Sun Tracking Solar Panel

Final Report

Team 4

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Abstract

This paper presents a design and analysis of the sun tracking solar panel our group designed. The panel rotates to track the sun's movement and sends live data of the power generated by the panel to a wifi module, which sends the data to a phone application. The phone application displays graphs of the live voltage, current, and power of the panel. It is also able to turn off the sun tracking as well as manually control the panel's position. Photoresistors detect light and send voltage to a microcontroller, which decides which direction to turn the motors. This paper will go over the verification of the design as well as what future improvements can be made to it.

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1. Introduction

1.1 Problem

Stationary solar panels do not produce the maximum amount of energy possible at all hours of daylight. Setting up stationary solar panels requires finding an optimum tilt as well as an angle to face the average position of the sun in the sky. Calculation of these angles depends on the latitude and longitude at the panel's location.

1.2 Solution

Our proposed solution was to create a sun tracking solar panel that would rotate on two axises to face all directions to be perpendicular with the sun. This device would use photoresistors mounted behind the panel which would try to minimize the light in their view, sending data to a microcontroller which would tell the motors which direction to turn. This solution mitigates any calculation for a stationary angle and also would eliminate any need for setup. This panel would send its power data to a web application.

The device we created rotates on one axis to face the sun. The photoresistors are mounted on flaps on the side of the panel, with flaps for shading the photoresistors perpendicular to the flaps. We used a phone application instead of a web application. This application displays live graphs and data for the voltage, current, and power of the solar panel, and the voltage of the photoresistors. We can also turn off the sun tracking and use manual control of the panel from the app.

