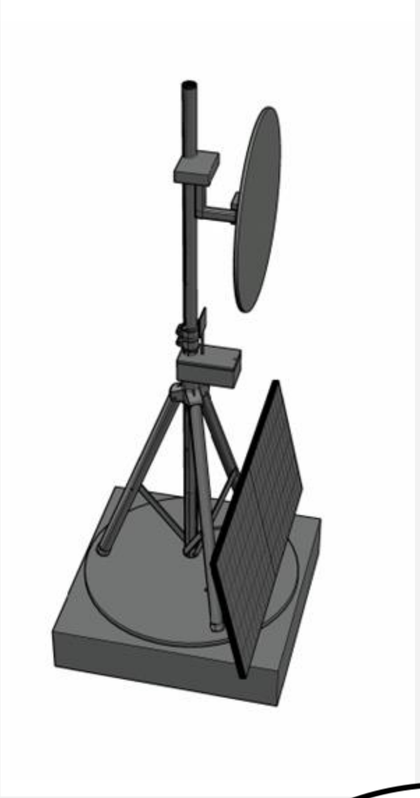
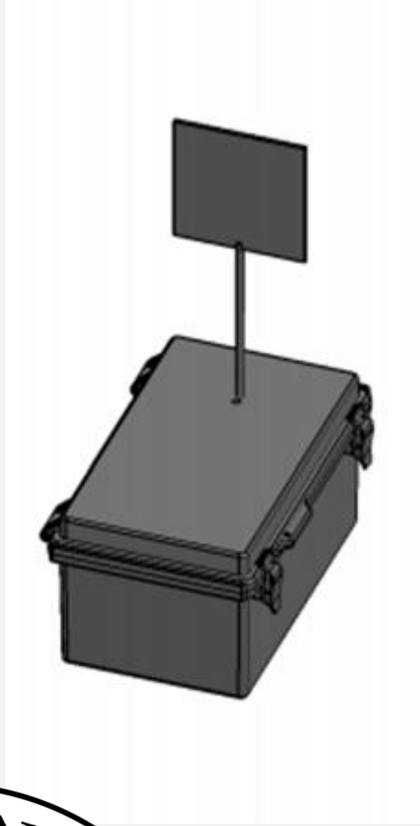
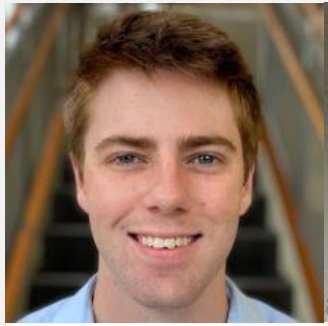



A.S.T.R.O.COM.

ADVANCED SOLAR TRACKING AND ROVER OBSERVATION COMMUNICATION




Alex Fiset	Pedro Kasprzykowski	Stephen Martin	Binh Pham
Electrical Engineering	Computer Engineering	Computer Engineering	Computer Engineering

Project sponsored by Florida Space Institute (FSI)

MOTIVATION AND BACKGROUND

- South Pole of Moon is area of interest for researchers
- Lunar south pole has many craters that are in permanent darkness due to the sun's path across the lunar south pole's sky
- Approached by FSI to solve a few problems for lunar exploration:
  1. Permanently dark locations on the moon are difficult to explore
     - Lack of power infrastructure on the moon limits exploration
     - Permanently dark locations are a valuable location for research
  2. Communication on lunar surface is limited
     - Range of communication limits exploration of craters
     - Limited communication infrastructure on moon

MOTIVATION AND BACKGROUND

- Proposed Solution:

1. A heliostat tower
   - To reflect light from the sun into permanently dark locations
   - Equipped with communication capabilities

2. A smaller communication beacon
   - Carriable by rovers
   - Form a communication network with rovers

GOALS

Overall Goals (High Level)

- Build a tower to handle rover communication.
- Build a tower to handle sunlight diversion to targets.

Stretch Goals

- P2P Networking for communication and mirror tower with rovers.
- Wireless charging and/or docking station for communication tower.

OBJECTIVES

Mirror Tower Objectives (Lower Level)

- Identify optimal sun location based on lux value from sensor.
- Receive requests from communication tower using protocols.
- Create a heliostat algorithm to orient towards the target with motors.
- Create a self-sustainable power supply using solar and battery power.

Communication Beacon Objectives (Lower Level)

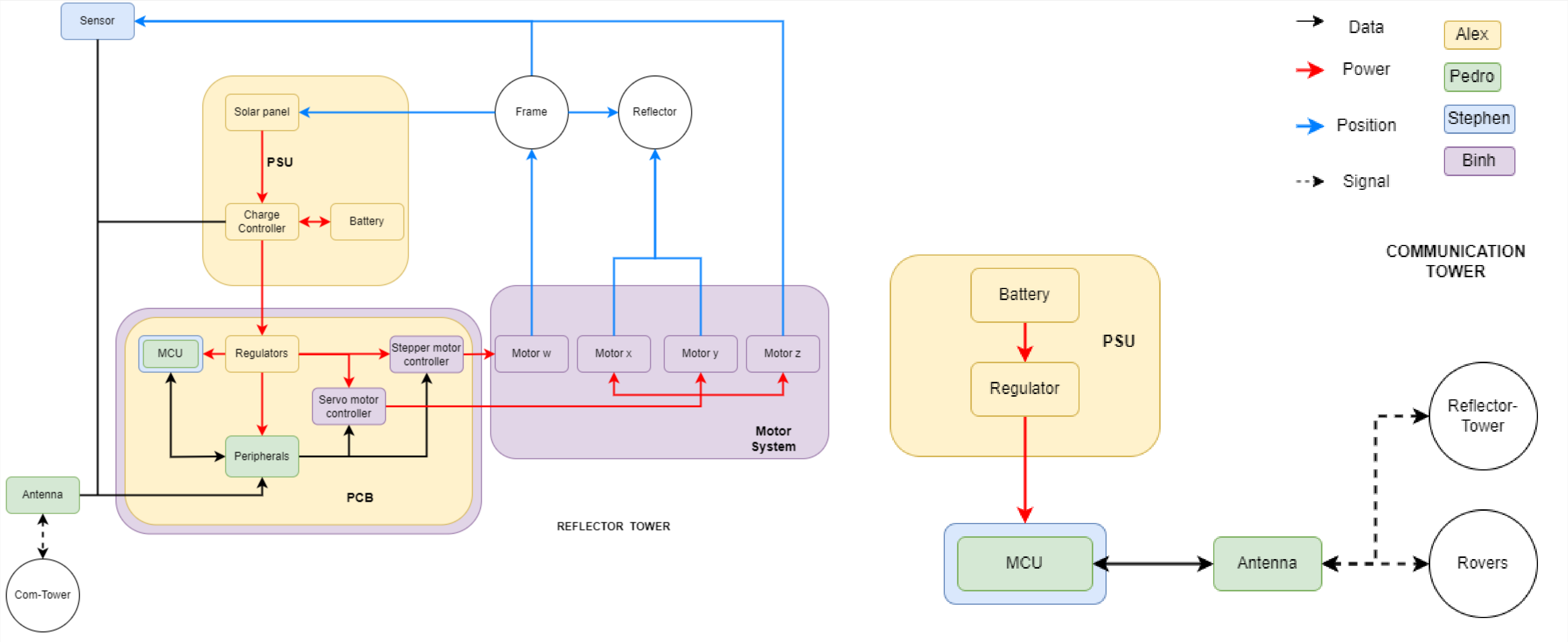
- Receive requests from target through mesh network protocols.
- Relay requests to mirror tower using communication protocols.
- Create a small and portable tower that can be moved by rovers.

SPECIFICATIONS TABLE

Heliostat Tower	
Minimum Temperature	-40°C
Reflector	
Minimum Reflectivity	90%
Response Time	3 minutes
Solar Panel	
Minimum Power	30W during sunlight hours
Maximum Voltage	24V
Battery	
Minimum Lifespan	2 weeks without sun
Communication Tower	
Minimum Network Range	20m
Communication Rate	2400MHz
Maximum Current Draw	500mA
Latency	1 second
Maximum Power	5W

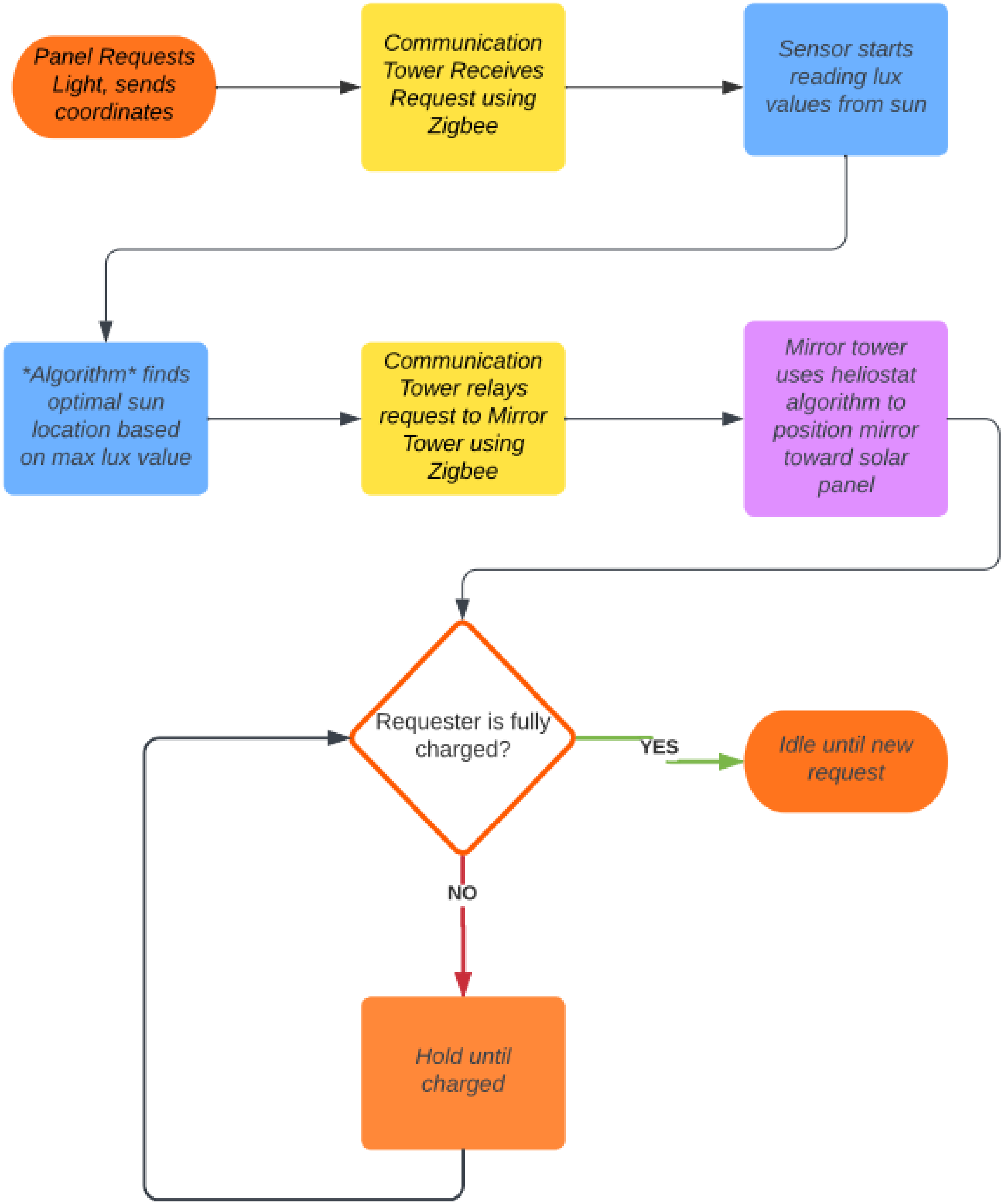
1. A heliostat tower
   - Respond time to change reflection target estimated to be maximum 3 minutes
   - Minimum power can be usage to all component estimated to be 30W
2. Communication tower
   - Maximum power usage estimated to be 5W

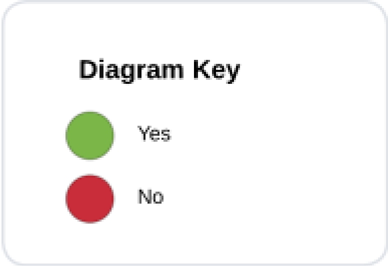
HARDWARE BLOCK DIAGRAM



SOFTWARE BLOCK DIAGRAM

- Fully integrated code software flowchart
  - Perspective of Mirror Tower
  - Yellow is signal from Communication Beacon





MICROCONTROLLER UNIT

	ESP32	MSP430	Raspberry Pi 0	Arduino MKR1310	Arduino MK1010
Cost (USD)	9.18	20	15	46	38.6
Zigbee	Yes	No	Yes	No	No
I2C	Yes	Yes	Yes	Yes	Yes
Flash Memory	4 MB	128 KB	None	256 KB	256 KB
RAM	520 KB	2 KB	512 MB	32 KB	32 KB
Power (W)	1.3644	1	12.5	0.5082	0.5082

- Microcontroller was chosen over FPGA
  - Low power consumption, cost, and high amounts of documentation.
- ESP32 is low cost, low power and networking capabilities and all connections required.

