# Single Mode Autonomous Solar Spectrometry

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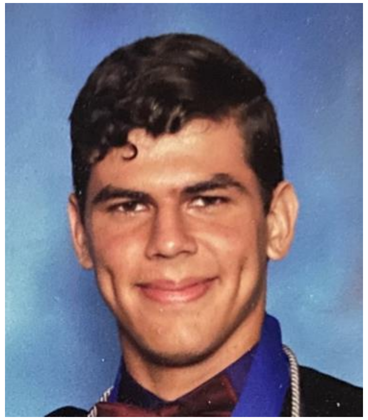

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# Motivation/Background

**Studying the sun's radial velocity as it rotates and wobbles around the solar system's center of mass is important in space exploration.**

Utilizing the Doppler effect, researchers can examine the Sun's spectrum for redshift

**Solar flares and storms result in unpredictability in measurements**

Constant monitoring throughout the day can account for this

# Our Project

- Requested based off a mini telescope designed by the Astrophotonics research group that collects light from the Sun
- Utilizes spectrometry to collect raw images of the Sun's spectrum
    - Not just a product, but rather a steppingstone in the development of advanced study of the Sun

# Overview: Two System Project

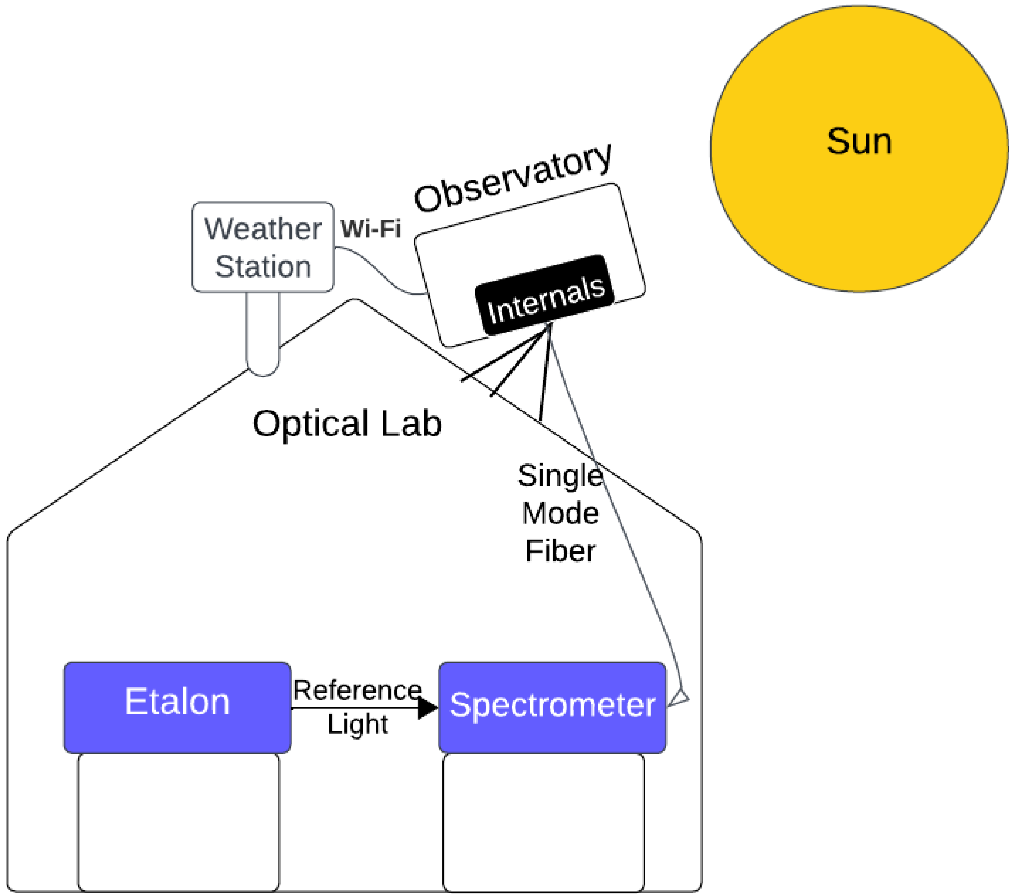
## Autonomous Rooftop Observatory

- Houses components that enable the system to track the sun
- Weather protected

## 2. Optical Lab Processing

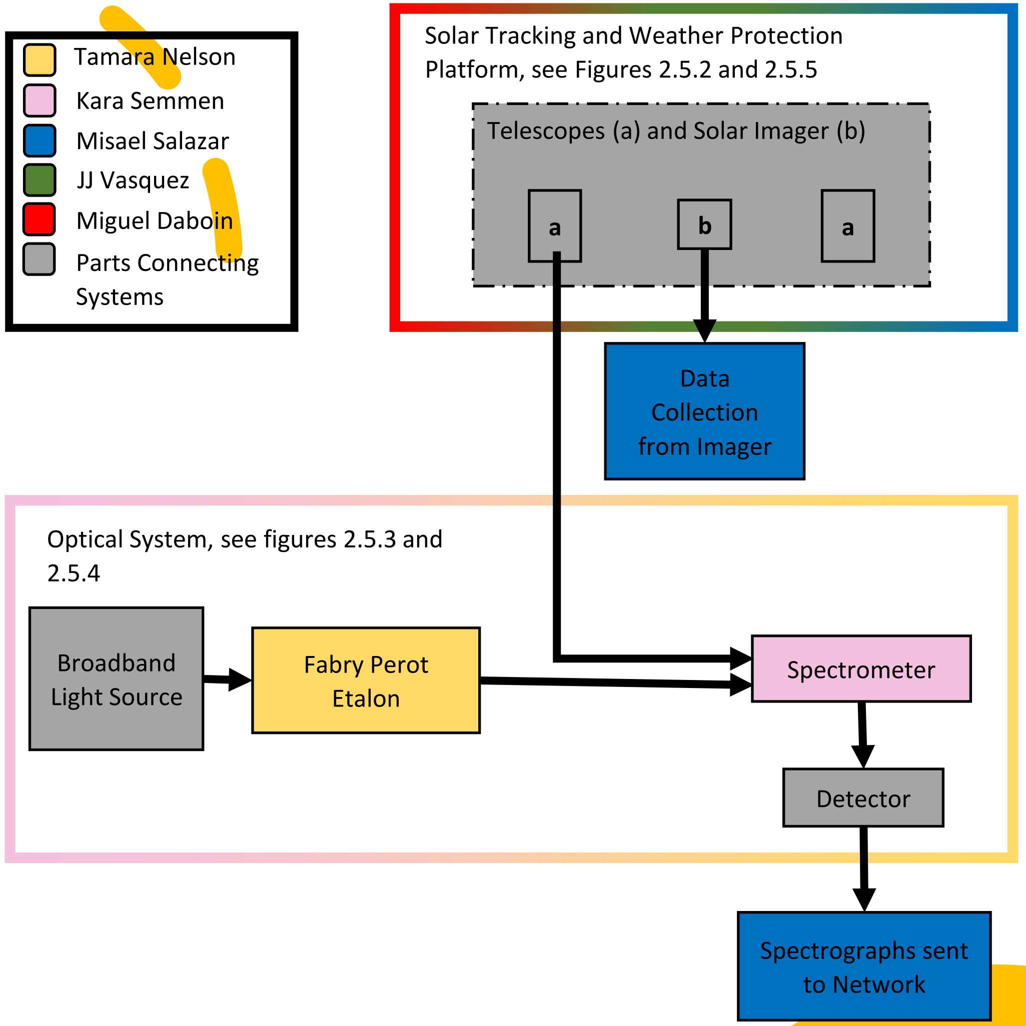
- Single Mode Spectrometer
- Fabry-Perot Etalon

Note: The electronics in the rooftop system are not meant to connect directly to the optical lab, but rather enable the weather resistance and monitoring requested by the sponsor. The connection is from a component the observatory houses: a mini telescope to capture light from the Sun



# Overall Design

- Here  is a diagram depicting the overall plan of the system, depicting how the optical, electrical, and software systems connect. Which also depicts with highlighted colors the work distribution among the team.



# Goals and Objectives

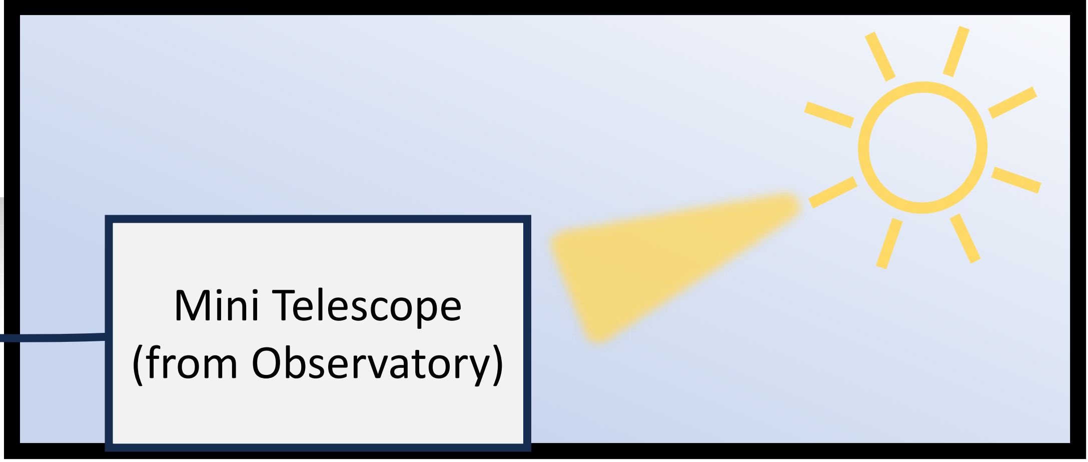
| Goals | | Objectives |
|---|---|---|
| Basic | Tracking of the sun | |
| | Weather protection of rooftop system | |
| | Spectrometer to output spectrum of sun | Implement a single mode fiber from telescope to spectrometer |
| | Spectrometer calibration | Filter broadband, continuum light source through a Fabry-Perot etalon as a parallel spectrometer input to create a comb-like pattern for comparison |
| Advance | Improve Optical stability | Implement a thermostable mounting design for the Etalon |
| | | Implement fiberglass mounting to minimize vibration |
| | | Add enclosure with insulation and foam for sound absorption |
| | | Incorporate cross-dispersion in spectrometer to… |
| Stretch | Implement a second telescope and fiber connection | TBD |

# Engineering Specifications

| Description | Specifications |
|---|---|
| Spectrograph Resolution Element | 6e9 Hz |
| Free Spectral Range of Etalon | 18 – 30 GHz |
| Start-up Time | ~1 minute |
| Weather Resistance | IP66 equivalent |
| Weather Model Accuracy | > 50% |
| Power Consumption | < 100W |
| Solar Imager: Image Interval | 10 seconds |