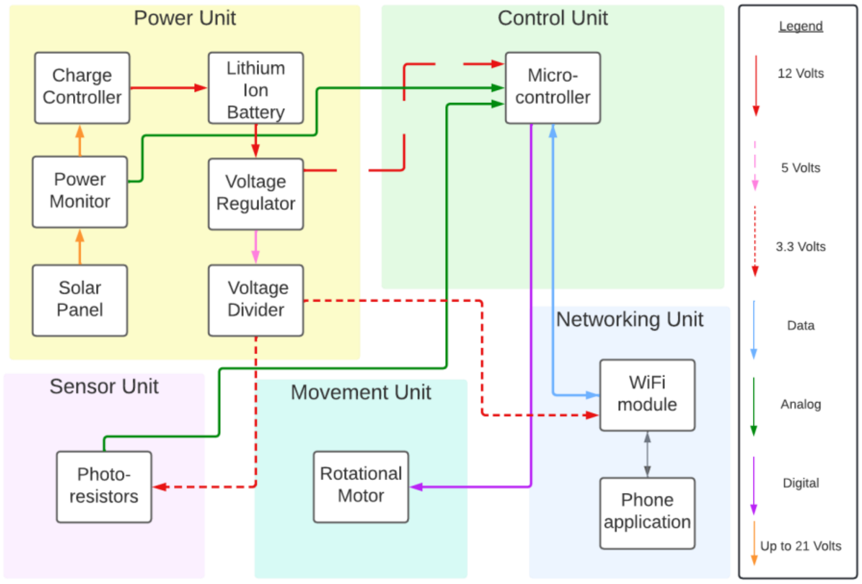

Figure 1. Block Diagram

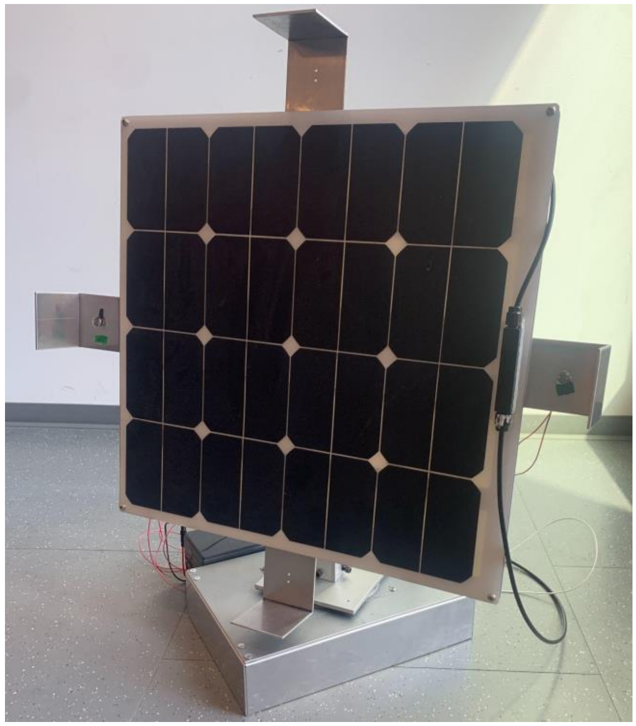

Figure 2. Our Sun Tracking Solar Panel

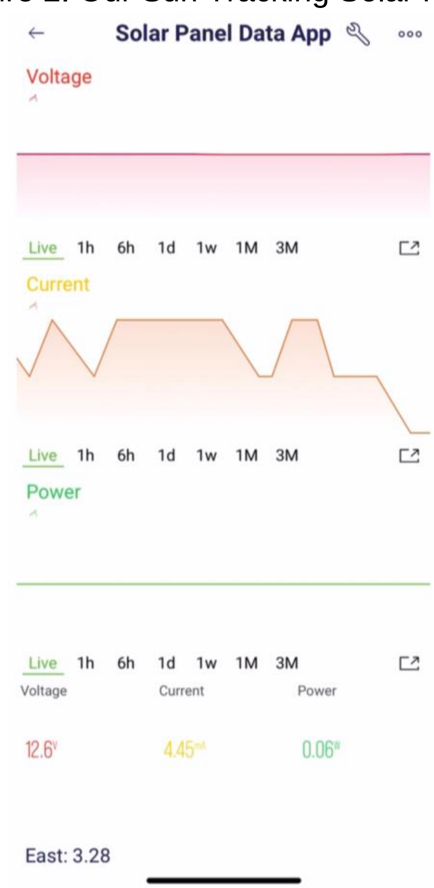

Figure 3. Phone Application GUI

1.4 High Level Requirements

- The panel must utilize the photoresistors to be perpendicular +/-10° to the sun at all hours of the day to maximize energy production. It must perform a 180° tilt at nighttime to reset it for the morning.
- The panel must generate and store power in a battery used to power its functions, while still producing at least 15% more net power than a stationary solar panel.
- The panel must send a stream of data including the power generation and efficiency to a webapp which will display live graphs and data.

2. Design

2.1 Power Unit

2.1.1 Solar Panel

The solar panel is the source of power for the circuit and also the focal point of the project. We intended to design the project so the solar panel would produce enough power to power the circuit and the motors while still supplying more power than a stationary solar panel but we're unable to actually test it. The solar panel is mounted on a frame which angles with the tilt motor and rotates with the rotation motor. Our tilt motor didn't end up functioning so the solar panel was stationary on the tilt axis, but still had about a 30 degree tilt.

2.1.2 Power Converter

The power converter circuit converts the power from the solar panel into voltage that works with our microcontroller and other components. We intended on having 12 volt, 5 volt, and 3.3 volt regulators, but when testing those, they burnt out in our pcb, bringing up the traces with it, so we moved them onto a perfboard. We purchased better regulators from the supply center, but they did not have a 3.3 volt regulator so we used the output of the 5 volt regulator and made a voltage divider to bring it down to 3.3 volts.

2.1.3 Battery

The 12 V battery is charged by the solar panel, also serving as a load for the power monitor to track current. The battery is connected to the battery output of the charge controller. This functioned well, and the battery was able to be charged, as well as discharged when needed to power anything else.

2.2 Control Unit

2.2.1 Microcontroller

The microcontroller used for this project is an ATmega328P. This microcontroller was intended to be used on our PCB, running on 5V. However, due to complications, an ATmega328P on an Arduino RedBoard is used to run our sun tracking algorithm.

The microcontroller was programmed with an algorithm to use feedback from the photoresistors to position the solar panel in an optimal position to produce power. The microcontroller reads a collection of sample voltages from the photoresistors, and calculates the average value. Then the percent difference of the photoresistors on the same axis is calculated. If the percent difference is greater than a set threshold, the microcontroller will decide to turn the panel across that axis. If both values are greater than the threshold, the microcontroller will choose to move the panel in the direction of the greater difference. A high and low signal is sent to the power and ground pins of the motor to turn the motor one direction, and the reverse is sent to turn the motor the opposite direction.The direction the panel is turned is always in the direction corresponding to the photoresistor with the smaller voltage read. The duration of rotation is always one second per update. By determining the time needed to rotate 360 degrees, we can calculate how many times we can rotate the panel in a direction before we decide to prevent it going any further to avoid tangling wires.

