ECE 492 - Team Alpha

Devin Arnold, Samuel Ehgartner, Austin Pelayo, Michala Dennis, Alexander Labell, Corin Nosow, Jack Horowitz

Review of Team Organization

- All members split into three design sub-teams:
  - Mechanical Design: Devin Arnold, Corin Nosow & Samuel Ehgartner
  - Electrical Design: Jack Horowitz
  - Embedded Control & User Interface: Michala Dennis, Austin Pelayo & Alex Labell
- With the added administrative responsibilities:
  - Team Leader: Jack Horowitz
  - Assistant Team Leader: Samuel Ehgartner
  - Quality Assurance Manager: Austin Pelayo
  - Treasurer: Devin Arnold
  - Organization Manager: Michala Dennis
  - Website Manager: Corin Nosow
  - Techno Lead: Alex Labell

Review of Project Requirements: The MARGE System

- Driveway security system with multiple operational modes
- The MARGE is composed of:
    - A remote, locomotive robot: The Rover
    - A fixed, solar powered charging station: The Docking Station
- System operates autonomously to detect and authorize vehicles
- Can be manually overridden at any time
- Is a self powered, and contained system

Review of System Components

The MARGE system will be divided into two parts, each of which are responsible for their own tasks:

<u>The Docking Station</u>

- Charging the MARGE Rover
- Sensing the presence of incoming vehicles
- Providing navigational aid
- Sending commands to the Rover
- Communicating with Remote Controllers

<u>The Rover</u>

- Traveling between the Docking Station and the midpoint of the roadway
- Act as a responsive or passive indicator to cars entering the roadway

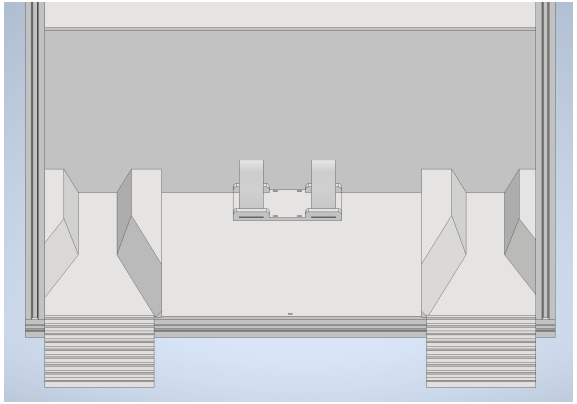
Team Alpha Design Pt.1: Mechanical Systems

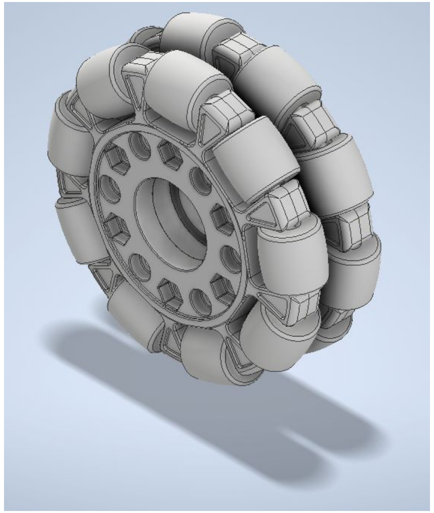
1. The Docking Station
    a. Rover entry compartment
    b. Power accumulation and delivery compartment
    c. Logic compartment
2. The Rover
    a. Drivetrain
    b. Locomotion Platform
    c. Barrier Actuation
    d. Thermal Regulation
    e. Component Mounting

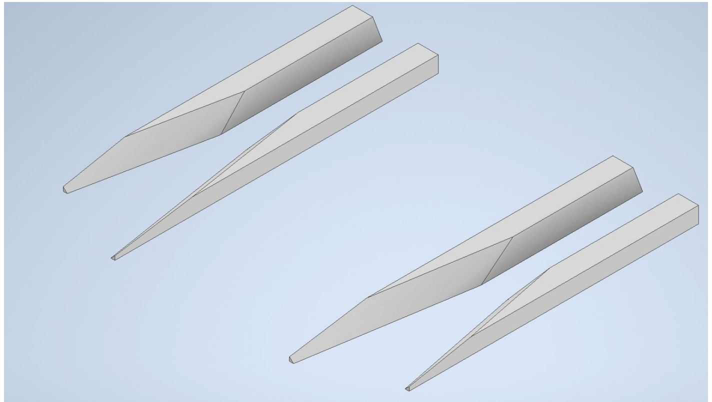
The Docking Station - Rover Entry

- The portion of the docking station where the rover physically enters and parks
  - Used to protect the rover from the elements and charge its battery
- Features the Mechanical Guidance System:
  - An input track that guides the rover into place and reduces error
- Illuminated at night when the rover is navigating to the docking station
- Aruco tag mounted on the back wall
- Switched charging contacts on the base to seamlessly connect to the rover in a dry environment

The Docking Station - Rover Entry Compartment Depiction



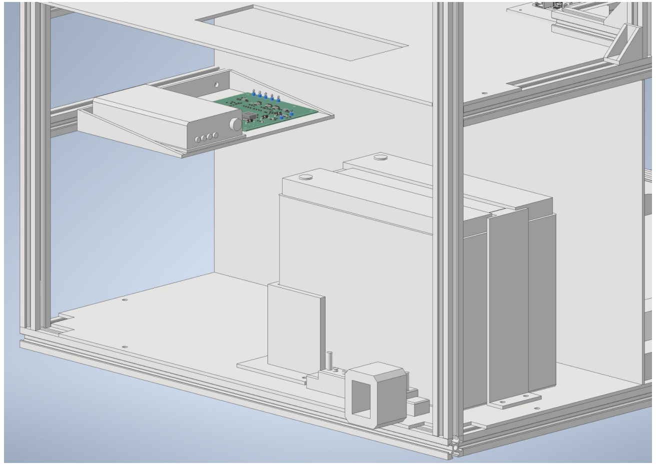


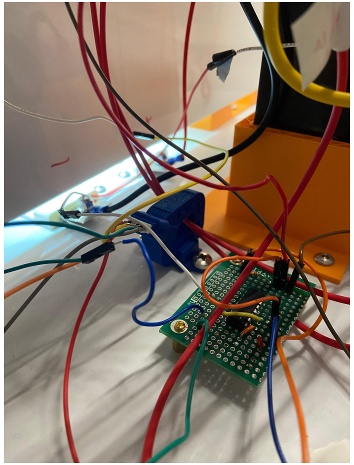


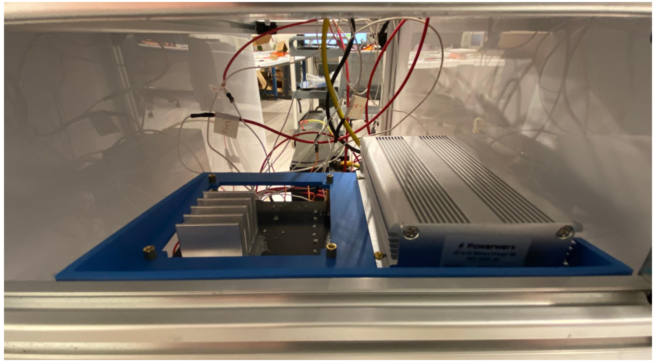
The Docking Station - Power Accumulation & Distribution

- The portion of the docking station where the battery, charge controller and power distribution board is located
- Includes an external SAE standard DC charging port
- Includes master ON/OFF switch
- Physically segregated from other compartments for protection

The Docking Station - Power Compartment Depiction





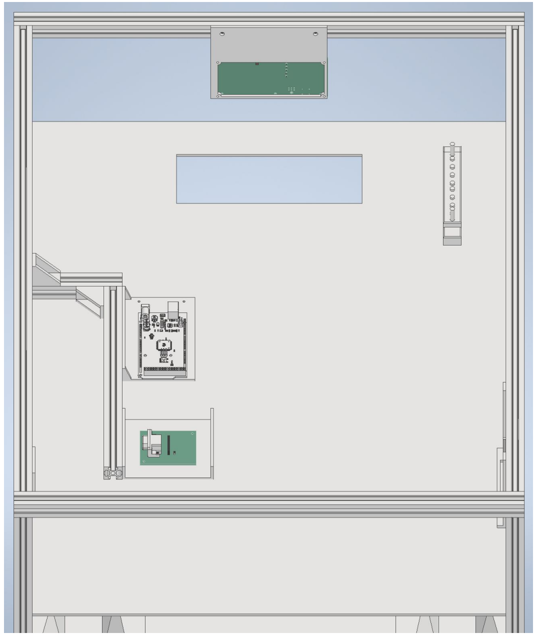


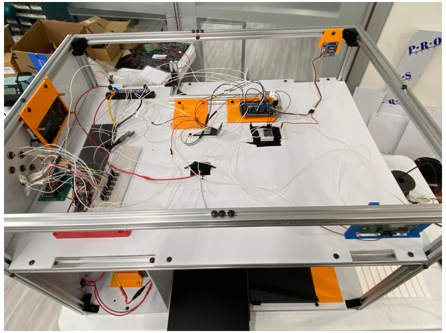
The Docking Station - Logic & Sensing

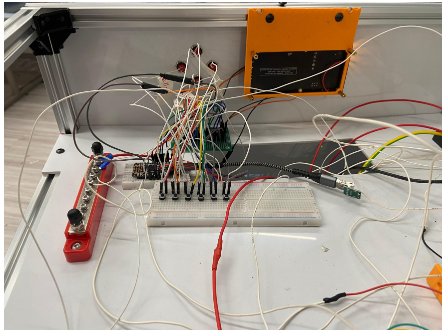
- The portion of the docking station where the the logic, communication, user interfacing and sensing is located:

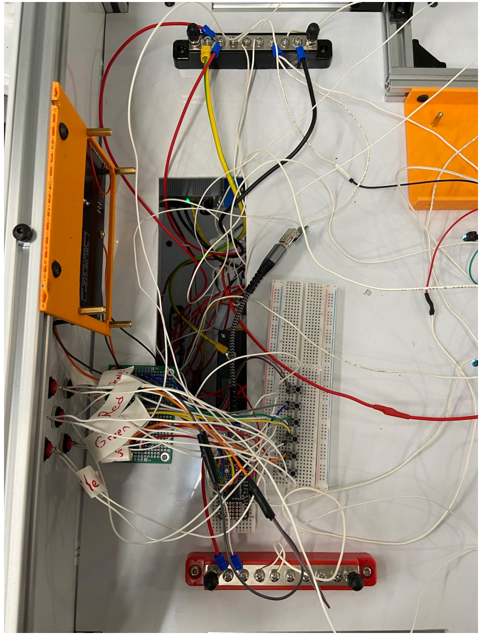
1. Arduino Mega 2560 rev3 & real time clock (RTC)
2. Forward & Aft radars
3. Radio communication module
4. User display interface and control

The Docking Station - Logic Compartment Depiction





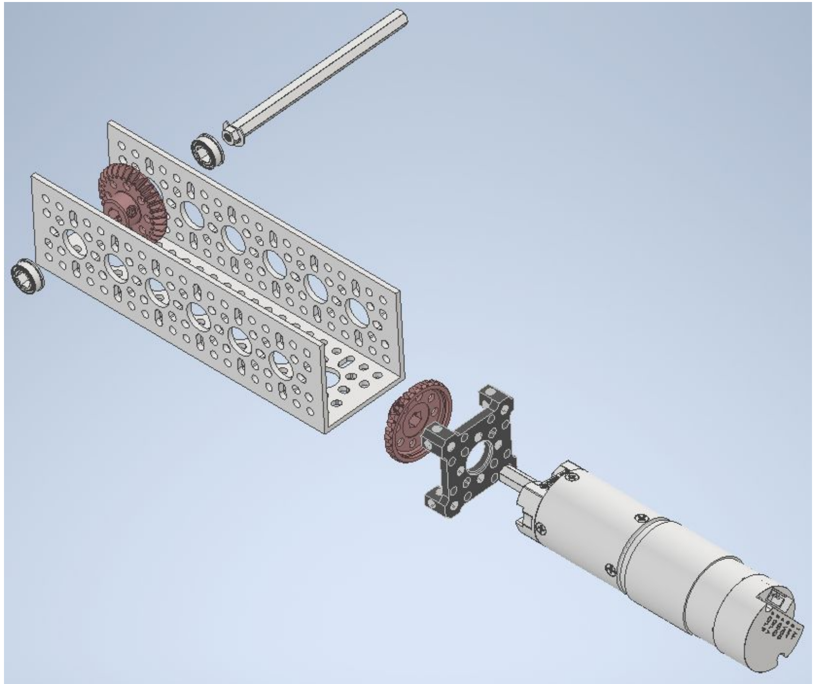


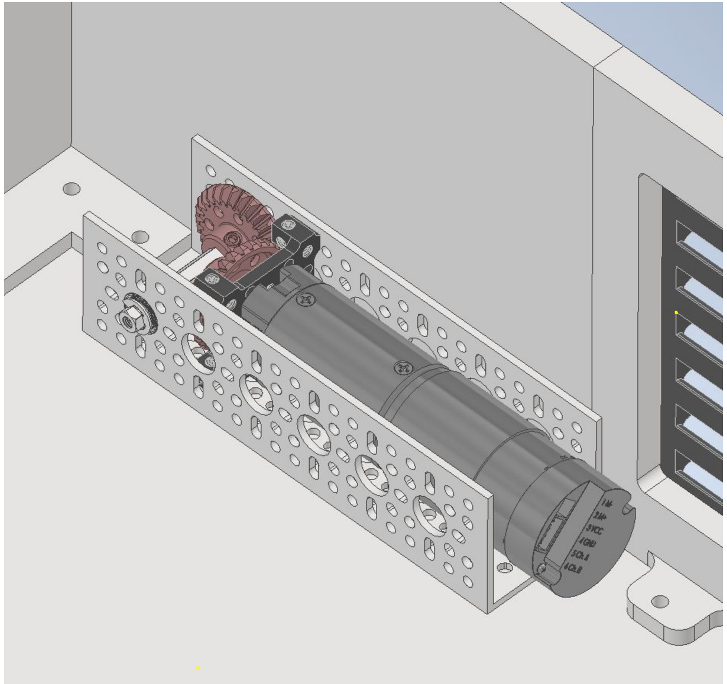


The Rover - Drivetrain

- The Rover is driven on a differential, rear wheel drive configuration
- Has two, 12V nominal, brushed DC motors designed for high torque (99.1:1 gear ratio)
- Has a 1:1 external drivetrain gear ratio with bevel type gearing, so that the motors are angled 90 degrees to the driveshaft
    - This allows for the weight of the rover to be isolated off the motor shaft

The Rover - Drivetrain Depiction

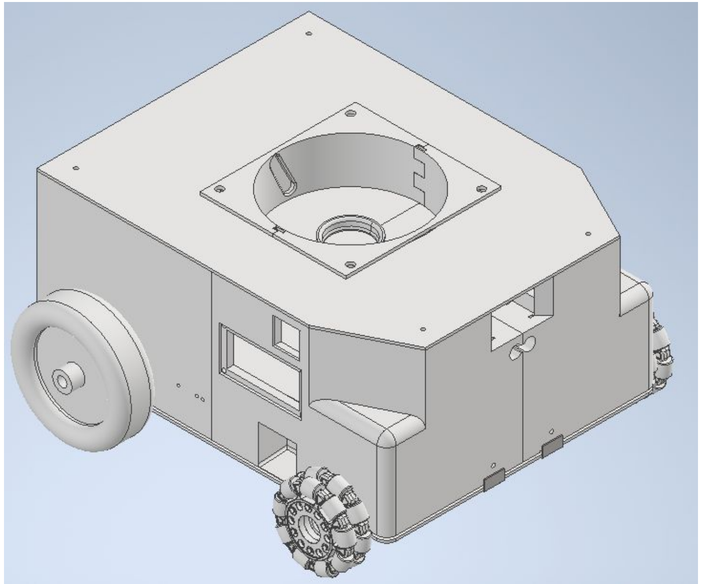


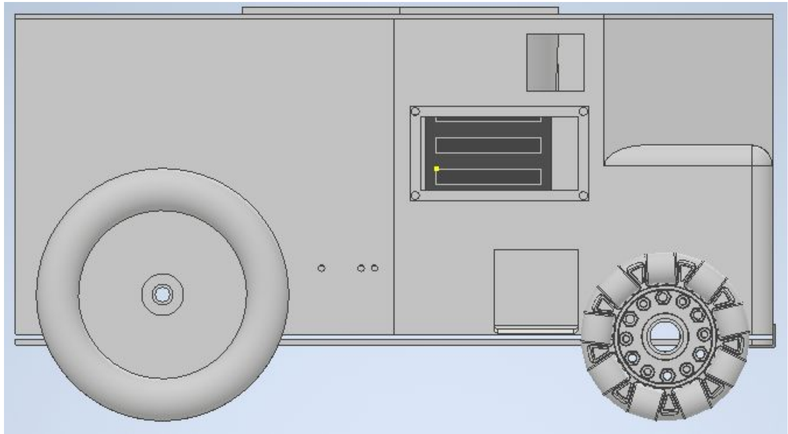


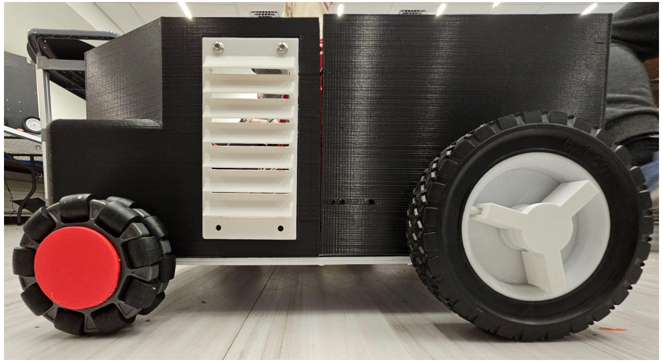
The Rover - Locomotion Platform

- The Rover drives off four wheels: two rear, powered wheels and two front, omnidirectional wheels
- The omnidirectional wheels have dedicated spinnerets on them, allowing for lateral motion just as much as linear
- Wheel axles are all independent, and located at different heights between front and rear, to maintain constant ground clearance

