

OUC's All-In-One Photovoltaic Sensor Phase II

Group 6

Sponsored by The Orlando
Utilities Commission, OUC



GROUP 6



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MOTIVATION



Solar Power is becoming more appealing

- Provides clean, renewable energy
- Reduces reliance on traditional fuels
- Installed and managed on-site

To ensure Solar Panels are working their best, they must be monitored

- Generation is not obvious, therefore issues are not
- Small issues can heavily decrease power generation
- Solar Monitoring solutions exist, but can be expensive or reliant on others

Rubin York aims to create a simple sensor that can monitor a panel locally

- Traditional monitoring methods depend on third party companies
- The All-In-One Photovoltaic Sensor will be this product
- Able to measure and record generated voltage & current and a panel's temperature & irradiance

DESIGN GOALS & REQUIREMENTS



This project is a continuation of a previous Senior Design project, considering us to be Phase II. In Rubin's new vision, the following will be implemented.

The All-In-One PV Sensor (AIO PV Sensor) should be able to

- Withstand as much as 40 Volts, DC at 10 Amps
- Measure a Solar Panel's voltage, current, temperature and irradiance
- Transmit the 'Panel-Level' data wirelessly to a local node for data storage
- Connect via MC4 connections to be inserted in existing Solar Array strings

With these restraints, the AIO PV Sensor will accomplish

- Creating a simple sensor that can be installed on existing arrays
- Allowing OUC to have easy access to Panel-Level data
- Having a locally managed database for data analysis
- Reducing the reliance on third parties to read Panel-Level Data



SPECIFICATIONS

Sponsor Requirements

Requirement	Priority
Capable of handling & sensing 40 V, 10 A, DC.	High
Modular design for Temperature & Irradiance Sensing	High
MC4 Insertion or Connections	High
Wirelessly communicate with local node for data storage	High
About or below \$20 per sensor	Moderate
Plastic enclosure capable of withstanding outdoors	Low
Year-long lifespan	Low

Engineering Requirements

Requirement	Constraint
Voltage Accuracy	±5% of actual value
Current Accuracy	±5% of actual value
Temperature Accuracy	±5% of actual value
Irradiance Accuracy	±5% of actual value
Data Transmission Interval	<10 seconds between datapoints
Wireless protocol	Self-Generated Wi-Fi or Bluetooth
PCB Power	Powered by Panel Generation, no external battery

DESIGN APPROACH AND PROPOSED IMPLEMENTATION

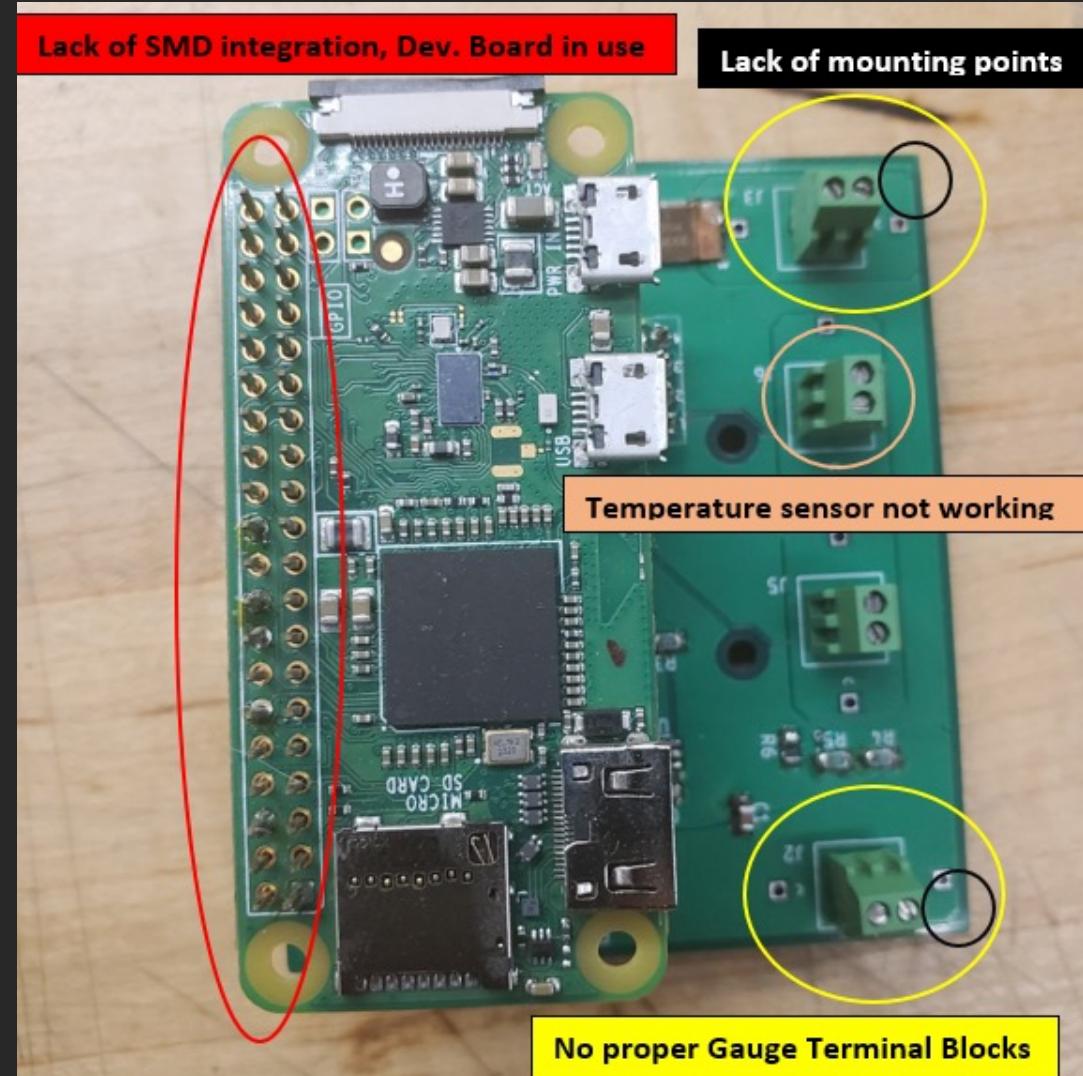


Phase II design approach:

- Analyze Phase I attempt.
- Analyze phase I cost per unit assuming everything worked.
- Fixing or redesign “All-in-One-PV Sensor” design from phase I.
- Lower Research Cost by using Phase I Raspberry Pi 4 for the main data storage node.
- Research cost effective system components for every major sensor circuit.
 - Multifunction Integrated chips reduces board size and complexity.

Phase II design Implementation:

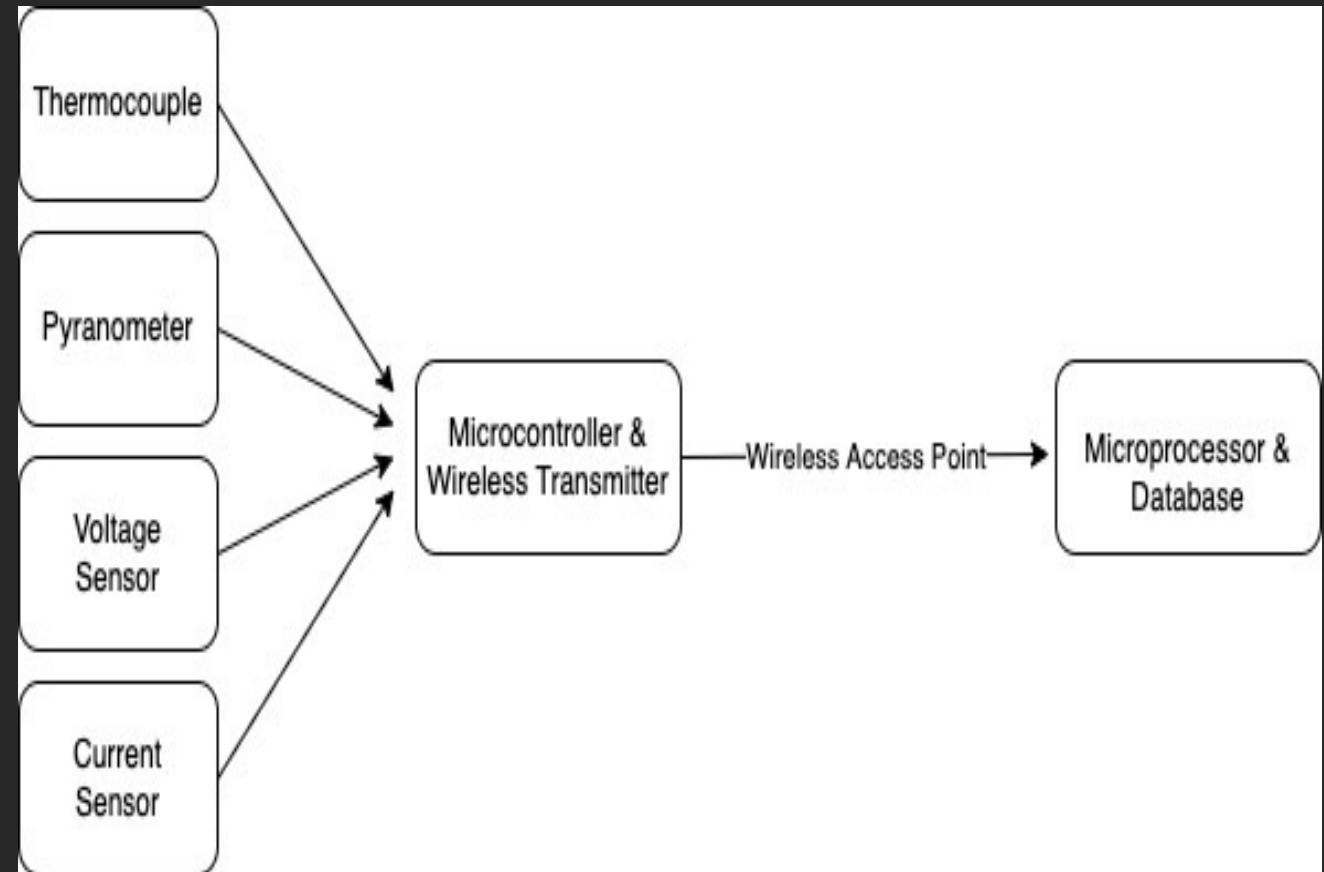
- ESP-32 based sensing node for transmitting sensor data via WIFI and interpreting sensors input signal.

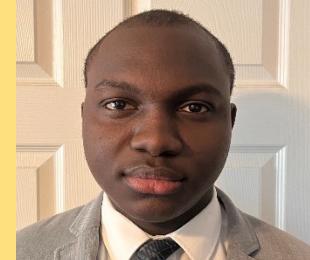




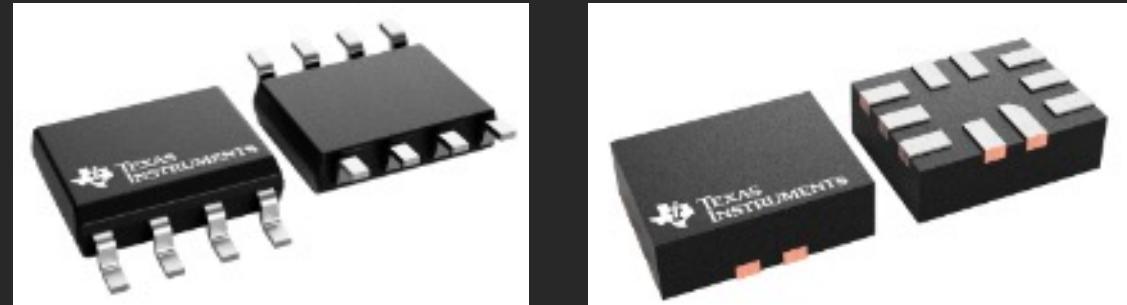
HARDWARE BLOCK DIAGRAM

Data is collected from each sensing component: thermocouple, pyranometer, voltage sensor, and current sensor. Once these devices have collected data, the ESP32 microcontroller will organize the data into a string which will then be sent to the Raspberry Pi microprocessor via a dedicated ESP32 access point and then parsed into a MySQL database.