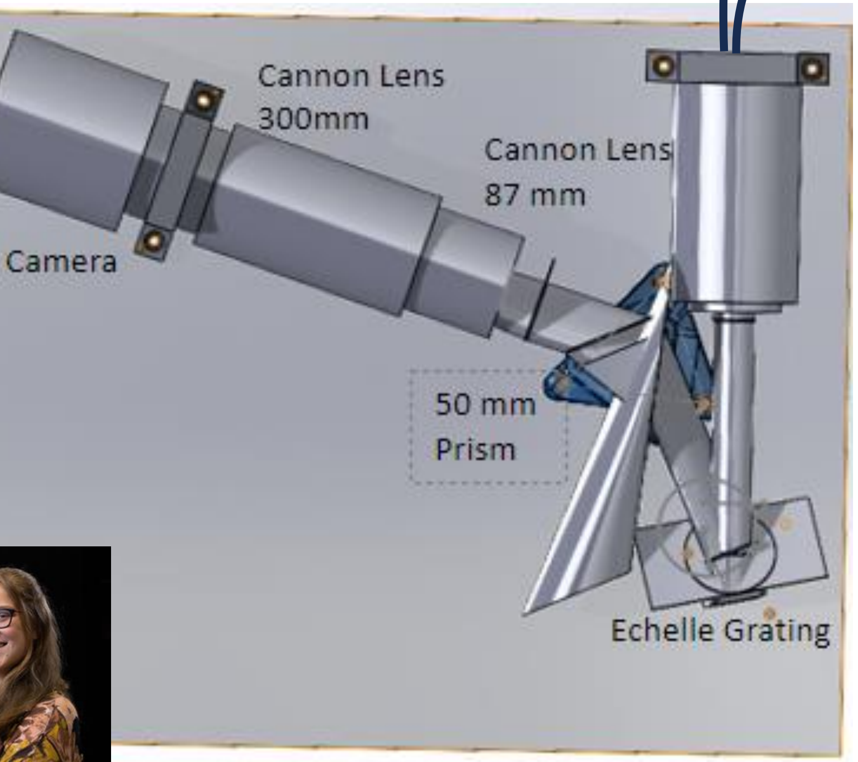
# Optical Laboratory System

- Two subsystems connected by a Single Mode Fiber

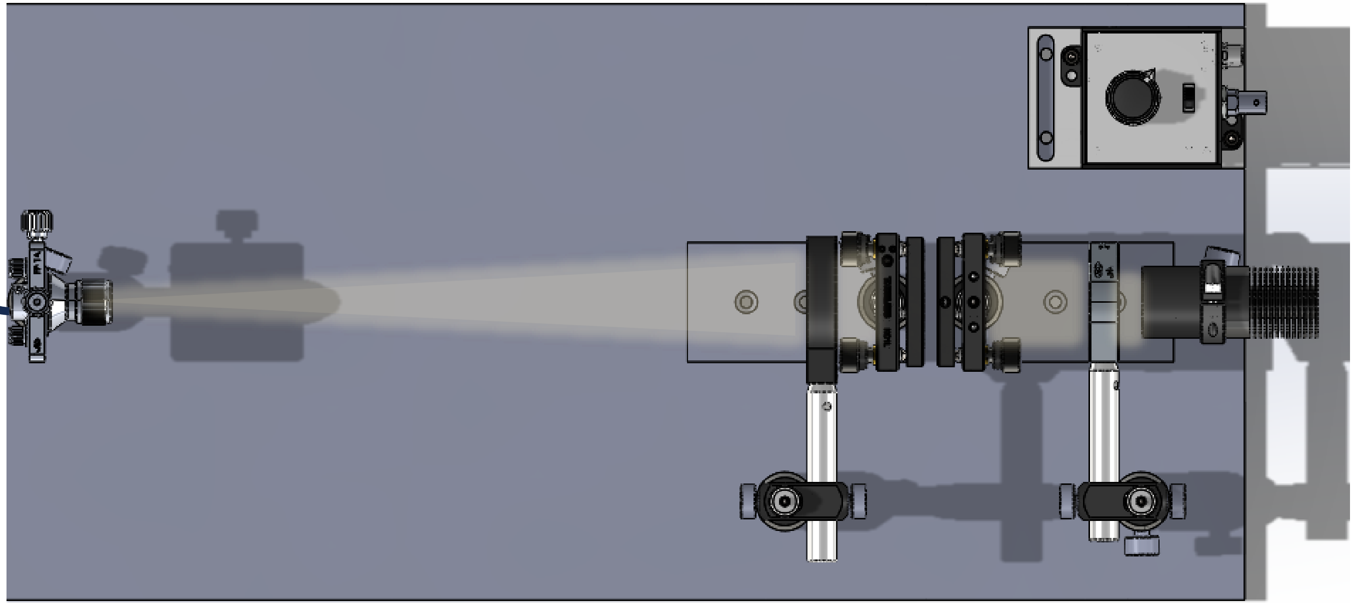



Single Mode Fiber

1. Spectrometer

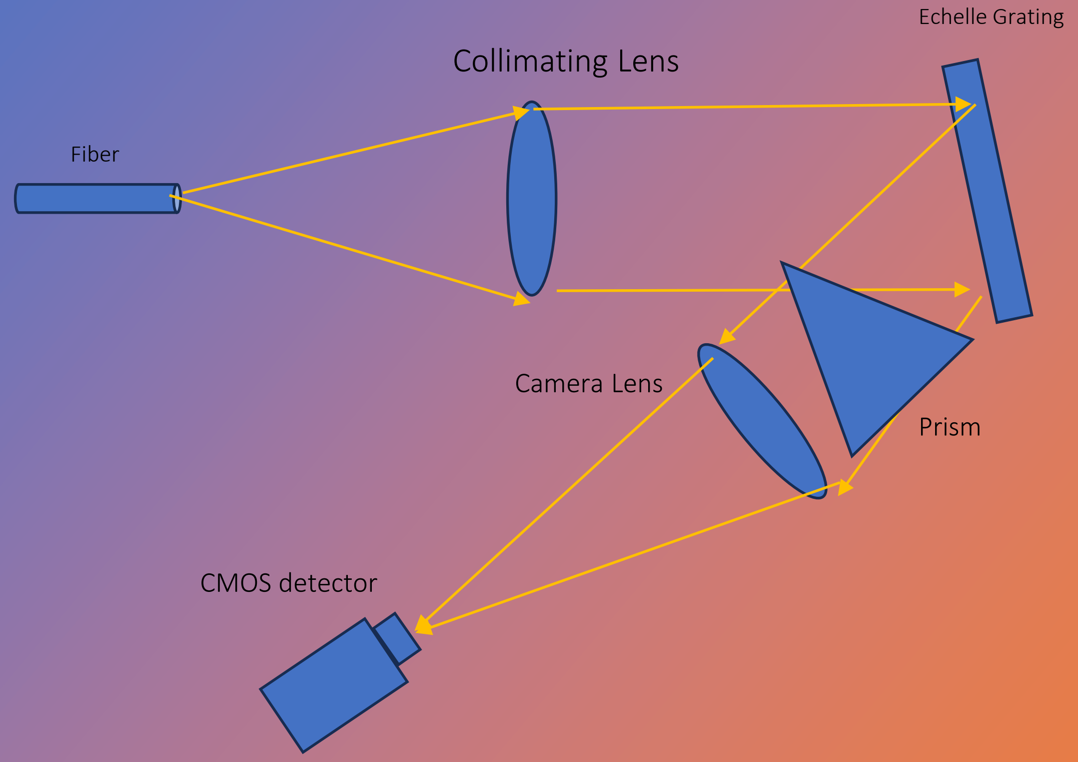



2. Fabry-Perot Etalon

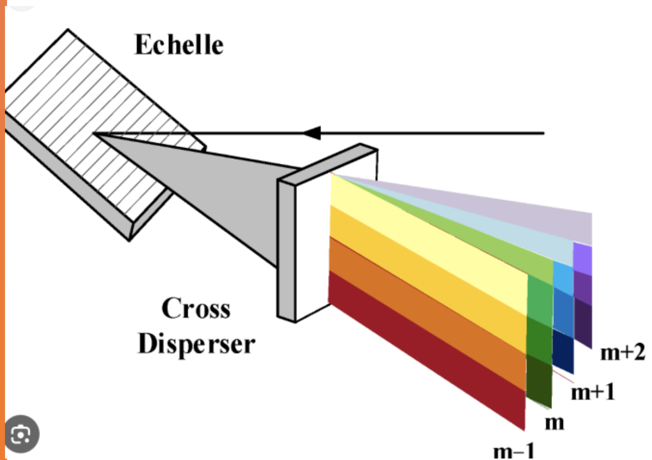


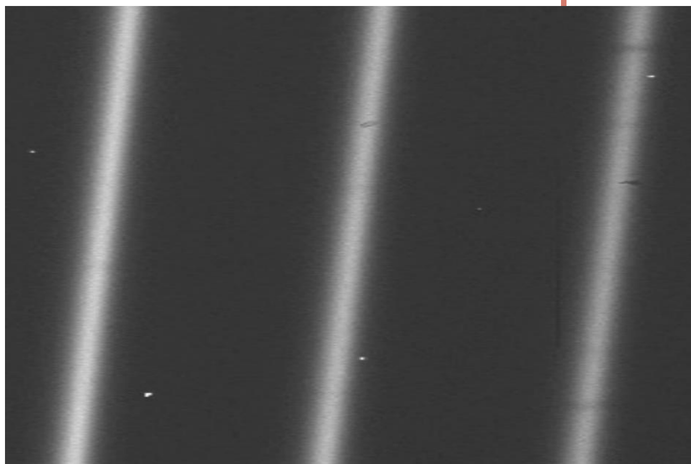
Optics: Spectrometer

# Design




- Two-dimensional dispersion.
- Light is dispersed twice as it passes through the system. First by the grating and then by the prism
- First dispersion will result in a vertical line with a small range of spectrum varying by vertical distance from the center.
- Second dispersion will spread out the overlapping lines to show a large bandwidth of color.



# Overall Spectrometer Specs

3.5x magnification

Resolving power between 50,000 and 100,000

Bandwidth of 400 nm to 700 nm

# Optics: Spectrometer
# Single Mode Fiber (SMF) Comparison and Selection

| Fiber | Operating wavelength | Coating Diameter | Coating Material | Operating temperature (degrees Celsius) | Attenuation | Mode Field Diameter (MFD) | Numerical Aperture |
|---|---|---|---|---|---|---|---|
| Thorlabs SM400 | 405-532 nm | 245 ± 15 µm | Dual Acrylate | -55 to 85 ℃ | ≤50 dB/km @ 430 nm ≤30 dB/km @ 532 nm | 2.4-3.5 µm | 0.12-0.14 |
| Newport: F-SAOptical | 488-633 nm | 245 µm | Dual Acrylate | Not Given | 50 dB/km @ 488 nm | 2.8-4.1 µm | 0.1-0.14 |
| Thorlabs SM600 | 633-780 nm | 245 ± 15 µm | Dual Acrylate | -55 to 85 ℃ | ≤15 dB/km | 3.6 – 5.3 µm | 0.1-0.14 |

# Optics: Spectrometer

## SMF Selection

Thorlabs SMF 400

- Chosen for smallest fiber core size (mode field diameter in table), to achieve high resolution.
- Also chosen for bandwidth. Designed for 532 nm, which is the peak wavelength we seek to measure in this system.
- Peak wavelength transmittance of 400-532 nm, MFD of 3µm, designed to operate at temperatures ranging from  -55 to 85 degrees Celsius.

# Optical Grating Specs

- Must be made for the visible to near infrared wavelength range (400 to 900 nm)
- Must have a pitch which allows for high resolving power (50,000 to 100,000)
- Bandwidth must fit on detector (roughly 35 mm across).
- Size must be large enough for incident beam to fit on grating
- The desire for large bandwidth with significantly high resolution leads us to solely compare echelle gratings whose blazed grooves are designed to maximize intensity of the higher diffraction orders (higher diffraction order provides greater spectral resolution).

Optics: Spectrometer

# Grating Comparison and Selection

| Grating | Groove density | Dimensions | Blaze angle | Price |
|---|---|---|---|---|
| Echelle ruled reflective grating | 31.6 grooves/mm | 50x25 mm | 63.9 degrees | $284 |
| Echelle ruled reflective grating | 79 grooves/mm | 50x25 mm | 63 degrees | $284 |
| Echelle ruled reflective grating | 79 grooves/mm | 50x25 mm | 74 degrees | $284 |
| Echelle ruled reflective grating | 316 grooves/mm | 50x25 mm | 63 degrees | $284 |

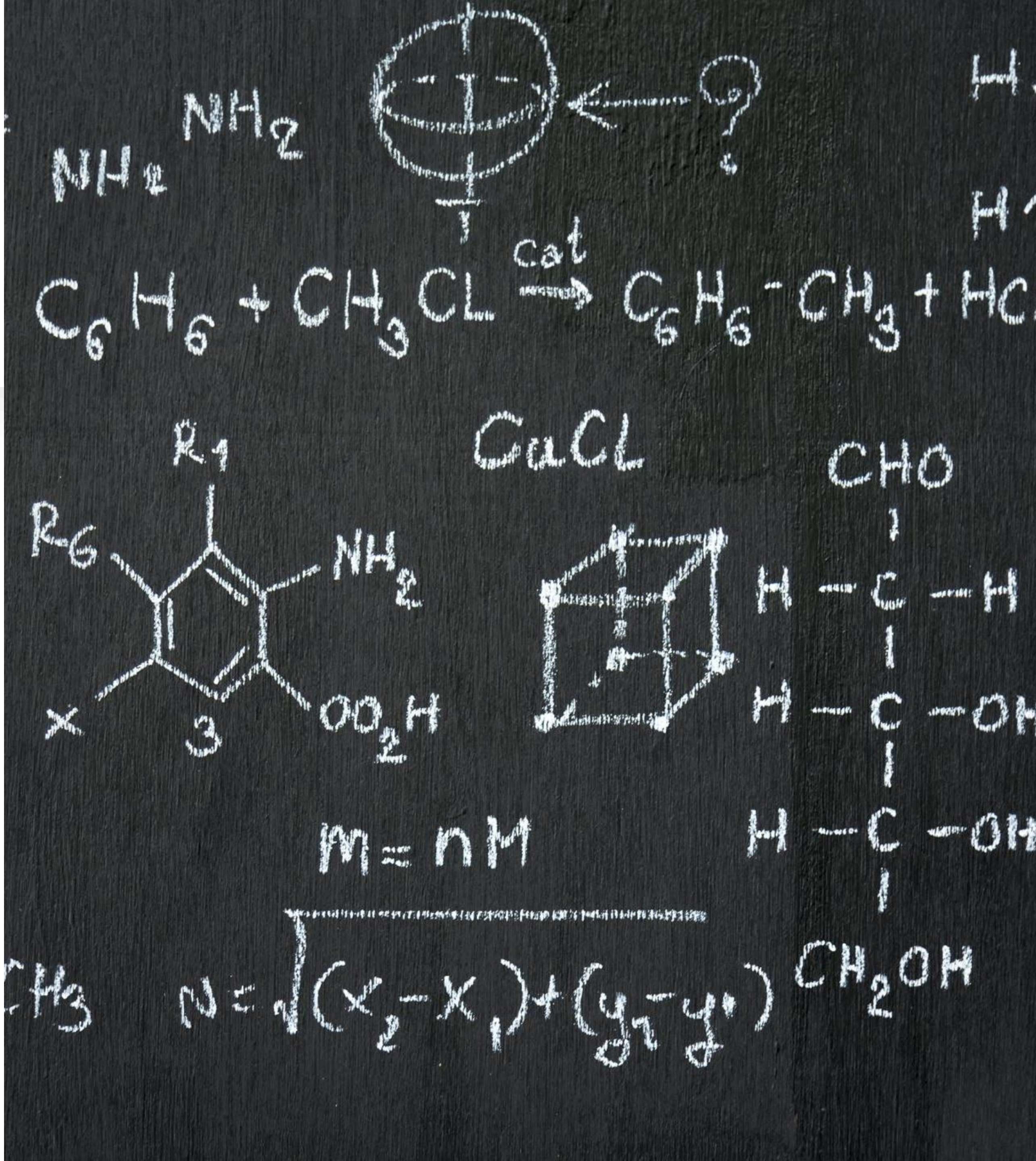
- Higher blaze angles result in a spectrum too large for detector
- 63.9 degree blaze angle sacrifices some resolving power but produces higher diffraction efficiency
- Reflective grating allows for a more compact design than a transmission grating.

# Collimating and Camera Optics Specs

- The ratio of the camera lens focal length to the collimator focal length must be equal to the desired magnification, 3.5x
- Collimating lens: focal length of 87 mm
- Camera lens: focal length of 305 mm
- Size of lens must be large enough to capture beam.
- Lenses must have an antireflective coating
- Lenses must be achromatic to diminish chromatic aberrations
- Must be cost and time effective

# Criteria used to check system functionality:

- Arclamps with known wavelengths used to measure the actual bandwidth and magnification of the system
- Resolution calculated utilizing the equation, $R=\lambda/\Delta\lambda$



# Lens Comparison

- A single lens for either the collimating or camera lens produces too many aberrations to be a viable choice for this system.
- The alternatives are to:
  - Design and assemble a custom optical design with multiple lenses for both the collimator and camera optics in the system
    - Expensive
    - Lead time for custom made lenses adds time to project timeline
    - Guaranteed to obtain the exact lenses needed
  - Acquire a lens system already designed for minimal aberrations with the necessary focal length and F/#.
    - Affordable
    - Possible conflicts with available lens systems on the market
    - No custom optical design needed.


# Lens Selection

- EF 75-300mm F/4-5.6 Cannon Lens
- Adjustable focus: the same lens can be utilized for both collimating and focusing components
- Minimized aberrations
- Cost: $300

# Long term Optical Design:

- For the project that will evolve from this initial spectrometer, a large custom setup for the camera and collimator optics is feasible. The initial design of a custom optical system was done by this group for future implementation by the research group.


# Prism

- Prism added to system to design a cross-dispersive spectrometer
- This will disperse overlapping orders to increase bandwidth range of device.
- No prism comparison necessary
- Edmund Optics equilateral prism used for this design
- F2 glass

# Detector Specs

- The research group that funded this project already had a suitable detector in inventory. This saves money for the research group.
- Must detect light in the visible to near infrared wavelength range
- High Quantum efficiency
- Low read noise

| Detector | Pixel size | Detector size | Read noise | Frame rate | Price |
|---|---|---|---|---|---|
| ATIK APX60 CMOS detector | 3.76 µm | 36 mm x 24 mm | 1.2 e- | 2 fps | Already in inventory: Won't add any additional cost. |

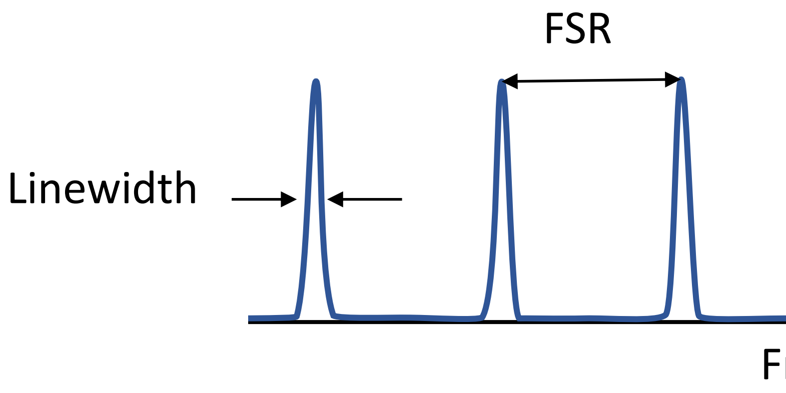
# Mounting and Alignment

- The greatest challenge when building the spectrometer is the alignment of the system.
- Two-part dispersion and single mode fiber increases the sensitivity to alignment errors.
- Light cannot be traced through system with the bare eye
- Alignment performed with Zemax and Solidworks.
- Aluminum plate and lens mounts designed using modeling software.

