first need to check for correct image capture. To check the issues with the video transmission and reception system parts prior to the current part in the pipeline need to work. For example, the video transmitter cannot properly be checked without first checking that the camera is transmitting a valid video signal. After checking the validity of the camera signal, the signal will then be fed to the video transmitter. To make sure the video transmitter is working properly we need a device able to receive the transmitted signal. The video transmitter has a variety of usable bandwidths, so the receiver will need to cycle through the possible bandwidths to see if the signal at that frequency changes when the transmitter is turned on. To do this the group could use a frequency spectrum analyzer to view the transmitted video signal.

Testing for the FPV video receiver will commence after making sure the video transmitter works properly. To make sure the FPV video receiver works, it would be best to check with two different 5.8GHz receivers at the same frequency and test that both signals received are the same. If both of the signals received differ by a large factor, it can be assumed there is something wrong with one of the receivers. It is expected that the signals will not be exactly the same because of differences in noise, distance, etc. Minor changes will not be taken into consideration for testing. If the signal is being received properly, the next thing to compare will be the quality of the video signal directly connected to the display versus signal received from the video receiver. If the video receiver signal loses too much information due to noise, the same considerations taken for the video transmission will be used here. If the signal is still too noisy after removing possible sources of interference, then a new video receiver will need to be used.

Further testing of the video transmission needs to be done at varying distances to ensure the 5.8GHz video transmitter and video receiver will work at varying distances. The 5.8GHz frequency band is known to not work well when the transmitter and receiver don't have direct line of sight. To make sure the video transmitter and receiver work well for this use case they will be tested in environments as similar to the FAR competition environment as possible. The transmitter and receiver will be tested with various obstructions such as bushes, trees, electronics, plastic, walls, people, etc. If the video signal retains enough visual information to identify environmental obstacles and overall orientation, then it will suffice for the live video feed.

Once all of the parts mentioned are tested as outlined, the display will need to be tested to make sure it displays at the proper quality the group decided upon.

6.1.5. Remote Control Movement

This section will explain the testing behind the rover's conversion of the received remote control signals into usable movement. It will determine if the rover can be controlled by the rover control station.

6.1.5.1. Test Procedure

This system will be tested using two Texas Instrument breakout boards: the MSP430 launchpad and an accompanying board that has a joystick on it that can be directly mounted to the first board. To take out the variable of distance and radio transmission from this test, this direct method will be utilized.

The code that is presented in section 6.3.1 will be used in this section as well, but with edits for the different MCU. This test will use two motors, and they will be connected directly to the breakout board using the same connections discussed in section 6.1.1 with one difference. The 12V power will instead pass through a load switch that provides power to the motors, and the load switches will be connected to the breakout board as well. These motors will act as if they are on opposite sides of the rover to test both linear motions and rotational motion.

The MCU will read all four axis positions outputs from the joystick for this test. As discussed in the design section 5.10, the joystick signals will be converted as percentages 0-100% in increments of 10 based on the range of the joystick. The direction control will also be derived from the joystick, where forward on the joystick is forward for both motors, backward is backward for both motors, left is backward for the left motor and forward for the right, and right is forward for the left motor and backward for the right.

The second feature of the code is to control the load switches the motors are connected to based on the joystick position. When the joystick is in the fully neutral position (0 in all directions) the load switches should be opened, and the motors should stop moving. THis would allow the real rover to be motionless when intended.

Once again, each motor will have a piece of tape attached to its output shaft to allow for easy visualization of their direction of rotation. The joystick will be moved in all four directions and the correct rotation of the motors must be observed for each joystick direction. The joystick will also be evaluated at the neutral state to ensure the motors will be stopped via the load switch as intended in the final design when no movement should happen. This code altogether will allow the joystick control to be evaluated for its duties in the rover mission, and will give confirmation that the motors can be controlled as designed.

6.2. Capsule Systems Testing

This section will cover the design of the capsule subsystems of the CLASS system. The testing of the prototype of the capsule design that allows it to land in the correct orientation will be shown. The main CLASS subsystems that will be covered are the landing process, landing sensing, and autonomous locking release. Each section will present the test procedure and the results. A picture will be included of the testing when applicable.

6.2.1. Capsule Landing

This section will cover the prototyping and testing of a scale capsule used to test the capsules ability to land in the correct orientation due to its structural design. The design presented in chapter 5 will be evaluated here.