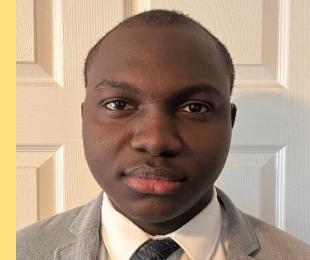




SENSING AMPLIFIER



	TLV342A	INA216
Feature	Low-Voltage Rail-to-Rail	High precision current sense
Supply voltage	$5.5 \text{ V} < \text{Vin} > 1.5 \text{ V}$	$5.5 \text{ V} < \text{Vin} > 1.8 \text{ V}$
No. Op Amp	Two	One
Price	\$0.323	\$0.442



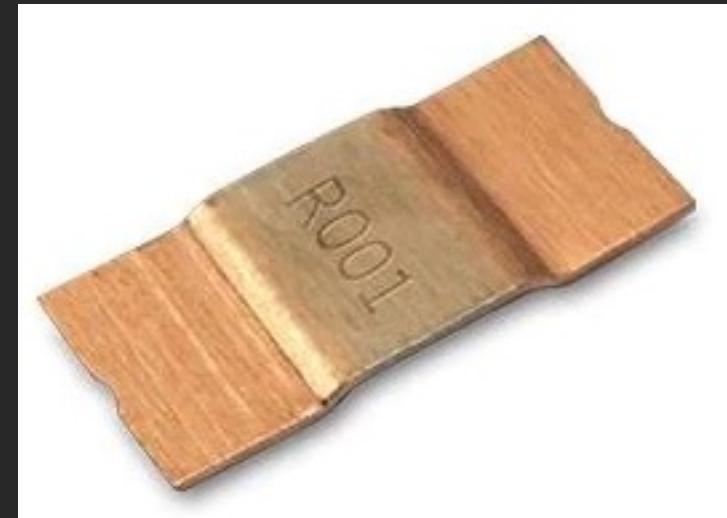
CURRENT SENSING

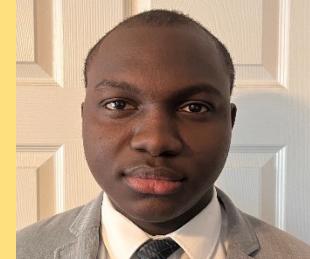
Current Shunt:

- One Milliohm shunt resistor
- Power Rating Of 4 W can handle 8.91 A

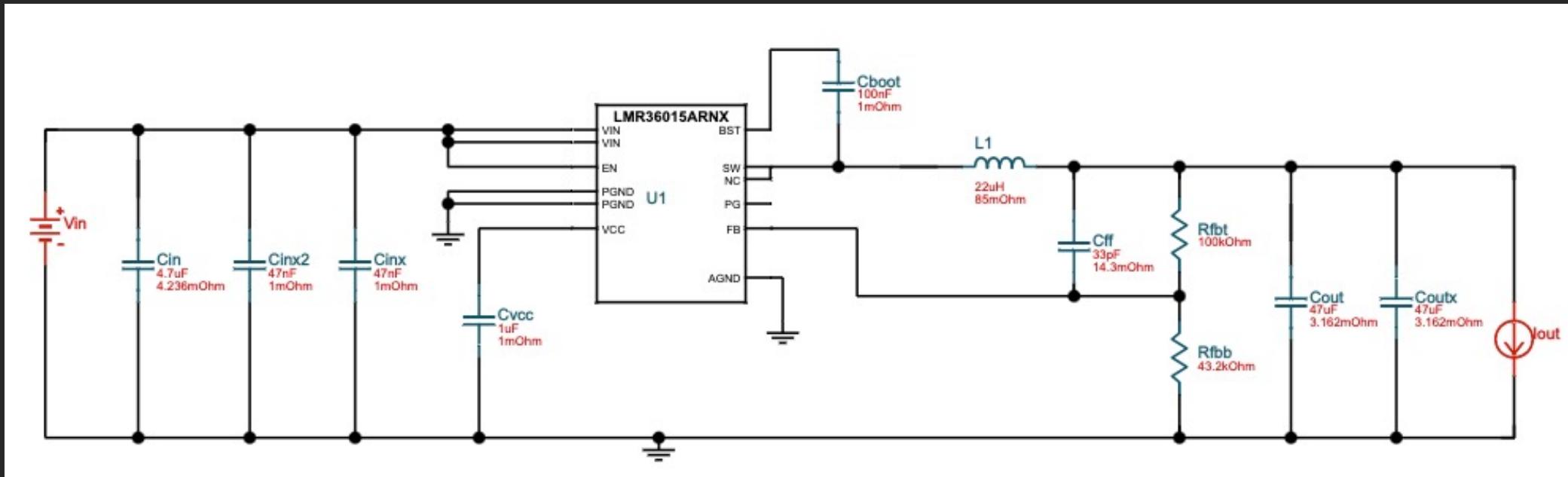
Voltage drop Across the Shunt is measured, and it is sent to ADC

Very small voltage drop to measure , therefore amplification is needed





VOLTAGE REGULATOR-LMR36015



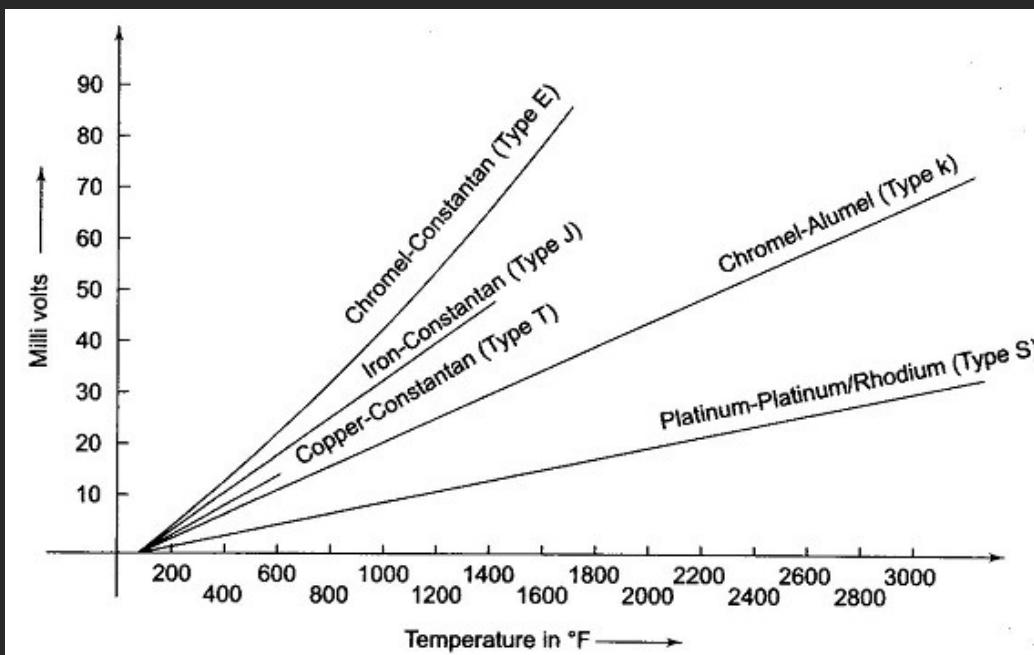
- 4.2 V – 60 V Buck Converter
- Supplies 3.3 V and up to 1.2 A
- Readily available for purchase

THERMOCOUPLE SELECTION



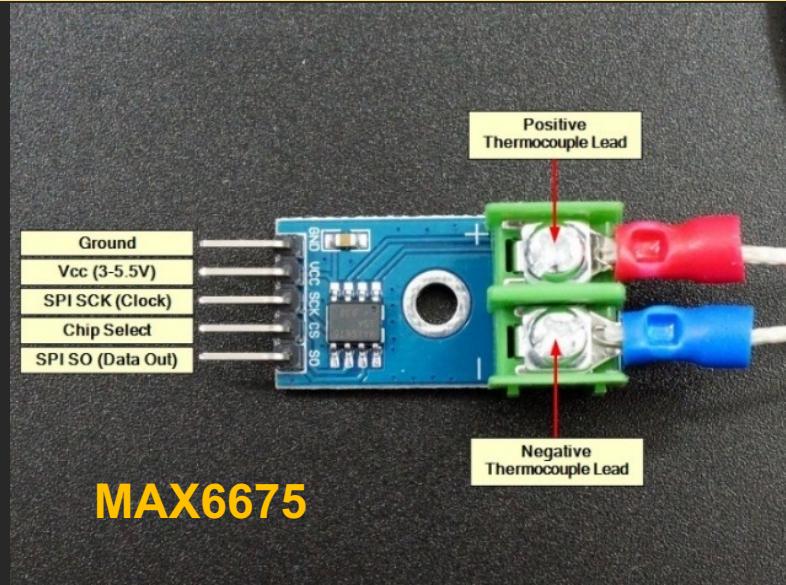
To select the best thermocouple, we can implement in our design we most take the following in consideration:

- Cost-effective with out mitigating performance.
- Fast Response Time.
- Easy to mount on solar cell without extra hardware.
- Highly Linearized for maximum accuracy.
- Weatherproof for outdoor use.



Type	Response Time	Operation Temperature Range	Material	Mount Option	Wire Insulation	Price
J	0.4 Sec.	0°C to 1400 °C	Iron-Constantan	N/A	PFA	\$90.36
T	0.3 Sec.	0°C to 600 °C	Copper Constantan	Self-Adhesive	PFA	\$83.99
E	0.2 Sec.	0°C to 1600°C	CHROMEGA™-Constantan	N/A	PFA	\$100
K	0.3 Sec.	0°C to 3500 °C	CHROMEGA™-ALOMEGA™	Self-Adhesive	PFA	\$83.98

THERMOCOUPLE SIGNAL CONDITIONING SELECTION



Conditioning System IC	Thermocouple Compatible	Resolution	ADC	Operational Voltage	Detection	Price
MAX6675	Type T and Type K	0.25°C	14-bit	3V-5V	Open Circuit	\$6
MAX31885	Type K, Type T, Type J, Type S, Type R, Type N, and Type E	0.0078125°C	12-bit	3V- 3.6V	Short and Open Circuit	\$17.50

IRRADIANCE SENSOR

For a sensor such as the All-In-One PV Sensor, a pyranometer is commonly used to measure irradiance.

For this application, the Pyranometer must be able to be removed with no impact to the primary functionality of the PCB. OUC decided that the cost of the pyranometer would not be considered in the final sensor cost.

Despite this, a cheap and self-standing solution was needed to successfully implement a pyranometer to our All-In-One PV Sensor.