SOLAR PANELS

A monocrystalline 50W panel from Renogy was selected due to the low cost and high performance.

Model	**RNG-50D-SS**	**HQST-50P-US**	**SP-52-L**
Brand	Renogy	HQST	Solbian
Technology	Monocrystalline	Polycrystalline	Monocrystalline
Price	$ 59.99	$ 65.99	$ 499.00
Pmax at STC	50 W	50 W	52 W
Voc	22.3V	23.3V	10.9V
Vmp	18.6V	19.8V	9.1V
Imp	2.69A	2.53A	5.7A

VOLTAGE REGULATION

Specifications	Linear Regulators	Switching Regulators		
		Buck	**Boost**	**Buck-Boost**
Efficiency	Moderate	High		
Heat	Moderate	Low		
Voltage Output	Step-Down	Step-Down	Step-Up	Up or Down
Output Ripple	Low	Low	High	Low
Complexity	Low	Moderate	Moderate	High
Cost	Low	Moderate	Moderate	High

Switching Buck regulators were chosen for their simplicity and low cost, being commercially available cheaply from many manufacturers.

VOLTAGE REGULATION

The TPS53JA2 was selected due to the high output current, supported the intended voltage input, and was high efficiency.

Model	LM1085IT-5.0/NOPB	DROK MiniBuck Converter	LM2596	TPS54JA20
Brand	Texas Instruments	DROK	Texas Instruments	Texas Instruments
Input Voltage	2.6-26V	2.5-24V	3-40V	2.7–16V
Output Voltage	3.3 or 5	3.3 or 5	1.5 to 35	0.5 to 5.5V
Output Current	3A	3A	3A	12A
Price	2.19	1.97	1.495	0.65
Type	LDO Buck	Buck	Buck	Buck

CHARGE CONTROLLER

- Two broad categories of Solar Charge Controllers:

1. PWM
   - Basic pulse width modulation
   - Lower efficiency
   - Cheaper
2. MPPT
   - Tracks highest power producing operating point
   - Higher efficiency
   - Typically, more expensive

CHARGE CONTROLLER

The SR11004 from SMARAAD offered the right voltage output, and was compatible with the selected battery chemistry for the lowest price.

Model	BQ25798RQMR	SR11004	Adventurer
Brand	Texas Instruments	SMARAAD	Renogy
Input Voltage	24V max	26V max	50V max
Output Voltage	18.8V max, Programmable	12/24V	12/24V
Output Current	5A	10A	30A
Price	6.25	39.99	59.99
Power	Not Specified	260W	1500W
Type	MPPT	MPPT	PWM

REFLECTORS

- Material Chosen to fabricate:

1. Aluminum: high heat resistance, durable, and high reflectivity in the moon environment.
2. Mylar: increase reflectivity, high heat change resistance, won’t crack, and don’t reduce quality of refection

- Proof of concept: Acrylic panel as cheaper alternative and easier to fabricate.

MOTORS

1. Stepper motor: Nema 23 robustness and strong torque to control the rotation of the whole tower. Can be used on DC system
2. Servo Motors: a cheaper alternative for smaller part movements.

- Incorporated gearbox to increase movement range and control for stepper motor.

Types of Motors	**AC**	**Stepper**	**Servo**
Financial Cost	\$200-\$2,000	\$20-\$200	\$10-\$50
Torque	203000Ncm-610000Ncm	10-10000Ncm	10-1000Ncm
Speed	1800-3600 rmp	Low	High
Voltages requirement	115V/208V/230V	3V-100V	3V-100V
Durability	High	High	Low

MOTOR CONTROLLERS

1. Stepper Controller TB6560-V2, cheap and can handle the at least 2 amperage from Nema23
2. PCA9685 PWM: Design specific for servo and can control all three servos planned in the system

Controller Models	DRV8434S, 2A Max.	TB6560	Stepper Motor Driver 36v4	HiLetgo PCA9685
Cost (USD)	$12.95	$11.39	$29.95	$9
continuous current (A)	1.2	3.5	4	3A
Micro stepping	1/256	1/16	1/256	I2C
Operating Voltage (V)	4.5-48	10-35	8-50	5-10

BATTERIES

- The battery selected was a Howell Energy LiFePO4 battery.
  - Higher amp hours
  - Lower weight
  - Smaller size
  - Higher price

Model	ML5-12	HW-4F7	PQ12V/6AH
Brand	Mighty Max Battery	Howell Energy	Power Queen
Voltage	12	12	12.8V
Amp Hour	5	7	6
Technology	SLA AGM	LiFePO4	LiFePO4
Price	16.99	32.99	19.59
Charging Requirements	CV	CC 3.5A, CV 14.6V, Built-in BMS	Not Specified, Built in BMS

ANTENNA

- The combination of the certain gain range, circular polarization, high-efficiency and wideband characteristics made patch and helical antenna types the ideal choices.
- The PC140’s circular polarization while also being above average in gain and efficiency made it the preferred antenna product.
- The sponsor chose for us to replace the antenna with their choice of the wlaniot.

	PC140	WPC.25A	FXP74	PC17	FXP70
Avg Gain (dB)	-1.92	-1.14	-2	-3.6	-2
Peak Gain (dBi)	1.67	5.15	4	.9	1.1
Efficiency (%)	64	76.9	50	44	63.7
VSWR	<2	<2	<2	<1.5	<1.5
Polarization	RHCP	Linear	Linear	Linear	Linear
Cost (USD)	$27.26	$9.21	$7.69	$16.60	$27.09

SENSOR

Sensor Final 4 Options:

- VL6180X and SI1145 include IR which is not needed
- MAX44009 only has breakout board; does not work for PCB

- VEML7700 best choice for price/ability

	VL6180X	MAX44009	SI1145	VEML7700
Cost (USD)	$14.49	$5.96	$9.95	$4.95
Measuring Principle	TOF/IR Laser Photodiode	Photodiode	IR-LED Photodiode	Photodiode
Max Lux	100000	188000	128000	120000
Ambient Light Sensing	Yes	Yes	Yes	Yes
Operating Current (mA)	0.3	0.003	7	0.045
I2C	Yes	Yes	Yes	Yes

DEVELOPMENT ENVIRONMENT: LANGUAGES AND REPOSITORIES

Programming Languages

- C: best choice for MCU programming, low-level
- Java: best for object-oriented programming, low-level
- Python: best for existing libraries, high-level

Choice: C

Repositories

- GitHub: most popular repo, widely used among many software devs
- Bitbucket: Git based repo, includes task scheduling and team goal software

Choice: GitHub

VECTORING AND POSITIONING / SOLAR TRACKING ALGORITHM

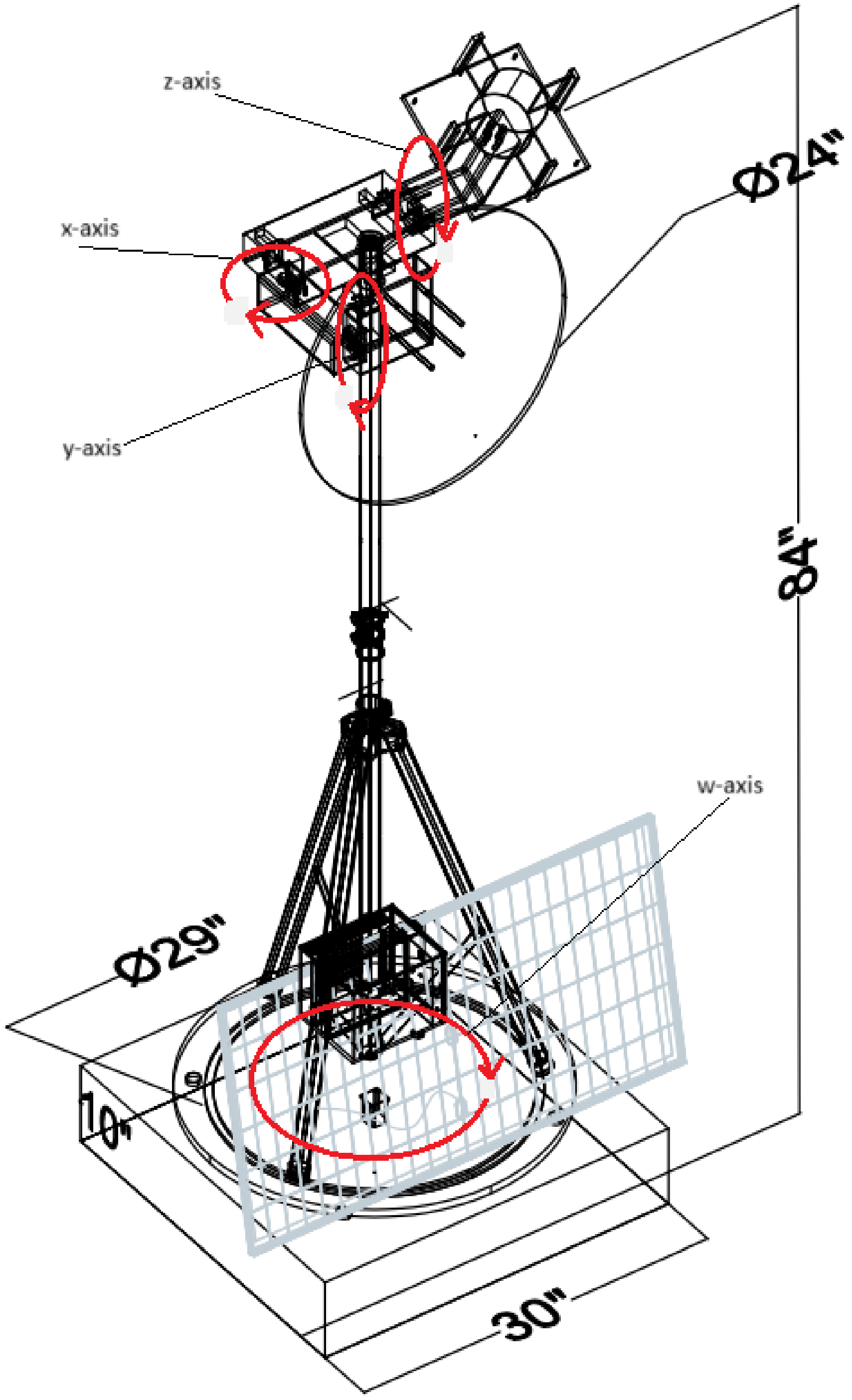
1. Heliostat algorithm chosen as it is open source and availability. Good capability with ESP32-C6 and C language