# Fabry-Perot Etalon: Technology Comparison and Selection

| | Frequency Comb | Hollow Cathode Lamp | Broadband Fabry-Perot Etalon |
|---|---|---|---|
| **Precision and Stability** | < 5 cm/s | < 1 m/s | Dispersion shifts |
| | Potential for atomic clock stabilization | | Sensitive to temperature and environment |
| **Price, Availability, and Development** | Expensive | Relatively Inexpensive | Inexpensive |
| | | Readily available | Easier development to match most spectrograph specifications since the FSR is a function of the cavity width |
| **Spectral Range** | Visible-Infrared | Visible-Infrared | Visible |
| **Spectral Lines** | Densely packed (spectrographs resolving power not high enough) | Narrow lines | Dense grid with uniform intensity over entire spectral range |
| | | Limited number of reference lines | |
| | | Irregular line distribution | |
| | More narrow wavelength coverage than spectrograph | Undesirable spectral features from impurities | |
| | | Blending | |

# Fabry-Perot Etalon Criteria




**Free Spectral Range (FSR):**

- Chosen to provide the maximum spectral calibration information (commonly 3-5x the resolution element of the spectrograph)

$$R = \frac{\lambda}{\Delta\lambda_{res}} = \frac{\nu}{\Delta\nu_{res}}$$

$$10^5 = \frac{500\ nm}{\Delta\lambda_{res}} = \frac{6\times 10^{14} Hz}{\Delta\nu_{res}}$$

$$\Delta\nu_{res} = \frac{\nu}{R}$$

$$\Delta\nu_{res} = 6\ GHz$$

$$FSR = \Delta\nu_{etalon} \approx m\cdot\Delta\nu_{res}$$

$$FSR = \Delta\nu_{etalon} \approx 3\cdot\Delta\nu_{res} = 18\ GHz$$

$$FSR = \Delta\nu_{etalon} \approx 5\cdot\Delta\nu_{res} = 30\ GHz$$

**Linewidth:**

- Narrower than the etalon's FSR to prevent line blending

$$< \frac{\Delta\nu_{res}}{10} \text{ to } \frac{\Delta\nu_{res}}{2}$$

$$< 0.6\text{-}3\ \mathrm{GHz}$$

**Finesse:**

- Ratio of $FSR/Linewidth$
- Requested > 25-50

# Fabry-Perot Etalon: Part Comparison and Selection

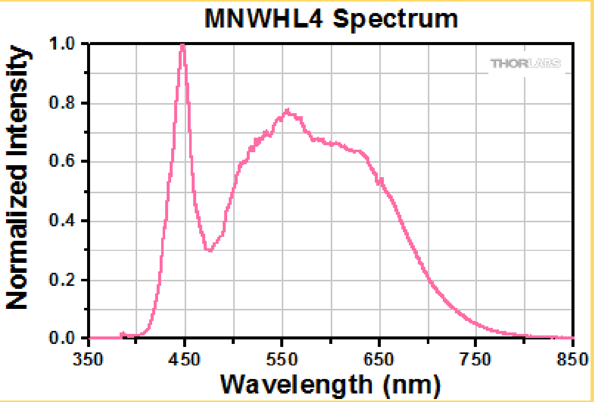
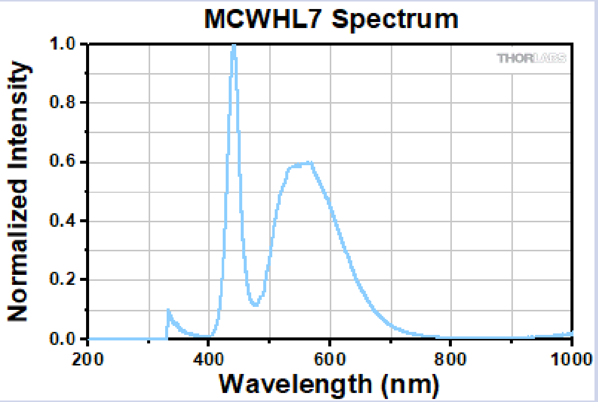
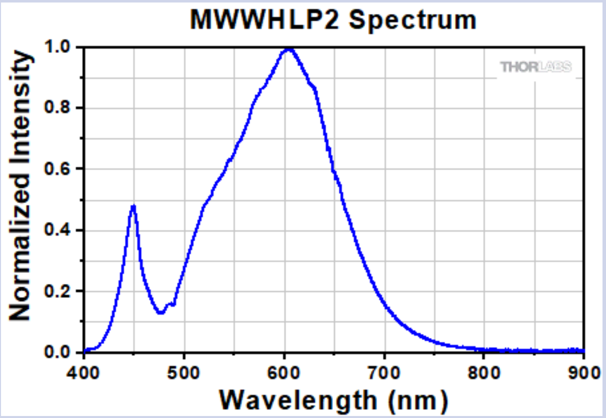
Mirrors:

- Back Polished Surface, Front surface partially reflective
- Zerodur – low thermal expansion

| | Identifier | Reflectance | Cavity Length (mm) | FSR (GHz) | FWHM (GHz) | Finesse | Notes |
|---|---|---|---|---|---|---|---|
| **Thorlabs** | BB1-E02P | 99% @ 400-750 nm | 6 | 25 | 0.0792 | 315.738 | Good range, FSR = goal Finesse >> goal, FWHM << goal, |
| | PF10-03-P01P | 97% @ 450 nm – 2 µ | 6 | 25 | 0.235 | 106 | Slightly limited visible range, FWHM< goal Finesse>goal |
| ***Edmund Optics** | 24-029 | 98%-99% @400 - 750 nm | 6 | 30 | 0.19-0.0792 | 158-315.738 | Middle ground between the Thorlabs options, Zerodur |

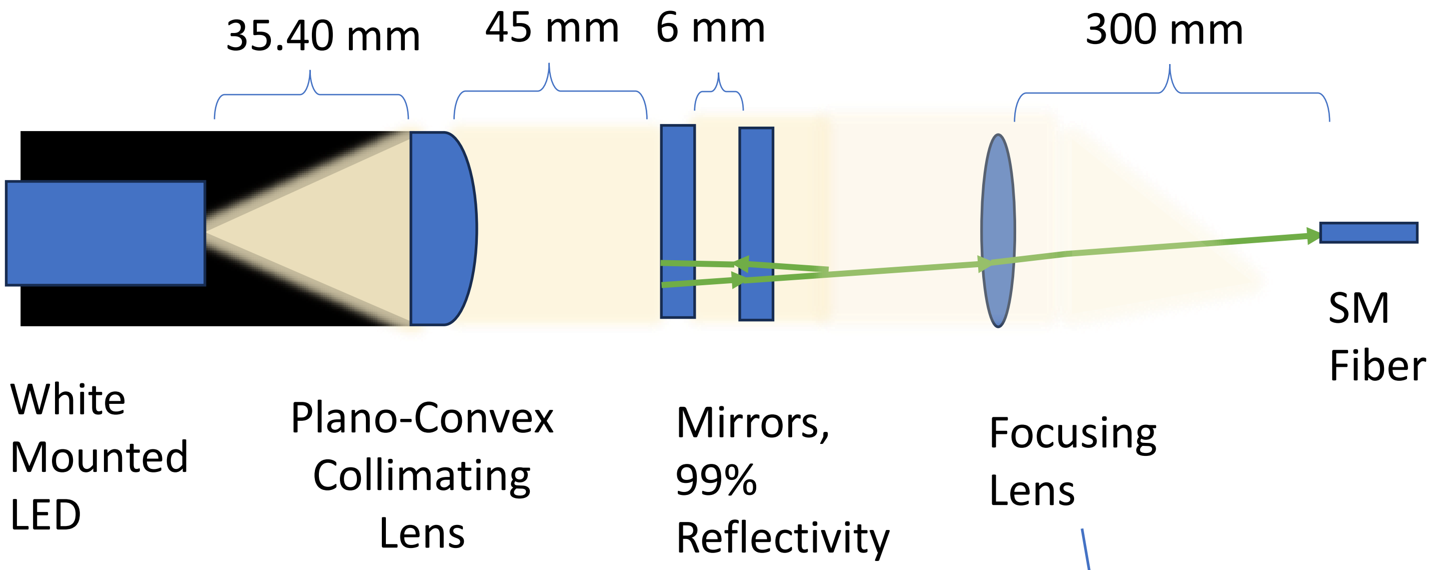
# Fabry-Perot Etalon: Part Comparison and Selection

## Broadband Source Selection: 4900 K, 740 mW Mounted LED

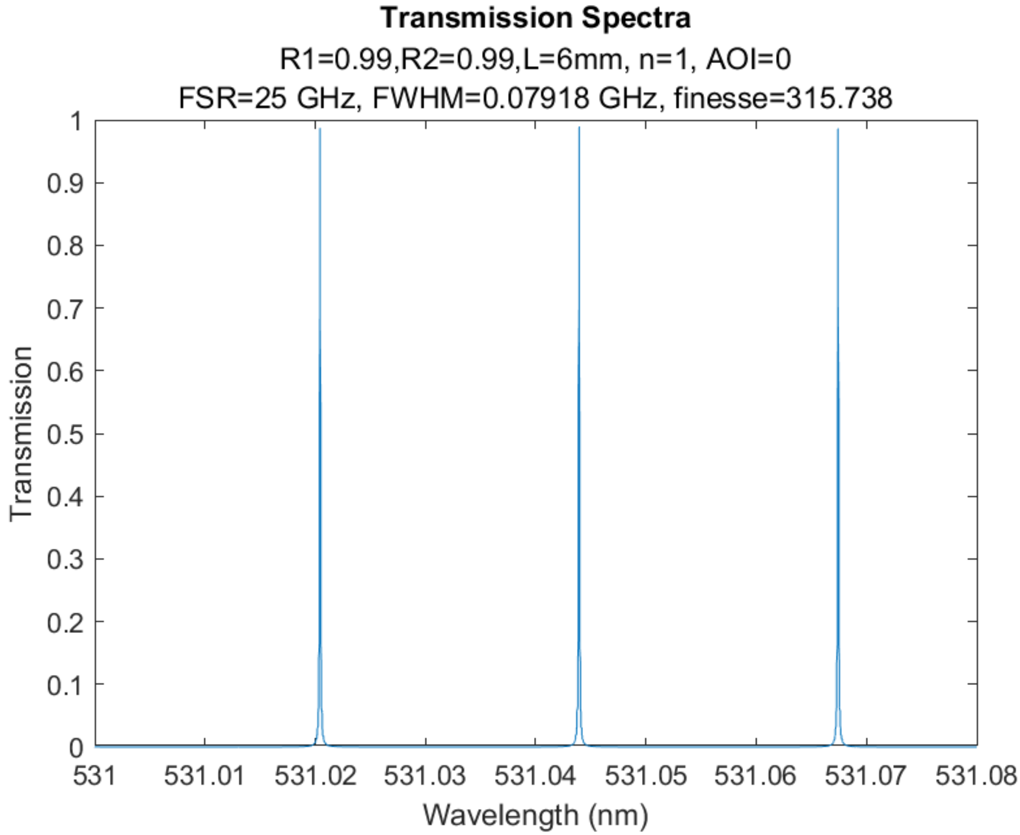
| | MNWHL4 | MCWHL7 | MWWHLP2 |
|---|---|---|---|
| Output Power (mW) | 740 | 930 | 1713 |
| Color Temperature (K) | 4900 (Neutral White) | 6500 (Cold White) | 3000 (Warm white) |
| Spectrum |  |  |  |

# Fabry-Perot Etalon Design

| | FSR (GHz) | FWHM (GHz) | Finesse | Reflectance | Cavity Length (mm) | Wavelength Range (nm) |
|---|---|---|---|---|---|---|
| **Criteria Ranges** | 18 - 30 | < 0.6 - 3 | >25-50 | 86%-95% | 5 – 8 | 400 - 700 |
| **Calculated Ranges** | 18.75 - 30 | 0.12 - 0.19 | 160- 315 | 98%-99% | 5 – 8 | 400 – 750 |

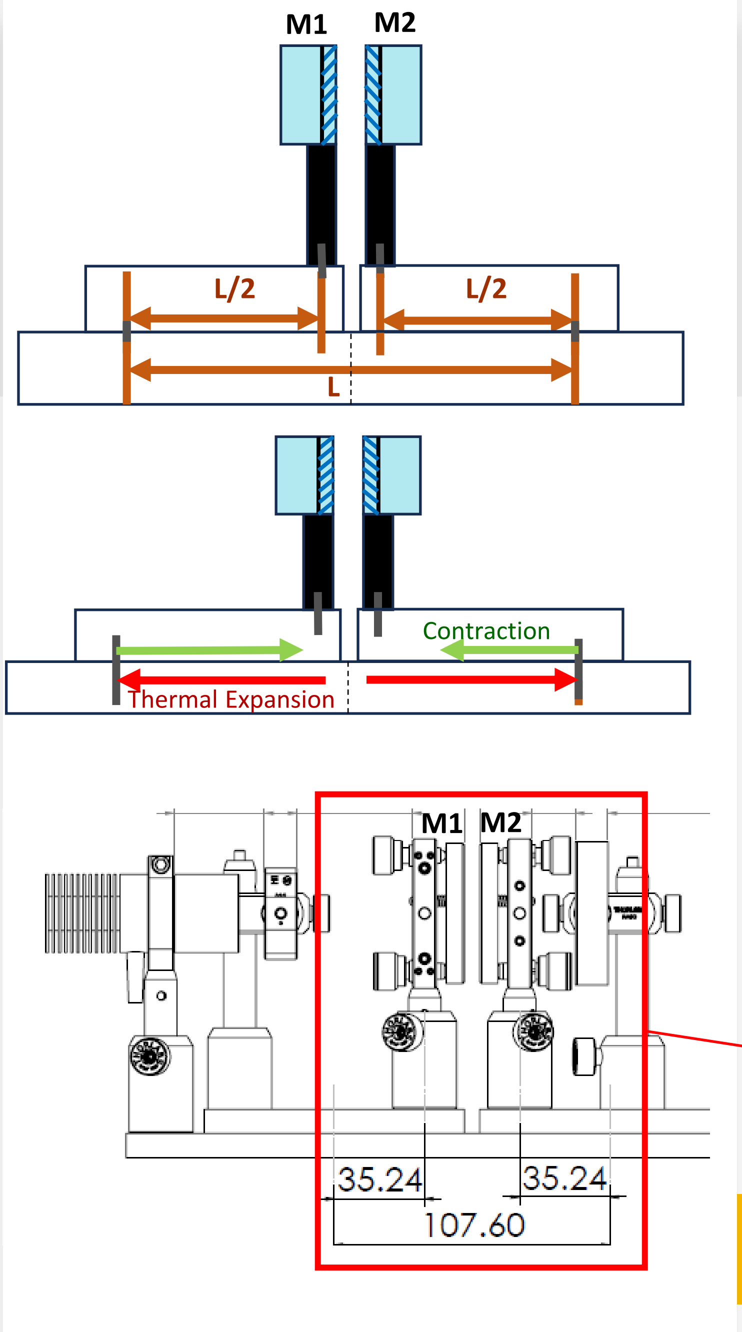



$$w_{in} = \frac{\lambda_0 f}{\pi w_{out}}$$



# Fabry-Perot Etalon: Stability Challenges

- The greatest challenge in the design and fabrication was the etalon cavity's high sensitivity to the environment.
- Given the time and resources, several solutions were considered




# Fabry-Perot Etalon: Mounting Designs

**Linear Thermal Expansion:**

$$\Delta L = \alpha L_0 \Delta T$$

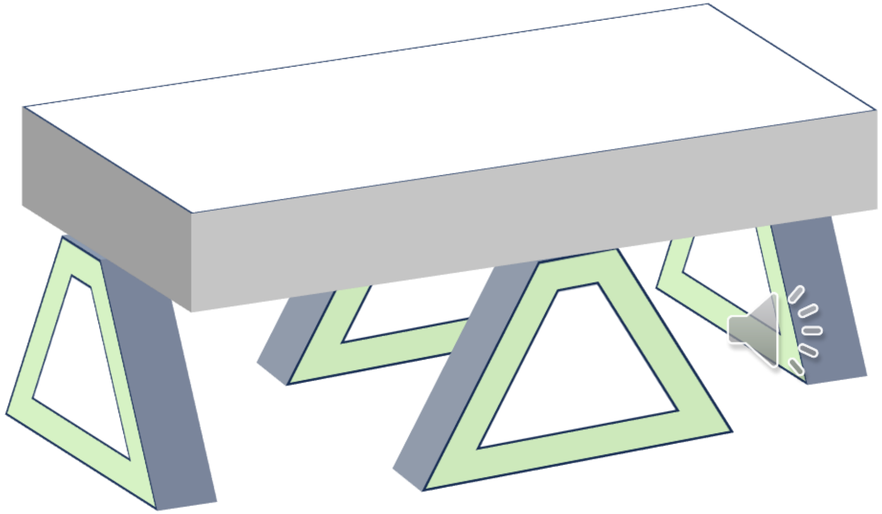
| Material | Coefficient of Thermal Expansion, $\alpha$ $(ppm/℃)$ |
|---|---|
| Super Invar | • $0.72 \times 10^{-6}$ |
| Invar | $1.6 \times 10^{-6}$ |
| Steel Alloy | $12 \times 10^{-6}$ |
| Aluminum | $23 \times 10^{-6}$ |