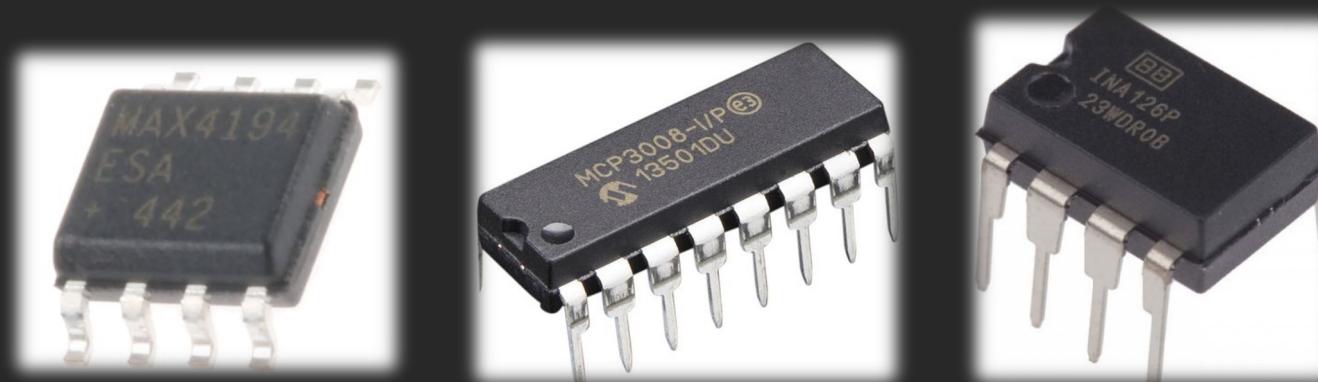


PYRANOMETER SELECTION



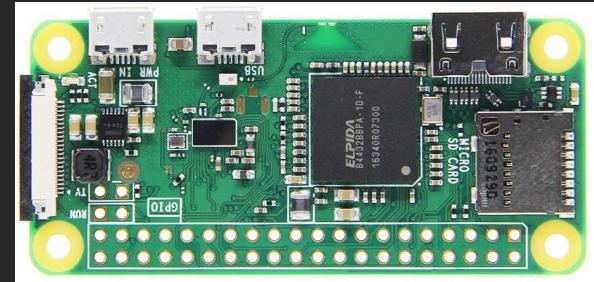
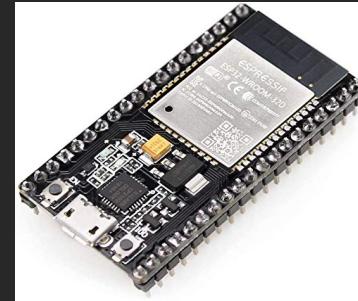
Pyranometer	SP-110-SS	SP-510-SS	CS320
Technology	Silicon-Cell	Thermopile	Thermopile
Output	Analog, ~100mV	Analog, ~400mV	Digital Signal
Power Supply	Self-Powered	Self-Powered	6~24 VDC
Response Time	<1ms	0.5 s	2 s
Average Cost	\$230	\$330	\$524

PYRANOMETER IMPLEMENTATION



Pyranometer	MAX4194	MCP3008	INA126
Technology	Instrumentation Amplifier	Pseudo-Differential ADC	Instrumentation Amplifier
Voltage Supply	2.7 – 7.5 V	2.7 – 5.5 V	0 – 36 V
Current Supply	93µA	500µA maximum	10 mA
Output	Voltage, 0-3V	Digital Signal	Voltage, 0-3V
Average Cost	\$6	\$3	\$4

MICROCONTROLLER IMPLEMENTATION

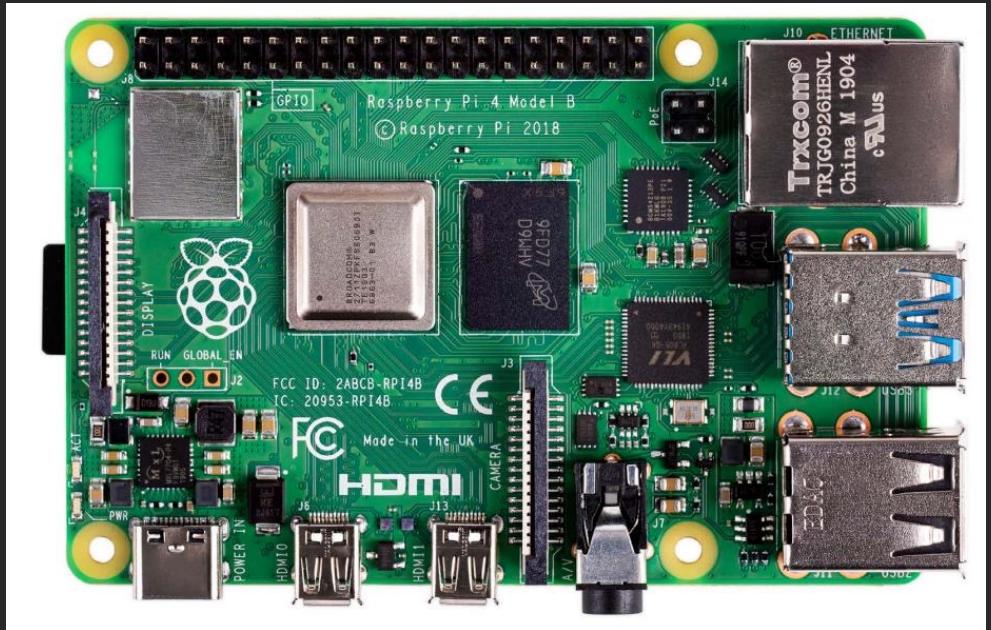


Microcontroller	ESP32	Raspberry Pi Zero
CPU	Xtensa single-core 32-bit LX6 microprocessor, 240Mhz	Broadcom BCM2835 1Ghz, Single-core
RAM	520KB	512MB
Wi-Fi/Bluetooth	Yes	Yes
Power	3.3V or 5V, supplied via GPIO pins or 5V, supplied via micro USB connector	5V, supplied via micro USB connector
Average Cost	\$5	\$10

MICROPROCESSOR IMPLEMENTATION



The microprocessor we chose for our design is the Raspberry Pi 4 Model B+. The Raspberry Pi features everything we need for our design, such as a programmable operating system, Wi-Fi and Ethernet, HDMI/video ports, and USB. Additionally, with a microSD port for the main storage, the Raspberry Pi can utilize up to 2 TB of storage. For our purposes, we have chosen a 128 GB microSD card that stores our operating system and MySQL database with over 100 GB to spare for years' worth of datapoints.



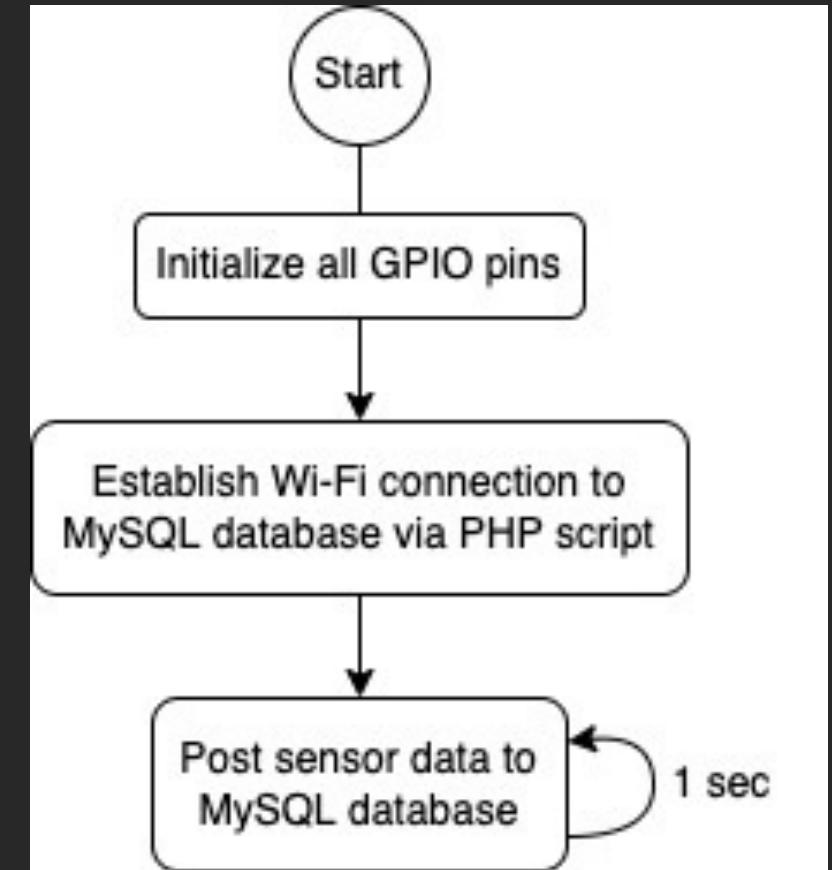
MICROCONTROLLER PROGRAM FLOW



At the start of the ESP32's C code, each GPIO pin that will be used to transmit data from the collecting sensors to the microprocessor will be initialized.

Next, the ESP32 establishes a Wi-Fi connection to the microprocessor's MySQL database via a PHP script.

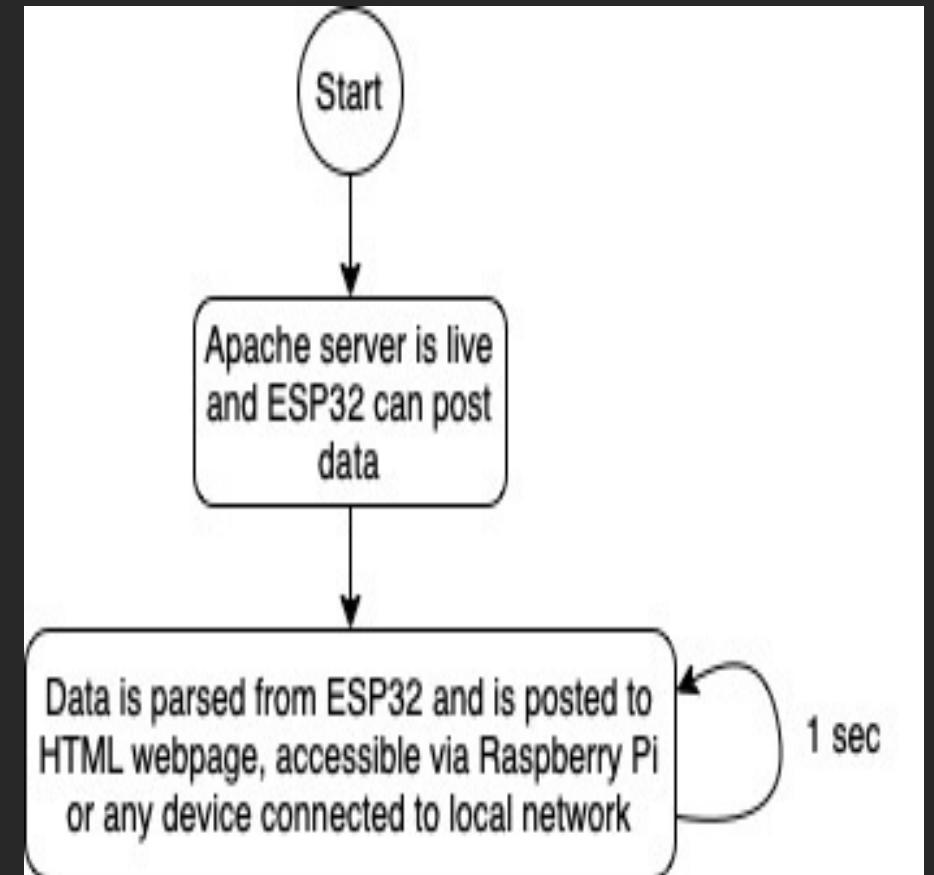
Finally, the ESP32 will post collected data to the microprocessor's MySQL database until powered off.