Algorithms	Heliostat	Kalman Filtering	Ray Tracing
Financial Cost	Open Source	Ambiguous	Not available
Sensor	Ambient Light	Ambient Light	Ambient Light
Algorithm code library	Available on GitHub	Available in python	Available in Research paper
Efficiency	High	Low	Medium
MCU compatibility	Good (C Language)	Fair (Python)	Good (C Language)

COMMUNICATION TECHNOLOGIES

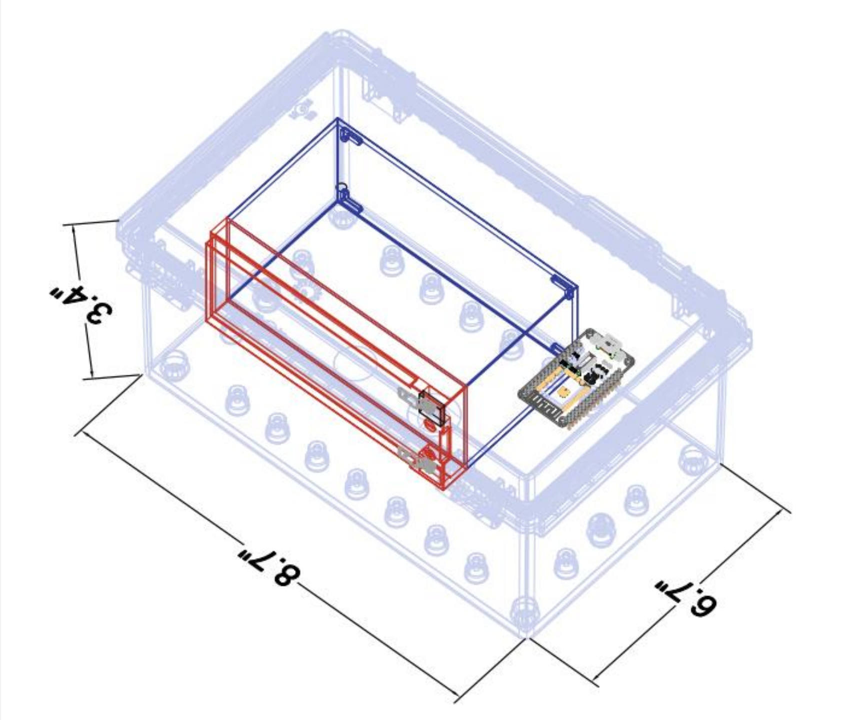
- The combination of low power consumption, suitable range, options for frequency and high scalability made Zigbee the ideal communication technology to implement.

Criteria	Wi-Fi	Bluetooth	Zigbee	Z-Wave
Range (m)	45	10	980	800
Data rate	54 Mbps	1 Mbps	250 Kbps	100 Kbps
Power consumption	30 uA-250 mA	9 uA-39 mA	12 uA- 54 mA	1 uA-23 mA
Max devices	255	3-4	100	232
Scalability	✓	✕	✓	✓
Frequency	2.4/5/6 GHz	2.4 GHz	915 MHz/2.4 GHz	908-916 MHz

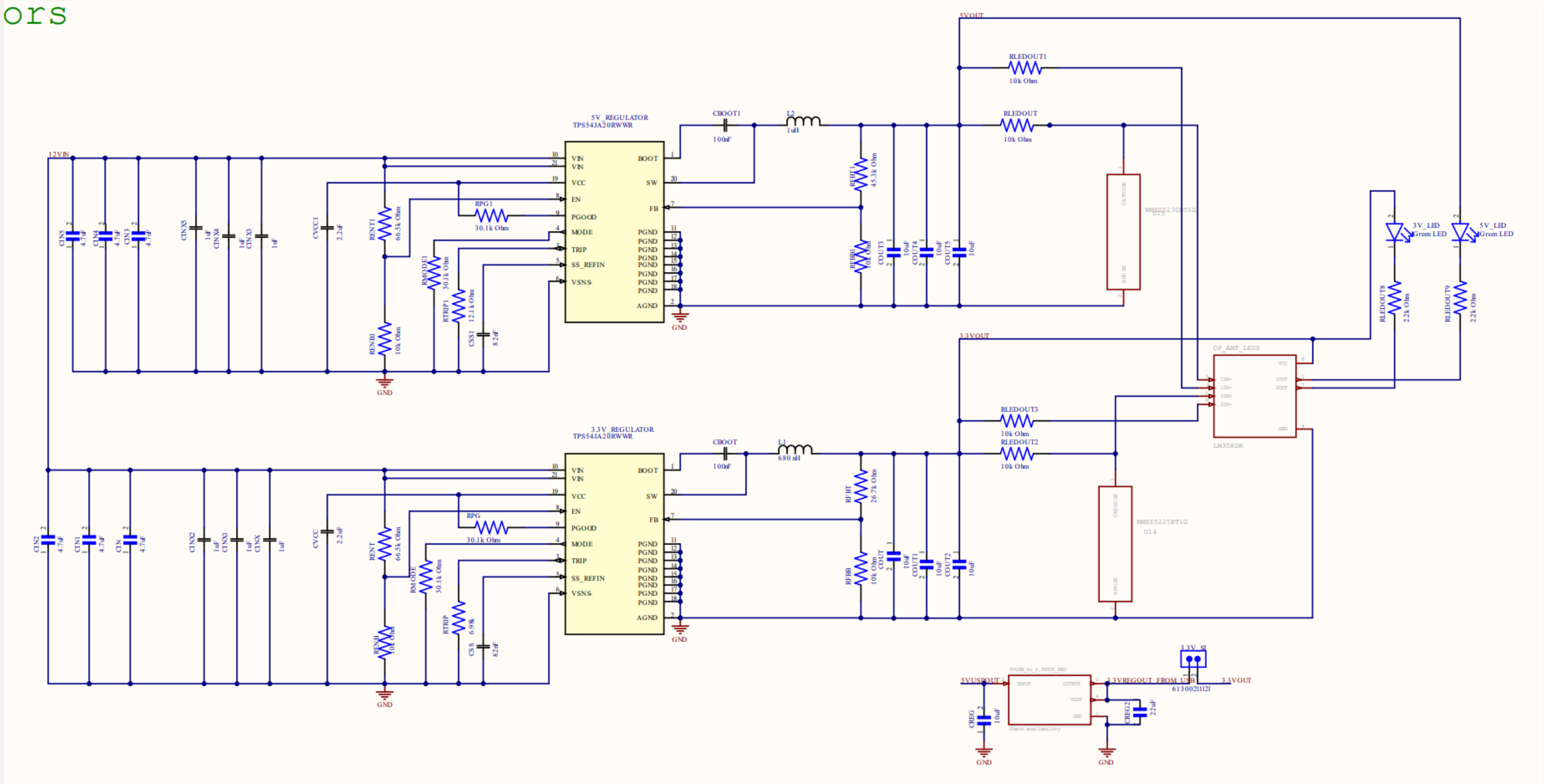


HARDWARE DESIGN

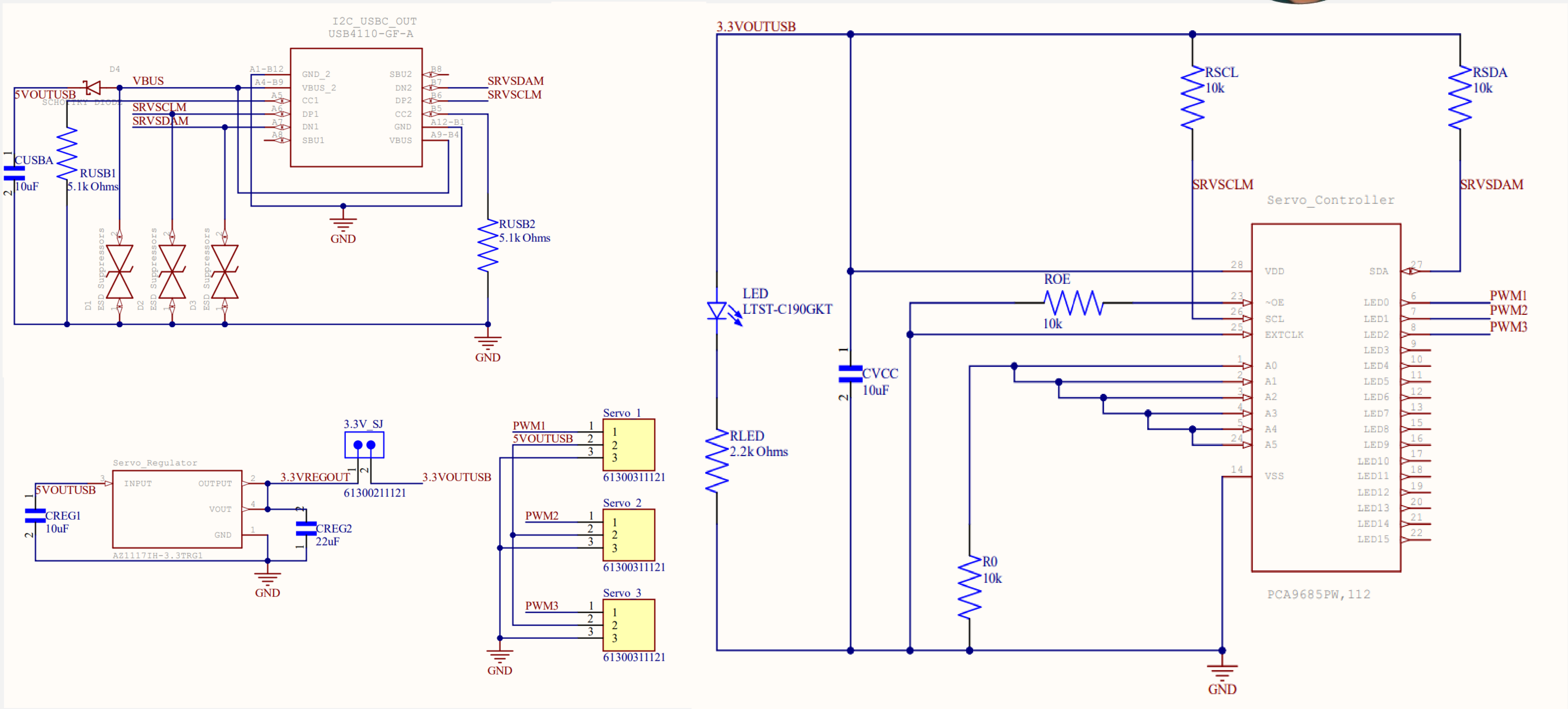
- Design two separate towers, each with their own design constraints
- Majority of focus is on heliostat tower, as it is more complex
- Schematics and PCB designs
- Heliostat structure
- Tripod on a "Lazy Susan"
- Communication Beacon
- Antenna on an enclosure