The Rover - Locomotion Platform Depiction



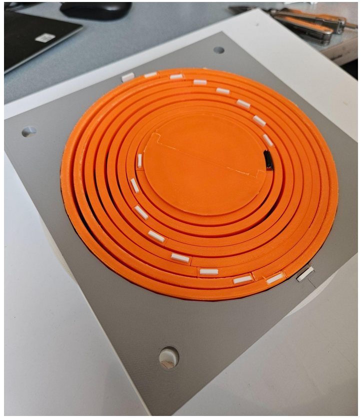


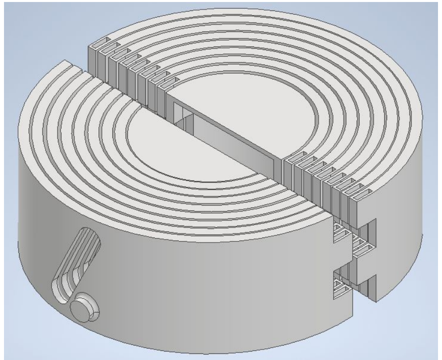


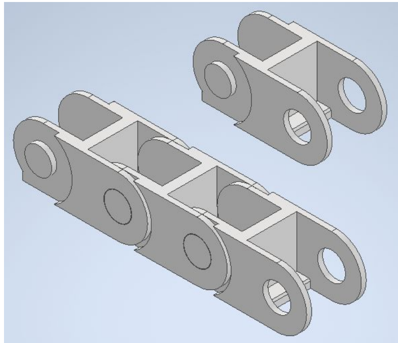
The Rover - Barrier Actuation

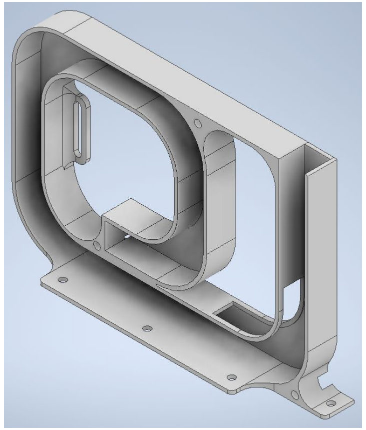
- The Rover includes a top-mounted extendable ‘cone’, from concentric, retractable cylinders
- Driven by the extension of a tensioned chain that curls into a holder upon retraction
- Extends 18” and has reflective tape for low-light visibility

The Rover - Barrier Actuation Depiction



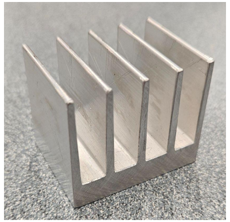


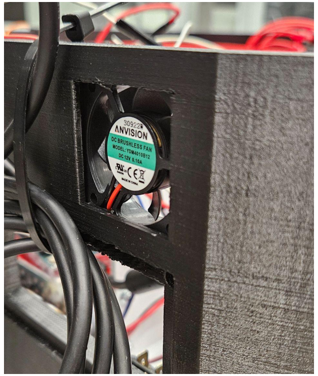


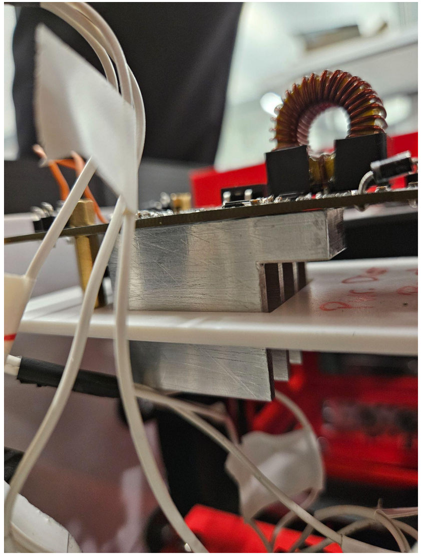


The Rover (and Docking Station) - Thermal Regulation

- Has a case mounted fan and vent for internal temperature regulation
- Power distribution boards have distinct heatsinks for sustained operation





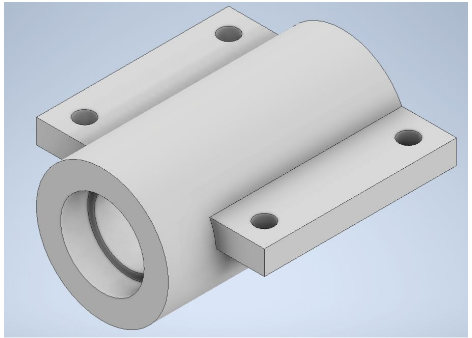


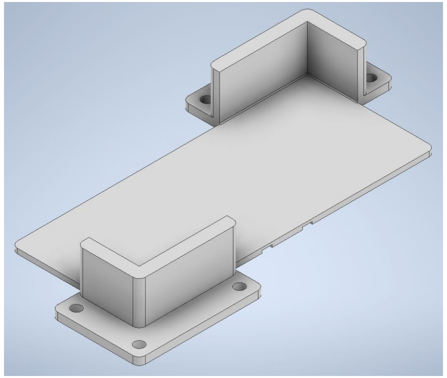
The Rover - Component Mounting

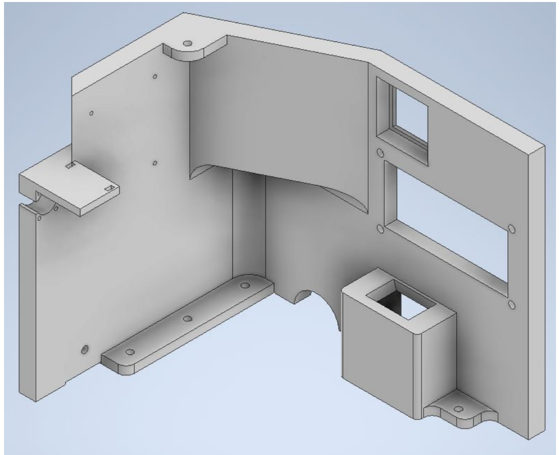
- The Rover features numerous mounting solutions for boards, components and sensors:

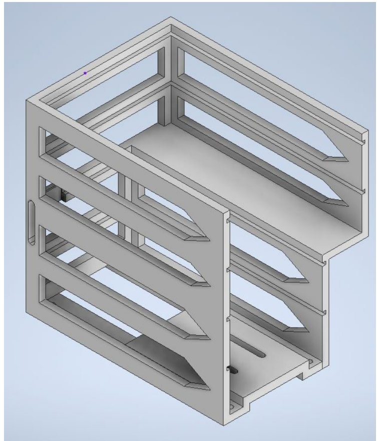
1. Shelving
2. Baseplate mounts
3. Wall mounting
4. Wall cutouts

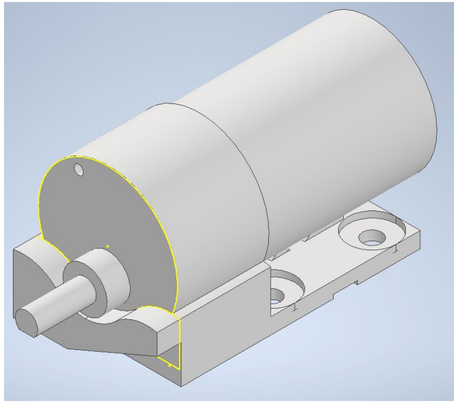
The Rover - Component Mounting Depiction