We also use the microcontroller to send statistics from the power chip to the Wi-Fi module to be displayed on the phone application. The voltage and current going through the power chip directly from the solar panel is read by the microcontroller. The microcontroller then outputs these values to the Wi-Fi module.

2.3 Sensor Unit

2.3.1 Photoresistors

The photoresistors were originally designed to be on our PCB, but since we had issues with the microcontroller, we put them on a separate breadboard. The photoresistors lie on either side of the panel and long wires are connected to a breadboard which has a voltage divider which sends an output to the microcontroller to record voltage of the photoresistors. A flap is on either side of the panel which shades the photoresistors when the panel is not aligned perpendicular with the sun, causing the voltage to go down. The photoresistors worked as intended, allowing us to track the sun.

2.3.2 Power Monitor

The output of the solar panel goes into the PCB, where it then goes into the power monitor chip as well as a voltage divider circuit. The voltage divider circuit brings the voltage of the panel down to 5 volts or less, allowing the microcontroller to be able to read it with an analog pin. The power monitor chip has a shunt resistor and other components inside it which allow us to connect its output up the microcontroller and record the current of the solar panel. This all worked as intended.

2.4 Movement Unit

2.4.1 Rotational Motor

The rotational motor's purpose is to rotate the arm holding the solar panel. It is a 12 volt gear motor, designed to turn the solar panel approximately 180 degrees in either direction from its fixed starting position. This ensures the solar panel can face in all directions to maximize its potential energy production. Also, this prevents the wires connecting the photoresistors and solar panel to the circuit in the base do not get tangled up.

2.4.2 Tilt Motor

The intended function of the tilt motor is to tilt the solar panel up and down. The motor used is the same as the rotational motor, a 12V gear motor, however this was not strong enough to tilt the solar panel. Given the weight of the frame and panel, a motor with a higher gear ratio would be needed to tilt and hold the solar panel up. The tilt motor should rotate the tilt motor 90 degrees in either direction from a starting position perpendicular to the arm.

2.5 Networking Unit

2.5.1 Wifi Module

The wifi module serves as a middleman between the phone application and the microcontroller. The wifi module was intended to be on the PCB, but we made some wiring mistakes, so we moved that onto the same breadboard as the photoresistors. It was first programmed with AT commands to be set up for our uses. We used the arduino serial monitor to send these commands. Then, it was set up to work with wifi. We weren't able to connect with the school wifi because it is an enterprise network, so we just used a hotspot to connect to. The wifi module uses TCP/IP to connect to wifi and send data. This module was tricky to set up with the AT commands, but once it was working it worked well with the phone application.

2.5.2 Phone Application

We used the Blynk API and application for our project. We originally were going to do a web application, but decided a phone application would work better, considering we would be doing testing outside. We set up an account with Blynk and then set up virtual pins on the Blynk website, which we can use as virtual Arduino pins we can use as inputs or outputs. Then, in the code for the microcontroller, we set up functions with timers which would send data whenever the timer was triggered, for use it was twice a second. We used pins to record data which was sent to the microcontroller. Then we just have to connect a phone to the same wifi, aka the hotspot, that we use for the wifi module and open the Blynk app. We set up graphs with the virtual pins. The phone application displays live graphs of the solar panel voltage, current, and power, and the photoresistors' voltage. We also have buttons on the phone which send signals to the microcontroller that allow us to turn off the sun tracking functions, as well as take over manual control and send it rotating clockwise and counterclockwise with buttons on the app. This app worked much better than we predicted.

3. Design Verification

3.1 Power Unit

3.1.1 Solar Panel

To verify the solar panel, we put it out in broad daylight and measured the output using a multimeter. It outputted 350-590 mA and 12 to 18V in direct sunlight and was able to charge a battery.

3.1.2 Power Converter

To verify that the power converter outputs the different voltage levels required for the different components, we used a multimeter to measure each voltage level.

3.1.3 Battery

To verify we measured the appropriate voltage out of the battery, we measured the voltage of the battery with a multimeter and observed that the voltage was the correct value.

3.2 Control Unit

3.2.1 Microcontroller

We tested the functionality of our microcontroller by first uploading a basic algorithm for testing. This included sending different controlled voltages to the digital pins, and printing to screen these values. To verify that we could correctly send signals, we tested sending different voltages directly from the microcontroller to the motors to make sure they could be controlled properly.