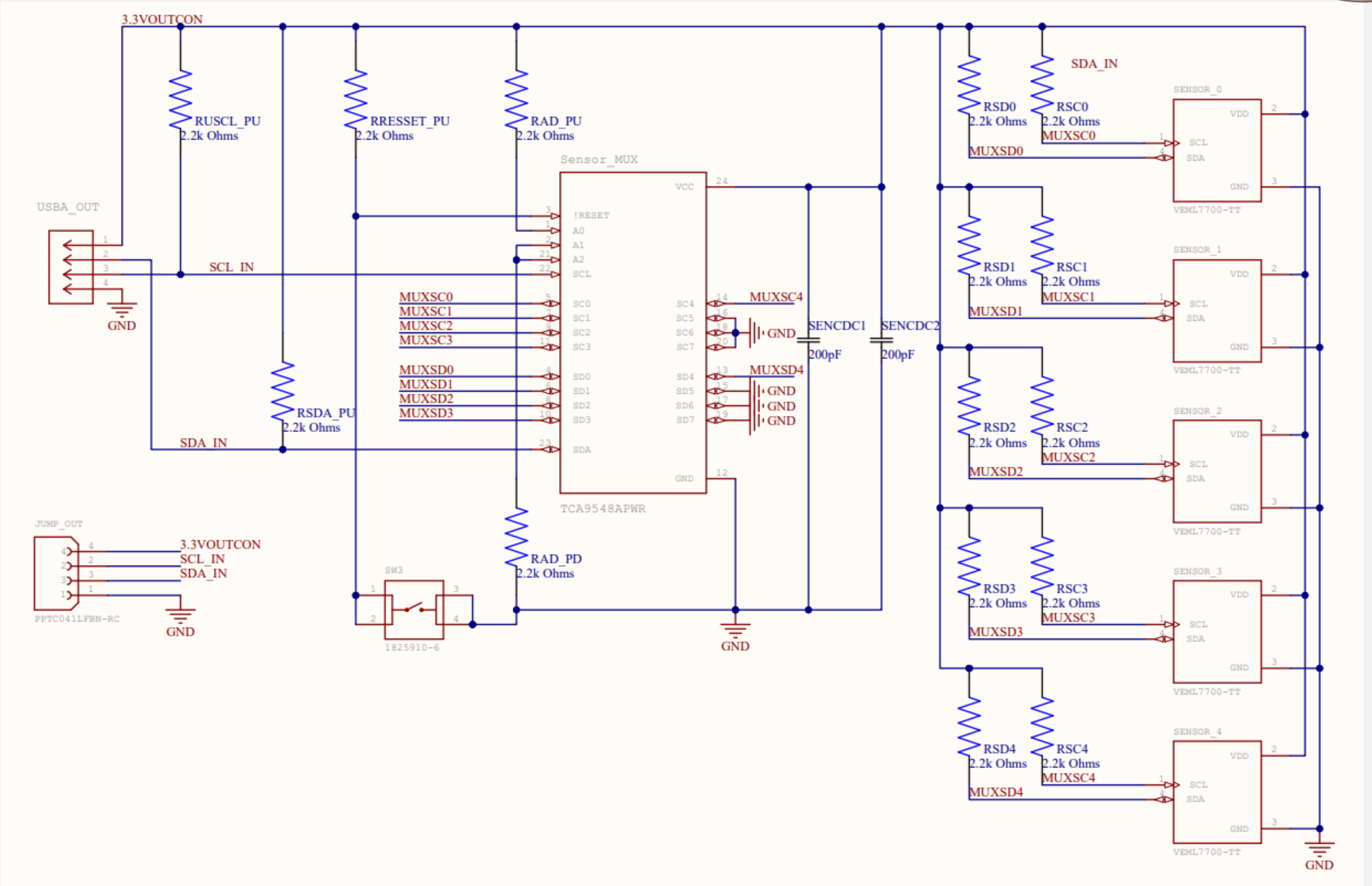
POWER DELIVERY/ ELECTRICAL POWER SYSTEM



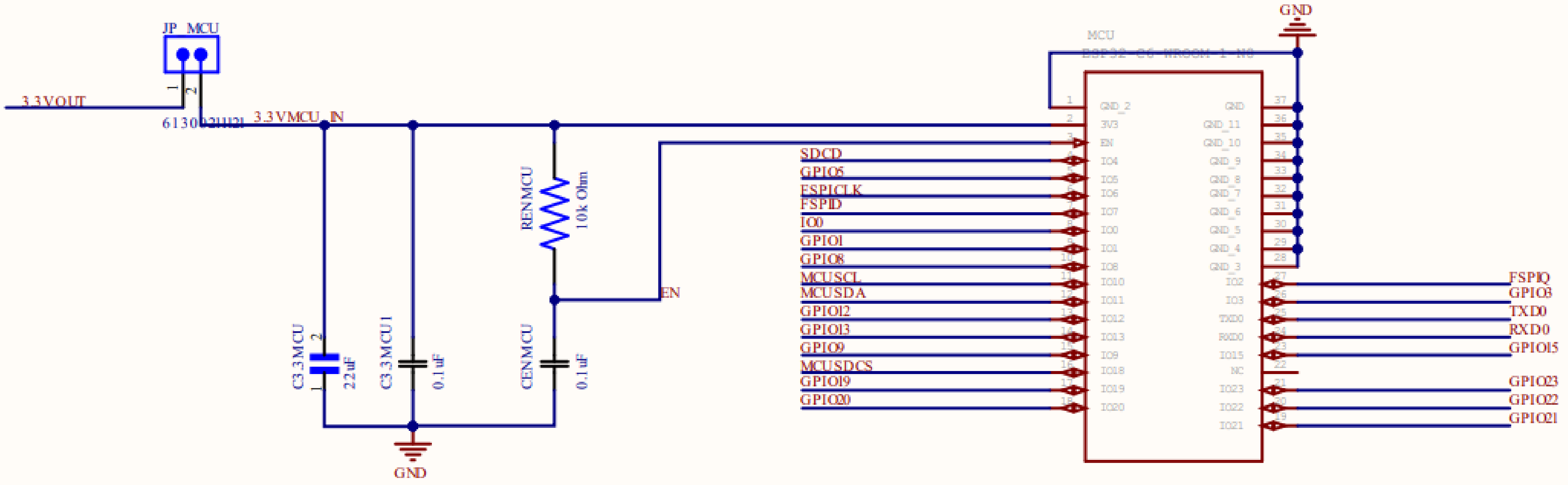
SERVO MOTOR CONTROLS



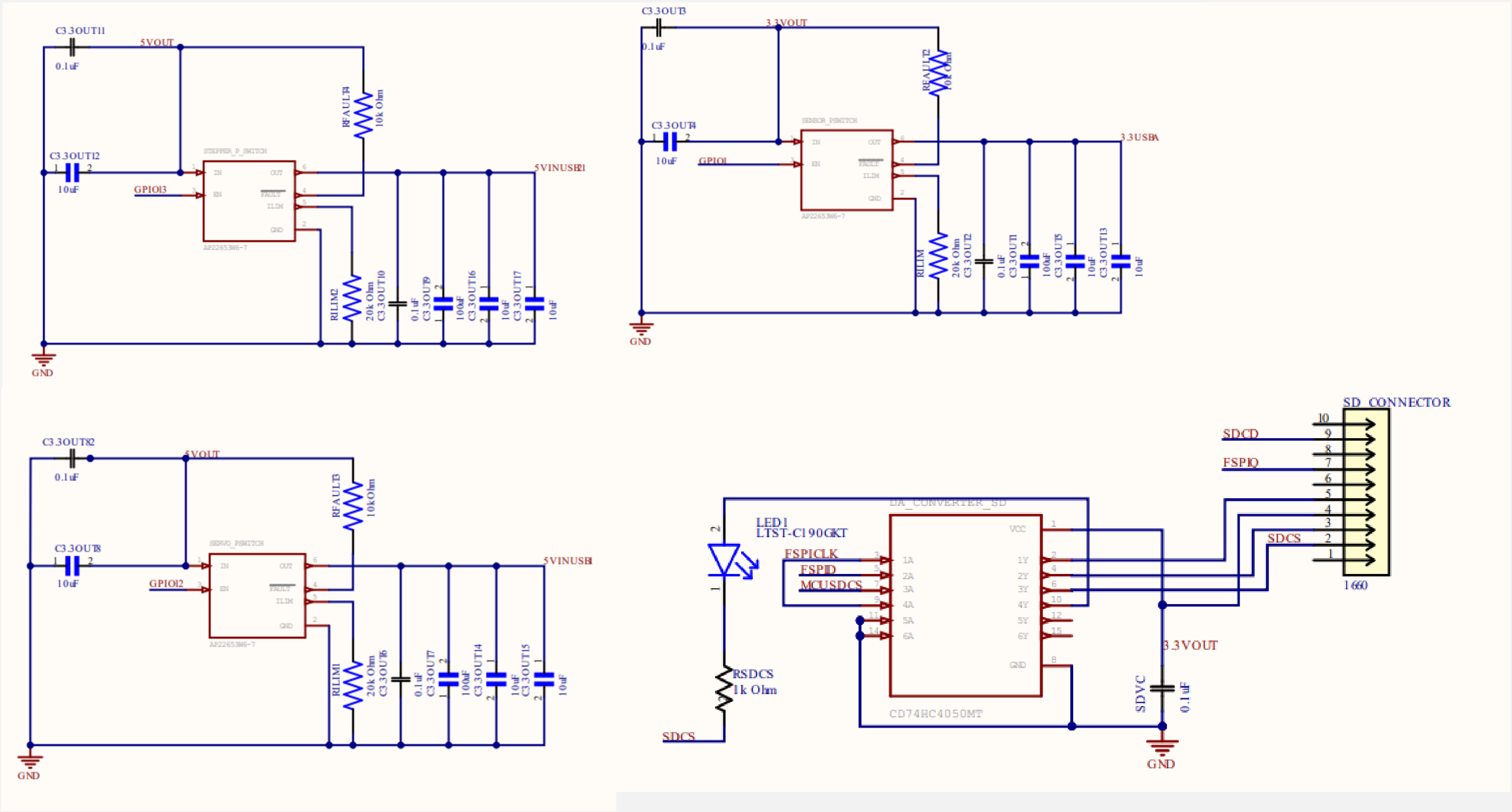
SENSOR CONTROL



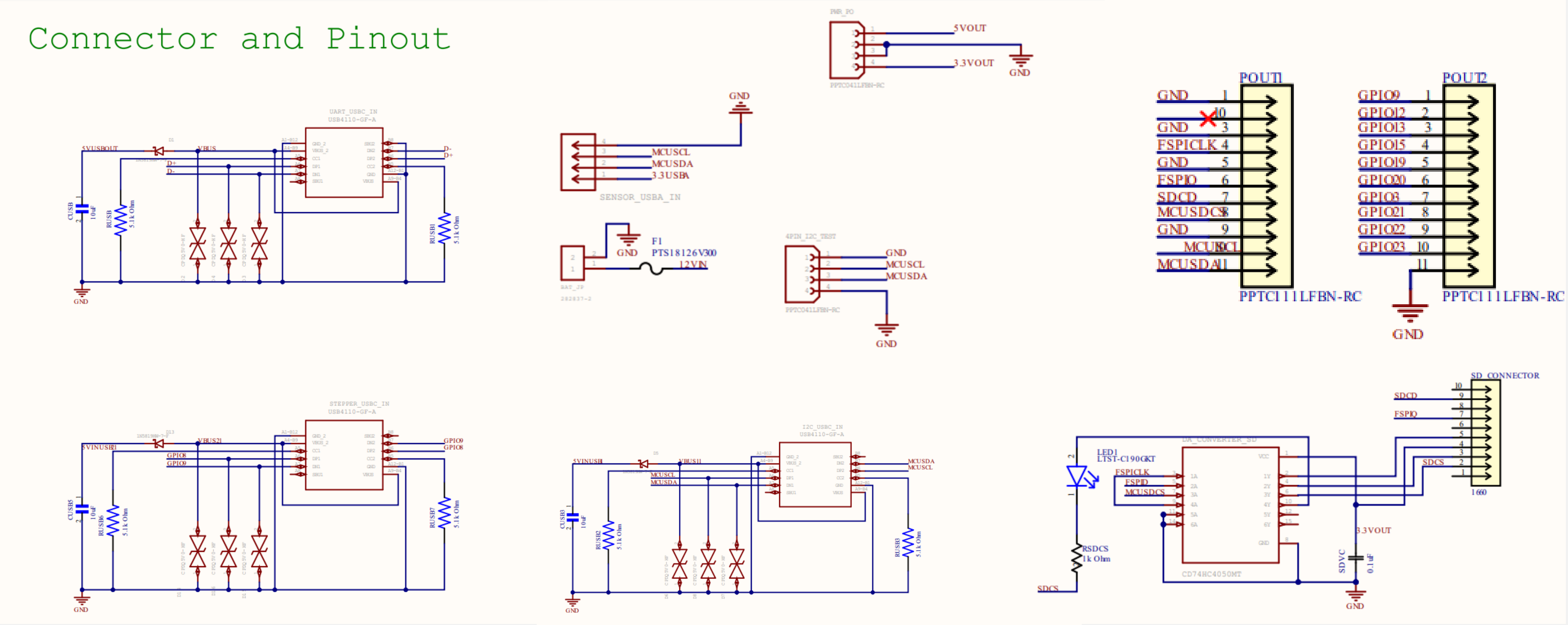
MCU SYSTEM


JP_MCU
3.3VOUT
3.3VMCU_IN
RENMCU
10k Ohm
EN
C3.3MCU
22uF
C3.3MCU1
0.1uF
CENMCU
0.1uF
GND
MCU
GND
SDCD
GPIO5
FSPICLK
FSPID
IO0
GPIO1
GPIO8
MCUSCL
MCUSDA
GPIO12
GPIO13
GPIO9
MCUSDCS
GPIO19
GPIO20
FSPIQ
GPIO3
TXD0
RXD0
GPIO15
GPIO23
GPIO22
GPIO21