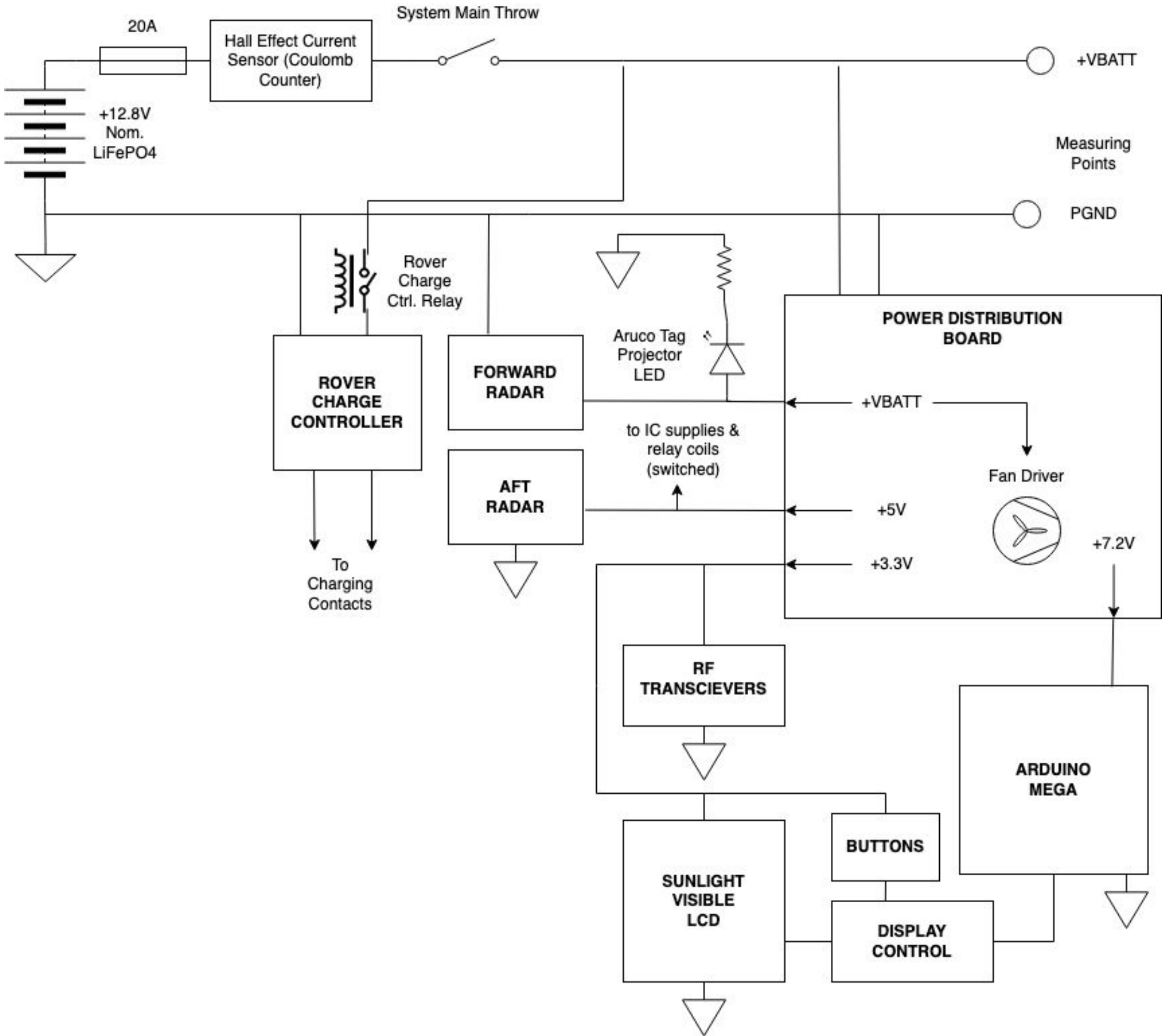




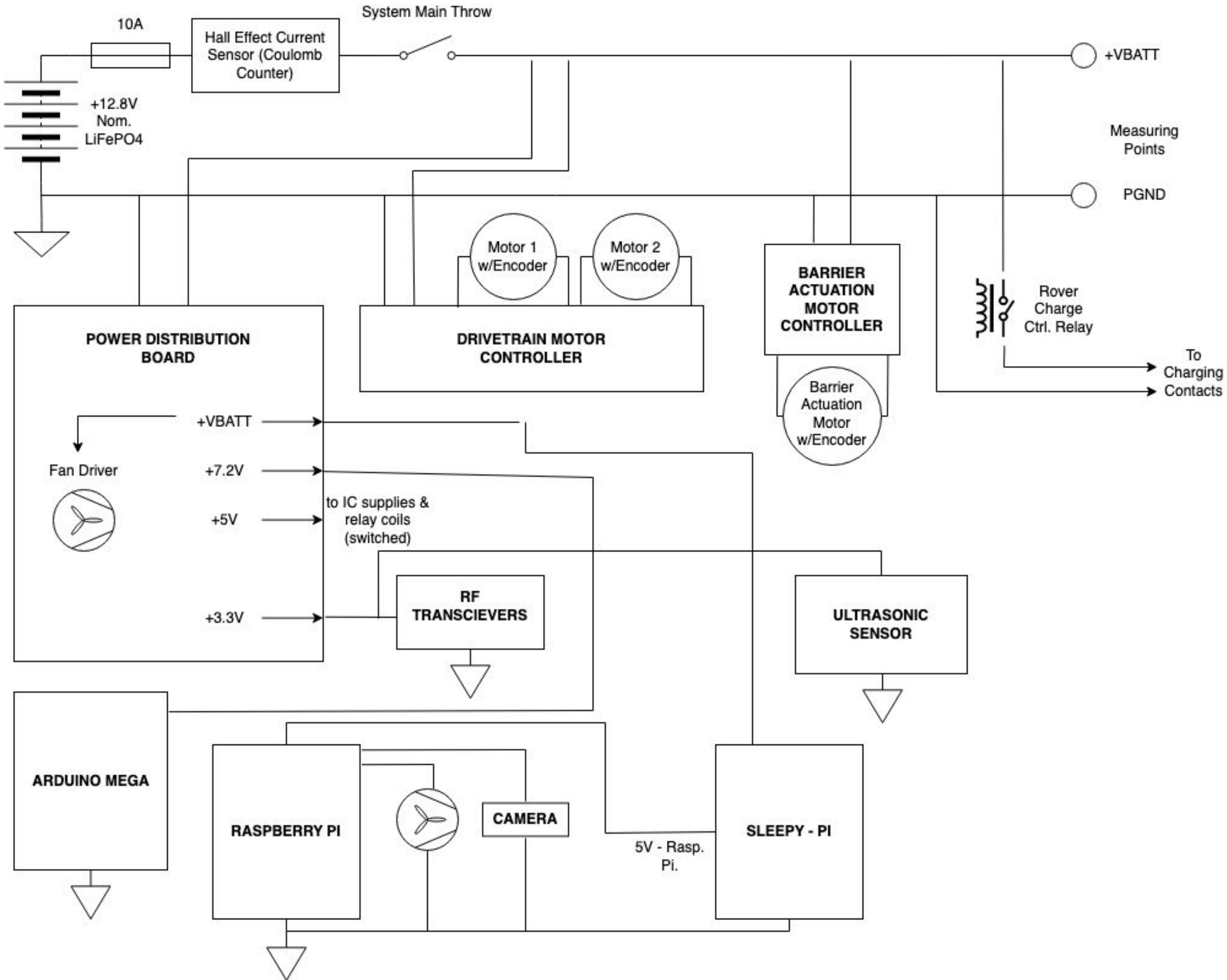
Team Alpha Design Pt.2: Electrical Systems

1. Top-Level Design: Docking Station
2. Top-Level Design: Rover
3. Vehicle Sensing
4. Navigation Computation & Sensing
5. Power Distribution
6. Battery Management
7. User Interfacing
    a. Display Control
    b. Remote Control
8. Motor Control

Top-Level Design: Docking Station



Top-Level Design: Rover



Vehicle Sensing

- A pair of radars perform vehicle detection in opposing directions of the adjacent pathway:
  - Forward radar: 200m viewing range with narrow horizontal azimuth
  - Aft radar: 30m viewing range with wide horizontal azimuth
- Radars communicate over UART to the docking station MCU (microcontroller unit)
- Docking station uses radar outputs to send drive command to Rover

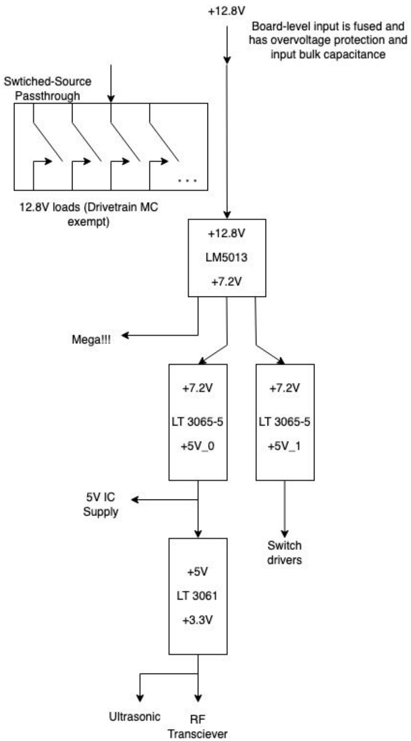
Navigation Computation & Sensing

- The Rover navigates in three primary ways:
    - Motor encoders
    - Rover-mounted camera for CV algorithm (computer vision)
    - Ultrasonic sensor
- The CV algorithm runs on a Raspberry Pi 4, with the ‘sleepy pi’ shield for power management
- The navigation control algorithm runs on the Rover’s MCU

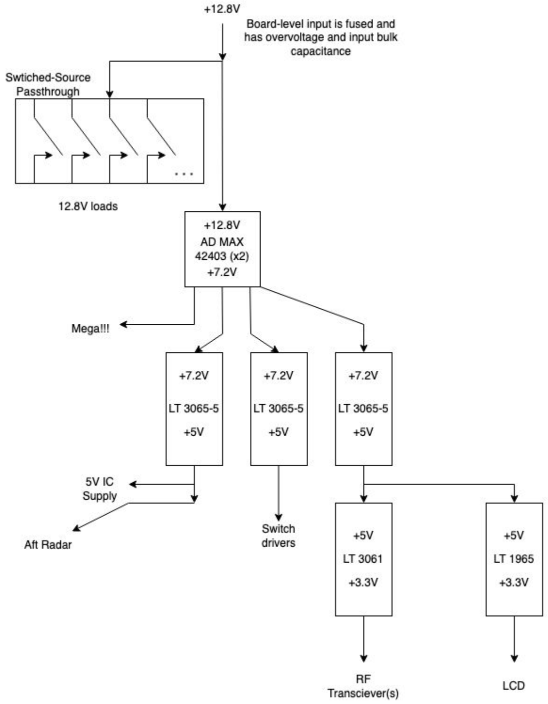
Power Distribution

- Both the Docking Station and Rover feature dedicated, custom power distribution boards with 'daisy-chained' supplies and load drivers