With thermostable design
$\Delta L =$ 0.0043 mm

Without thermostable design
$\Delta L =$ 0.0124 mm

# Fabry-Perot Etalon: Mounting Designs

- Hollow triangular mounts on each side
- G10 Fiberglass Board
    - CTE: $2 \times 10^{-5}\ ppm/°C$
- Highly resistant to vibration



# Fabry-Perot Etalon: Mounting Designs

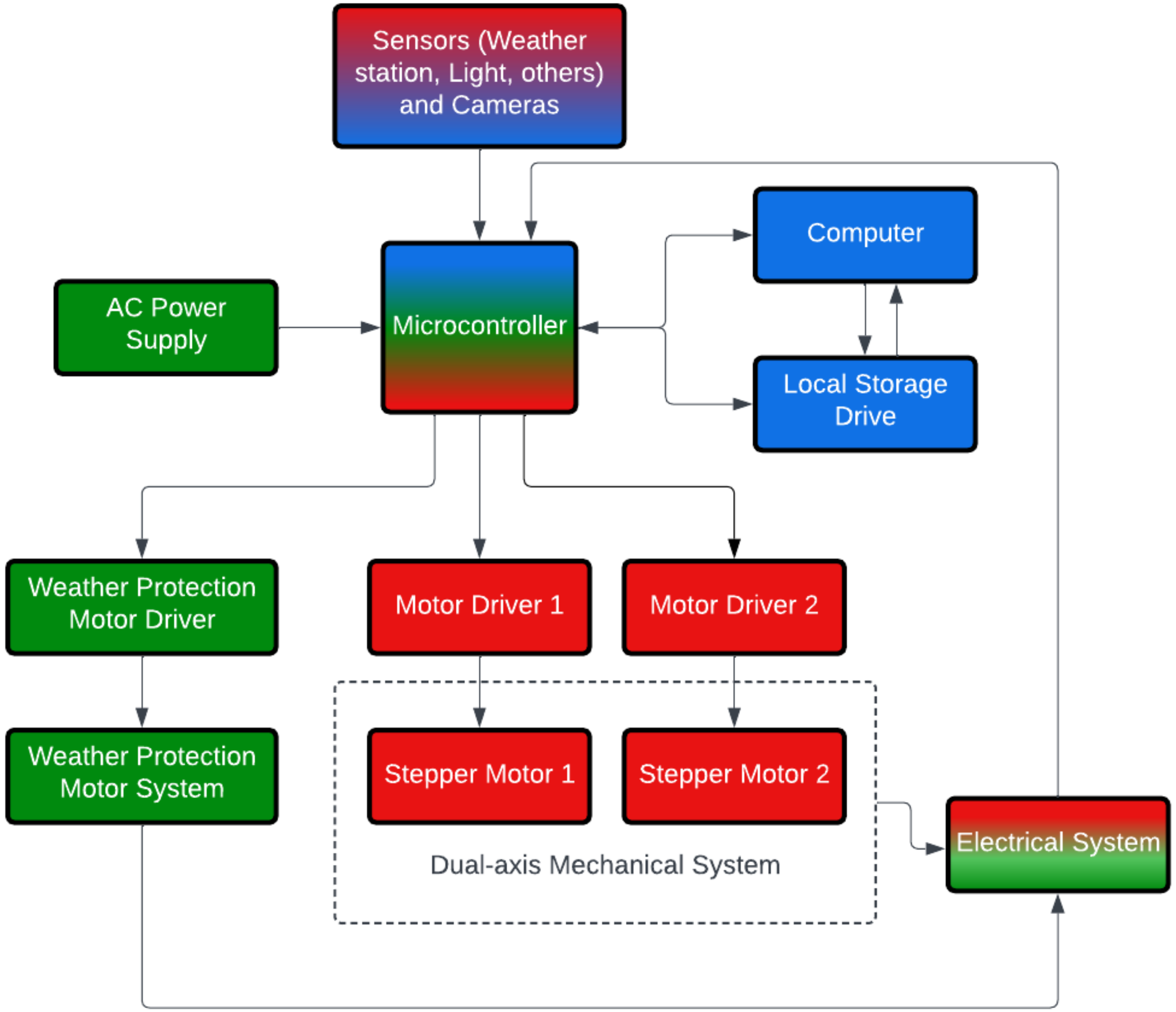
**Enclosure for both optical systems**

- Plexiglass box with a layer of black foam
  - Absorbs sound waves and stray light
- Layer of aluminum mylar for insulation

# ECE Hardware Block Diagram

## (Previous Design)

- Previous plan included the design of a dual-axis solar tracker. Two stepper motors following signal directions (up, down, right, left) from the Light Sensor PCB acting as a first-layer solar detection. SolarMEMS is the second layer due to its high accuracy and because it can give extra information (angles, radiation level, temperature, and other).



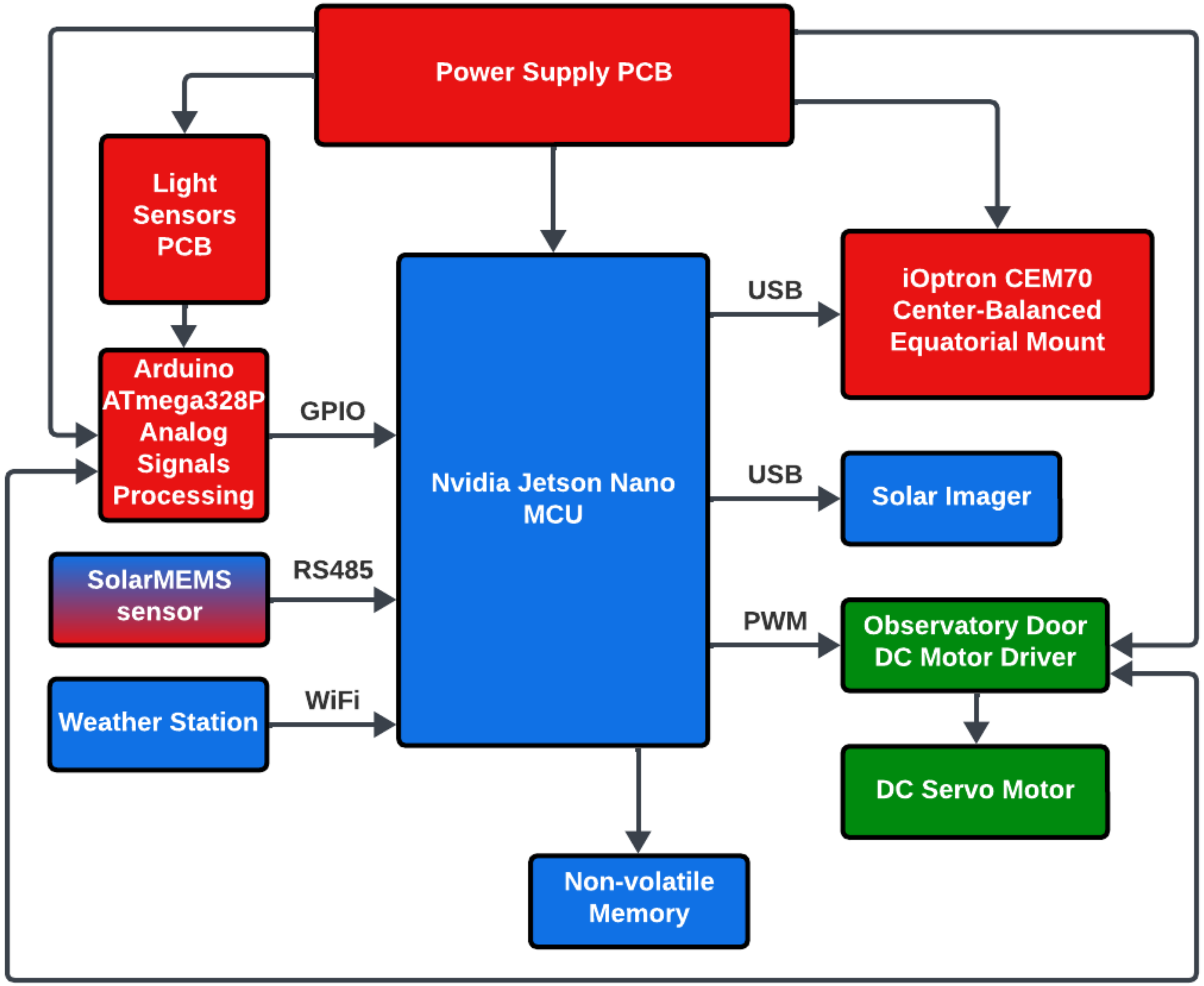

Misael Salazar

Jarolin Jimenez Vasquez

Miguel Daboin

# ECE Hardware Block Diagram

- After several discussions, our project sponsor recommended to use the iOptrom CEM70 Center-balanced Equatorial mount due to its very high accuracy and stability. We also added an Arduino ATmega328P slave-microcontroller to process analog signals and control the observatory door DC motor.

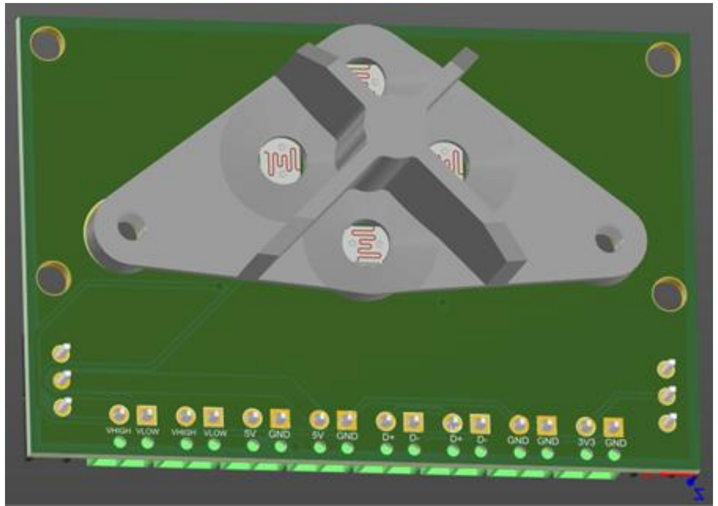


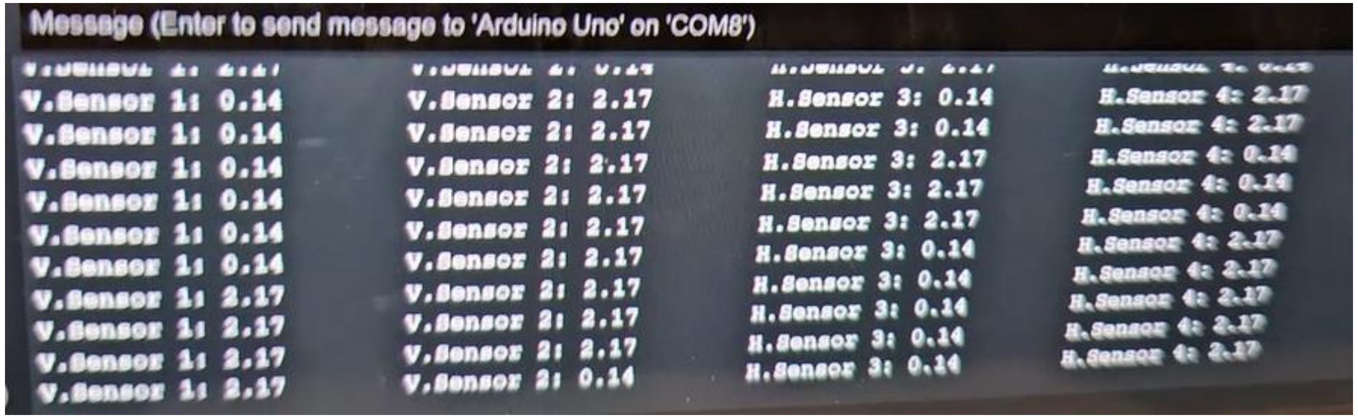

Misael Salazar
Jarolin Jimenez Vasquez
Miguel Daboin

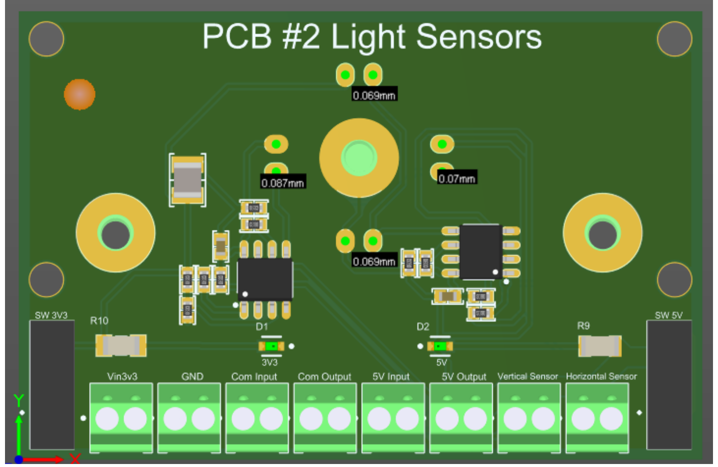
# Light Sensor PCB V2.1 – Final version

1st layer Solar detection - Solar Tracking System

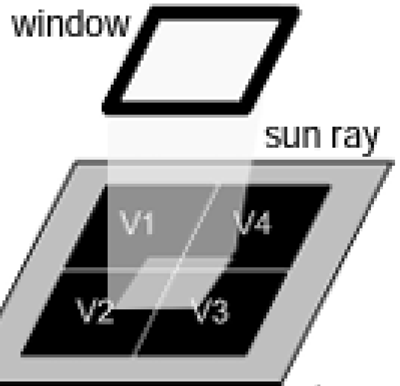
- Since our first design draft, we decided to create a 1st layer solar tracker device to be able to align the SolarMEMS (2nd-layer) on the right direction so it can receive the Sun's radiation. It is important to note that the SolarMEMS works with sun's radiation higher than 300 W/m2





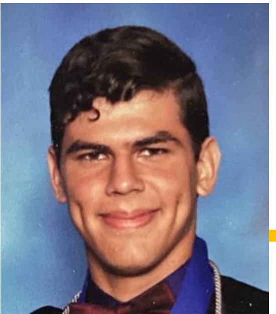
# SolarMEMS Sensor




- The Solar MEMS device measures the incidence angle of a sun ray in both azimuth and elevation based on a quadrant photodetector device. The sunlight is guided to the detector hrough a window above the sensor. Dependent f the angle of incidence, the sunlight induces hotocurrents in the four quadrants of the letector.

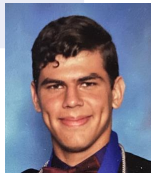
# Microcontroller Requirements

- Our observatory needs a computer capable of handling multiple tasks concurrently.
- We need enough I/O devices to connect to our weather station, solar camera, light sensor, and motors.
- Our computer needs to be able to capture images from the solar imager on a fixed timer.
- There needs to be enough processing power for us to run a weather model.