LOWER-LEVEL SUBSYSTEM



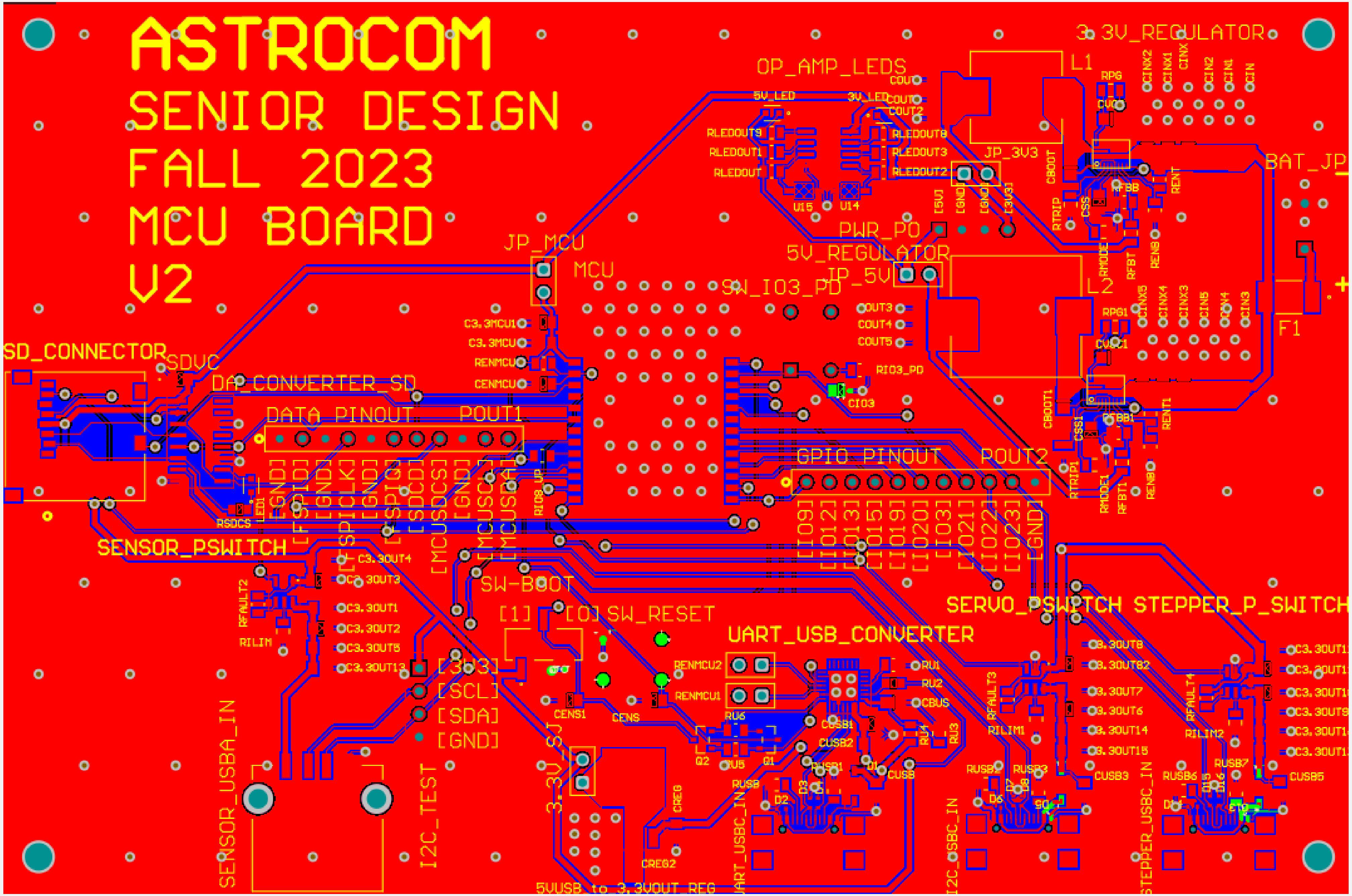
LOWER-LEVEL SUBSYSTEM

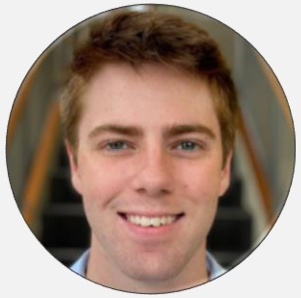


POWER CONTROL ALGORITHM

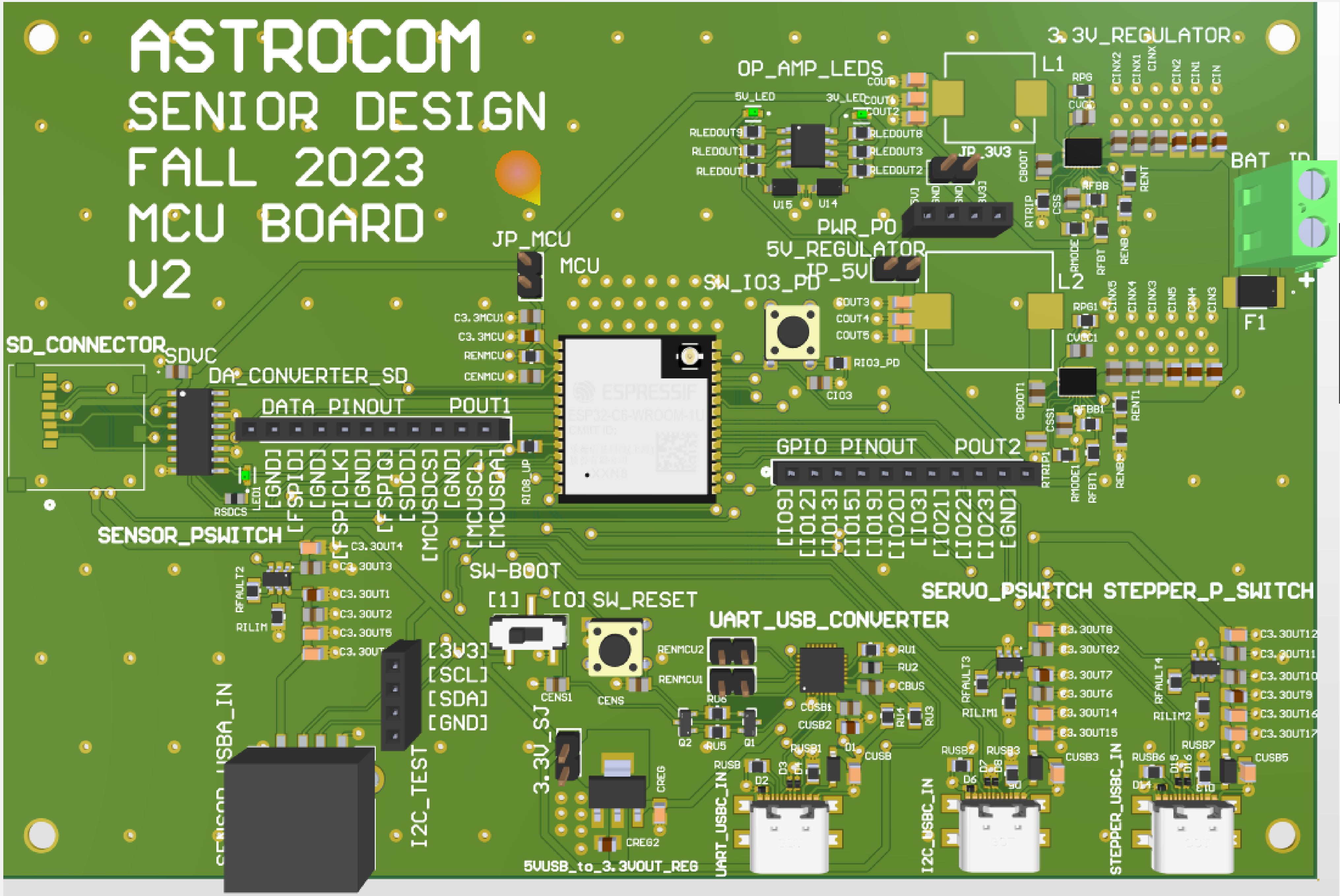
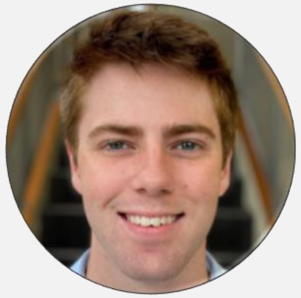
- Goal was to reduce power consumption when the sun would not be visible
- Reducing usage of non-essential components during these times would preserve battery charge

Component	Essential/Non-Essential	Low-Power Considerations
MCU	Essential	Low-Power Mode, only essential functions
Antenna	Essential	Receive only
Sensors	Essential	Sensors will be turned on periodically
Stepper Motor	Non-Essential	
Servo Motors	Non-Essential	