3.3 Sensor Unit

3.3.1 Photoresistors

To verify the photoresistors worked as intended, first we measured their resistance at maximum illumination and measured the resistance of the photoresistors to be between 5.4 and 12.6 kΩ. Then we completely covered the photoresistors and measured the resistance to be at least 1 MΩ. Then, to verify that the voltage across the photoresistors changed as their illumination changed, we used them in a voltage divider and measured that the voltage across them would increase as their illumination increased and their resistance decreased. We also measured that the voltage across the photoresistors decreased as their illumination decreased and their resistance increased.

3.3.2 Power Monitor

To verify that we could use the power monitor to measure the voltage and current generated by the solar panel, we connected the power monitor to the solar panel and the microcontroller. We used the microcontroller to visualize the voltage and current generated by the solar panel. We then manually measured the voltage and current generated by the solar panel with a multimeter and verified the values measured by the multimeter were equal to the values measured by the power monitor.

3.4 Movement Unit

3.4.1 Rotational Motor

To verify that the rotational motor worked as intended, we connected the motor to the power supply in the lab. Starting from a low voltage, we slowly increased it to the maximum voltage of 12 volts to verify that the motors would turn as intended. We also tested reversing the polarity of the voltage to verify that the motor would turn the opposite direction as well. Once attached to the solar panel structure, we performed the test again to ensure that the motor would turn the solar panel.

3.4.2 Tilt Motor

The tilt motor was tested in the same way as the rotational motor, by sending a controlled voltage to the motor with a power supply. However, when attached to the structure, the motor could not generate enough torque to lift the solar panel more than a few centimeters.

3.5 Networking Unit

3.5.1 Wifi Module

To verify the wifi module was set up the correct way for our uses, we used the Arduino serial monitor. When sending an AT command from the monitor, the wifi module needed to reply with readable English and say OK at the end of any message. All of the AT commands worked and it was set up to connect to wifi. Then, when setting up the wifi, the serial monitor must display the name of the wifi network and say it is ready to send messages. It would say it was ready and we would check the connections of the hotspot to confirm that the module was indeed connected. When connected, the hotspot would say that ESP8266 was connected to the network. We would verify that it was sending messages via the app, when the app said that our device was ready for connection.

3.5.2 Phone Application

To make sure the phone application was connected to the wifi module and thus the microcontroller, we set up an LED to one of the pins of the microcontroller and set up a virtual pin within Blynk and the microcontroller code. We set up a button within the app with a switch for the LED. When we were able to press the button and turn on the LED with at most .25 seconds of delay, we verified it was connected. To verify that it was getting live data, we connected a power supply to a microcontroller pin and set up a virtual pin for that pin. Then we set up a graph on the app for that pin’s voltage. We changed the voltage and would check that the app would update within a second.

4. Costs and Schedule

4.1 Parts

Part	Part Name	Quantity	Price
Motor	GEARMOTOR 100 RPM 12V METAL	2	$36.95
Motor Driver	DUAL H-BRIDGE MOTOR DRIVER WHICH	1	$2.74
Wifi module	ESP8266 (4MB Flash)	1	$6.95
Power chip (unused)	NOYITO INA226 Bi-Directional Current and Power Monitor Module	1	$9.80
Power chip (used)	ACS723	1	$4.51
Microcontroller	ATMEGA328-AU TQFP	1	$4.99
Arduino Redboard	DEV-12757	1	$14.76
Photoresistors	NORPS-12 LDR, 1 Mohm, 250 mW, 320 V	6	$3.16
5 V voltage regulator (unused)	IC REG LINEAR 5V 100MA TO92-3	1	$0.52
3.3 V voltage regulator (unused)	IC REG LINEAR 3.3V 100MA TO92-3	1	$0.44
12 V voltage regulator (unused)	IC REG LINEAR 12V 100MA TO92-3	1	$0.44
5 V voltage regulator (used)	LM7805ACT-ND	1	$0.63
12 V voltage regulator (used)	MC7812CT	1	$0.58
Battery	12V 3.6A lithium ion battery	1	Free
Charge controller	Sunworks PWM charge controller	1	Free
10 kohm surface mount Resistors	Thick Film Resistors - SMD 10 kOhms 250 mW 1206 5%	10	$0.11