6.2.1.1. Test Procedure

To test the force relationship outlined in section 5.2.2, a small scale capsule prototype will be made out of household materials and suspended by a string that simulates the parachute chord. A small weight attached to the inside of a cardboard roll will act as a simulated center of mass for the prototype. The string will be attached to one end of the cardboard offset from the center point of the cylinder's circular face. To recreate an angle of attack close to that calculated in section 5.2.2, the string will be attached 1.2 cm from the center point of the cylinder's circular face, and the mass will be placed 4.5 cm from the face where the string is attached. This will yield an angle of attack of 75.07 degrees which is very close to the previously calculated 75.96 degrees. Additionally, the opposite end of the prototype capsule will have a curved geometry similar to that of figure 5.2.2. It is important to include this feature in the prototype as this feature will be included in the final design and should be tested to ensure its helpfulness.

Once the prototype is assembled, a series of drop tests will be conducted with the capsule being suspended by its string and dropped to the ground at a constant velocity as close as possible to the expected landing velocity the final design is expected to experience with a parachute. This test will be complete when the capsule has been dropped 50 times. Each successful landing will be recorded and plotted against the measured drop velocity. Every unsuccessful landing will result in a thorough failure analysis and investigation. The success criteria for a test landing are as follows: if the capsule lands with the mass oriented on the bottom of the cylinder without the capsule rolling over first, that test will count as a successful landing. If the capsule rolls over or tips over its end, that test will be considered unsuccessful. In case the volume of the tests begins to damage or structurally compromise the prototype, additional prototypes will be constructed to carry out the remaining tests. A secondary item being tested is if the prototype achieves its calculated angle of attack. This will indicate whether the final capsule will be able to achieve the proper angle for landing.

Figure 22: Capsule Prototype Demonstrating the Balance of Forces and Angle of Attack

6.2.2. Landing Sensing

Due to this system being made of the same parts and containing the same logic as the one presented in 6.1.1, it will not be repeated here. Look at 6.1.1 to see the testing and verification procedure of the landing sensing system.

6.2.3. Rover and Capsule Door Locks Release

To recap, this function will detach the rover coupling from the capsule and will unlock the solenoid that holds the capsule door shut to allow the rover to leave. This section will cover how this was tested, and the results found.

The first step is to assemble the prototype. Individually, each lock (the solenoid and the electromagnet) will be connected to a power supply for testing. Each lock type will have its own test to verify if it will work due to the different nature of their operation.

6.2.3.1. Test Procedure - Rover Lock

The electromagnet will be tested for its ability to hold the rover in place. Rated with up to 50kg of holding force, the lock should be plenty strong to hold the rover but this must be tested to ensure rover security during the mission. With the lock engaged (powered with 12V from the power supply) it will be put under multiple stresses. The lock will have to endure two types of force in the direction of stress. The first force is the impulse created by the parachute deployment and rocket launch. The second force is the static force of holding the rover while in freefall and during launch.

It was determined that the parachute and rocket launch can be simulated by yanking the both sides of the lock away from each other at the same time via two team members pulling on leads connected to the two ends. This should provide more force than the parachute deployment or the rocket launch.

To test the static force, the electromagnet will have a 40lb weight suspended from one end while the other end is held in the air by a team member. If it can hold this weight, it will be able to hold the rover which will only exert a theoretical maximum force of 35 kgf on the lock. The lock will also be tested to ensure that it can hold lock with 5 lbs of force for 30 mins to ensure its stability.

6.2.3.2. Test Procedure - Capsule Lock

The capsule door solenoid lock will have a different test methodology to simulate its functioning environment. The door lock will also experience the same two forces of impulse and static force under the same events discussed above. Both of these will be tested with the difference that the lock holds the capsule door from moving to the open position, and the fact that the solenoid is the locked position when it is unpowered.

To test the impulse forces the contact surface of this lock will be subjected to light taps from a mallet or similar striking device. Due to the higher mass of a mallet head than what the capsule door will be, the strikes will not be free floating strikes, but instead the hammer head will rest on the locking surface and the back of the mallet will be hit by hand to simulate an impulse on the lock. If this does not forcefully retract the lock, the lock has succeeded.

To test the static force that the lock will observe, a weight of 10lbs will be placed on the locking surface of the lock and will remain for 30 minutes. This will ensure the lock will not give way and release the door while in flight as this will be much more force than the door would exert on the lock.