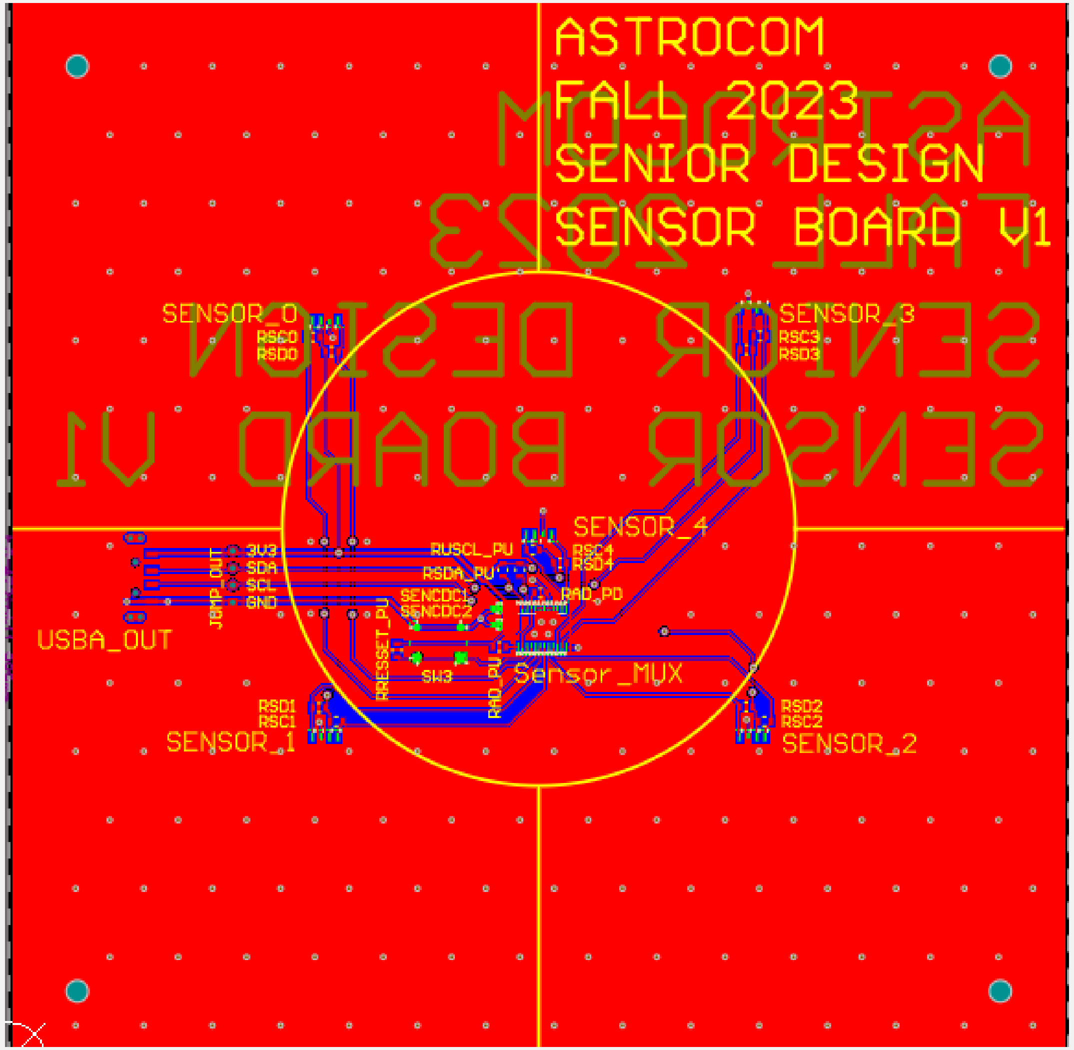

ASTROCOM
SENIOR DESIGN
FALL 2023
MCU BOARD
V2
OP_AMP_LEDS
3.3V_REGULATOR
5V_REGULATOR
JP_MCU
MCU
SD_CONNECTOR
DATA_PINOUT
GPIO_PINOUT
SENSOR_PSWITCH
SW_RESET
UART_USB_CONVERTER
SERVO_PSWITCH
STEPPER_P_SWITCH
SENSOR_USBA_IN
I2C_TEST
5VUSB to 3.3VOUT REG

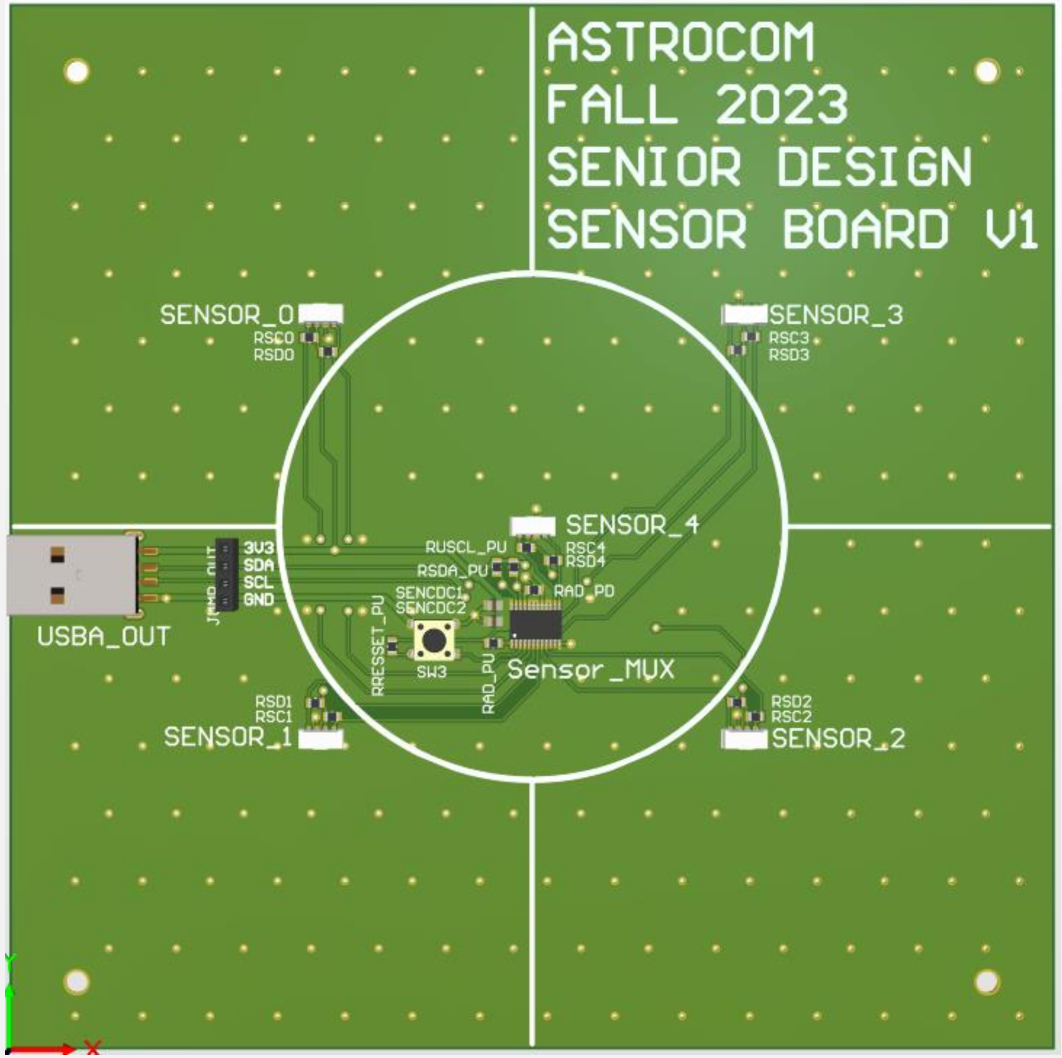


MCU PCB


ASTROCOM
SENIOR DESIGN
FALL 2023
MCU BOARD
V2
OP_AMP_LEDS
3.3V_REGULATOR
L1
JP_3V3
PWR_PO
5V_REGULATOR
JP_5V
SW_IO3_PD
L2
BAT_IP
F1
JP_MCU
MCU
SD_CONNECTOR
SDVC
DA_CONVERTER_SD
DATA_PINOUT
POUT1
GPIO_PINOUT
POUT2
SENSOR_PSWITCH
SW-BOOT
[1] [0] SW_RESET
UART_USB_CONVERTER
SERVO_PSWITCH STEPPER_P_SWITCH
[3V3]
[SCL]
[SDA]
[GND]
I2C_TEST
3.3V_SJ
5VUSB_to_3.3VOUT_REG
UART_USBC_IN
I2C_USBC_IN
STEPPER_USBC_IN