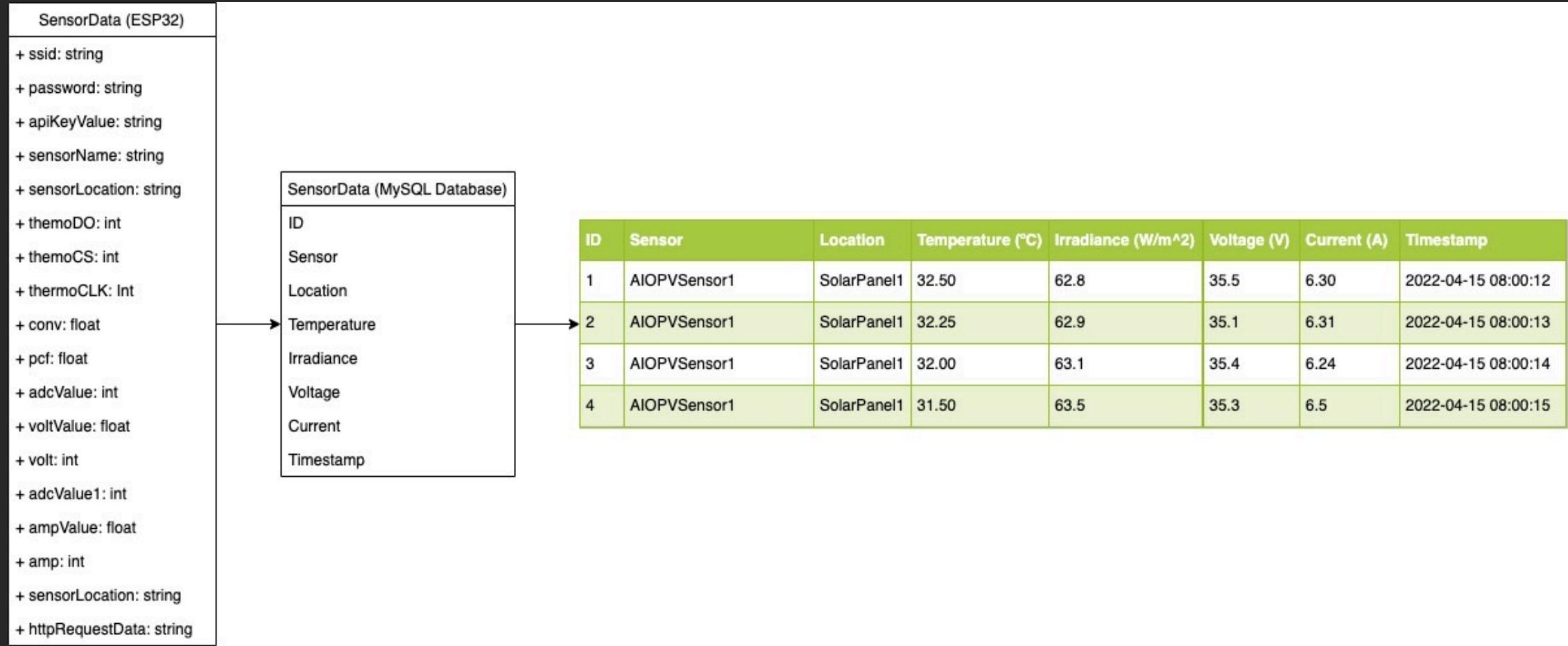
MICROPROCESSOR PROGRAM FLOW



The Raspberry Pi will house multiple programs to support the wirelessly connected AIO PV Sensor. The software bundle installed on the microprocessor can be referred to as a LAMP (Linux, Apache, MySQL, PHP) server. The LAMP server uses each of its components in tandem to be able to wirelessly receive and post collected data to an HTML webpage. It is called a LAMP server because the **L**inux operating system controls the **A**pache server and data is queried using **M**ySQL and **P**HP scripting.



MICROPROCESSOR PROGRAM FLOW, CONT'D



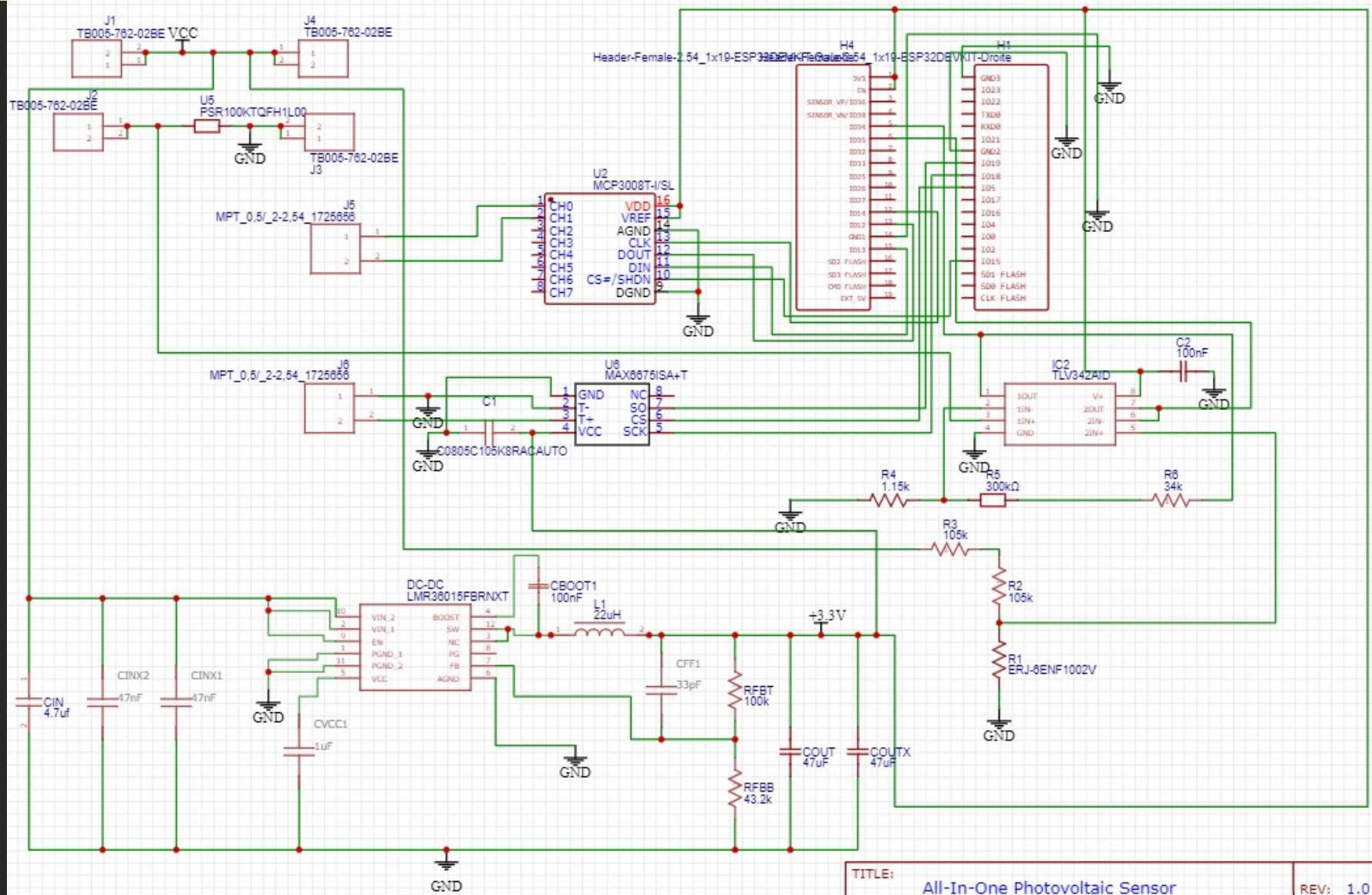
MICROPROCESSOR DIFFICULTIES

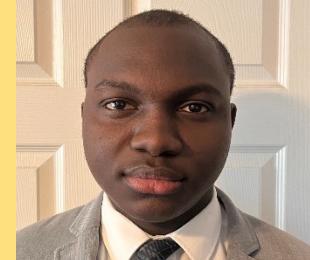
There were some difficulties encountered along the way of designing the software running on the Raspberry Pi. Those difficulties include being unable to set a static IP address. We sought to set a static IP address for the Raspberry Pi so our ESP32 could easily access post data to the Raspberry Pi without having to modify the IP address included in the ESP32's code.

Additionally, we ran into some issues with modifying the SQL query code to add additional columns for more datapoints.



PCB SCHEMATIC FOR V1.0



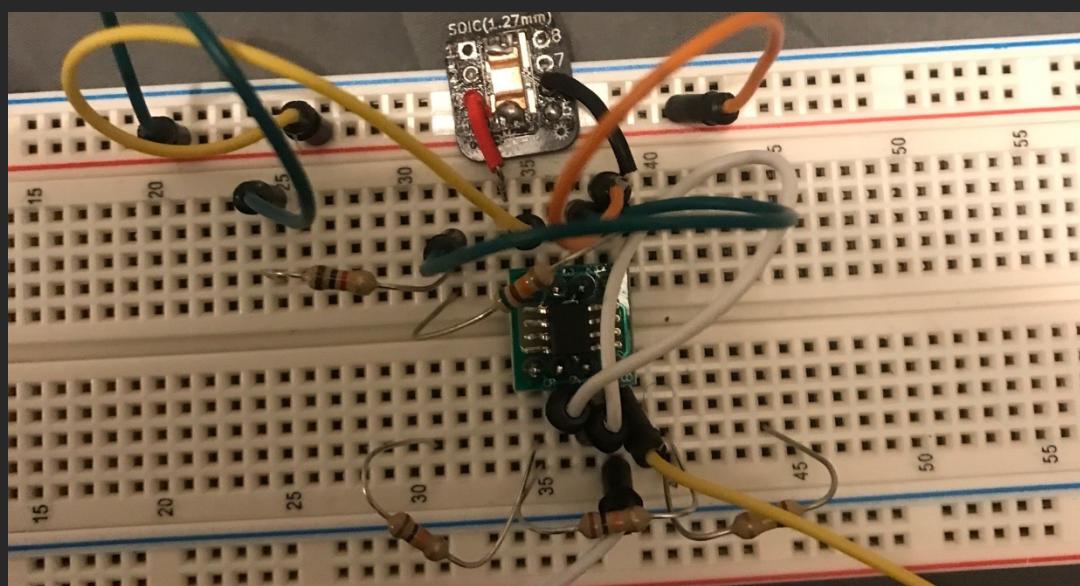
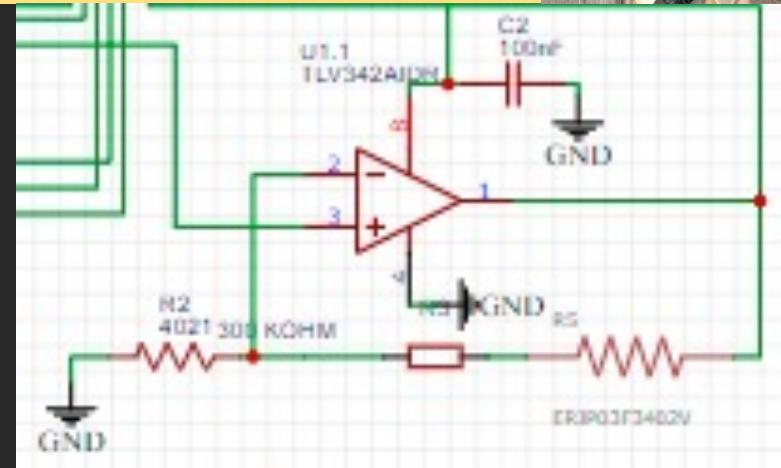