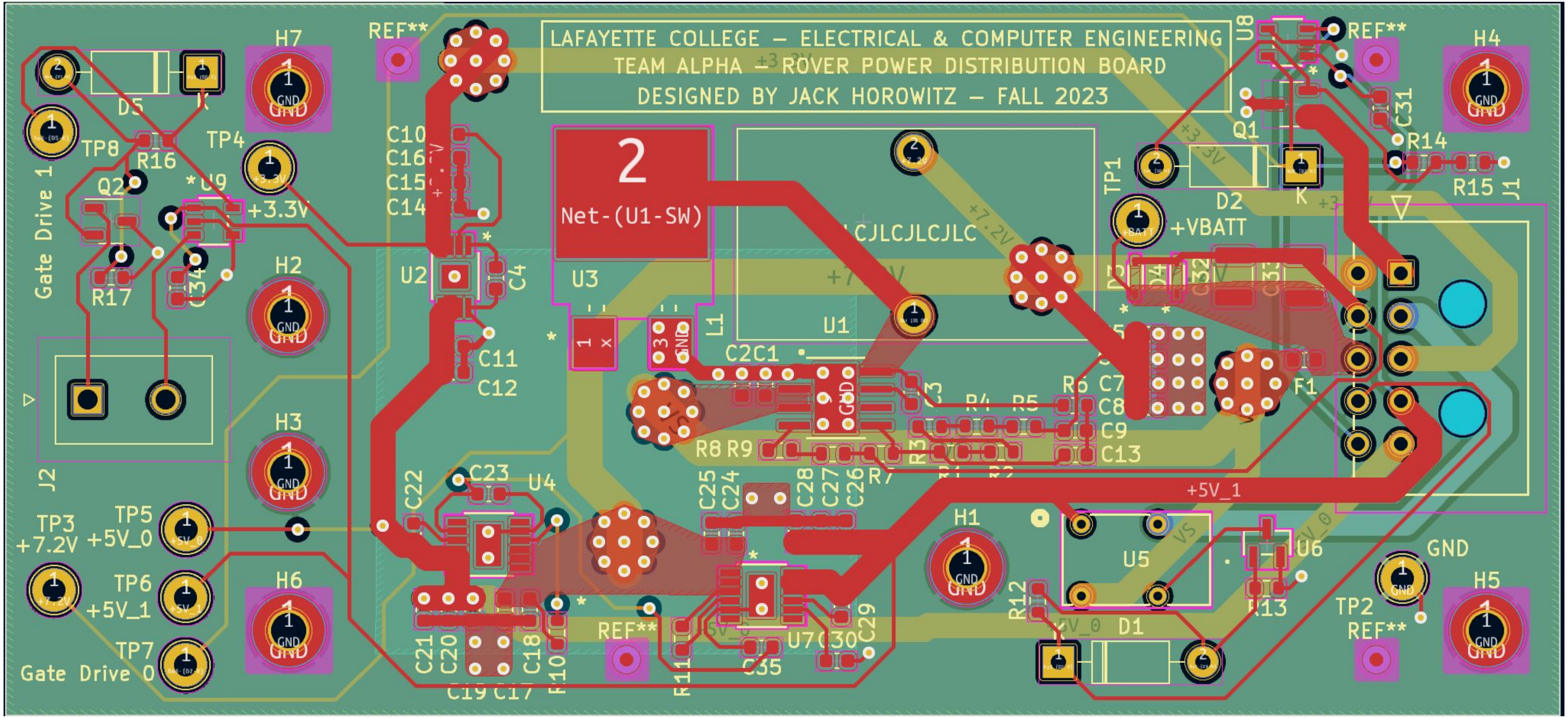
Rover:



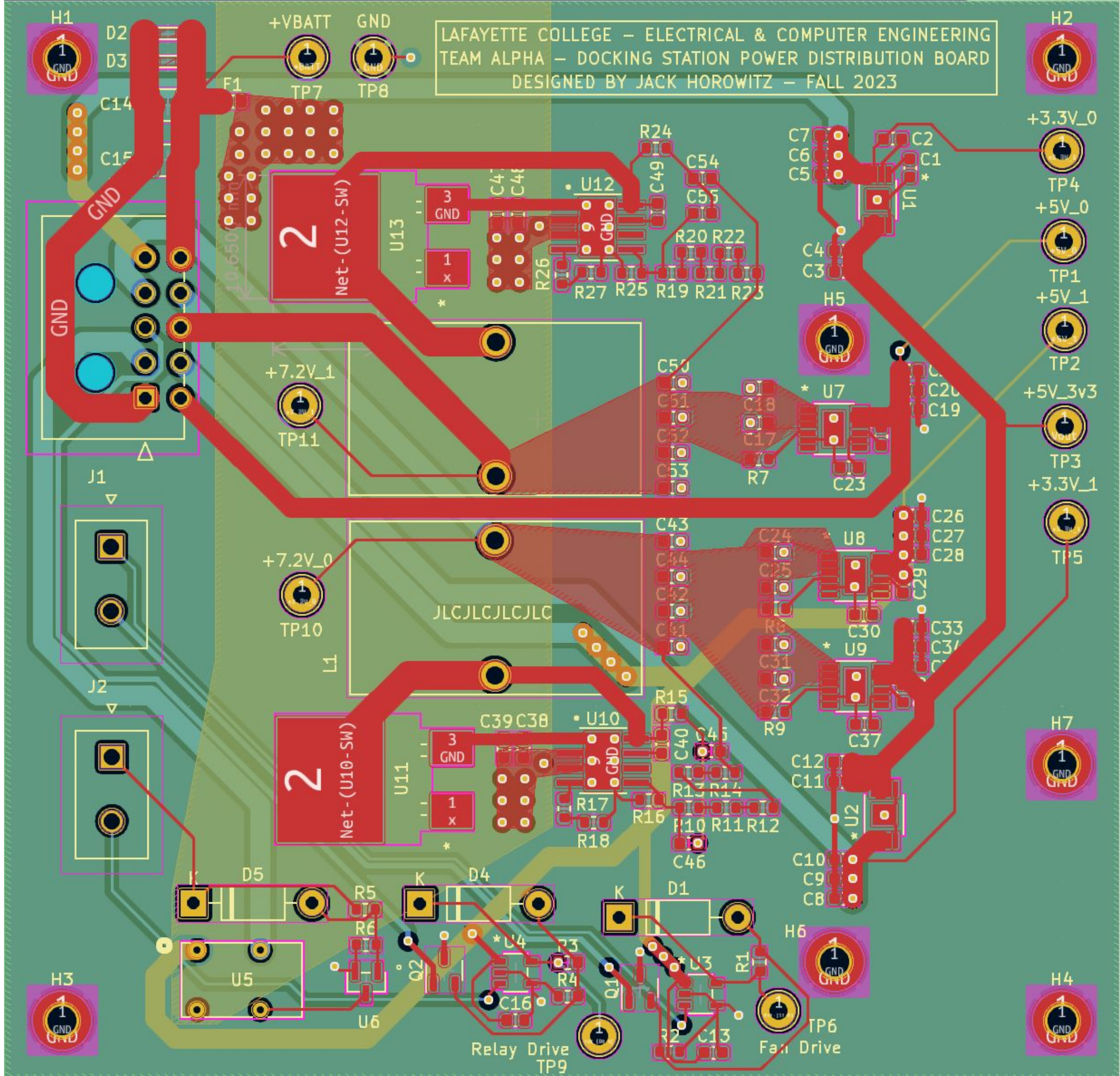
Docking Station:



Rover Power Distribution Board - Layout



Docking Station Power Distribution Board - Layout



Battery Management

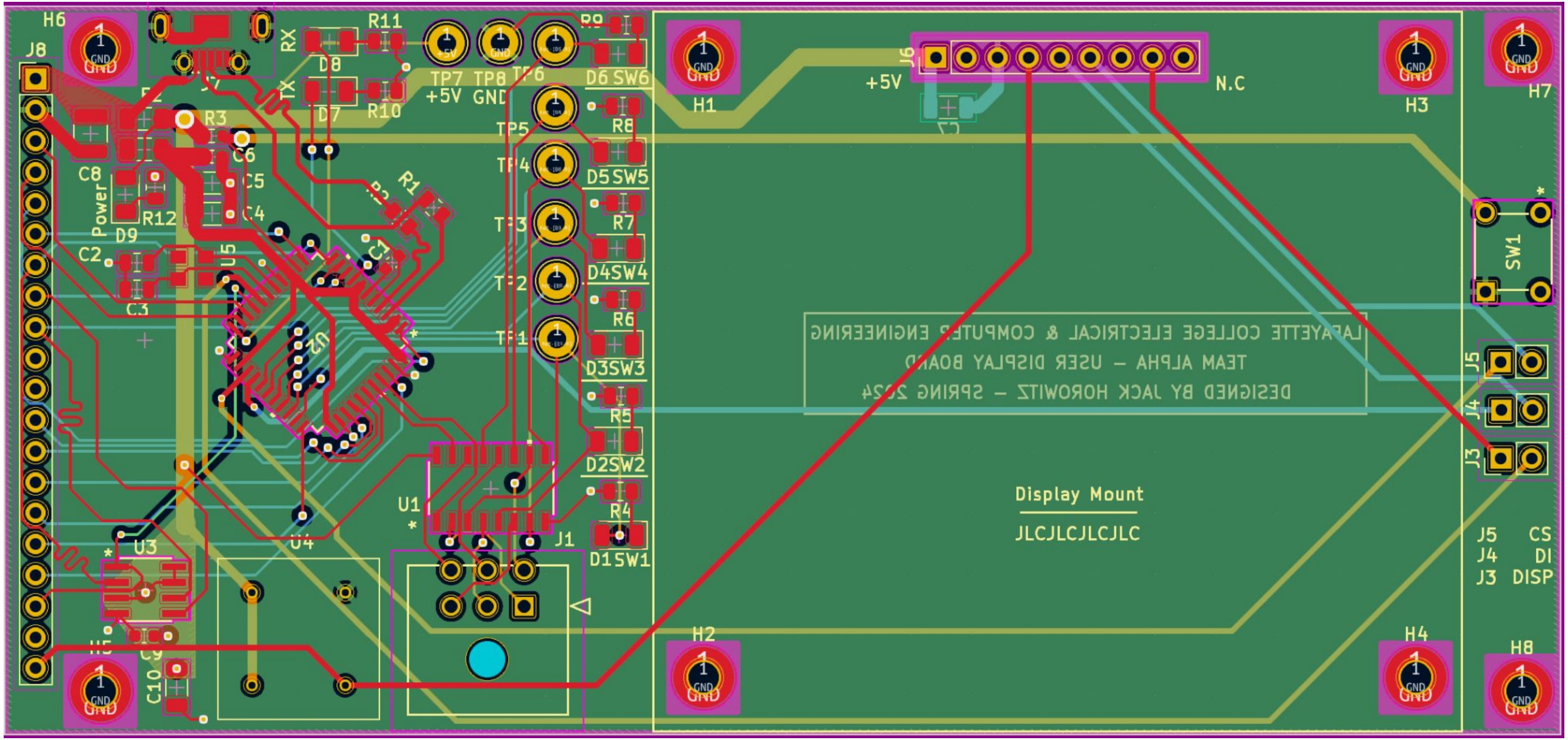
- In order to keep the system, but particularly the Rover, in a safe charge operational window, the battery's SOC (state of charge) is calculated
- Hall-effect sensors utilized as coulomb counters:
  - Differential output is processed by a differential amplifier and input to the MCU ADC (analog to digital converter) and SOC algorithm