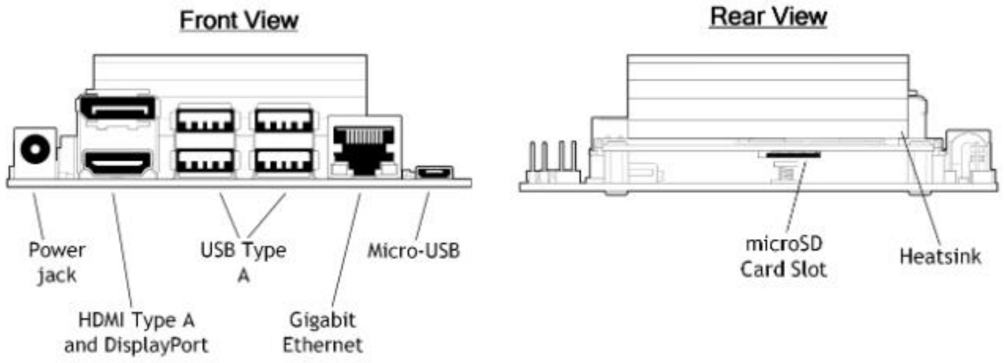
# Microcontroller Comparison

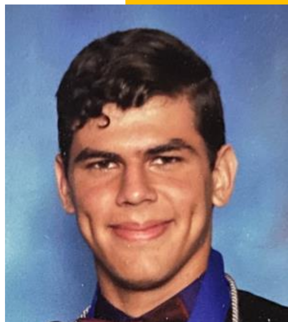
| | Jetson Orin Nano series | | Raspberry Pi | | |
|---|---|---|---|---|---|
| | Jetson Orin Nano Developer Kit | Jetson Orin Nano 8GB | Raspberry Pi 4 Model B | Raspberry Pi Zero | Raspberry Pi Pico |
| CPU | 6-core Arm® Cortex®-A78AE v8.2 64-bit CPU 1.5 GHz | | Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC 1.8 GHz | single-core CPU 1 GHz | Dual-core Arm Cortex-M0+ processor 133 MHz |
| Memory | 8GB 128-bit LPDDR5 | | 8GB LPDDR4-3200 SDRAM | 512 MB RAM | 264kB on-chip SRAM |
| USB* | USB Type-A Connector: 4x USB 3.2 Gen2, USB Type-C Connector for UFP | 3x USB 3.2 Gen2 (10 Gbps), 3x USB 2.0 | 2x USB 3.0, 2x USB 2.0 | micro USB On-The-Go (OTG) | 1x USB 1.1 |
| Display | 1x DisplayPort 1.2 (+MST) connector | 1x 4K30 multi-mode DP 1.2 (+MST)/eDP 1.4/HDMI 1.4** | 2x micro-HDMI | Mini HDMI | |
| Other I/O | 40-Pin Expansion Header(UART, SPI, I2S, I2C, GPIO), | 3x UART, | 40-pin header | 40-pin header | 26 GPIO pins, |
| | 12-pin button header, | 2x SPI, | | | 3 Analog inputs, |
| | 4-pin fan header, | 2x I2S, | | | 2 UART, |
| | microSD Slot, | 4x I2C, | | | 2 SPI, |
| | DC power jack | 1x CAN, | | | 2 I2C, |
| | | DMIC & DSPK, | | | 16 PWM |
| | | PWM, | | | |
| | | GPIOs | | | |
| Power | 7W - 15W | 7W - 15W | 15 W | | |
| Mechanical | 100 mm x 79 mmx 21 mm | 69.6mm x 45mm | 56.5mm x 85.6mm | 65mm x 30mm | 51mm x 21mm |
| | (Height includes feet, carrier board, module) | 260-pin SO-DIMM connector | | | |



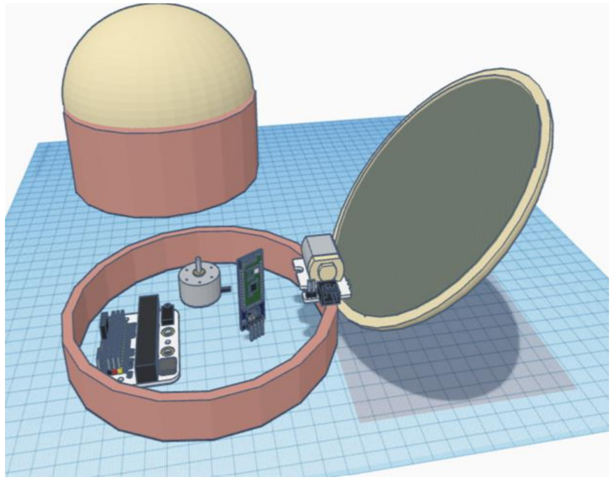
# Microcontroller Selection

- Our team decided to go with the NVIDIA Jetson Nano Developer Kit as the main computer for our project. The Jetson Nano offers great computing power, a comprehensive software development environment and a large community of developers.
- The Jetson will perform the computations necessary to track the sun, capture images, and predict incoming weather to protect the observatory platform.

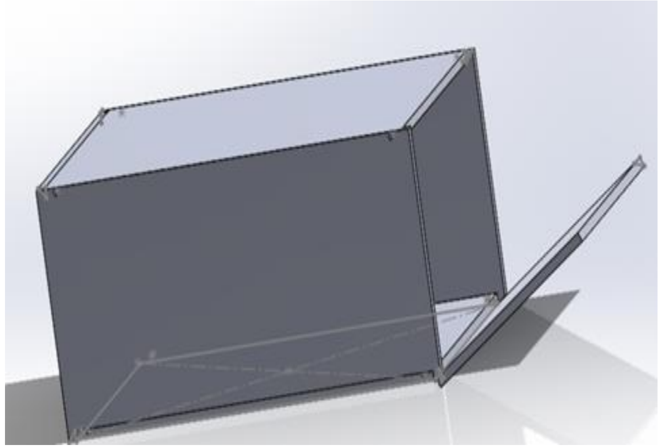


# Structural (Mechanical) Design



ORIGINAL DESIGN



FINAL DESIGN

- For our weather protection system design, we decided to go with a rectangular box after the considering of the original plan of a dome that was made of Plexi glass, since it was one of the material types that we founded to be durable, not too heavy so that we can stay withing the weight specifications that we need to meet and water resistant. Inside we have all the main electrical and telescope components: The linear actuator motor that will be for closing and opening of the door of the box, the MCU that will be taking care of the telling the components what to do, and solar spectrometry equipment.

# Motor Comparison and Selection

- After doing all the necessary research to pick the right motor for the attachment of the weather machine that will be in our system, we concluded that the best choice for this would be the DC Linear Actuator motor. Which will give us longer lifetime and a high efficiency, with meeting  the requirement of at least 12 V rating. Which will help us get the torque necessary to close the lid of our system for weather protection.

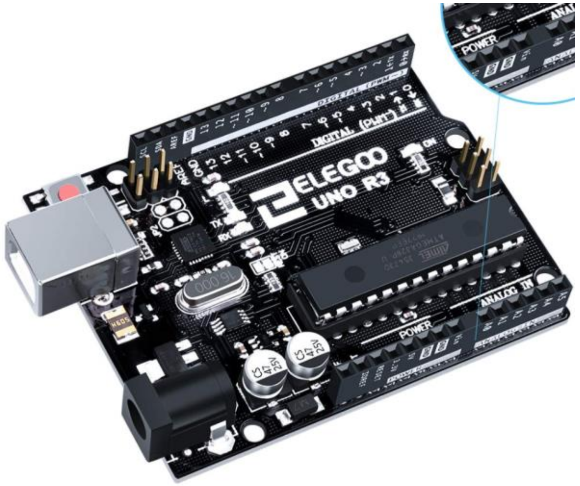
| Comparisons | Trinamic Motion Control Gmbh | ECO-Worthy linear Actuator |
|---|---|---|
| Torque rating (oz-in/mNm) | 8.85/62.58 | 1000N |
| Current rated (Amps) | 5 | 3 |
| Efficiency (%) | 85 | 80 |
| Voltage rating (VDC) | 24 | 12 |
| Price range | $90.00 | $41.00 |
| Weight (lbs) | 0.662 | |

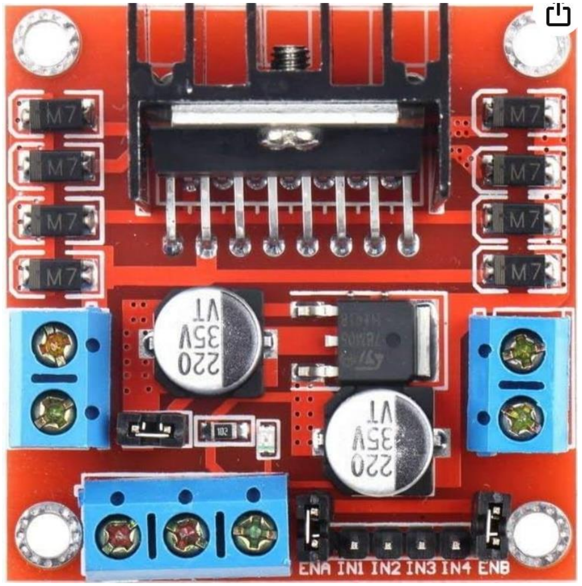
# Selected Motor Actuator Specifications

- ECO-Worthy Linear actuator
- Rated load of 1000N
- Max travel speed 14mm/s
- Rated Voltage of 12VDC
- Rated Current of 3Amps
- Operation Temperature of –65F to +400F
- Protection Class IP65

-Used the L298N motor driver controller board to control the actuator.

-Used the Arduino uno /ELEGOO uno R3 to connect to the motor controller and MCU to be able to program and create the attached code that makes the motor attached to our door open and close base on what the weather machine tells the MCU.




ACTUATOR_MOTOR_CODE.ino

```
const int open = 2; //connect to L298N Pin In1
const int close = 3; //connect to L298N Pin In2
const int MCU_TX = 11; //connect to MCU D14/8
const int MCU_RX = 8; //connect to MCU D15/1

void setup() {

pinMode (open, OUTPUT);
pinMode (close, OUTPUT);
pinMode (MCU_TX, OUTPUT);
pinMode (MCU_RX, INPUT);
digitalWrite (open, LOW);
digitalWrite (close, LOW);
Serial.begin(9600);
}

void loop() {
Serial.print(digitalRead(MCU_RX));
Serial.print("\n");
if(digitalRead(MCU_RX)==LOW) {
  digitalWrite(open, HIGH);
  digitalWrite(close, LOW);
}

if(digitalRead(MCU_RX)==HIGH){
  digitalWrite(open, LOW);
  digitalWrite(close, HIGH);

}
delay(100);
}
```

Output   Serial Monitor ×

Message (Enter to send message to 'Arduino Uno' on 'COM6')

```
1
1
1
```

# Engineering Spec (EE)

Solar tracker system and MCU

Solar Tracker System Engineering Spec.:
Total Power Consumption <100W

| Component | Voltage Requirement | Current Requirement |
|---|---|---|
| MCU Nvidia Jetson | 5 VDC | 2.4 A<br>USB port |
| Arduino ATmega328P controller | 5 VDC | 0.05 A<br>USB port |
| iOptrom CEM70 | 12 VDC | 5 A |
| Servo Motor (door) | 12 VDC | 1.79 A |
| Light Sensors PCB | 3.3 VDC | 0.1 A |
| **Totals** | **3.3 – 12 VDC** | **9.34 A** |

Total Power Consumption = 94.06 Watts

- One of the main challenges we faced was figuring out how to distribute power across the many components.
- Based on these requirements we comply with one of the design requirements to have a <100W electrical system.

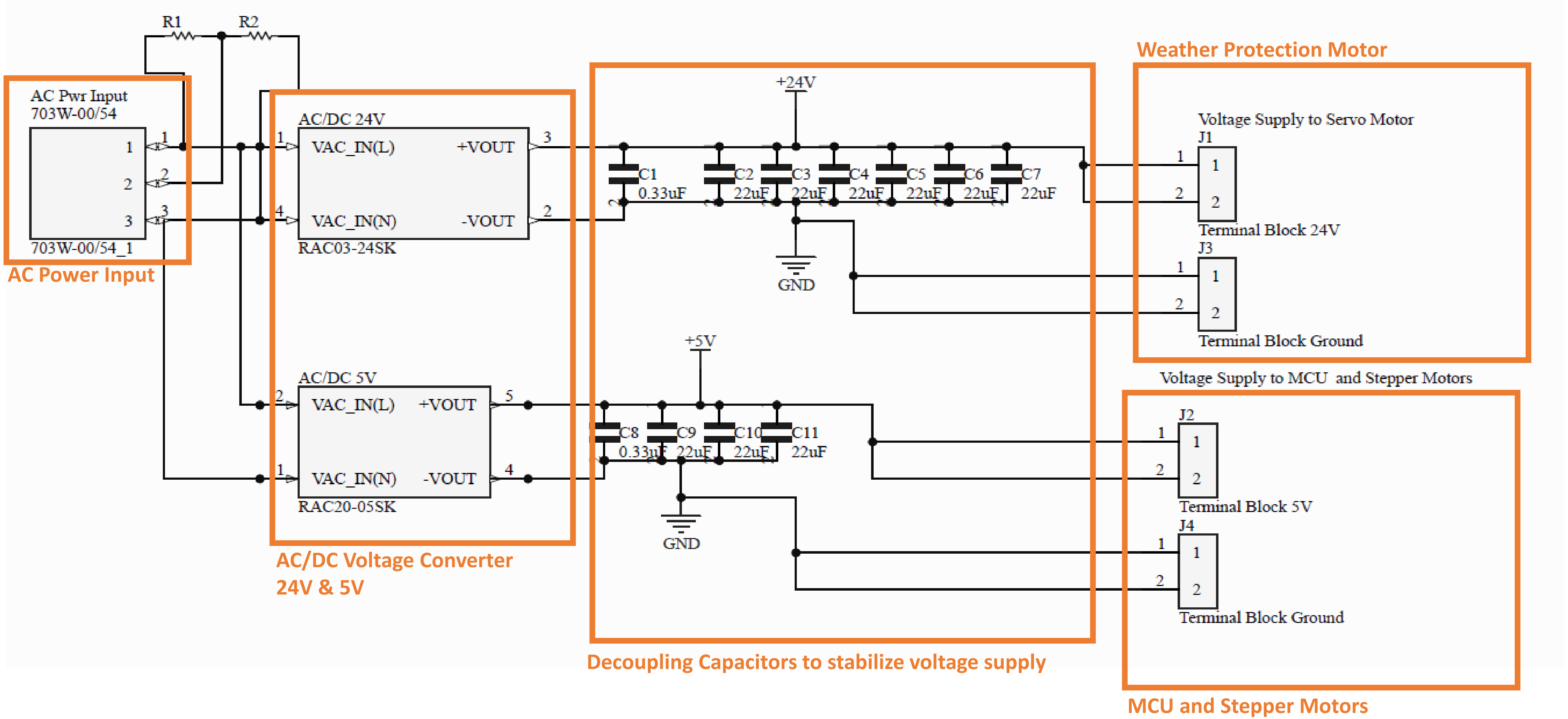
# Weather Station Selection

| Brand | Product model | Sensors | Features | Price |
|---|---|---|---|---|
| Ambient Weather | WS-2000 | Anemometer, rainfall, UV, solar radiation, barometric pressure, temperature, humidity, dew point, wind chill | LCD display tablet, Water/dust resistant, Wi-Fi, 5V DC adaptor, Power Consumption 0.5W and 1.25W during Wi-Fi config mode | $299.99 |
| AcuRite | Atlas 01108M | Anemometer, rainfall, UV, Light intensity, barometric pressure (from the screen), temperature, humidity, Lightning detection | Non-WiFi HD Display, 5V power adapter, battery option for backup, lightning detection 1 to 25 miles, Water/dust resistant | $218.16 |
| Davis Instruments | SKU 6357 | Anemometer, Rain detection, temperature, humidity, | Solar-powered with lithium battery backup, extreme testing, corrosion protected, UV protected | $350 |
| Oregon Scientific | WMR89A | Anemometer, rainfall, optional UV, humidity, barometric pressure, heat index, dew point, wind chill | Water/dust resistant, LCD screen, long-range transmission 330ft., AC adapter and battery for backup | $199.99 |

- After a deep research on weather stations with the required capabilities for data acquisition and weather protection system, we selected the Ambient Weather WS-2000 due to its reliability and weather resistance.