6.3. Remote Control Station Systems Testing

This section will cover the subsystems of the RCS. The main RCS subsystems are reading joystick signals, remote control transmission (sending the joystick signals), and video reception and display. Each section will present the test procedure and the results. A picture will be included of the testing when applicable.

6.3.1. Reading Joystick Positional Data

This section will cover the testing of the ability of the joystick data to be read by an MCU board. The testing verifies the schematic designed for the joystick and verifies the data output of the joystick is as expected and as explained in sections 5.8 - 5.10.

6.3.1.1. Test Procedure

To test the ability of the joystick's positional data to be read by an MCU board, the joystick will first be connected to an Arduino board which uses an ATmega328P microcontroller. This is the same microcontroller chosen to be used in the final design of the remote control system. The analog joystick has a total of 5 pins, but only 4 of them are necessary for the required operation. The GND, +5V, VRx, and VRy pins of the analog joystick will be connected to the GND, 5V, A0, and A1 pins and terminals respectively as described in section 5.8.

The first test will determine whether the positional data of the analog joystick can be read accurately. The VRx and VRy pins of the analog joystick provide the measurements in the X axis and Y axis respectively in a range of values from 0 to 1023. The value 0 represents the negative end of an axis while 1023 represents the positive end of an axis so the value 512 provides the neutral reading of the analog joystick. A program will be written to display the value of the VRx and VRy value onto the computer screen which the Arduino is connected to.

The expected results of this test will display coordinate values for the positional data of the analog joystick. When the joystick shaft is pushed all the way up, the program should display the coordinate (512, 1023). When the joystick is not being moved the program should display a coordinate around (512, 512). When the joystick shaft is pushed all the way to the right the program should display coordinate values around (1023, 512).

The next test will use a different program but the same analog joystick and Arduino set up as before. The new program will classify the various coordinate values as whether it will make the rover move forward or backward then if the rover will turn left or right. It is not required for the rover to move and turn at the same time so these classifications will not be applied. The analog joystick's coordinates will be labeled as moving forward if the Y axis value is above 1000 and it will be labeled as moving backwards if the Y axis value is below 100. The X axis values will be used to classify the direction in which the rover will turn. When the X axis value is above 1000 the rover will turn right and when the X axis value is below 100 the rover will turn left.

The expected results of this second test will display the coordinate value of the analog joystick and display whether the coordinate is classified as moving forward, moving backward, turning left, or turning right.

6.3.2. Remote Control Transmission and Reception

This section will cover the testing that will determine if the joystick data can be sent between the control station and the rover itself. This will be done using the same transceivers to be used in the final implementation.

6.3.2.1. Test Procedure

To test the remote control transmission and reception of the radio frequency signal transmission system the connection between the transceiver modules chosen will be tested first. The LoRa REYAX RYLR896 was chosen to be used as the transceiver for this rover. The transceivers will use a frequency of 868 MHz or 915 MHz. One transceiver will be placed on the rover and one will be located on the remote control system.

To test the connection between the two transceiver modules, each transceiver module will be connected to an Arduino board that uses an ATmega328P microcontroller. This is the same microcontroller that will be used in the final design of the rover and the remote control system. The transceiver modules consist of 6 pins labeled as VDD for power supply, NRST for active-low reset, RXD for UART data input, TXD for UART output, and GND for ground. The transceiver modules will be connected to the Arduino as described in section 5.9.

First both transceiver modules need to be configured to be on the same network. This is done by using AT commands to set the network id for each transceiver module. Next both transceiver modules must be able to find one another using a unique address which can also be set using AT commands.

The first test will determine whether data can be passed accurately from one transceiver module to the other. One transceiver module will be programmed to act as a transmitter. This is done by connecting the TXD pin of the transceiver module to the RX pin of the Arduino. The RXD pin will be connected to the TX pin of the Arduino. AT commands will be used to send a string message from the transmitting module to the receiving module. REYAX provides a LoRa AT Command Guide which can be used to program the transceiver modules. When writing a program to transmit data it is important to include the baud rate for serial communication necessary for the timely communication between the rover and the remote control system.