1 uF surface mount capacitors	Multilayer Ceramic Capacitors MLCC - SMD/SMT 10V 1uF X7R 0805 10% Flex Soft	10	$0.75
Solar Panel	n/a	1	Free
Programmer	ATMEL 51 AVR USB ISP ASP	1	$10.89
3.8 kOhm resistor	RES SMD 10K OHM 5% 1/3W 0805	5	$0.83
4.7 kOhm resistor	RES 3.83 KOHMS 0.1% 1/5W 0805	5	$0.10
1 kOhm resistor	RES SMD 4.7K OHM 5% 1/3W 0805	5	$0.14
2 kOhm resistor	RES SMD 1K OHM 1% 1/3W 0805	5	$0.20
1 uF capacitor	RES SMD 2K OHM 5% 0.4W 0805	10	$0.33
22p capacitor	CAP CER 1UF 50V X7R 0805	10	$0.03
0.1 uF capacitor	CAP CER 22PF 25V C0G/NP0 0201	10	$0.12
1 nF capacitor	CAP CER 0.1UF 50V X7R 0805	10	$0.08
Screw terminals	9.52 MM TERMINAL BLOCK, HORIZONT	4	$1.69
Diode	DIODE SCHOTTKY 20V 500MA SOD123	5	$0.35
Jumper	Jumper - 2 Pin	2	$0.35
Oscillator	CRYSTAL 16.0000MHZ 12PF SMD	3	$0.84

4.2 Labor

A University of Illinois ECE graduate makes on average $105,879 [0]. With 2080 working hours in a year that makes the hourly wage $50.90/hr. We each plan to spend at least 10 hours working on this project a week and with 9 weeks left before the project demo that makes $50.90/hr * 10 hrs/week * 3 people * 9 weeks = $13,743 in labor costs.

4.3 Schedule

	Daniel	Rohan	Tyler

2/21	Design Doc/PCB	Design doc/PCB	Design doc/PCB
2/28	Order parts	Test/simulate PCB	Finalize PCB
3/7	Talk to machine shop	Test/simulate PCB	Research programming microcontroller
3/14	Start web app	Test PCB	Program microcontroller
3/21	Work on integrating web app with microcontroller	Make PCB revision	Test PCB with microcontroller
3/28	Combine modules	Combine modules	Combine modules
4/4	Final assembly	Final assembly	Final assembly
4/11	Testing	Testing	Testing
4/18	Mock demo	Mock demo	Mock demo
4/25	Demonstration	Demonstration	Demonstration
5/2	Presentation and final paper	Presentation and final paper	Presentation and final paper

5. Conclusion

5.1 Accomplishments

Theoretically, our completed project functioned as intended, with the exception of the tilt functionality. We successfully programmed the microcontroller to read values from photoresistors, parse the data, and correctly decide which direction to move the panel to increase energy production. The project was also capable of sending live data of the solar panel’s power statistics to our phone application. Our phone application was also capable of controlling the motors for turning the solar panel, as well as capable of toggling on and off the sun tracking algorithm. The only shortcoming was the functionality of the tilt motor, which could not generate enough torque to tilt the solar panel up.

5.2 Uncertainties

While the majority of our project did work, there were still some areas that were not fully functional. We were not able to test the solar panel over a whole day or against a stationary panel so we’re not totally sure how well it performs over a stationary panel. Also with the tilt motor not working we’re not sure how well it would live up to our projections. Also, we didn’t get the whole circuit on a PCB which we planned on using as a load, and our battery was fully charged, so we didn’t get the maximum power output we could’ve.

5.3 Future Work

Going forward, the most immediate and impactful improvement would be implementing a motor that could generate more torque to tilt the solar panel. Being able to tilt towards the sky would drastically improve the power generation, especially around midday when the sun is at its peak. Also, the flaps used to shade the photoresistors could be improved by adding more cover with a less reflective surface. We could also replace the PWM charge controller with an MPPT charge controller for more charge efficiency.

We would also like to improve the circuit components used in the project, as well as have a better way of securing the components within the solar panel structure. This could be done by having all the circuit components on a single printed circuit board, rather than on several breadboards. For mounting the components, we would design a metal panel that could be attached to the bottom of the base of the structure. We would be able to mount the circuit components to this panel, and have them hidden within the base.

5.4 Ethical Considerations

Section 1.1 of the IEEE Code of Ethics states: “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment” [2]. This relates to our project because we will be working with lithium ion batteries and electrical power. We will uphold Section 1.1 of the Code of Ethics and make sure to follow safety procedures with our battery. Also, we will keep in mind the sometimes questionable ethics of solar panels. Polysilicon, a key component of solar panels, has a lot of poor environmental and labor practices where it is mined [3]. Also, the recycling of solar panels limits their ideal use for environmental sustainability [4].