User Interfacing - Display Controller

- The Docking Station has a user display for controlling system modes, with hardwired buttons for interfacing
- The display is an LCD/E-ink hybrid with sunlight visibility in mind, controlled by a 3-wire SPI interface
- Display controller board features a built in MCU, hardware debouncing and the display mount

Note: This board was not used fully in the end application

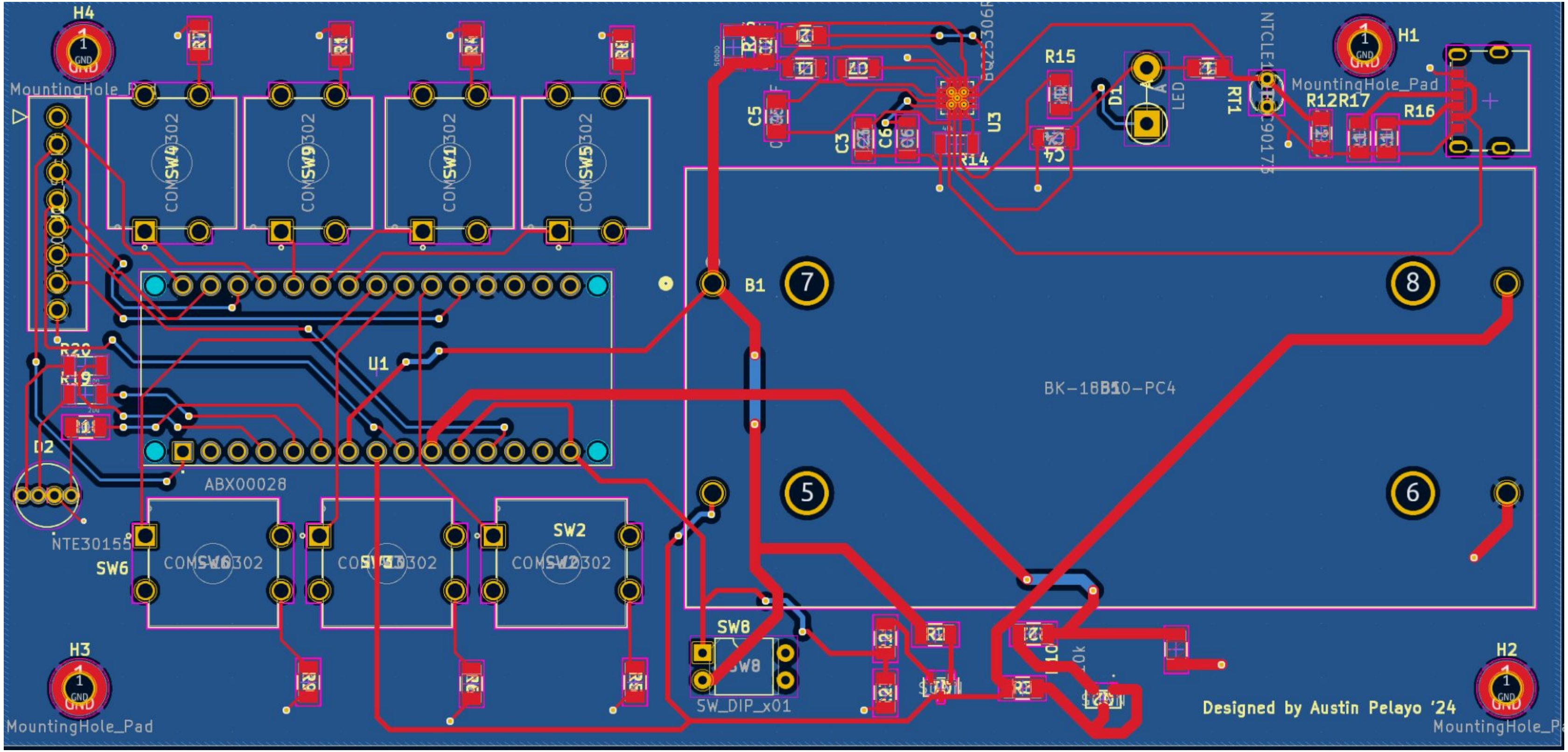
Display Controller - Layout



User Interfacing - Remote Controllers

- The project requires user intervention from not only the display, but a remote controller and vehicle authentication device
- For the final product, these functionalities were integrated into a single controller with two distinct modes
- Operates off a radio communication module (LoRa) and an Arduino Nano, controlled by buttons available to the user
- Designed by the Embedded Team, in collaboration with the Electrical team

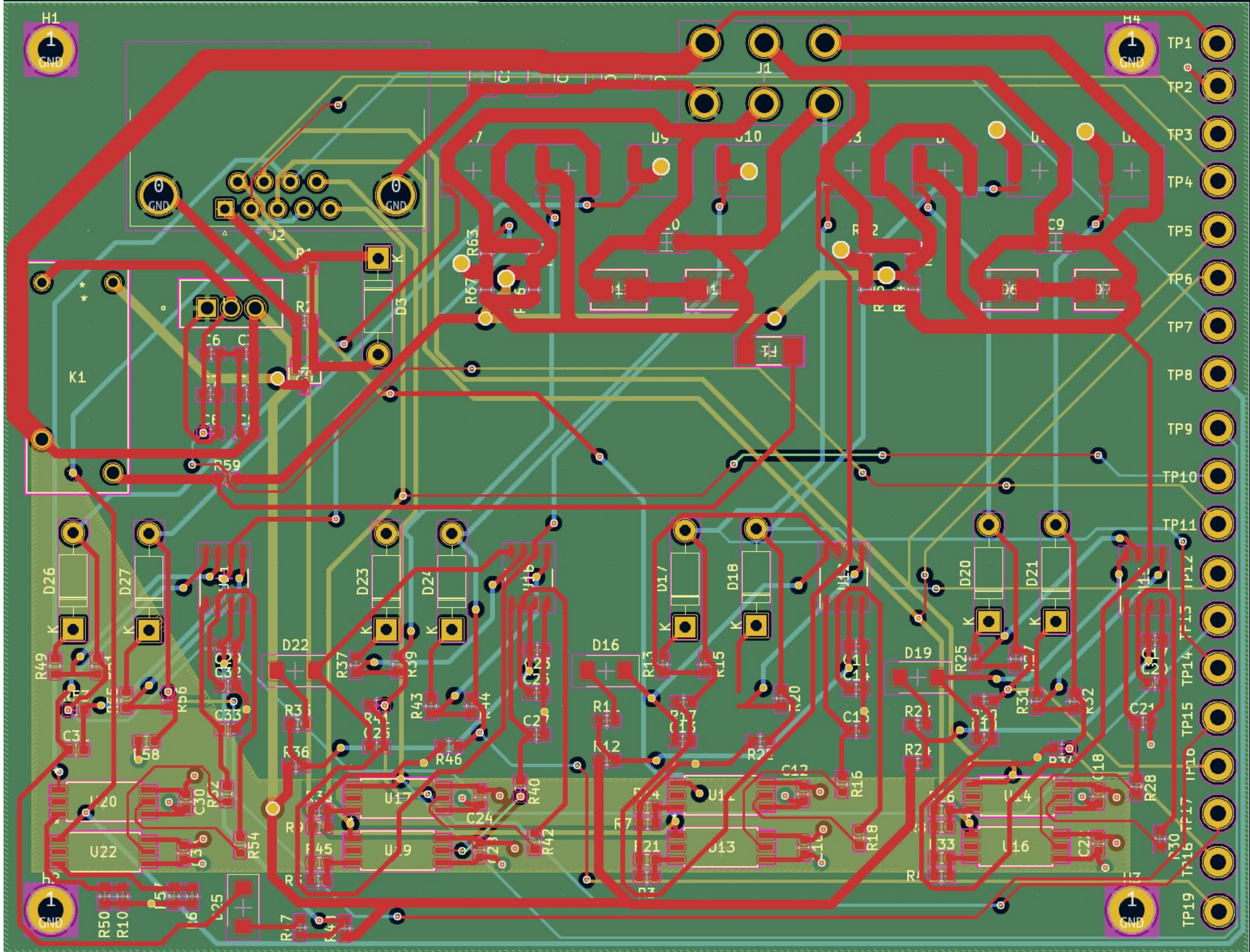
Remote Controller - Layout



Motor Control

- The Rover has two motor controllers, of identical design:
  - Drivetrain Motor Controller
  - Barrier Actuation Motor Controller
- The controller design is a dual, all N-channel H-bridge
- Features:
  - A boot-strap supplied gate driver with PWM deadtime control and shoot-through prevention
  - Relay switched control for easy disconnect from battery
  - Motor overcurrent & overvoltage protections
  - Opto-coupling on inputs for MCU protection
- Designed as a collaboration with Team Beta