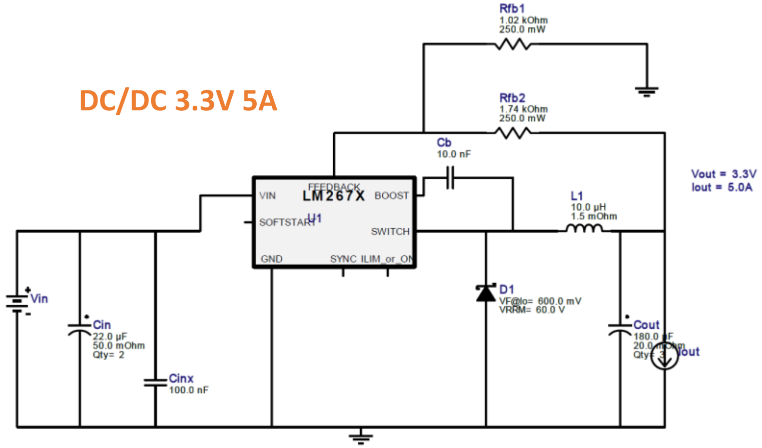
# Power Supply design v1 draft

Designed using Altium Designer Pro Software

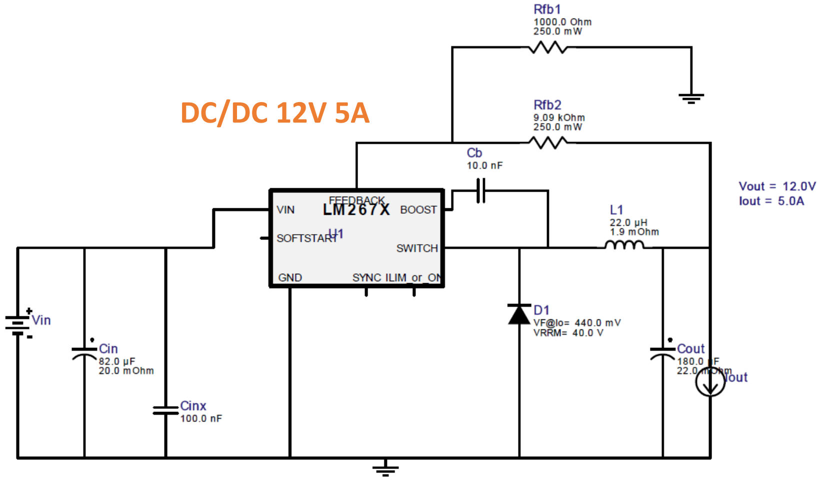


# Power Supply design v2

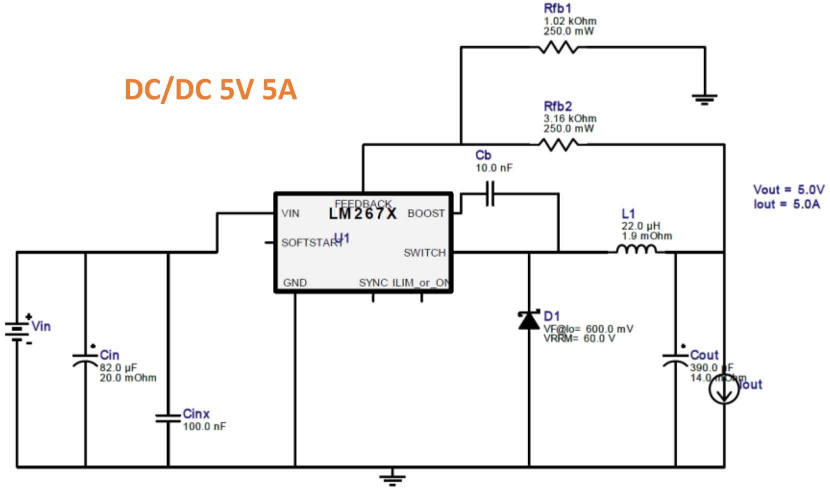
DC/DC 3.3V 5A




DC/DC 12V 5A




DC/DC 5V 5A

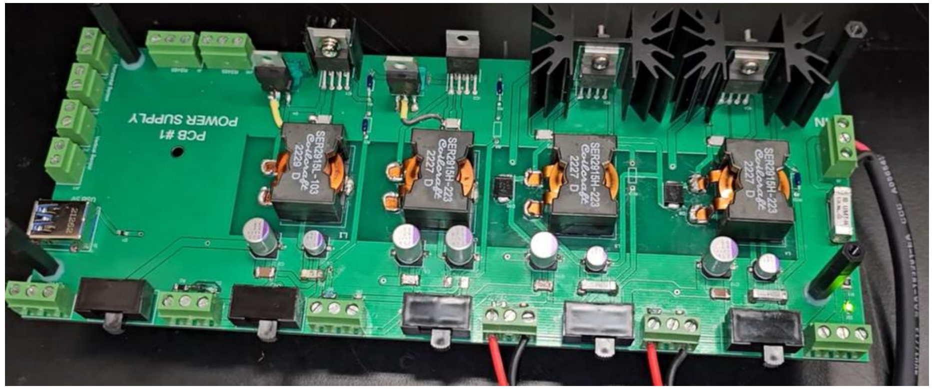


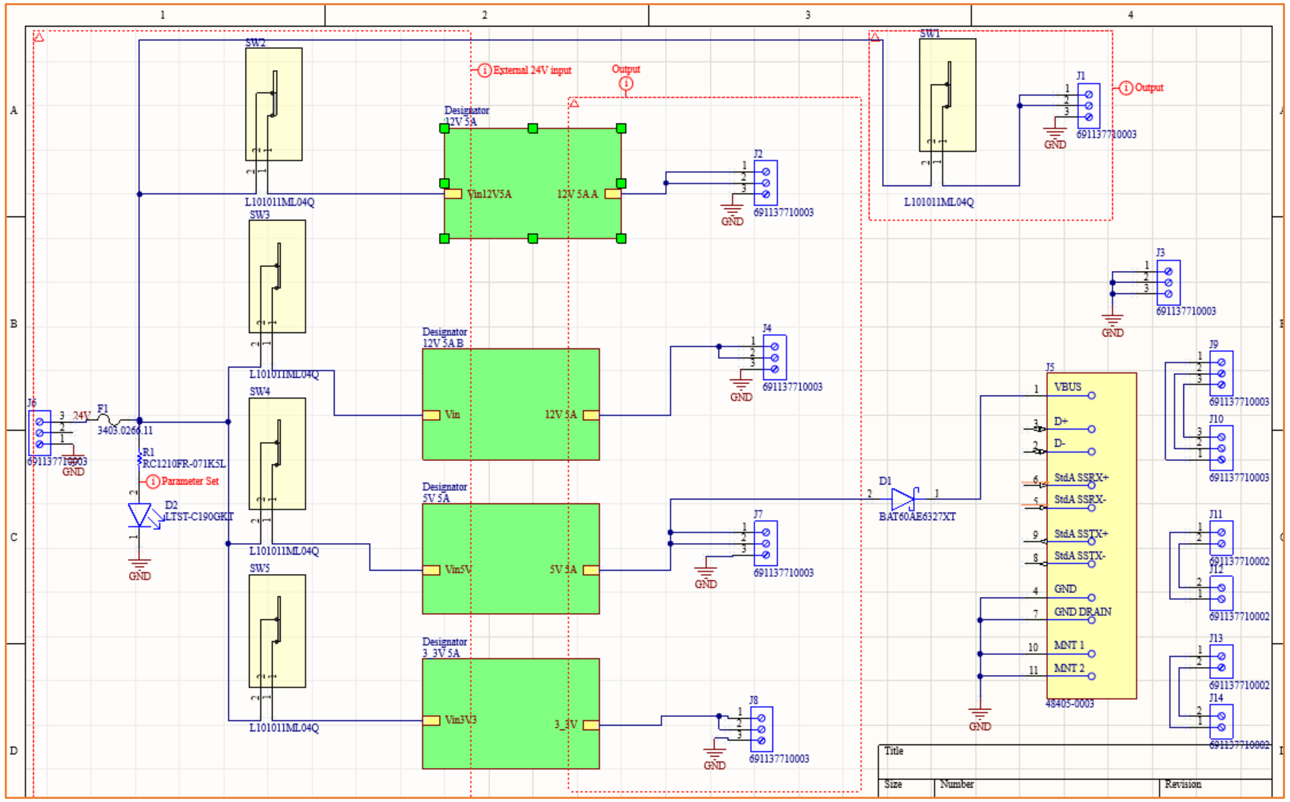

- Second power supply design had the purpose to serve a 1st test with the components. All components worked fine except for the 5V 5A line connected to the Nvidia Jetson Nano.

# Power Supply PCB v2.2

Designed using Altium Designer Pro Software (Voltage Regulator LM2678T)

- There are three voltages that are needed to supply our system. We are supplying 5V to the Nvidia Jetson Nano Developer Kit (MCU) and the Arduino Uno slave-microcontroller. At the same time, our Solar MEMS device and the Camera will be connected directly to the MCU. On the other hand, 12V is required for the iOptrom CEM70 mount and for the Servo Motor that will be in charge on opening and closing the weather protection case that will protect our core devices. 3.3V will be supplied to the Light Sensors PCB that will be connected to the Arduino Uno microcontroller.

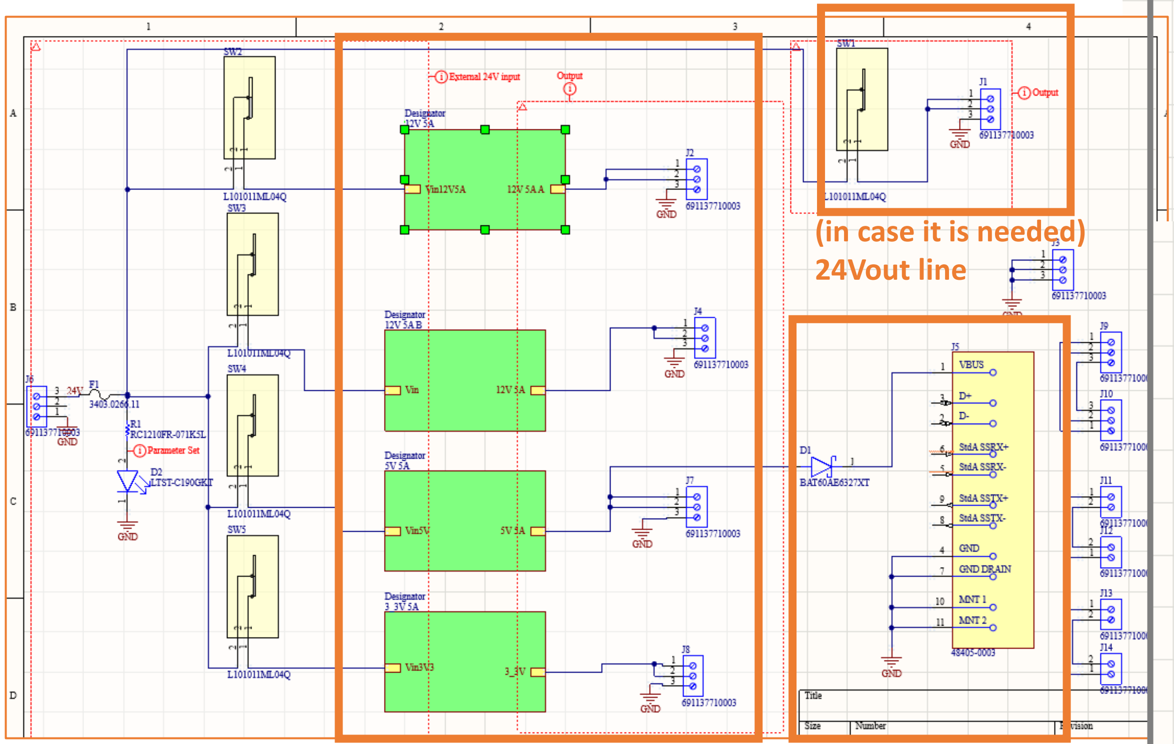


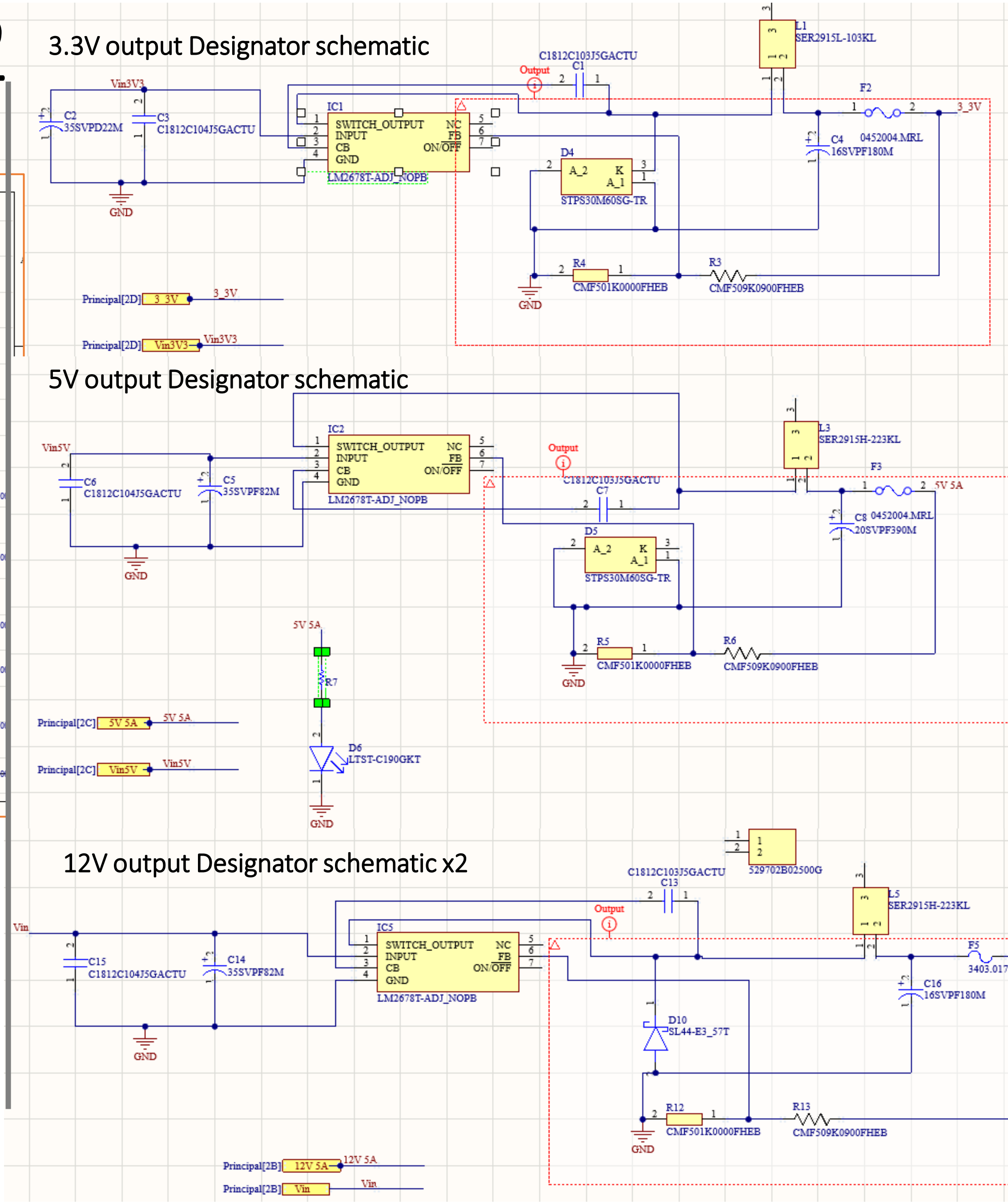



Power Supply PCB overall design with Designators for each Voltage-output phase.