References

[1] “Data Portal,” *Engineering Career Services*. [Online]. Available: https://ecs.engineering.illinois.edu/data-portal/. [Accessed: 24-Feb-2022].

[2] “IEEE code of Ethics,” *IEEE*. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 24-Feb-2022].

[3] J. Gudmundsen, 2020 Jason Hayes | March 25, and 2020 Jack McHugh | December 18, “There are ethical concerns surrounding solar energy,” *Mackinac Center*. [Online]. Available: https://www.mackinac.org/the-ethical-concerns-surrounding-solar-energy. [Accessed: 24-Feb-2022].

[4] V. Taylor, “The complicated ethics of solar power,” *Mic*, 26-Oct-2021. [Online]. Available: https://www.mic.com/impact/solar-power-ethics-sustainability/amp. [Accessed: 24-Feb-2022].

Appendix A Circuit Schematics

Below are schematics used for the components in the project and referenced when assembling the final design.

A.1 Photoresistors

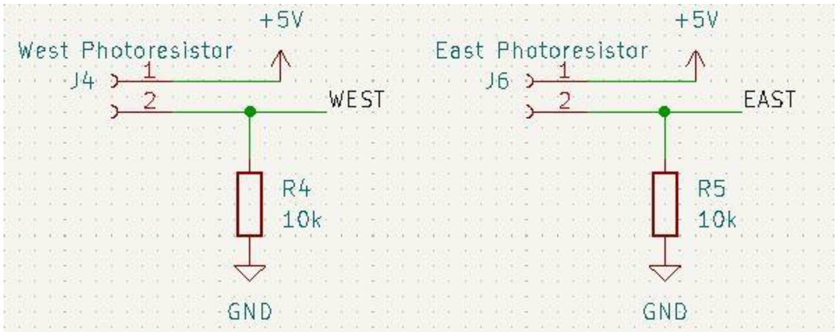

Figure 4. Photoresistor Circuit Schematic

A.2 Wifi Module

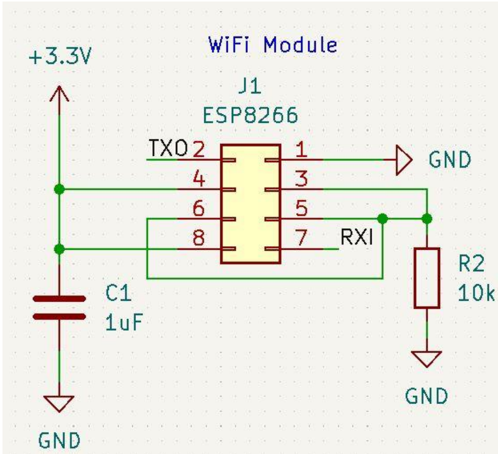

Figure 5. Wifi Module Circuit Schematic

A.3 Power Monitor

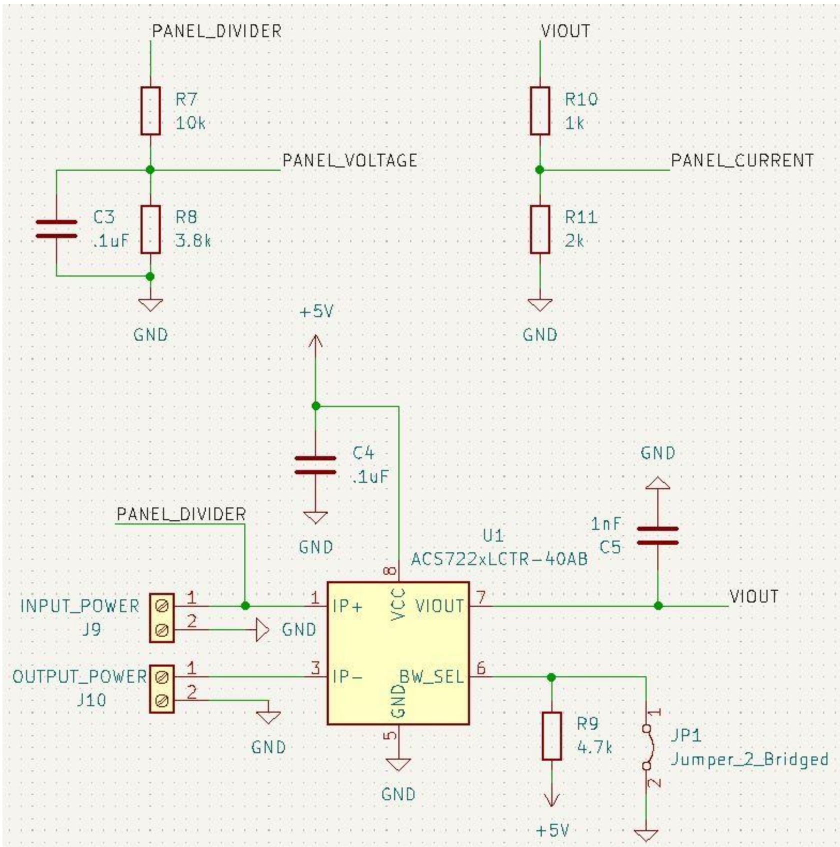

Figure 6. Power Monitor Circuit Schematic

Appendix B Requirements and Verification Tables

Battery

Requirements	Verification	Verification status (Y or N)
1. The battery will receive and store power from the solar panel, and send it to the rest of the components. It must supply >500 mAH of charge at 12V +/- 5%.	1. Connect a fully charged battery to the system a. Discharge battery at 100mA. b. Use a voltmeter to ensure the voltage remains within the 12V threshold.	Y

Power Converter

Requirements	Verification	Verification status (Y or N)
1. Provides 5 V +/- 5% and 3.3 V +/- 5% from a 12 V source with currents from 0-590mA.	1. Connect the input to a 12 V source and draw 590 mA. a. Measure the voltage output using a multimeter to ensure it is within 5 V +/- 5% or 3.3 +/- 5%.	Y

Solar Panel

Requirements	Verification	Verification status (Y or N)
1. Outputs 350-590 mA between 12 and 18 V in direct sunlight.	1. Put the solar panel outside in direct sunlight. a. Measure the current using a multimeter.	Y

Power Monitor

Requirements	Verification	Verification status (Y or N)
1. Power monitor chip accurately depicts voltage and current.	1. Measure the voltage and current across the solar panel using a multimeter. a. Verify that voltage and current is within +/-5% of the chip's output.	Y

Microcontroller