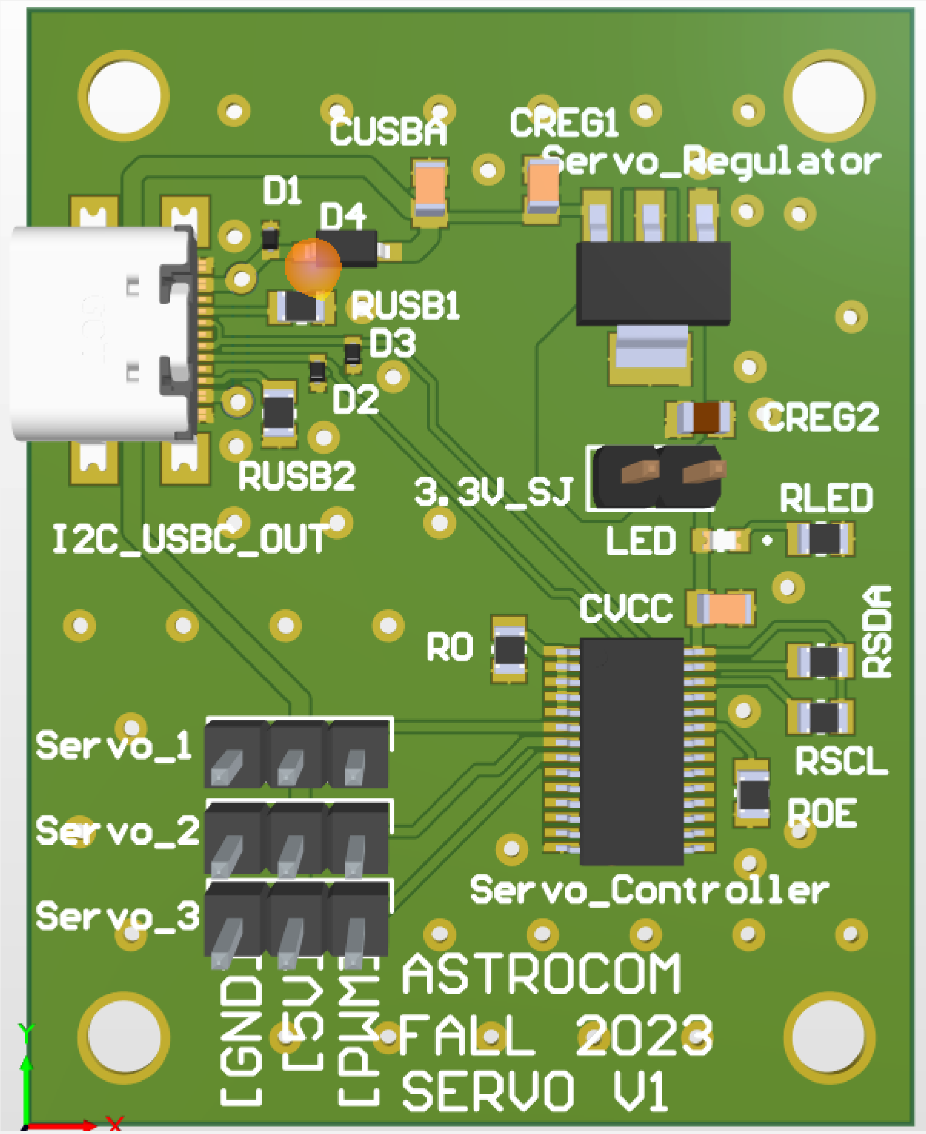
MCU PCB

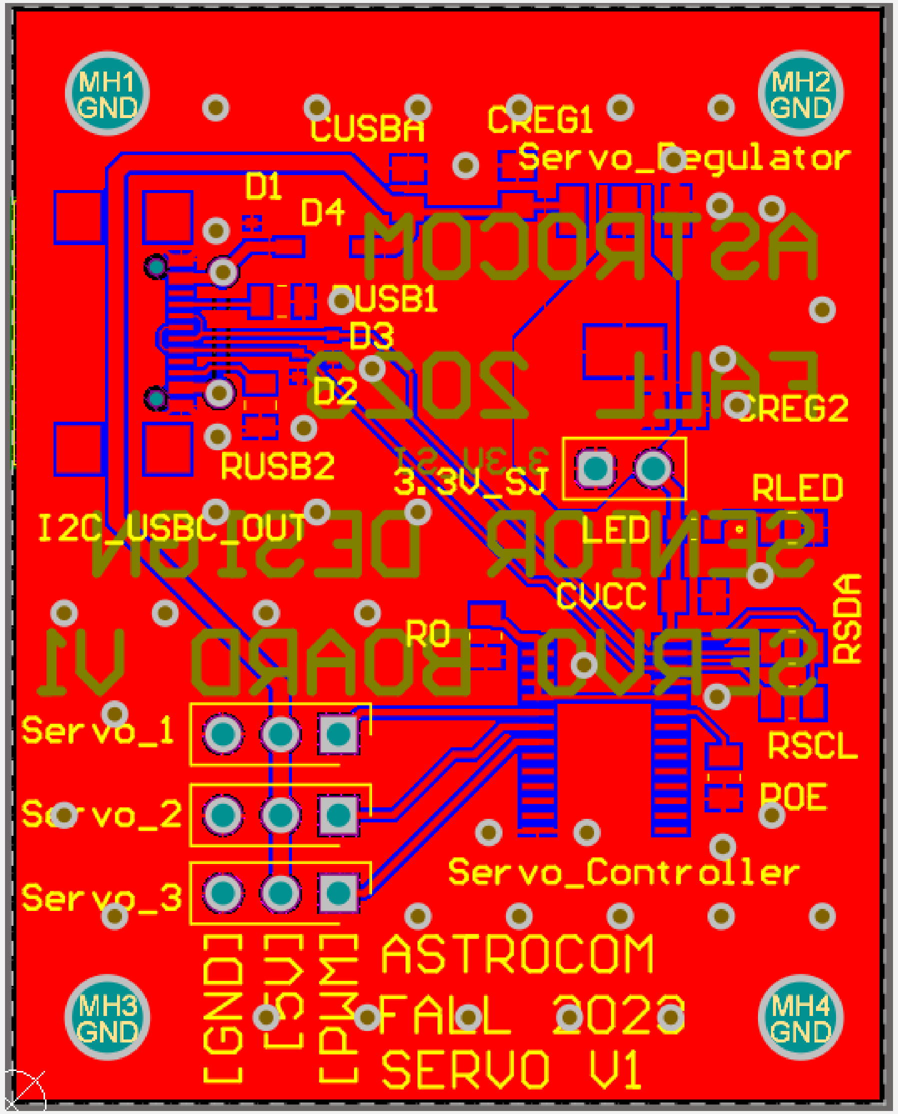

ASTROCOM
FALL 2023
SENIOR DESIGN
SENSOR BOARD V1
SENSOR_0
SENSOR_3
SENSOR_4
USBA_OUT
Sensor_MUX
SENSOR_1
SENSOR_2


ASTROCOM
FALL 2023
SENIOR DESIGN
SENSOR BOARD V1
SENSOR_0
SENSOR_3
SENSOR_4
USBA_OUT
Sensor_MUX
SENSOR_1
SENSOR_2

SENSORS PCB

SERVO MOTOR CONTROLLER PCB

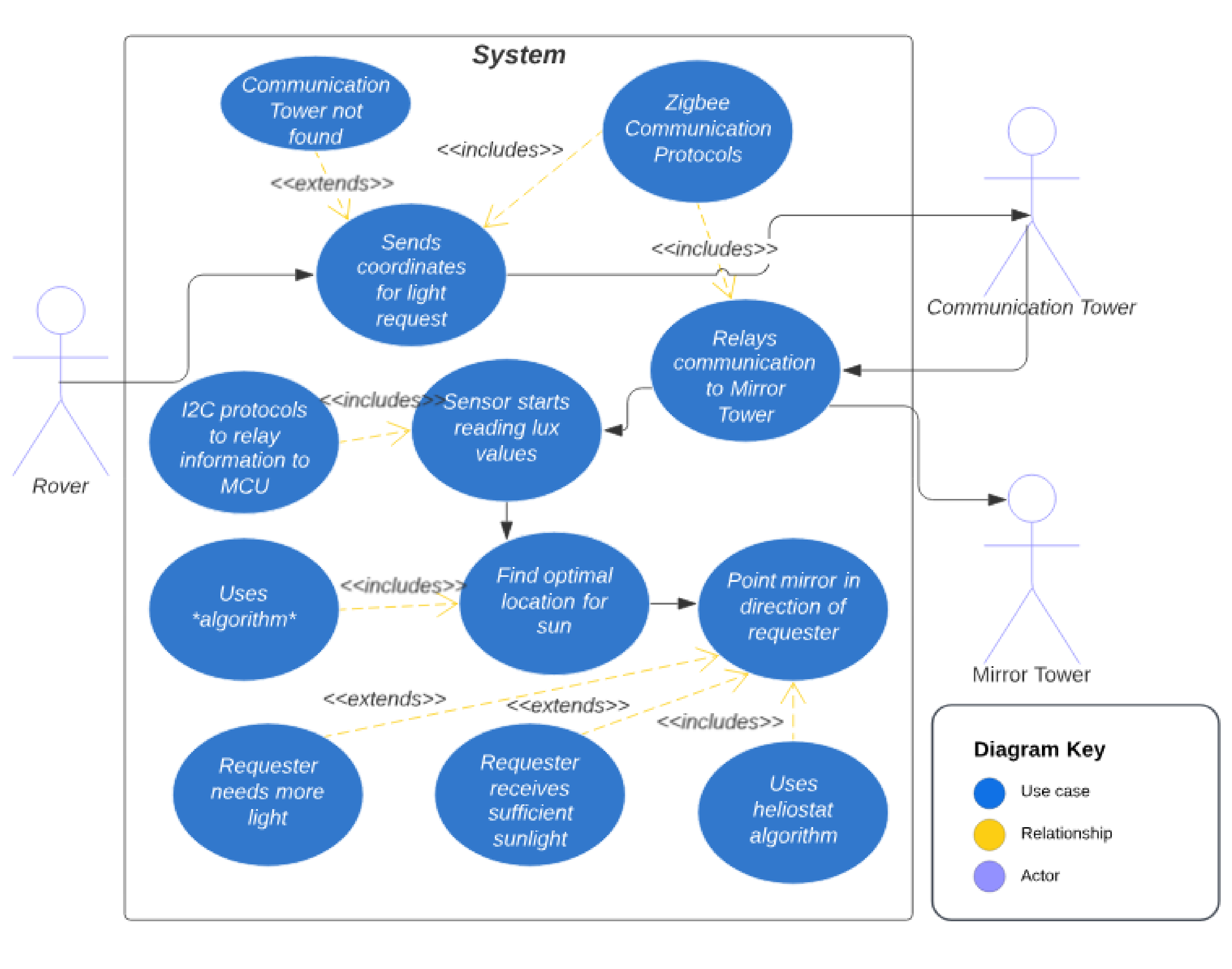




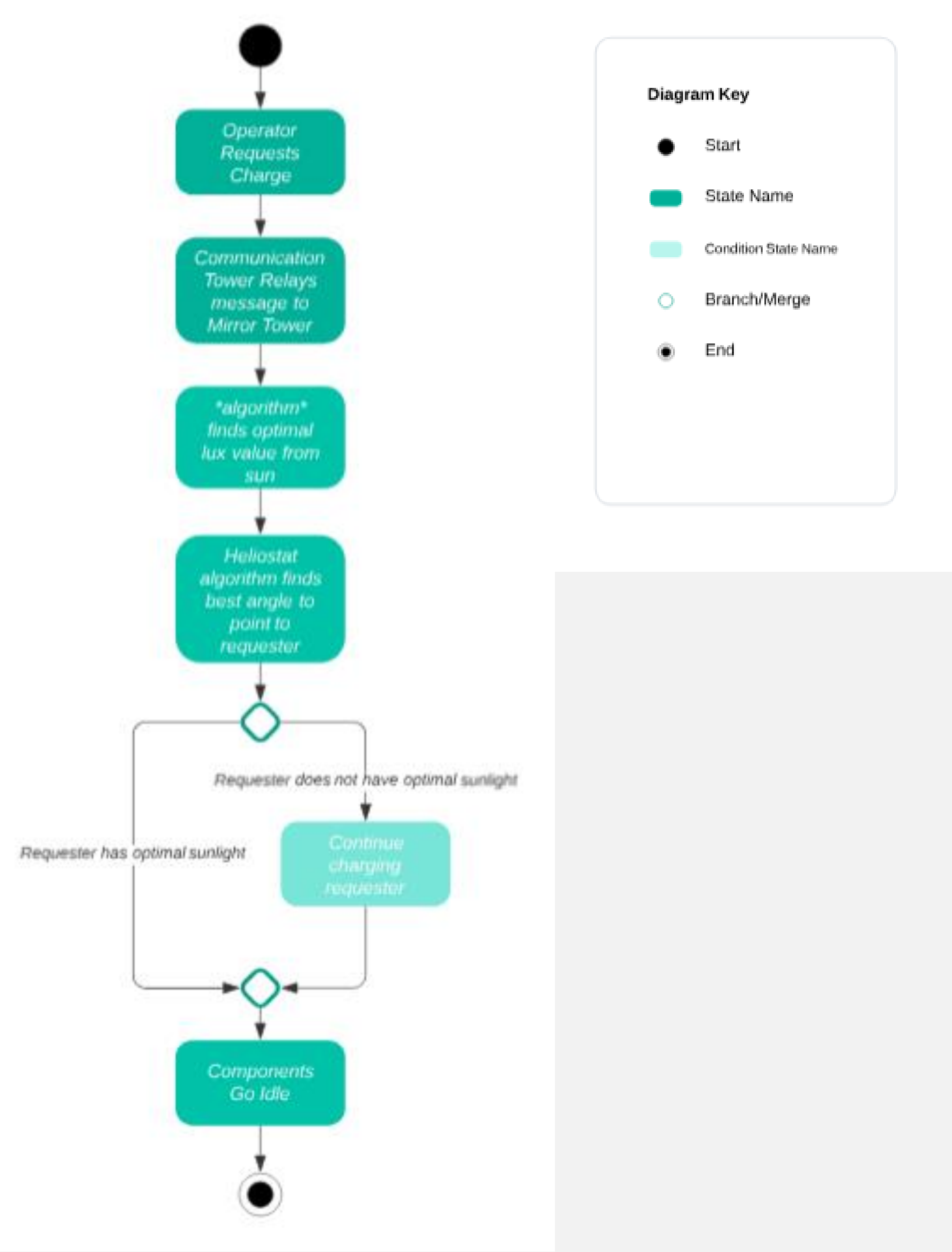
SOFTWARE DESIGN

- Details on software design for the overall system which includes:
- Communications through the mesh network
- Collecting sensor information
- Positioning reflector to deliver sunlight to target
- Represented with software diagrams