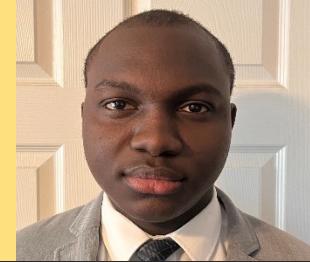
TLV342A CURRENT SENSING

Noninverting Differential gain amplifier:

- Amplifies Shunt Voltage
- $R_{in} = 1.15 \text{ K}\Omega$
- $R_f = 334 \text{ K}\Omega$
- $A_v = 291$
- Voltage sent to the ADC

Ohms Law will be used to obtain current value





VOLTAGE MEASURING

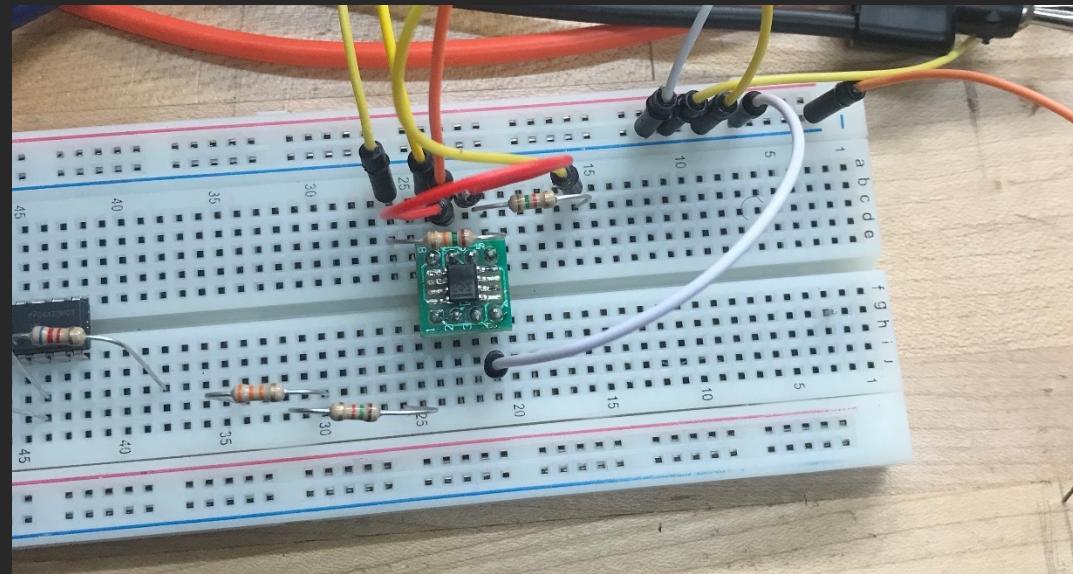
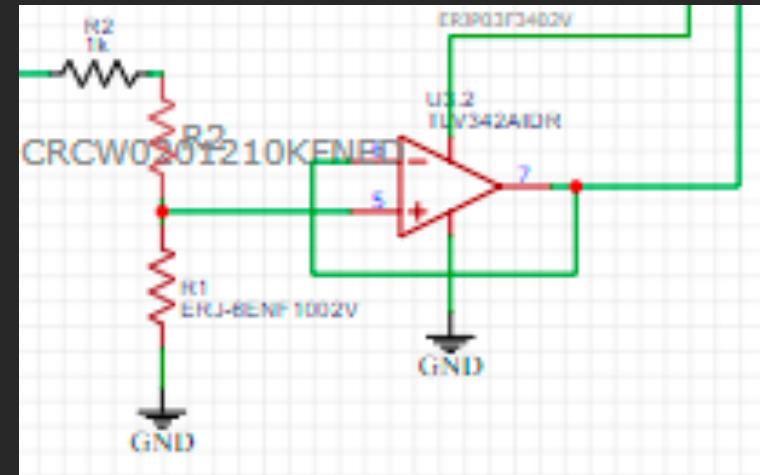
Voltage leaving solar panel is too high.

Voltage divider:

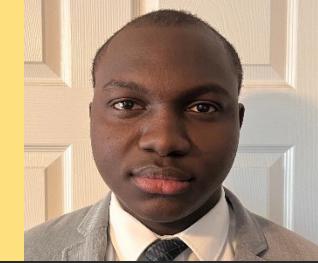
- Reduces 39 V to 1.77 V
- $R_1 = 105 \text{ k}\Omega$ (*2)
- $R_2 = 10 \text{ k}\Omega$

Unity gain buffer:

- Reduces Power consumption
- Reduces Noise



CURRENT AND VOLTAGE SENSING PCB IMPLEMENTATION

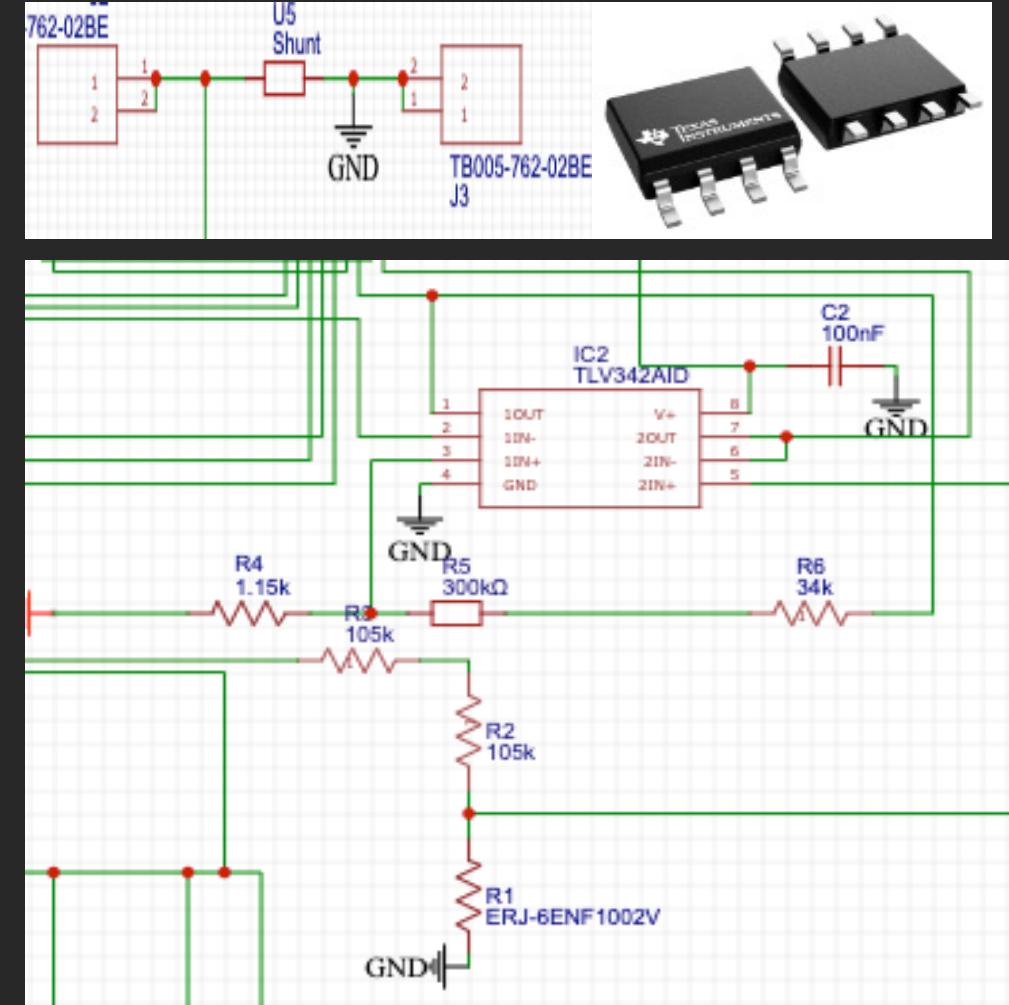


The TLV342 will have application in both the current and voltage sensing on the PCB.

Gain Resistors would amplify the voltage across the shunt, which would then be sent to the ADC of the ESP 32.

Voltage divider reduces voltage for measuring, then unity gain buffer will send the voltage to the ADC of the ESP32.

ESP32 send Data collected to a node.

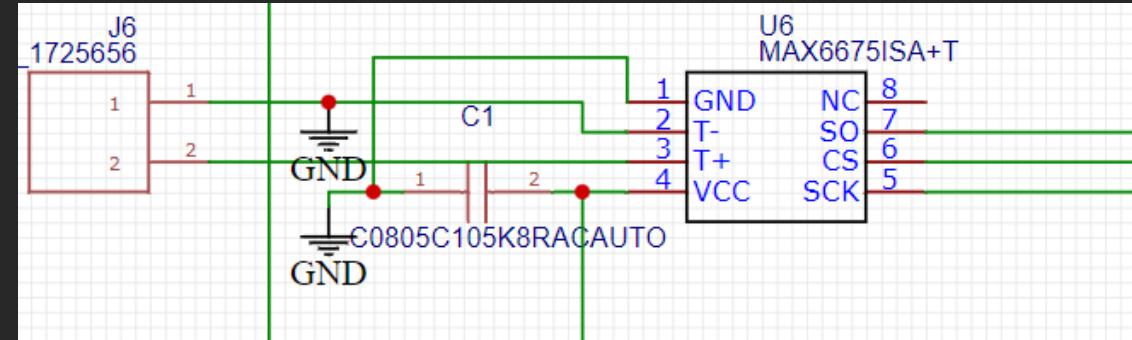


TEMPERATURE PCB IMPLEMENTATION



The MAX6675 was the most cost-effective component that we could use in our implementation that does not compromise thermocouple compatibility and resolution.

Even if only has 12-bit digital resolution, compared to the MAX31885. MAX6675 has a 0.25°C resolution that falls within require $\pm 10\%$ temperature offset.