Requirements	Verification	Verification status (Y or N)
1. The microcontroller will use the photoresistor values to tell the motors where to turn the solar panel. 2. The power generated by the solar panel will be recorded by the microcontroller, and sent to the WiFi module.	1. Verify that the resistance of the photoresistors matches the direction the solar panel is moved i. Use multimeter to record the values of the photoresistors b. Observe that the solar panel moves in the correct direction c. Check that the values of the photoresistors are +/- 5% of each other 2. Discharge a battery connected to the microcontroller. a. Verify the power input coming through the microcontroller data. b. Verify the data comes through in the web application.	1. Y 2. Y

Photoresistors

Requirements	Verification	Verification status (Y or N)
1. Horizontal photoresistors resistance changes as rotational motor rotates the base 2. Vertical photoresistors resistance changes as the tilt motor tilts the panels	1. Record the resistance of the photoresistors with the microcontroller. a. Ensure that the values of the photoresistors correspond to the direction the solar panel is moving.	Y

Rotational Motor

Requirements	Verification	Verification status (Y or N)
1. The motor must move within +/-2° of the value given by the microcontroller.	1. Send an input angle from the microcontroller. a. Measure the rotation of the motor using a protractor to ensure it is within +/-2°.	Y

2.5.2 Tilt Motor

Requirements	Verification	Verification status (Y or N)
1. The motor must move within +/-2° of the value given by the microcontroller.	1. Send an input angle from the microcontroller. a. Measure the rotation of the motor using a protractor to ensure it is within +/-2°.	N

WiFi Module

Requirements	Verification	Verification status (Y or N)
1. The module must be able to interface with the microcontroller and send data to the web application.	1. Send a number of watts to the WiFi module from the microcontroller. a. Send the data from the WiFi module to the web application. Verify the web application receives the data.	Y

Web Application

Requirements	Verification	Verification status (Y or N)
1. The web application must display live data and visualizations of the power consumed and generated by the panel.	1. Send random power signals to the microcontroller over the course of a few minutes. a. Verify the web application receives the data and graphs it over time.	Y