The receiving end will be programmed to interpret the data received by the LoRa transceiver module that acts as a receiver. Since the data is transmitted in the form of a string, a variable is declared in the form of a string. When the program senses that data has been received, this variable will be filled with the information from the transmission. Additional programming will allow the transmitted message to be displayed

The expected results of this test is to verify that the network id is the same for both transceiver modules and that both modules also have unique addresses. Next the receiving transceiver and Arduino set up must display the message sent from the transmitter module correctly.

Next the transmission of the analog joystick data from one transceiver module to the other will be tested. The analog joystick will be connected to the Arduino and transceiver module set up that is being used as the transmission side. The analog joystick does not need to be directly connected to the transceiver module. Both the analog joystick and transceiver need to be connected to the Arduino board so that the microcontroller can tell the transceiver module what data to transmit through the program written for the transmitter side.

The expected results of this test are the display of the analog joystick's positional coordinates. When the joystick shaft is pushed all the way up, the program should display the coordinate (512, 1023). When the joystick is not being moved the program should display a coordinate around (512, 512). When the joystick shaft is pushed all the way to the right the program should display coordinate values around (1023, 512). This will show that the positional data can also be transmitted accurately over the radio signal transmission system.

To test the range of the radio frequency transceiver modules the same set up and program can be used. An open field like a football field or airplane runway will be necessary to test the maximum range in which the transceiver modules can communicate. The transmitting Arduino and transceiver set up will be located at one end of the field while the receiving Arduino and transceiver set up will move to various distances to test the range.

The expected results of this test is to receive the transmitted message at a range of 2 kilometers minimum from the transmitting transceiver module. This is necessary because the control station will be located 1 km away from the rocket launch site, and the rocket can drift up to 1 mile away.

If the testing shows that the range of transmission does not reach the range that is necessary, there are tutorials available explaining how to extend the range through AT commands. If this does not work as well more research will need to be done to see how the range can be improved. Most likely the range can be increased by using a larger antenna, but the transceiver module comes with a PCB integrated wire coil antenna.

6.3.3. Video Display

This section will include all of the methods used to program and adjust the video livestream from the rover. This will include the process of wiring any equipment and highlight the strengths and weaknesses of components during testing.

6.3.3.1. Test Procedure

To test the video display it will need to be tested with a video signal known to not be noisy. To get this tested any device with an AV out cable can be used. A group member had an Xbox 360 with an AV out cable so it will be used to make sure the display works properly. First the Xbox 360 will be plugged into another AV display to make sure it displays correctly, then it will be plugged into the RCS display to be used as our control test. If the signal displays correctly from the Xbox 360, then the display works properly. If the display doesn't display properly when receiving the video signal from the video receiver, the problem could be wiring or another part of the video transmission reception system.

Once the display has been tested properly in the housing that it comes in, the monitor will be removed from the housing and tested again. This test is necessary to ensure the monitor will function when it is integrated into the 3d printed housing made for the RCS. If it doesn't work outside of the housing, it will most likely be due to a bad connection. If there are issues outside of the housing, the monitor will be tested again with the Xbox 360 AV connection. If the display doesn't work outside of the housing with the Xbox 360 AV connection, it's possible something was damaged in the removal of the monitor from the housing and a new display would need to be ordered.

6.4. Facilities and Equipment

This section will present all of the facilities used to conduct parts testing and prototyping. It will also address the equipment used in the facilities and any equipment used by the team members that was integral in testing and prototyping.

6.4.1. University of Central Florida Senior Design Lab

The Senior Design class provides access to the UCF Senior Design Lab for students to test, and build their projects. The space was used by the team to prototype the majority of the systems tested in the previous sections and is free to access.

6.4.1.1. Equipment Used

- Oscilloscope
- Voltage/function generator
- Soldering equipment
- Breadboards
- Wires and wire cutters
- Linear circuit components

6.4.2. Team Member Homes

Due to the distance of some team member homes from the university, and the nature of coding, and CAD modeling, there was some prototyping and testing done at team member homes individually. A majority of the code that will power the operation of the system was written on personal computers at the ECE team member's homes. The MAE student also developed their CAD models and ran their simulations at their home. They also used their home to create and test the prototype capsule model.

6.4.2.1. Equipment Used

- Personal Computers
- Code Composer Studio
- SOLIDWORKS
- AutoDesk EAGLE
- Code Composer Studio
- Arduino IDE

7. Administration

This section will provide the schedule of the project's functional milestones and the budget and cost of the project. The last section will individually present the budget, estimated costs, and actual costs for all purchased materials used in the project implementation.