Motor Controller Mk2 - Layout



Team Alpha Design Pt.3: Embedded Control Systems & User Interfacing

1. Top-Level FSM Design
2. Operational Mode A: Normally Open
3. Operational Mode B: Normally Closed
4. Operational Mode C: Scheduled
5. Remote Controls
6. Navigation
7. Battery Management
8. Vehicle Sensing
9. Radio Communication
10. User Interfacing

Operational Modes

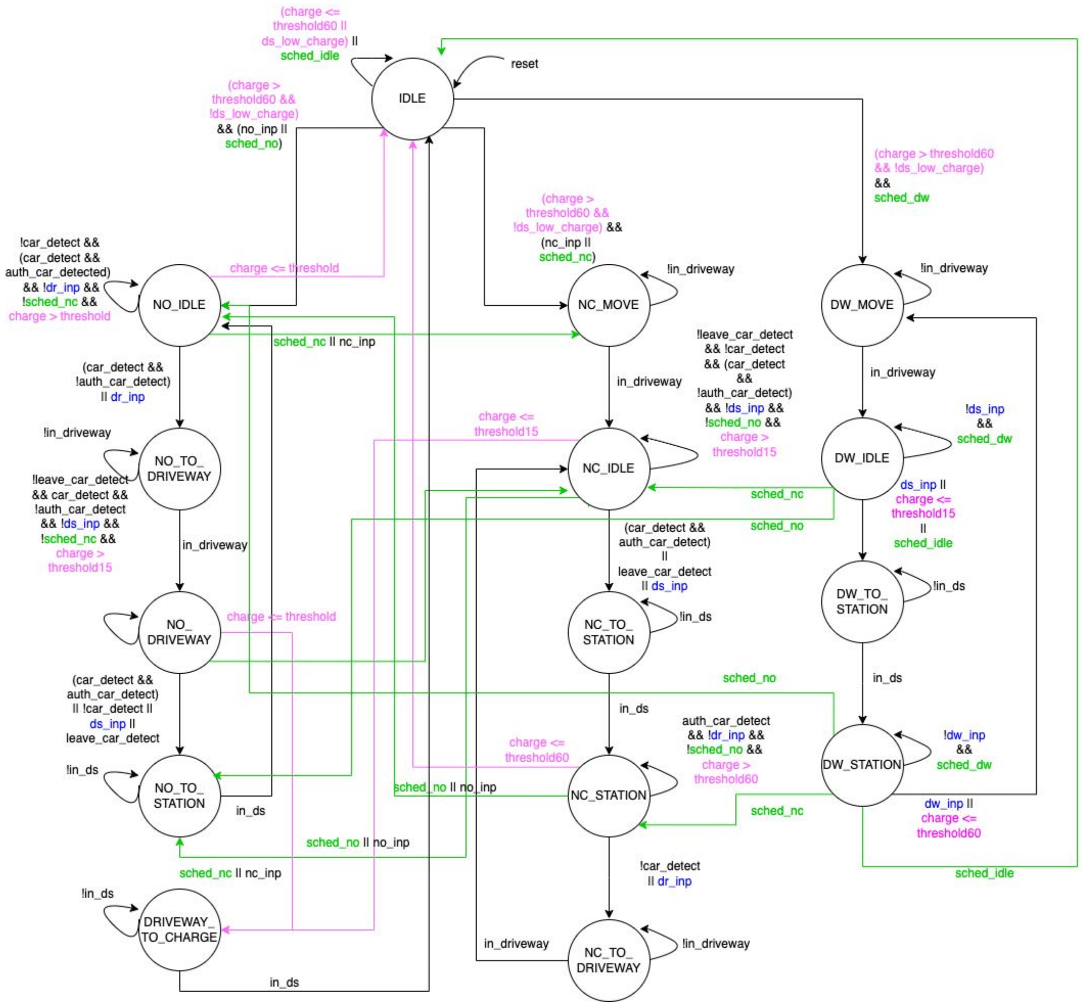
- The RFPP (request for preliminary proposal) outlined the requirement for the following modes:

Mode A (Normally open): “The MARGE device prevents passage when sensing unrecognized vehicles approaching, otherwise remains open”

Mode B (Normally closed): “The MARGE device allows passage only when sensing a recognized vehicle, otherwise remains closed.”

Mode C (Scheduled): “User defined open and closed schedule over 24-hour period.”

Top-Level FSM Design



Remote Controls

- In addition to the main operating modes, the system can be manually overridden at any time in the follow ways:
  - Hardwired display on the Docking Station
  - Dedicated Remote Controller
- The operating mode can be changed, in addition to commanding the location of the Rover (to pathway, to docking station)

Navigation

- The Rover must be able to autonomously navigate to/from the Docking station
- Upon exiting the Docking Station, the motor encoders are utilized for travelling to the halfway point of the pathway
- On return, the CV algorithm in junction with the MCU controller algorithm use the Aruco tag to navigate to the Docking station
- Once inside the Docking station, the ultrasonic sensor and mechanical guidance rails seamlessly take over to guide the Rover to the charging contacts

Navigation Continued…

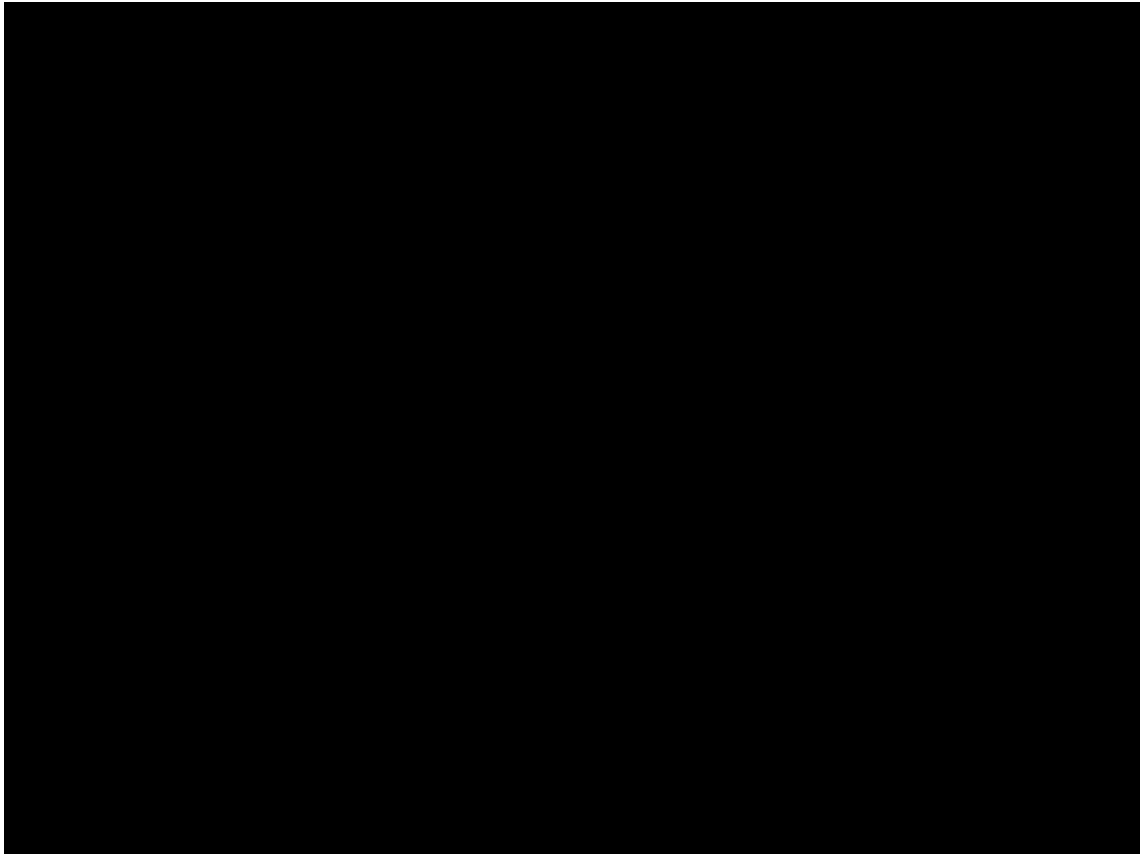
- CV Algorithm:
  - The Raspberry Pi is commanded on by the Rover MCU when return navigation is commanded by the Docking station, otherwise is off
  - The CV algorithm uses the known size (pixel count) of the Aruco tag, and its relative distortion to calculate distance and angle from target
- MCU Algorithm:
  - A custom PID controller is used to calculate a ‘pose’ and travel path for the Rover
  - A set of control signals (PWM and static) are generated and sent to the drivetrain motor controller