# P.S. PCB Schematic v2.2

## Voltage Regulator LM2678T

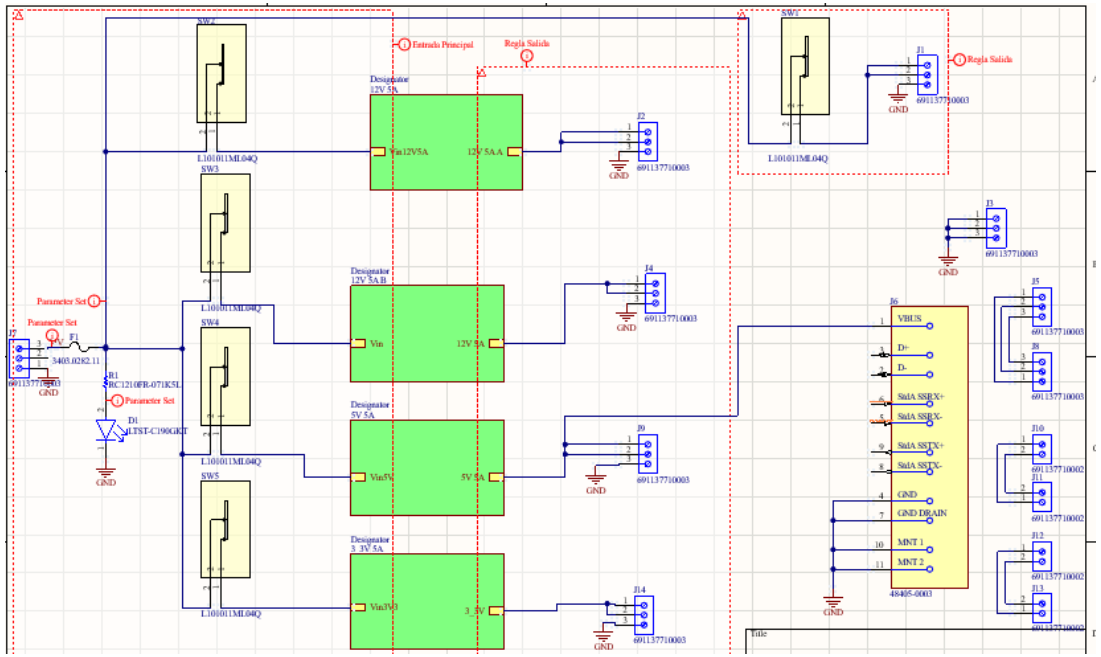


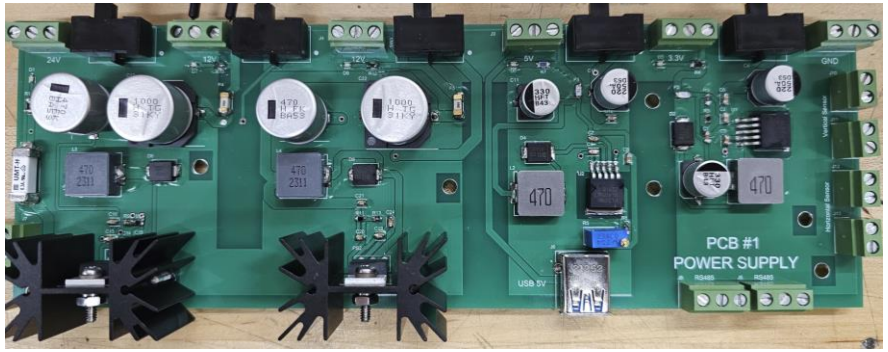

This design was working good in several tests until, on one of the tests, the power system started to have a drop in voltage every time we connected the load to the Jetson Nano. We couldn't find the cause of it.

# P.S. PCB Schematic v3

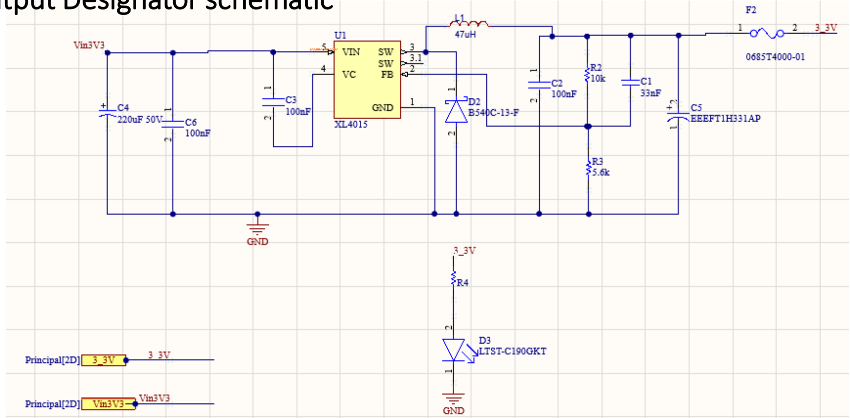
## New Voltage Regulators XL4015 & XL4016E1



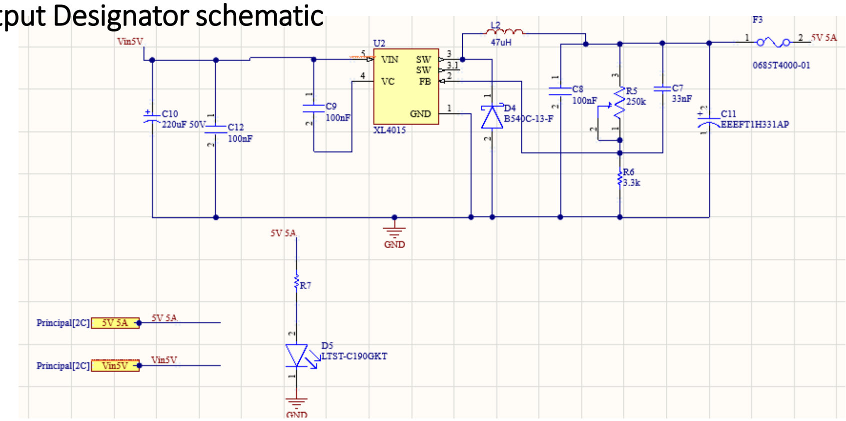
We designed a V3 of the power supply PCB to fix all the issues from v2.2. We succeeded and designed a great final product.



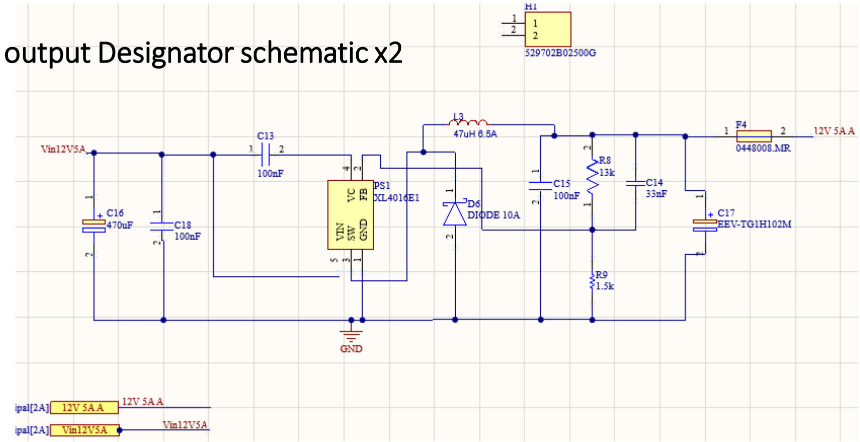

3.3V output Designator schematic



5V output Designator schematic

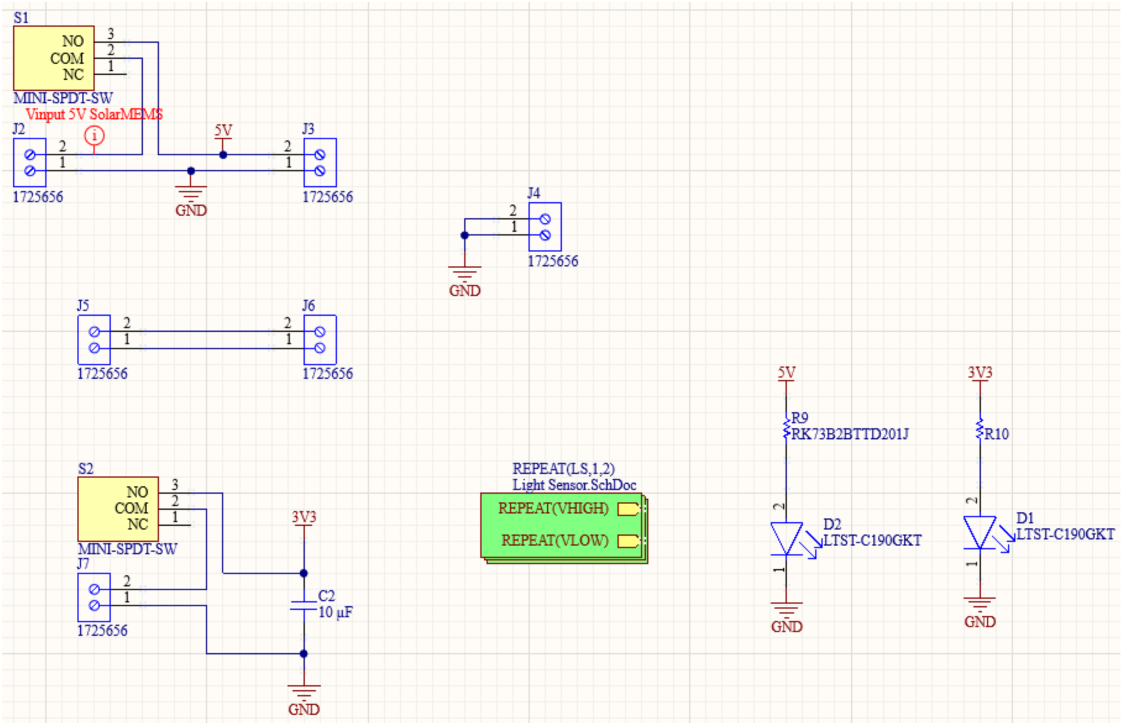


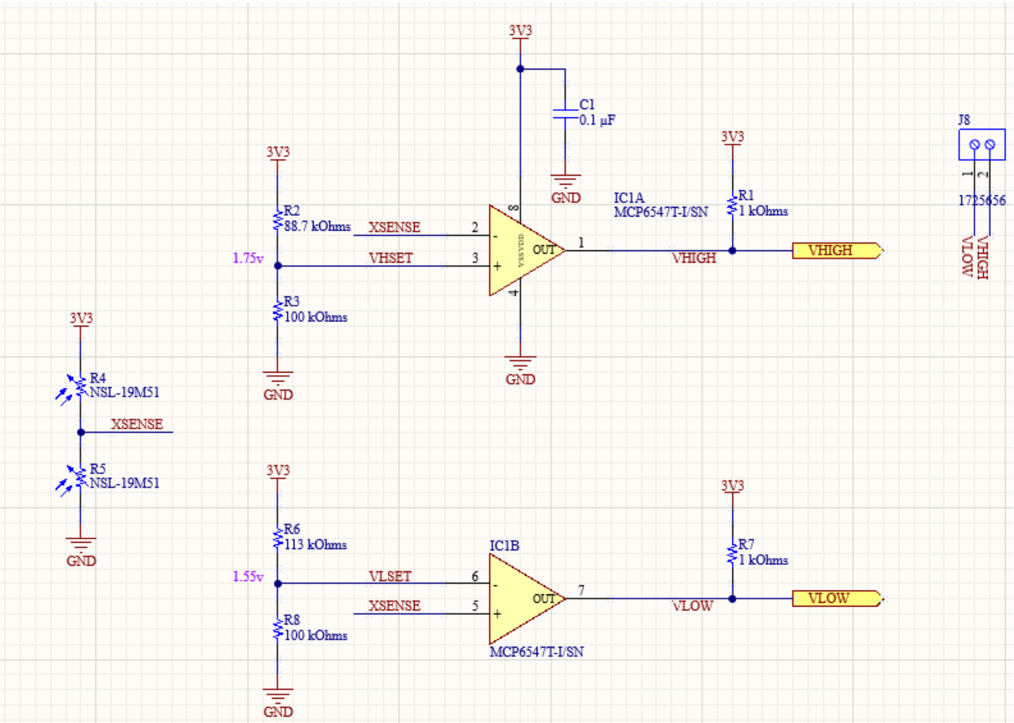
12V output Designator schematic x2



# Light Sensors PCB Schematic v2.1

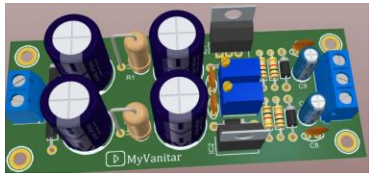
Designed using Altium Designer Pro Software



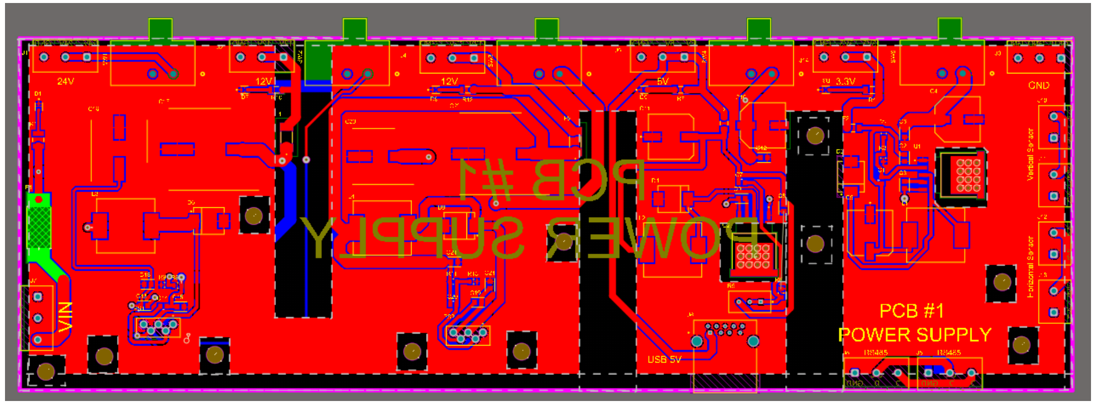

Light Sensors PCB overall design.