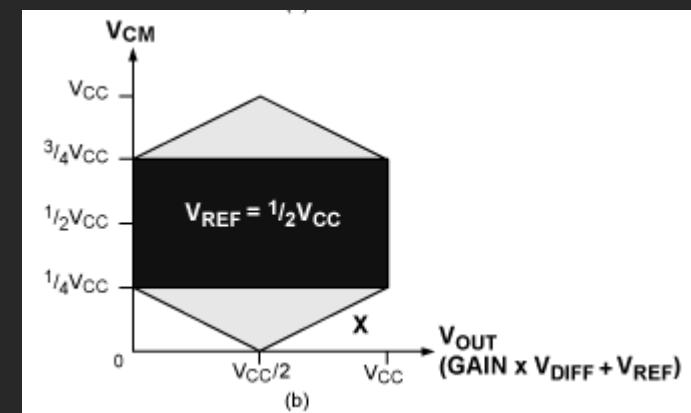
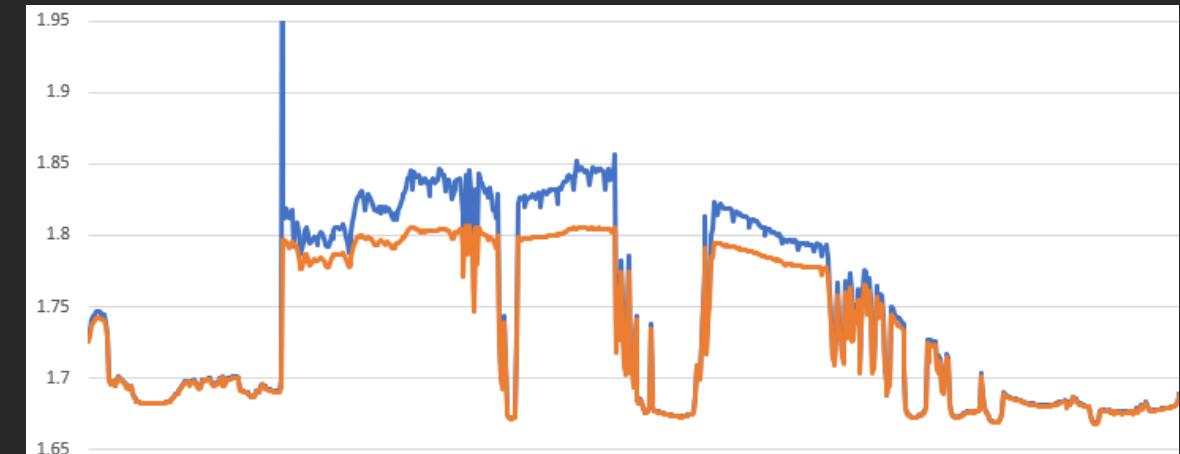
The thermocouple utilized in this application is both a Type T and Type K thermocouple self-adhesive.

IRRADIANCE IMPLEMENTATION DIFFICULTY

Initially, the MAX4194 was selected to amplify the pyranometer's signal to send to the ESP32's on-board ADC.

The datasheet was misleading, as the part advertised full functionality under a single supply. Due to the pyranometer's low and differential output, the signal could not properly be amplified without saturation.

Early tests showed that when operating on a single supply, the measured irradiance error grows as exposure to sunlight increases due to low comparative voltages.



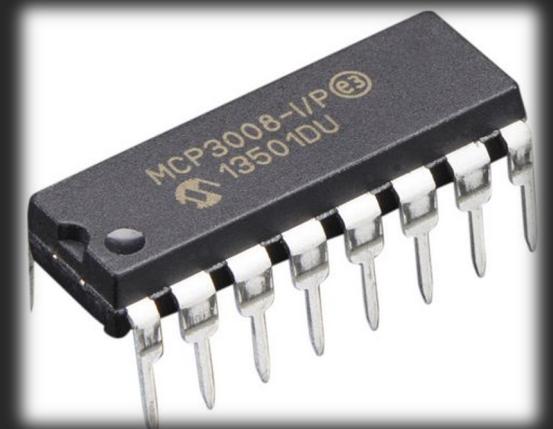
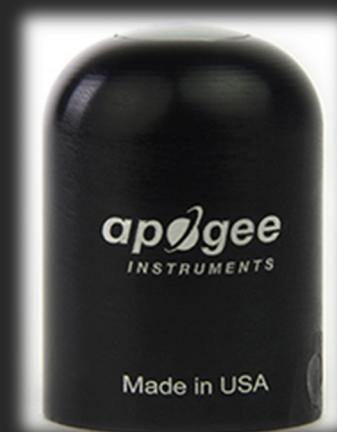
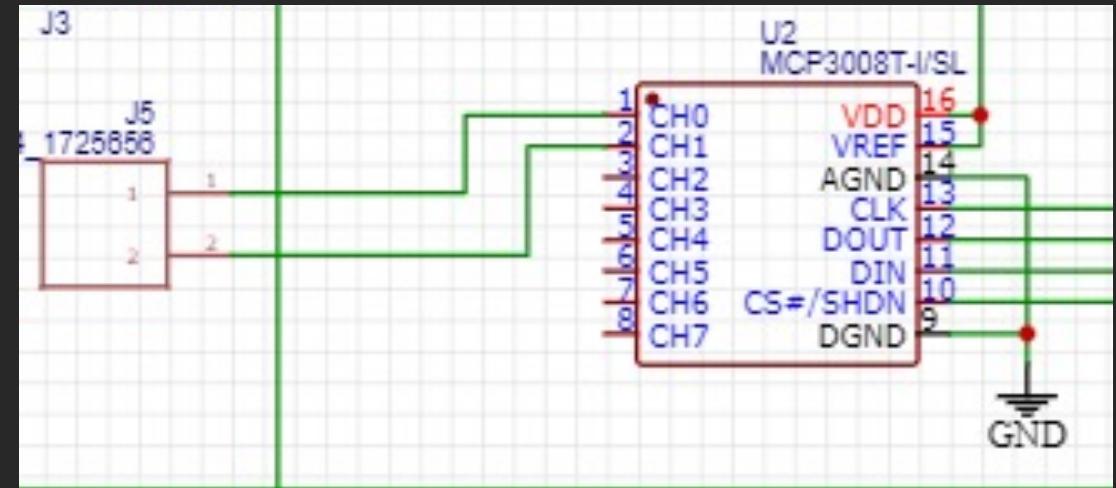
IRRADIANCE PCB IMPLEMENTATION



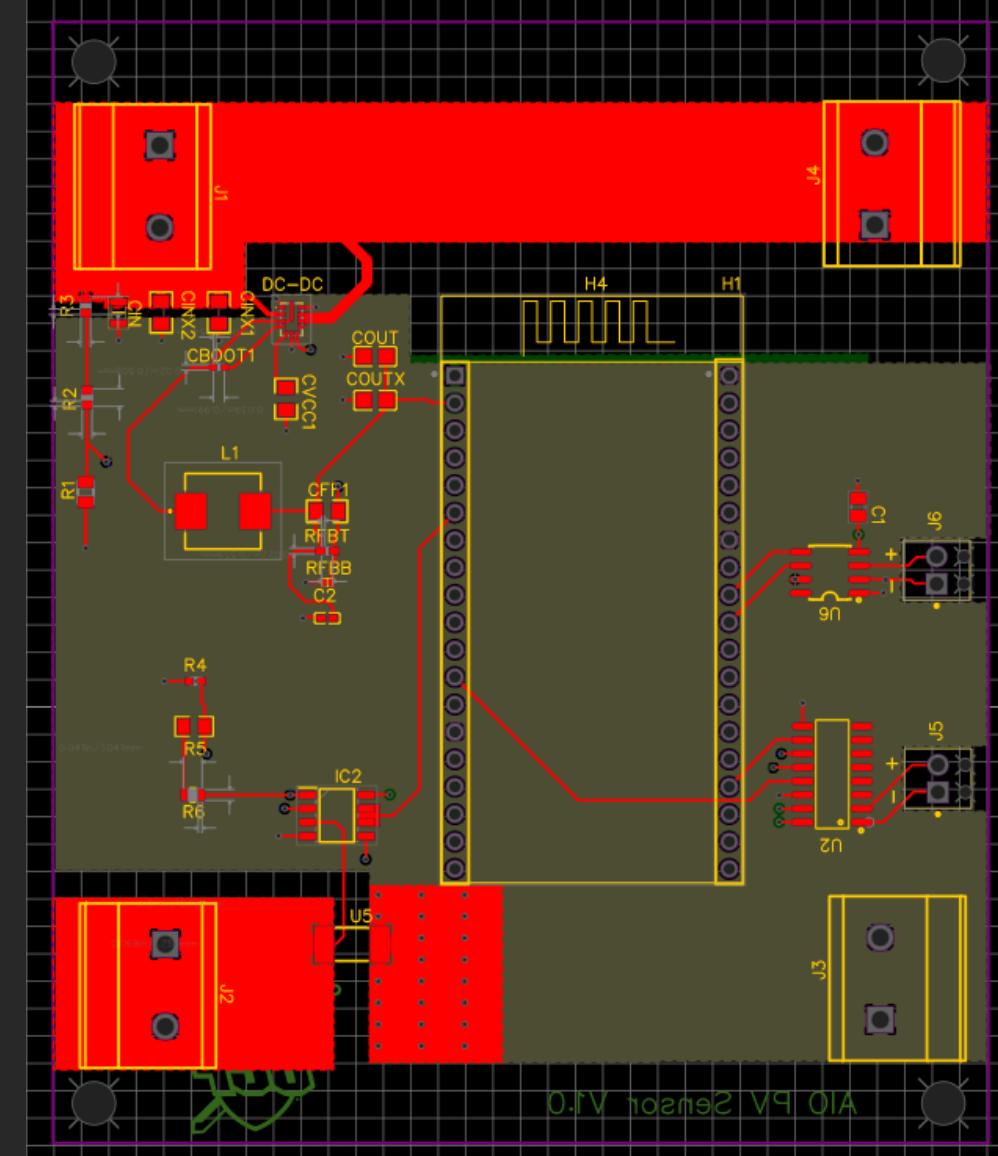
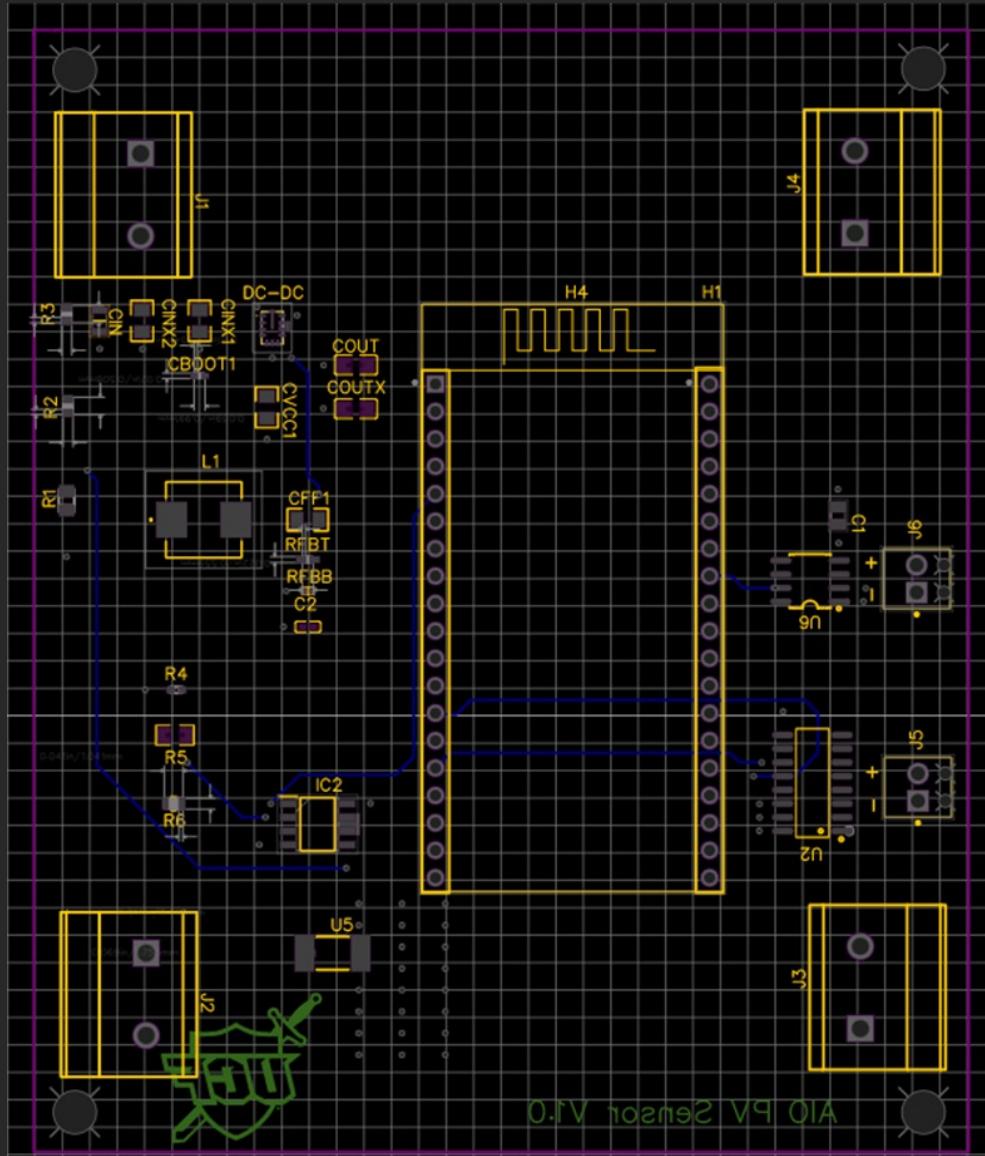
The MCP3008 was selected as the most practical and affordable option to integrate the SP-110-SS Pyranometer into the PCB.