Navigation Continued…

- Once within the Docking station, the MCU algorithm passes off the final docking procedure to the ultrasonic sensor
- The mechanical guidance rails will laterally correct any remaining error in travel path
- The ultrasonic sensor, using an analog output, guides the Rover straight in to a programmed distance from the back wall
- The docking procedure ends with the charging contacts being actuated, and the hall effect sensor meeting a threshold change in net discharge/charge

Video Demonstration

Link to Google Drive



Battery Management

- To avoid a situation where the Rover fails of battery exhaustion, the SOC is constantly being calculated and saved
- Used to provide data for thresholds of operation:
  - If the Rover meets a low battery threshold, custom for each operating mode, it will override its current command and return to the Docking station for charging
- Coulomb counting method is used at a set interval to sum a continuous ADC count against a target value (the battery amperage rating in uAh)

Vehicle Sensing

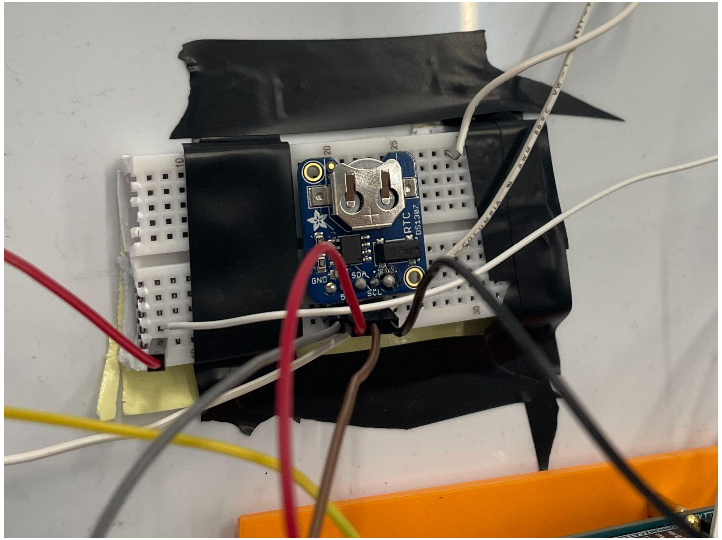
- The forward and aft radars on the Docking station are used to detect the presence of a vehicle
- The combination of a detection on the forward radar, and the presence of an authentication signal control entry
  - If granted: The Docking station commands the Rover to return
  - If denied: The Docking station commands the barrier actuation procedure for raising the cone
- The aft radar is used to always allow an exiting vehicle passage
- Both radars communicate over UART to the Docking station MCU

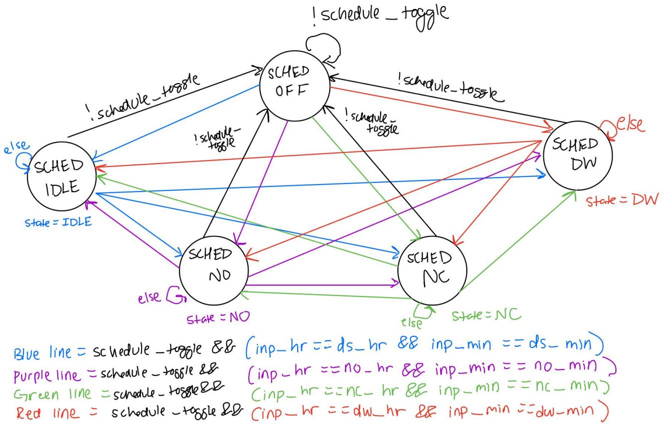
Radio Communication

- The LoRa RFM96 is used for all radio communication
- The Rover, Docking Station and remote controller each have their own radio module
- The system top-level FSM runs on the Rover, from there the Docking station is updated with the current running mode
- Movement of the Rover is commanded from the Docking station, though when navigating the Rover is autonomous
- The remote controller communicates with the Docking station

Real-Time Clock

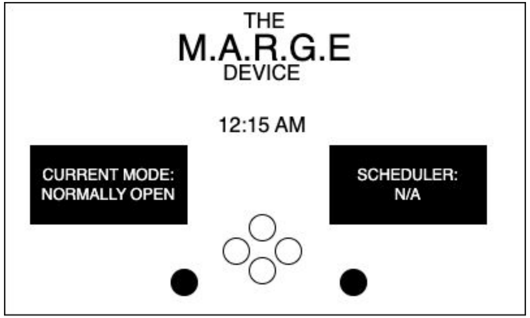
- DS1307 module
- Connects to DS Mega via I^2C and communicates real time through GPS
- Scheduled modes are set and sorted for proper scheduling protocol
- Real time sent to device and communicated for FSM inputs



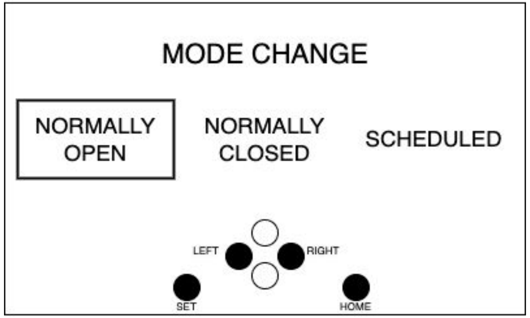


User Interfacing

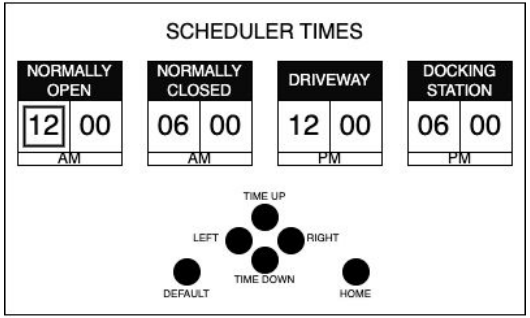
- The user can control the system from the remote controller or the hardwired display
- The same general functions are available in both interfaces, though more fine control is limited to the display, and are the following:
  - Operational mode selection (A, B or C)
  - Configuration of mode C (display only)
  - Command Rover movement (remote only)
  - Command barrier actuation (remote only)



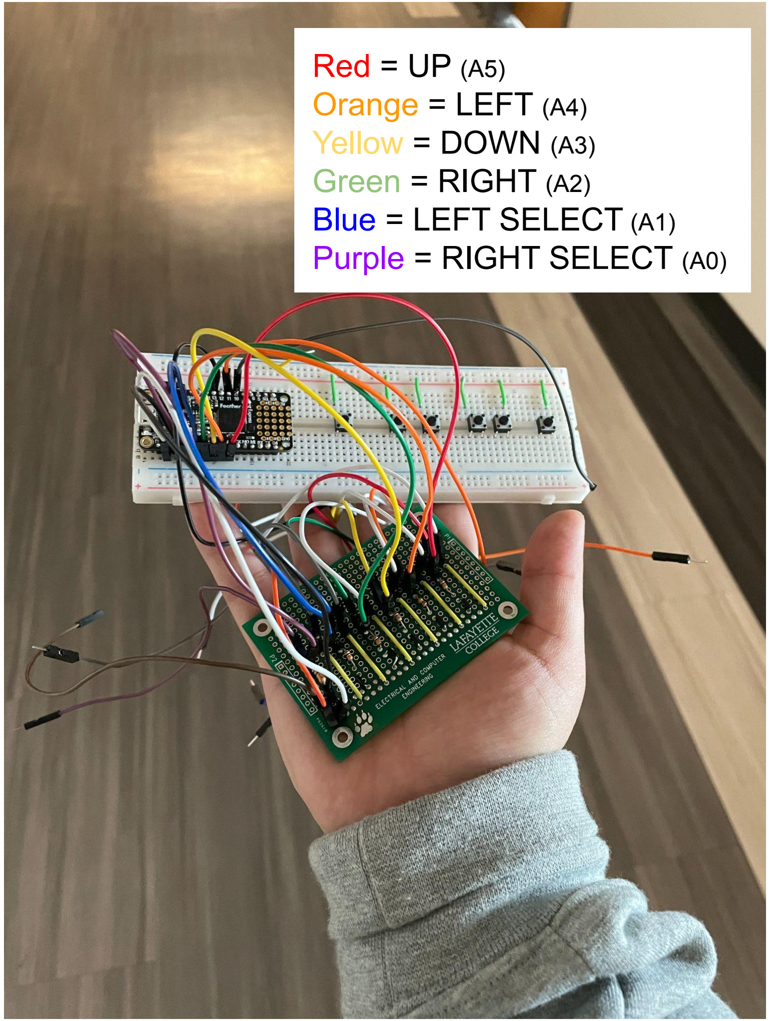
Home Screen



Mode Screen



Schedule Screen



Thank you for listening!

The team has worked very hard over the past year to bring this project to life, and careful consideration has been given to each aspect of design and development.

We hope you learned a lot and look forward to answering your questions!

- Team Alpha