7.1. Milestones

This section covers the estimated completion dates of the design and implementation of this project. The following three tables will provide a starting standard for the group's deadlines and will serve to keep the group on schedule.

Number	**Milestone Description**	**Planned Completion period (SD1)**
1	System planning and parts research	09/13/21 - 10/22/21
2	Order Parts	10/25/21 - 10/29/21
3	Design and test proof of concept radio control communication circuitry	10/25/21 - 12/03/21
4	Design and test rover sensing and power management circuitry	10/25/21 - 12/03/21
5	Design and test proof of concept live video transmission circuitry	10/25/21 - 12/03/21
6	Design and build proof of concept Rover Chassis with motors, tracks, and test movement with simple prototype code and MCU launchpad	10/25/21 - 12/03/21
7	Design and test rover capsule and sled assembly prototype	10/25/21 - 12/03/21
8	Design and test CLASS	10/25/21 - 12/03/21

Table 28.a: Project Milestones by Planned Week of Completion for SD1

Number	Milestone Description	Planned Completion period (SD1)
9	Design full main PCB (combine 3 and 4 and 5)	10/25/21 - 12/03/21
10	Design full RCS PCB (combine 3 and 4)	10/25/21 - 12/03/21
11	Design full CLASS PCB	10/25/21 - 12/03/21
12	Finish Semester One Document	11/29/21 - 12/03/21

Table 28.b: Project Milestones by Planned Week of Completion for SD1 Continued

Number	Milestone Description	Planned Completion period (SD2)
1	Order PCBs	11/06/21 - 11/10/21
2	Build PBCs	01/10/22 - 01/28/22
3	Fully assemble rover and write code	01/31/22 - 02/11/22
4	Test full deployment and mission lifecycle	02/14/22 - 03/18/22
5	Final testing and necessary revisions	03/21/22 - 05/10/22

Table 29: Project Milestones by Planned Week of Completion for SD2

7.2. Budget and Costs

In this section, the project budget will be presented to show the influence on part selection, a preliminary cost estimate used for project planning will be provided, and a full list of any hardware or software purchased will be given.

7.2.1. Budget and Estimated Costs

This project is funded by Aerojet Rocketdyne who have provided the University of Central Florida a sum of money to support each team. The following table provides a preliminary rough estimate of costs with a materials list gathered from high-level research into the type of components needed to satisfy the project requirements. The broad components listed in the following table may increase or decrease in quantity and estimated price as the system is finalized and specific parts are chosen.

Item	**Quantity**	**Estimated Price**
Microcontrollers	3	$20 total
Altimeters	2	$5 each
Accelerometers	2	$2 each
Video Camera	1	$20 each
Custom PCBs	3	$15 - 20 each
Transmitters and Receivers	4	$20 each
Lithium-ion Batteries	3	$15 - 20 each
Linear charging IC	6	$1 each
Load Switch	10	$0.50 each
Motors	4	$20 each
Rover Lock	1	$30 each
Capsule Door Lock	1	$5 each
3D-printed Rover Chassis	1	$40 each
Tank track assembly	2	$15 - 20 each
Rover Capsule	1	$40 each
Breakout Boards for Testing	4	$5 - 10 each
LCD Screen	1	$40 each
TOTAL (Estimated)	**X**	**$520 - 580**

Table 30: Estimated Total Cost to Implement the Project

7.2.2. Hardware BOM

This section presents the exact names and prices of the materials that will be used over the lifetime of the project. This list does not include minor circuit board components and will instead include an estimated total PCB production cost as well as the cost for the individual systems used on the PCBs.

Name	Amount	Cost
ADXL343 accelerometer breakout	1	$5.95
MPL115A2 Altimeter breakout	1	$7.95
800x480 RCA Video Screen	1	$40.00
Solenoid Piston Lock	1	$4.88
Electromagnetic Lock	1	$30.06
Run Cam Nano 2	1	$20.00
REYAX RYLR896 Radio Transceiver	2	$19.50
Video Transmitter and Receiver Combo	1	$27
SOP-8 testing board	5	$0.55
12V DC Motor with driver	4	$19.90
AP2401MP-13 Load Switch	8	$0.44
6Ah battery for rover & RCS	2	$21.90
1500mAh battery for Capsule	1	$10.90
Battery charger eval board	1	$10.50
AMS560702BA03-50 altimeter	2	$4.05
ADXL343BCCZ accelerometer	2	$3.10