3.3V input

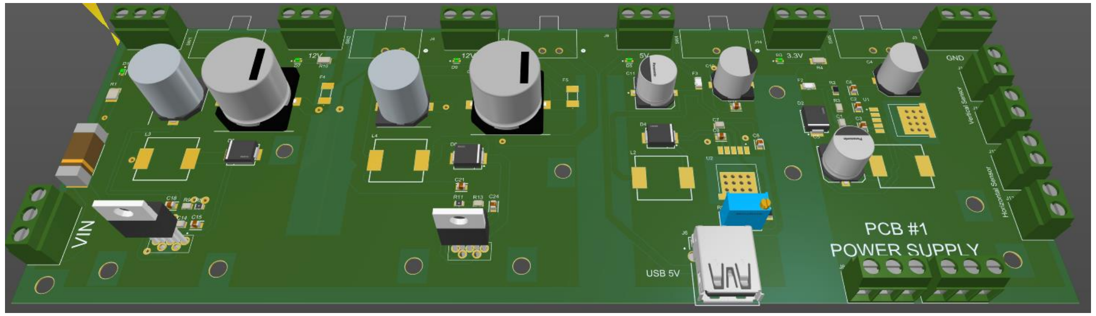



# PCB Design

## Power Supply PCB v3

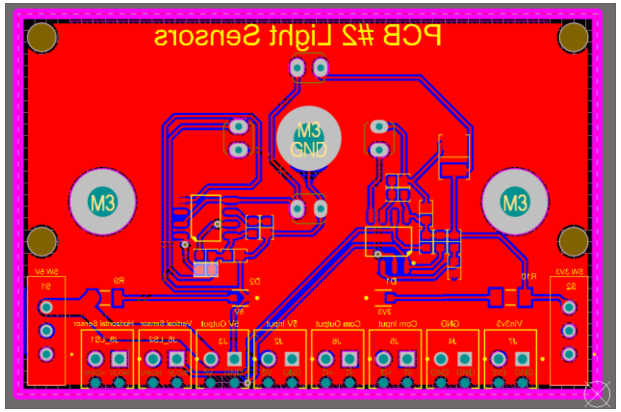



PCB 2D design view

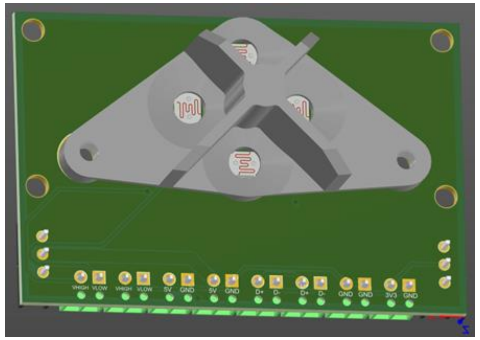



PCB 3D view

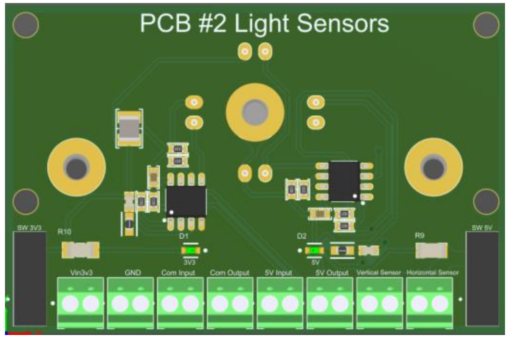
## Light Sensor PCB v2.1




PCB 2D design view



PCB 3D top view




PCB 3D back view

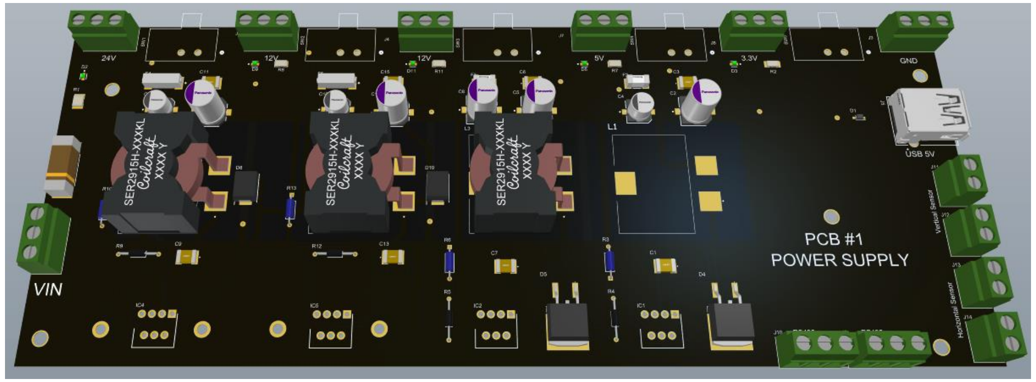
# PCB Design v2.2 – Lessons Learned

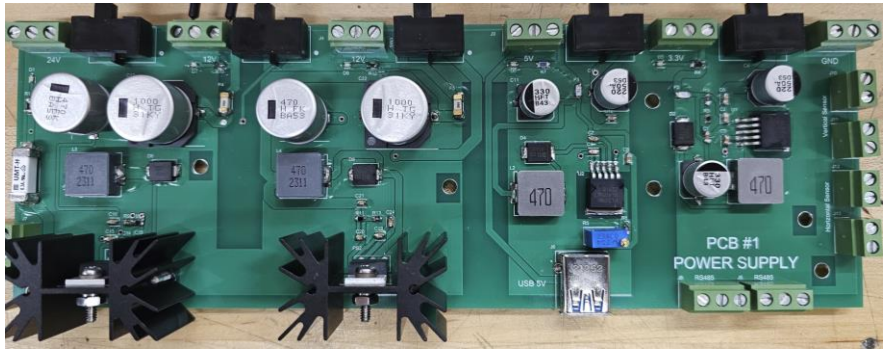
## Power Supply PCB v2.2

After several reviews and technical testing to our Power Supply PCB v2.2 we couldn't find the exact issues that was causing the voltage drop on the 5V 5A line.

Possible causes:

- 5A deficiency on the LM2678T voltage regulator
- PCB layout
- Distance between components
- Inductor Malfunctioning
- Not enough boost Capacitance
- GND bad layout

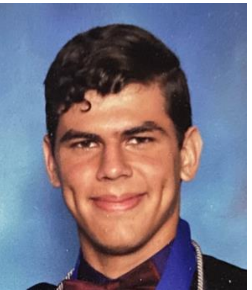


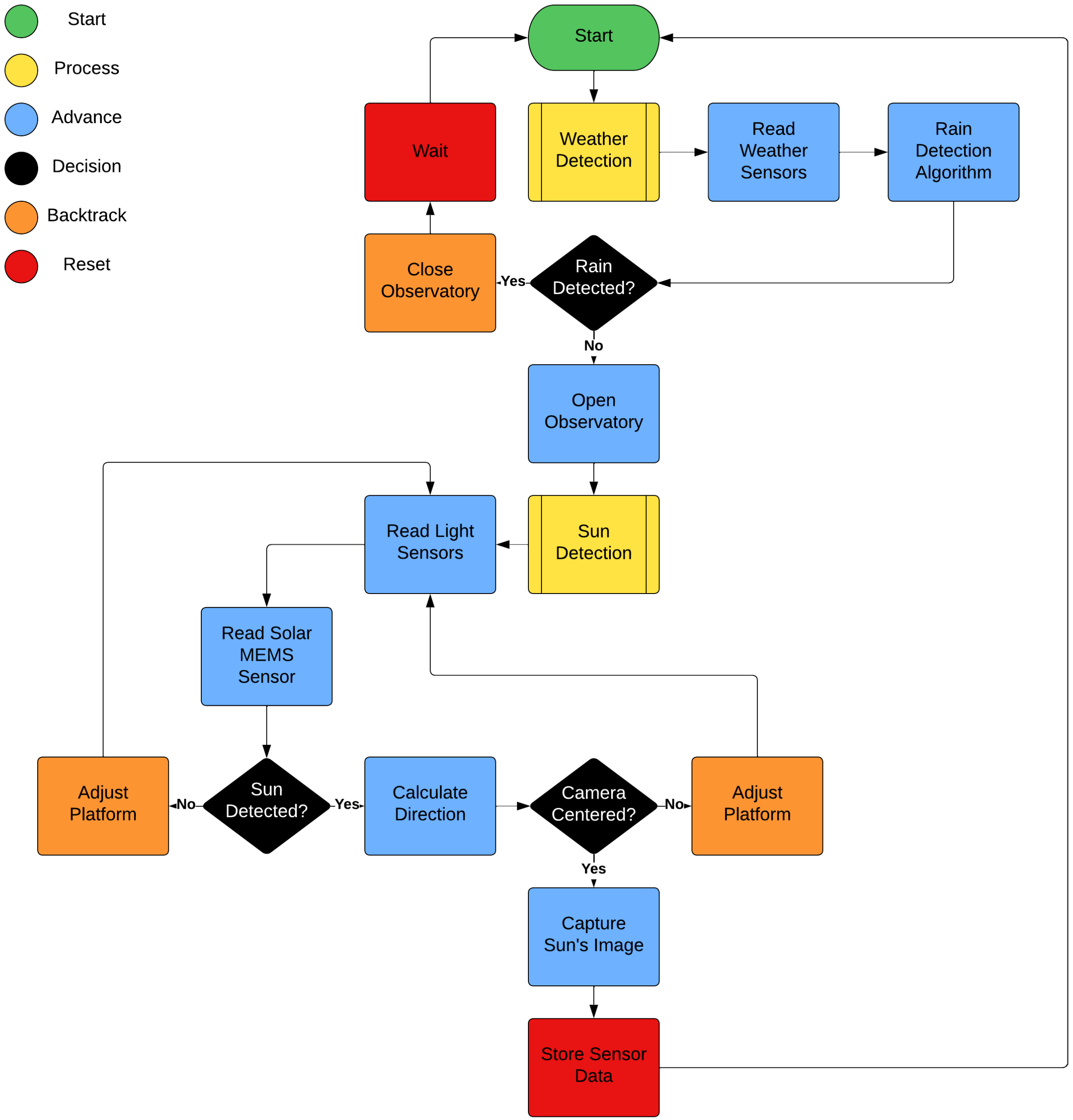



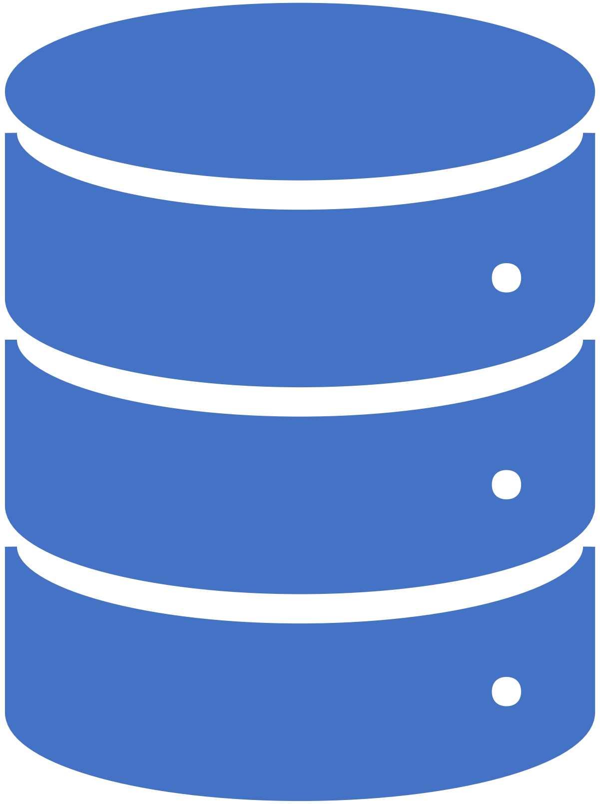

On the other hand, our new design **Power Supply PCB v3** worked perfectly fixing all the issues from previous versions and getting a better performance without any voltage drops

# Software Diagram

The software diagram depicts the general control flow of our programs. The weather detection runs first to ensure the protection of our equipment. Then the platform must be centered on the sun before an image of the Sun can be taken.

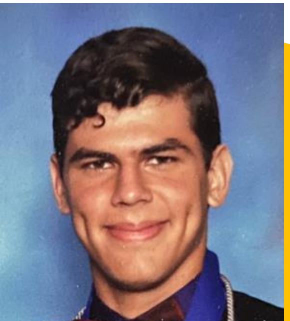






# Software Requirements

- Our software required us to integrate multiple different devices to automate the operations of the observatory.
- We needed to create a model that would predict incoming rainfall. We did this with a simple logistic regression algorithm.
- We were required to capture images from our solar imager at periodic intervals
- We needed to drive a motor to open and close the observatory.
- The software also controlled the movement of our observatory's mount, letting us continuously track the Sun.

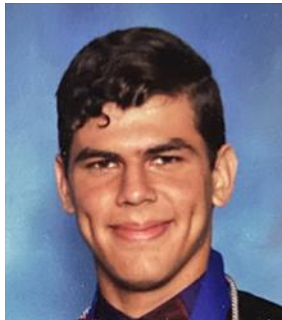


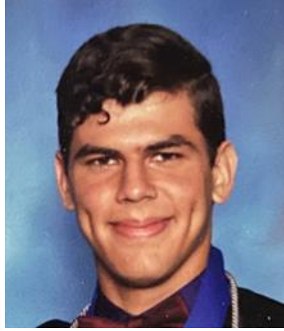
# Weather Model

- To protect our observatory from Florida's weather, we used a weather model to predict if there would be rain in the next hour or not.
- We collected weather data from the NCEI's Climate Data Online (CDO) database.
- Then, the data was used to train and test a simple logistic regression model.

| | precision | recall | f1-score | support |
|---|---|---|---|---|
| False | 0.96 | 1.00 | 0.98 | 46636 |
| True | 0.70 | 0.12 | 0.20 | 2156 |
| avg / total | 0.95 | 0.96 | 0.94 | 48792 |

Classification Report for the Logistic Regression





# iOptron Mount

- As requested by our project's sponsor, we used an iOptron CEM70 optical telescope mount to track the Sun.
- We programmed the iOptron using the Instrument Neutral Distributed Interface (INDI) library. INDI is an open-source software made to control astronomical devices.
- The mount moves to center the Solar MEMS and light sensor PCB towards the brightest light detected.


# Software Tools

- The main software for our observatory was written in Python. Python was used for its extensive collection of libraries, making it easier for us to integrate the components on our observatory.
- The Jetson Nano came with the NVIDIA Jetpack Software Development Kit (SDK), a full development environment. Including a Linux Kernel with an Ubuntu desktop environment.

# Administrative Content

- Budget
  - Based on what our sponsor suggested and the parts that were used for our project we were given a budget  with a range expenditure of 10k-20k.
  - After all materials and parts were obtained, we end it up at approximately $5,000.
- Work distribution
  - From the CREOL department Kara and Tamara are the ones responsible for the Fabric-Perot and Spectrometer aspect of the project.
  - For the electrical, mechanical structure, power supply and light sensors part of the project Miguel and Jarolin are the ones responsible.
  - For the data collection, the MCU and software Misael is the one responsible for this part of our project.

| Name | Primary | Secondary |
|---|---|---|
| Misael Salazar | Software, MCU, Weather Station & Camera & SolarMEMS data processing, iOptrom Mount setup/control | Hardware |
| Kara Semmen | Spectrometer | Fabry-Perot |
| Tamara Nelson | Fabry-Perot | Spectrometer |
| Miguel Daboin | Light Sensors PCB & Power Supply PCB Design/Fabrication/Soldering/Testing , Light Sensors Analog Signals Processing | WPS Motor, SolarMEMS |
| Jarolin Jimenez | WPS DC Motor, Controller & Main Door Mechanism design & implementation, Box Cutting | Hardware, Power Supply |

# Bill of Materials

| Quantity | Description | Price |
| --- | --- | --- |
| 1 | NVIDIA Jetson Nano Developer Kit | 149.00 |
| 1 | NexImage 5 Solar System Imager | 199.95 |
| 1 | Askar FMA180 Pro APO Sextupler Refractor | 399.00 |
| 1 | Eco wathy linear actuator | 41.00 |
| 1 | AC Power Plugs & Receptacles PLUG NEMA 5-15 125V WATERTITE | 45.03 |
| 1 | AC Power Plugs & Receptacles Right Angle Receptacle, SMT Solder Tabs, 2 Position | 1.64 |
| 1 | Edimax 2-in-1 WiFi and Bluetooth 4.0 Adapter | 21.50 |
| 2 | 25 mm 400 - 750nm Broadband Mirror | 150.00 |
| 1 | (a) 4900 K, 740 mW Mounted LED | 171.28 |
| 1 | (a) Adjustable Collimation adaptor with 1" Lens, 350-700 nm AR coating | 309.96 |
| 1 | T-Cube LED Driver | 348.22 |
| 1 | T-Cube Power Supply, 15V, 2.66A | 39.54 |
| 2 | 25.0/25.4mm Optic Dia., Side Flange Direct Mount | 63.00 |
| 1 | MicroSD Card 256 GB | 19.99 |
| 1 | Ambient Weather WS-2000 Home Weather Station with WiFi Remote Monitoring and Alerts & Thermo Hygrometer | 299.99 |
| 1 | ISSDX SUN SENSOR: Digital sensor | 381.40 |
| 10 | NORPS-12 - CDS Photoresistor | 24.62 |
| 4 | Motor cable angled, 2m | 121.60 |
| 8 | Plexiglass (per our discussion regarding plexiglass cover) | 600.00 |
| 1 | Fan-4020-PWM-5V for Jetson Nano Developer Kit | 8.35 |