Although it has a 10-bit resolution, it offers a pseudo-differential input reading and a low price point combined with high part availability. The pseudo-differential input allows the differential signal to be easily translated into a digital one.

This choice cut the price of integrating the pyranometer by half and greatly simplified the means of translating the signal to digital.



PCB LAYOUT V1.0

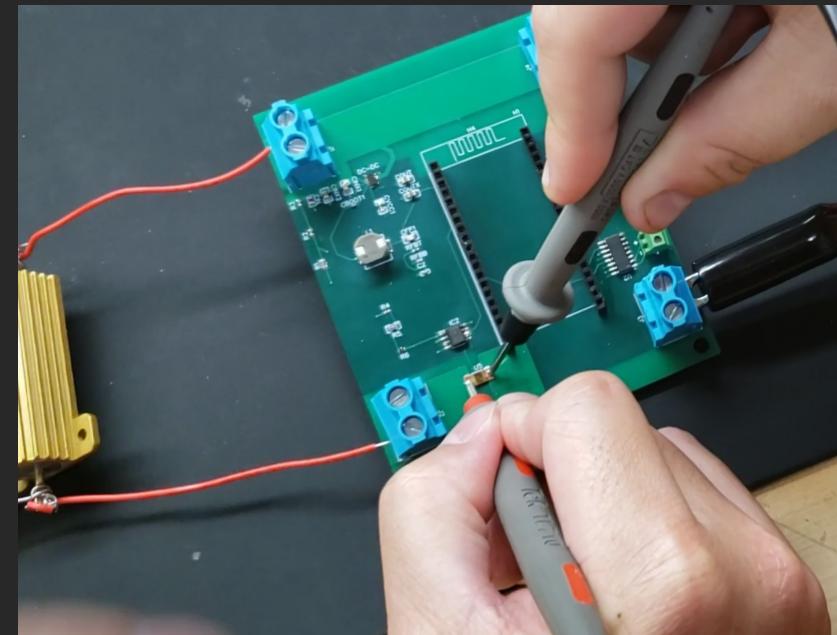
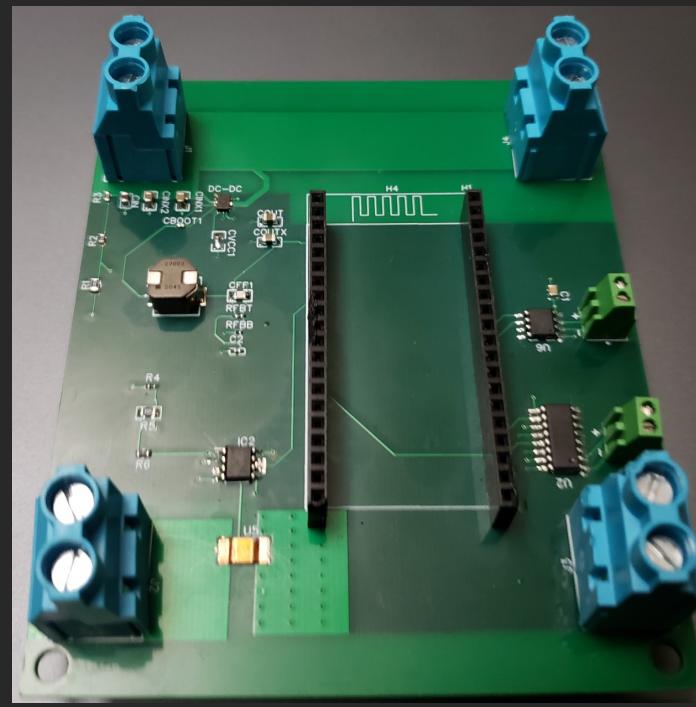
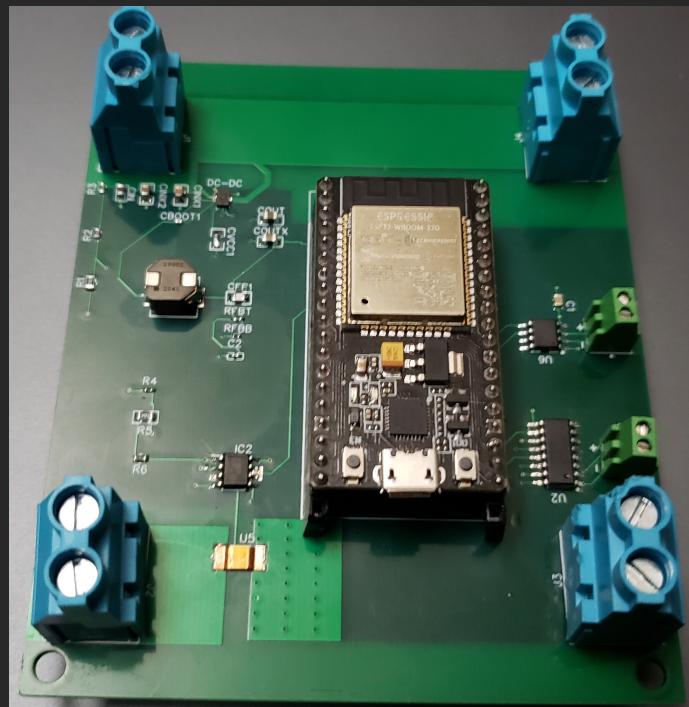


PCB PROTOTYPE V1.0 WITH DEV BOARD



For the first prototype we decided to implement an ESP-32 developmental board for our preliminary testing. This was done for various factors when it comes to testing such as:

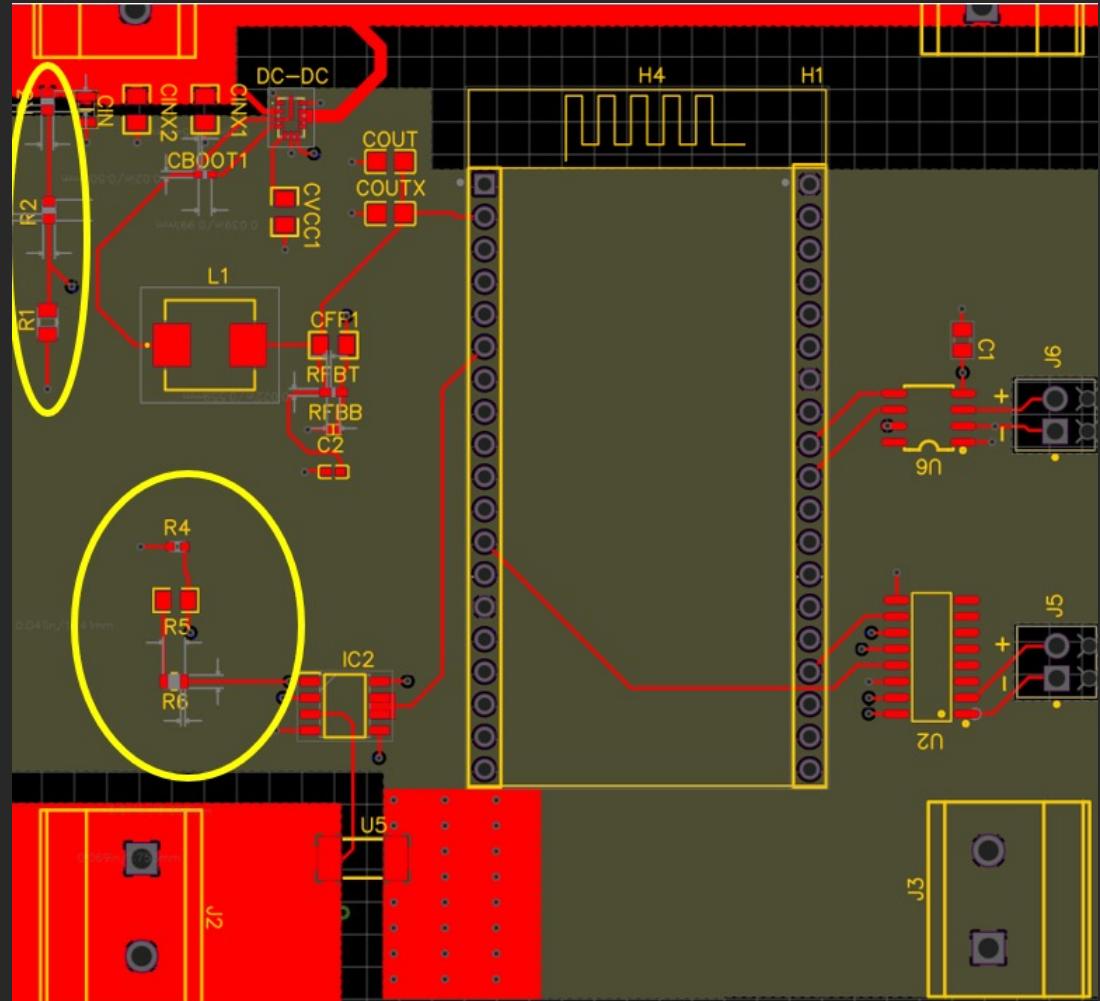
- Stress test the DC-DC Stepdown Converter with high voltage.
- Ease of multipoint probing.
- Allows ease of ESP-32 replacement incase of failure.