Table 31.a: Cost of the Project Using Realized Parts Choices

Name	Amount	Cost
MCP73833-NVI/UN battery Charger	6	$1.13
ATMega3209-AFR	2	$1.93
ATMega328 breakout board	1	$0
MSP430	1	$9.14
MSP430 breakout board	1	$0
Joystick	1	$0
Voltage regulator 3.3V	3	$3
Voltage Regulator 5V	3	$3
Voltage regulator 12V	3	$3
JST 2 cable	4	$0.95
JST 3 cable	4	$0.95
JST 5 cable	4	$0.95
DC 12V power cables	1	$9.90
Capsule manufacturing	1	$40
Rover chassis manufacturing	1	$40
Rover tank track pair	1	$30
PCB manufacturing	3	$15
TOTAL COST	**NA**	**$564.63**

Table 32.b: Cost of the Project Project Using Realized Parts Choices Continued

7.2.3. Software BOM

This section will prevent the software used. All software was free, but this section is here as an easy place to see the software together. Also due to this, there will be no cost column, and due to the nature of software, there will be no amount column. This software powered both the design of the circuits of this project, the construction of the circuits, and the programming of the circuits.

Name
Texas Instruments Code Composer Studio
Texas Instruments WEBENCH Power Designer
Arduino IDE
AutoDesk EAGLE
SOLIDWORKS
UltraLibrarian

Table 33: Software Used in the Project

7.2.4. Suppliers and Distributors

This project relied on materials from multiple suppliers and distributors. The suppliers and distributors used the hardware and software used this semester were: Adafruit, Amazon, Digikey, and Mouser, Texas Instruments, and AutoDesk. These websites provided the avenue for the procurement of the testing and prototyping parts used in chapter 6. In the future when PCB manufacturing and assembly, as well as rover and capsule manufacturing and assembly are completed, the supplier and distributor lists will expand, but this semester did not require the use of these other supplies and distributors.

The expected suppliers and distributors of the rover and capsule are expected to be Amazon, and UCF. The team will incorporate parts from Amazon in their designs, but they expect UCF will be the source of manufacturing materials and processes either via 3D printing or CNC machining. Therefore either the TI Lab or manufacturing lab on UCFs campus will be used for these two parts of the system.

The UCF College of Mechanical and Aerospace Engineering purchasing department was used for the procurement of all parts for this team. The parts were funded by the Aerojet Rocketdyne sponsorship money provided to the team for this project as discussed prior. The purchasing department at this college will be used as the intermediary for all parts purchasing until the end of this project.

8. Conclusion

This document fully covered all of the processes behind planning the Aerojet Rocketdyne sponsored Remote Control Rover Rocket Payload system. All of the work completed in the Fall 2021 semester by the members of this team exists in this document. This document will continue to be used as a reference for the team in the Spring 2022 semester when project implementation begins.

This document can be used to provide valuable insight into a reader's own design of a similar system. It can also be used to validate the system created by this team through repetition of system design and testing procedures outlined in this document. It is recommended that any reader who wants to build a system similar to this should use this document as a reference or inspiration for a design. They should also refer to the standards and constraints presented in this document to decide if their design fits their laws and goals, or to inspire research of other constraints and standards.

The Fall 2021 semester in which this document was created, presented many challenges to the team members. Between remote work, the global chip shortage, and the management of the complex and busy schedules the team members share, much communication and extra effort was needed to complete this design and prototyping phase of the two semester capstone project. The project was however still successful but one key part the team members wished to have done this semester was held back due to the following issue.

The team ran into a large issue regarding their ability to order parts to test their preliminary designs. Due to the nature of the project being sponsored, the team was unable to order parts on their own time since the university had to approve the purchases made. The process of submitting an order was originally planned with the expectation that it would take two weeks. Due to a series of events and struggles in the line of communication between the team and the parts ordering department, the process to submit an accepted parts order took six weeks. This set the group back from having parts in October, to the parts order being accepted the day before Thanksgiving in late November. This caused a massive delay in the group's ability to test and prototype. The group ultimately designed full testing procedures and are waiting for parts to come in to verify their design. Due to this, the results of parts testing and prototyping could not be included in this document. If the parts come before the university closes for winter break, the team will explore testing over the break, if not they will immediately test in the first week of senior design 2 in Spring 2022.