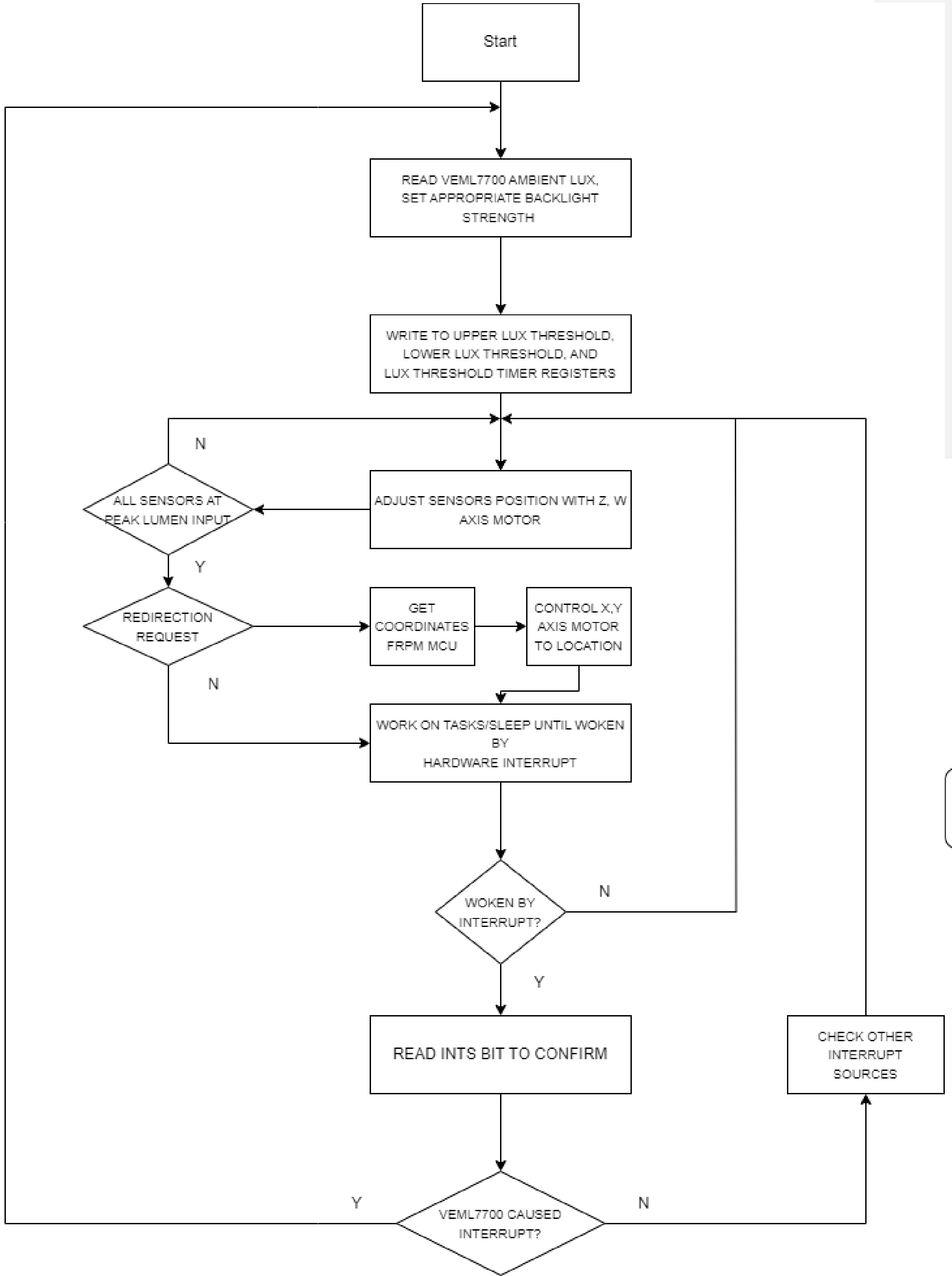
CASE DIAGRAM

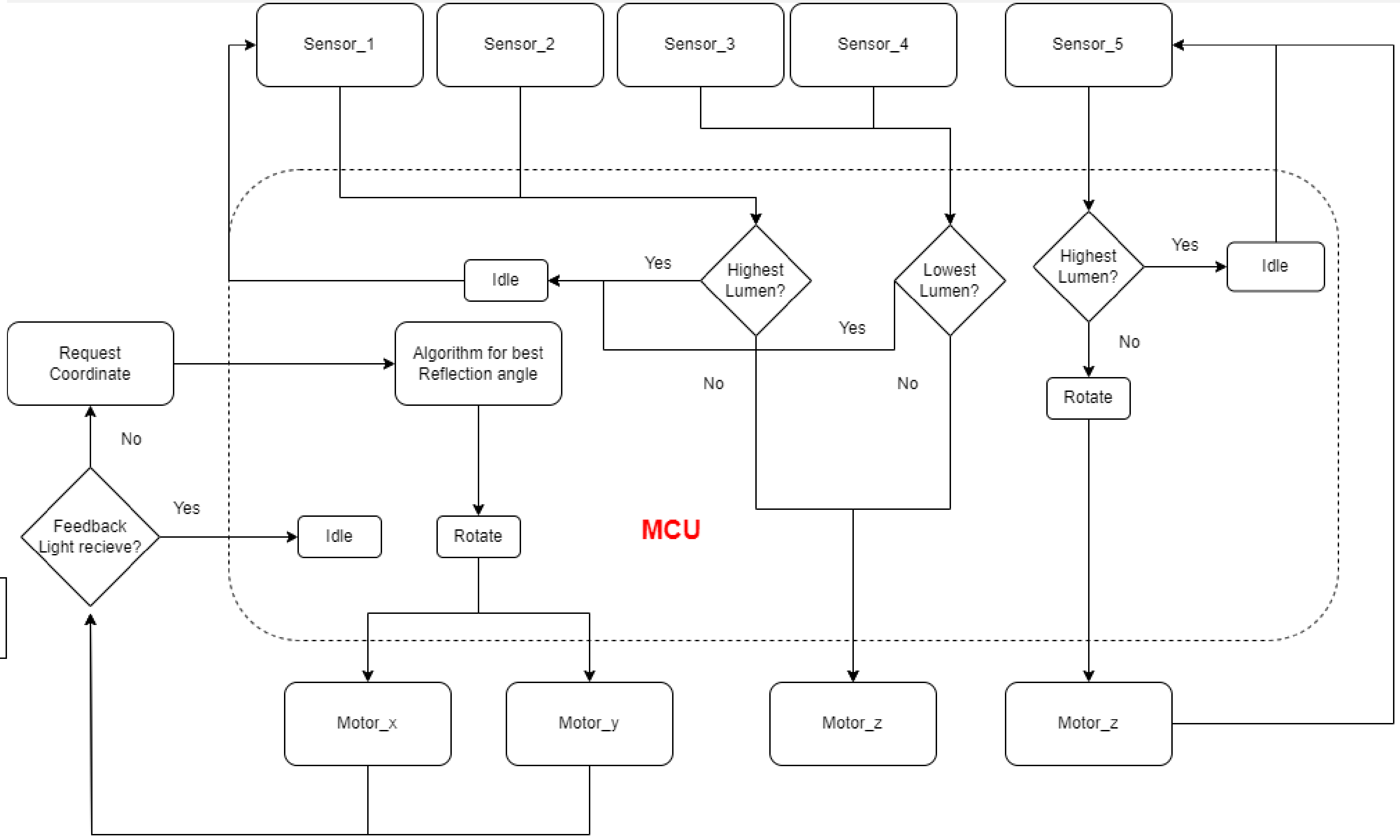


ACTIVITY DIAGRAM



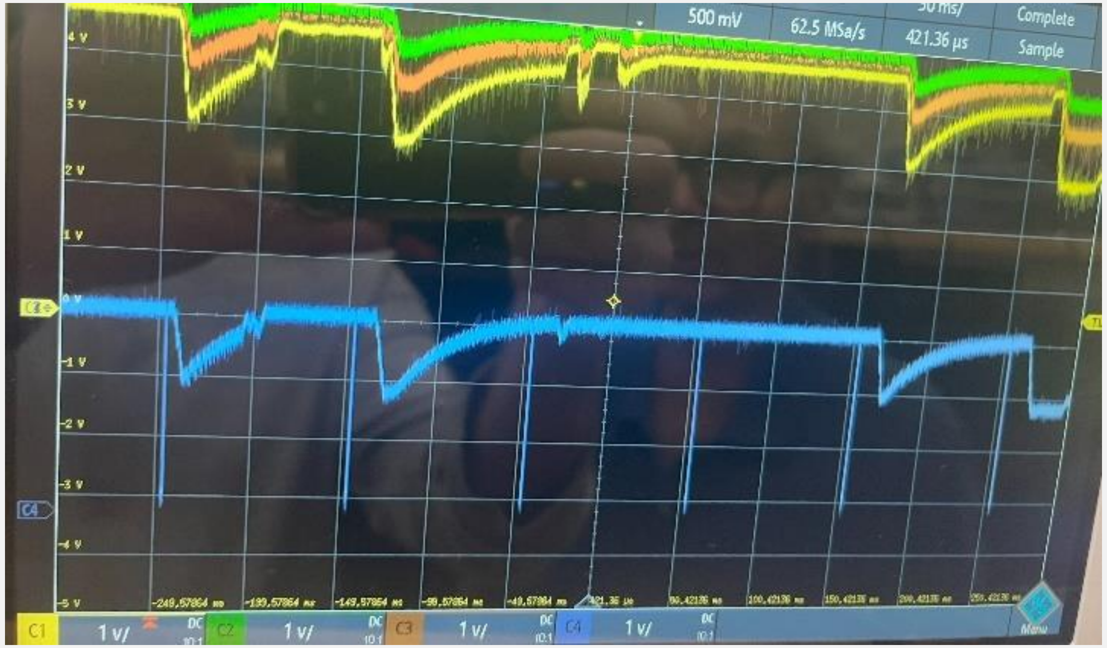
MOTOR POSITIONING OF REFLECTOR BASED ON LIGHT INTENSITY ALGORITHM.





HARDWARE TESTING

- Tested components and had great success.
- Did have a few issues during implementation including:
  - Strapping pins and UART TX/RX mix-ups
  - Higher than expected channel capacitance causing low rise time for I^2C
  - Voltage drop from servos, resetting the servo controller
- These issues were resolved with a mix of software and hardware changes.



SOFTWARE TESTING

- Transforming individual parts code to integrated code
  - Included interrupts to handle events
  - Sensors in certain locations are averaged and divided by each other to dynamically track movements
  - Scaling operations were needed to transform step sizes from different servos
  - Zigbee operations included to switch targets
- Created our own coordinator for testing but will use rover from G16 in live demo
  - This coordinator will relay information from communication box (Zigbee end device) to the reflector tower (Zigbee end device)

ADMINISTRATIVE CONTENTS

Electrical Engineering	Responsibilities
Alexandre Fiset	PSU Design and Implementation
	PCB Design
	MPPT Tracking Implementation
	Administrative Documentation
Computer Engineering	**Responsibilities**
Binh Pham	Reflector Technology and Design
	Motor and Motor Controls
	Vectoring Technology
	Project Lead
	Positioning and Vectoring Algorithm
Computer Engineering	**Responsibilities**
Pedro Kasprzykowski	MCU Selection and Implementation
	Software Design and Implementation
	Antenna and Communications
	Website Design and Management
Computer Engineering	**Responsibilities**
Stephen Martin	Sensor Selection and Implementation
	MCU Selection and Implementation
	Positioning and Vectoring Algorithm
	Software Design and Implementation

MECHANICAL'S BUDGETS

Component	Name	Price/unit	Quantity
Mirror	0.032" x 24" x 24", 3003-H14 Aluminum Sheet	$28.86	1
Mirror Coating	Mylar Sheet	$25.99	1
Frame	ADJ LTS-6 T-Bar Tripod Lightweight Lighting Stand	$54.99	1
Base Panels	Plywood Panels 4ftx8ft	$25.60	2
Communication Tower Box	Junction Box	$26.89	1
Wheel Hub Bearing	Rear Wheel Hub	$44.90	1

ELECTRICAL'S BUDGET

Component	Name	Price	Quantity
Battery	Howell Energy hw-4f7	32.99	1
Motor w	Nema 23	$30.73	1
Motor x-y-z	9.5-11kg*cm Servo Motor	$17.59	3
Charge Controller/BMS	Smaraad SR11004	$39.99	1
Solar Panel	RNG-50D-SS	$49.99	1
Microcontroller	ESP32-C6-DEVKITC-1-N8	$9.00	1
External Antenna	Wlaniot 2.4G	$17.98	2
MicroSD card	5251	$4.50	2
MicroSD card breakout board+	254	$7.50	1

Component	Name	Price	Quantity
Microcontroller for PCB	ESP32-C6-WROOM-1U	$3.48	1
Stepper Motor Controller	DRV8833PW	$2.84	1
Servos Motor Controller	PCA9685PW,112	$2.64	1
3.3V Regulator	TPS54JA20	$1.50	1
5V Regulator	TPS54JA20	$1.50	1
USB-A Connector	2057-USB-AP-S-RA-SMT-ND	$0.55	3
Sensor-MUX	TCA9548APWR	$1.78	1
Sensor	VEML7700	$1.88	5
USB-to-UART Bridge Controller	CP2102N-A02-GQFN28	$4.07	1
MicroSD Socket	1660	$1.95	1
Misc.	Resistors, Capacitors, Inductr, Jumpers, Etc.….	~$20.00	

PCB’S BUDGET