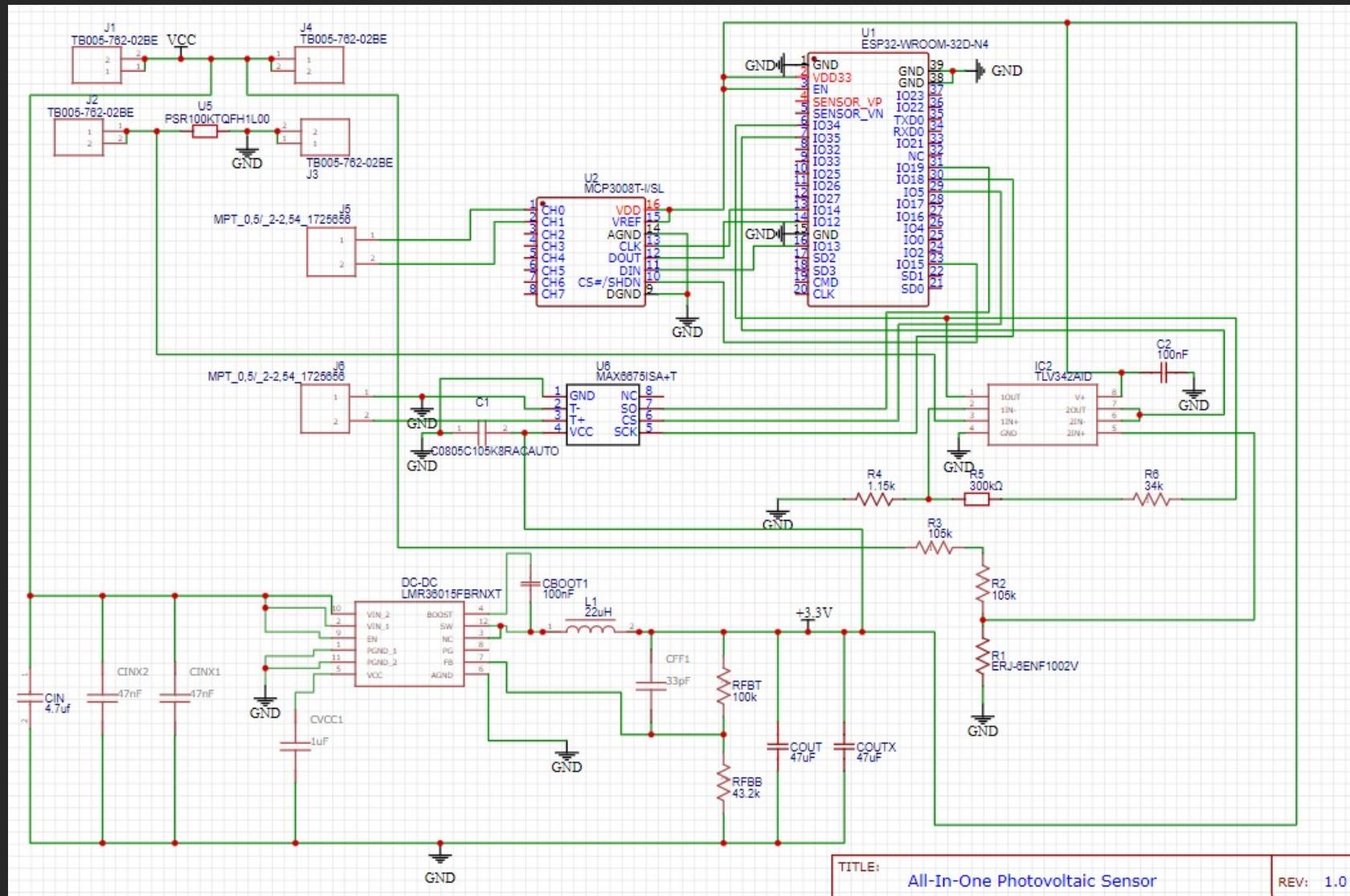
PROBLEMS AND DIFFICULTIES

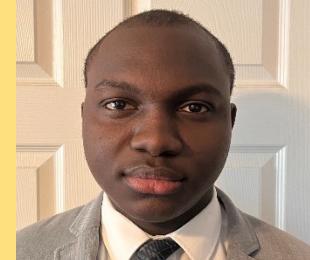


- Current Sensing
- PCB Layout Noise introduction due to part spacing.
- PCB 4 layers adding complexity.



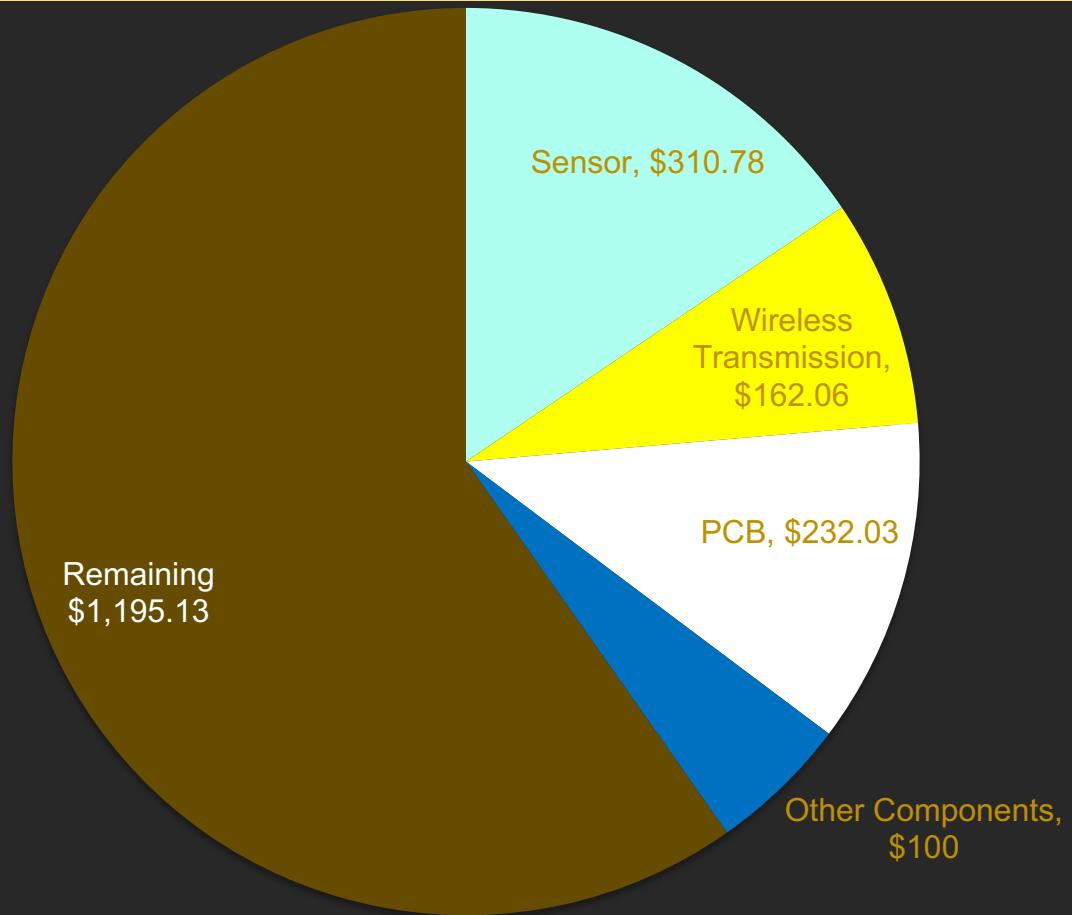
REVISED SCHEMATIC FOR V2.0



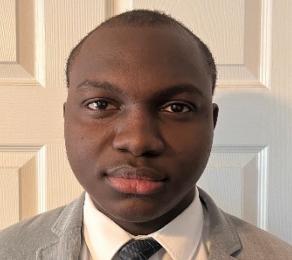


BUDGET

Gross Budget:
\$2000

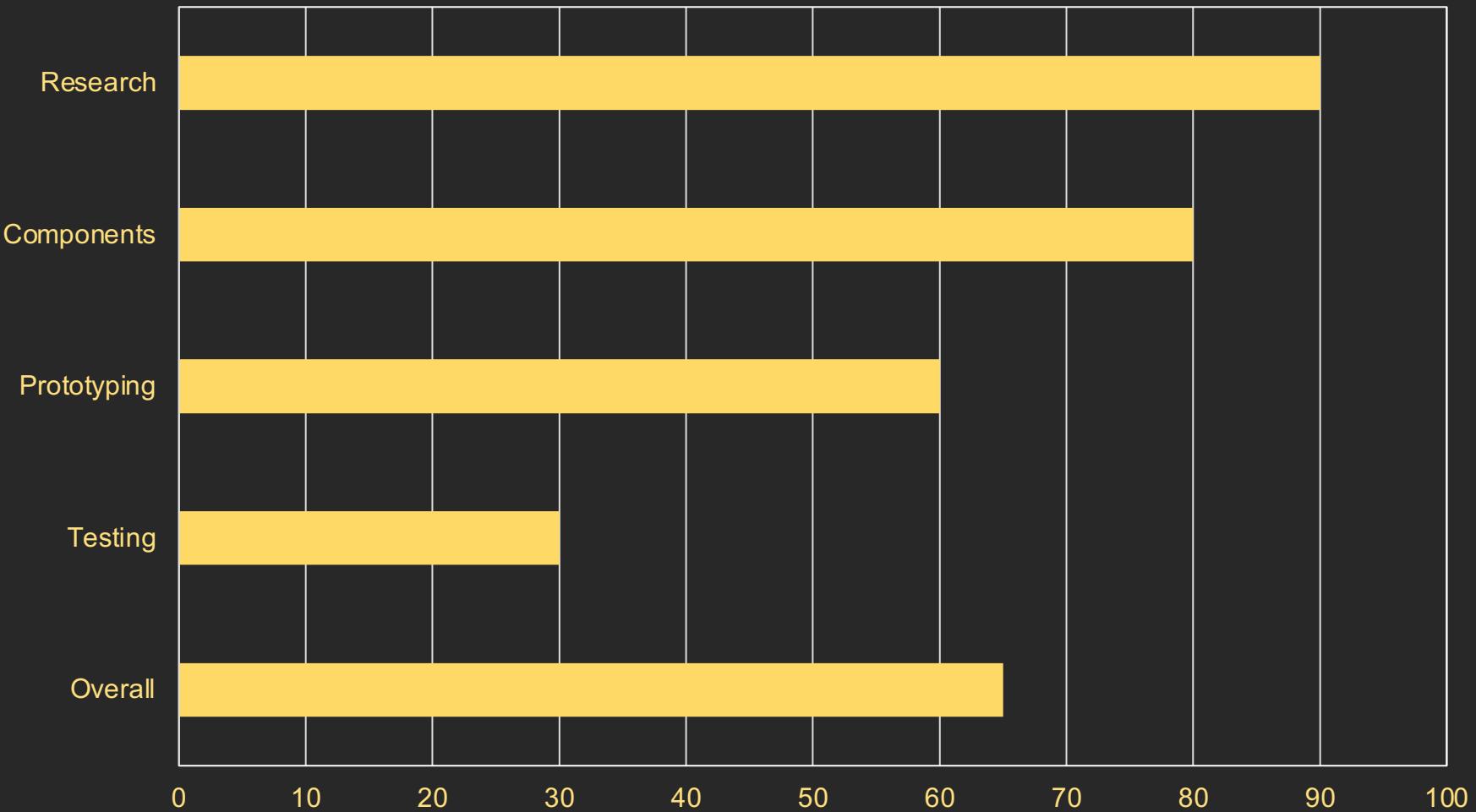


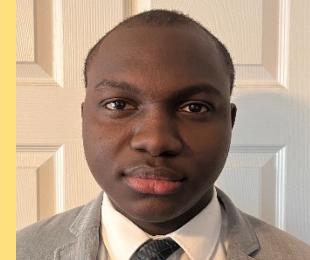
■ Sensor ■ Wireless Transmission ■ PCB ■ Other Components ■ Remaining



DEVELOPMENT

Current Progress





MILESTONE

Ordered
PCB

5/20

Components
Soldered

6/3

Field
Testing

6/13

Receive
PCB

6/23

Test
PCB

7/1



Received
PCB
5/26

Testing
Sensors
on PCB
6/6

Redesign
and
order
PCB
6/16

Solder
Components
6/28

THANK YOU



Any Questions?