The team is optimistic for the upcoming approach to the Spring 2022 semester. This next semester will allow them to fully build the design presented in this document and begin to test and revise where necessary until a functioning product is created that fits their specifications. They plan on testing their designs in the first weeks of the next semester, and then will order their first PCB revisions in week 3 or 4 to be on track for full product assembly down the line.

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Mak, Benjamin. "Basics of Load Switches (Rev. A)." Texas Instruments Incorporated, September 2018, https://www.ti.com/lit/an/slva652a/slva652a.pdf?ts=1633893140466&ref_url=https://www.google.com/.

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Christopher Keefer

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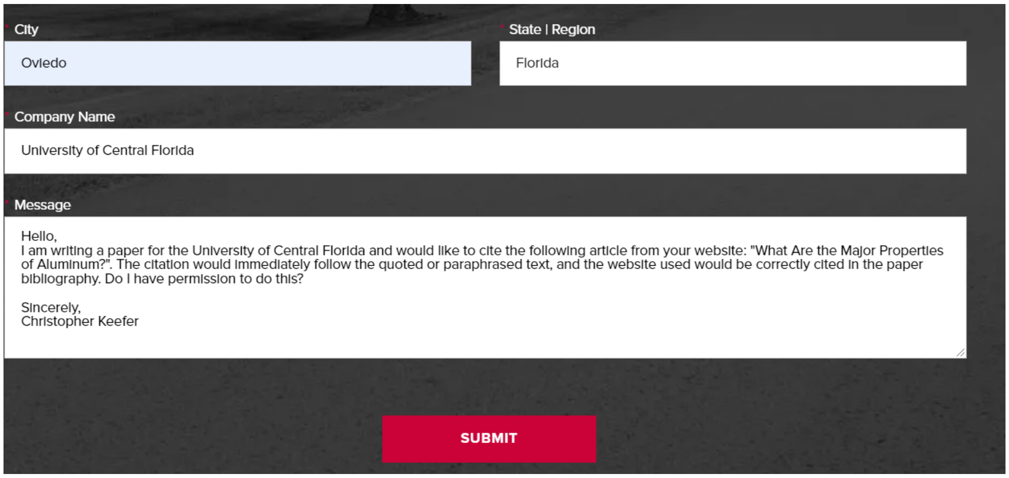
17. Kloeckner Metals Corporation permission request, no response was received:



City: Oviedo

State | Region: Florida

Company Name: University of Central Florida

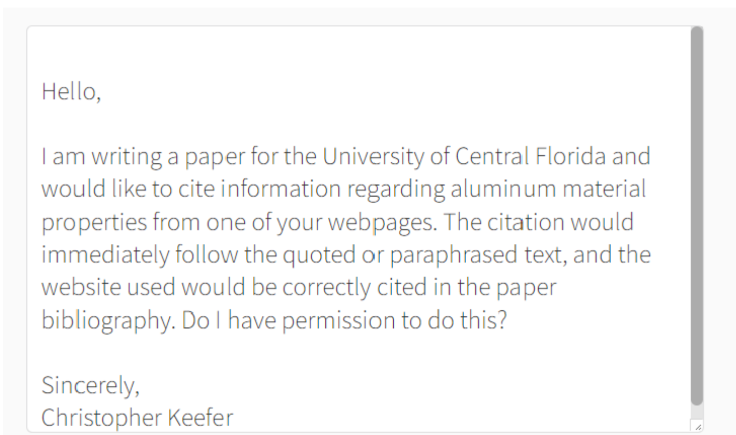
Message:

Hello,
I am writing a paper for the University of Central Florida and would like to cite the following article from your website: "What Are the Major Properties of Aluminum?". The citation would immediately follow the quoted or paraphrased text, and the website used would be correctly cited in the paper bibliography. Do I have permission to do this?

Sincerely,
Christopher Keefer

SUBMIT

18. All Metals Fabrication permission request, no response was received:



Hello,

I am writing a paper for the University of Central Florida and would like to cite information regarding aluminum material properties from one of your webpages. The citation would immediately follow the quoted or paraphrased text, and the website used would be correctly cited in the paper bibliography. Do I have permission to do this?

Sincerely,
Christopher Keefer