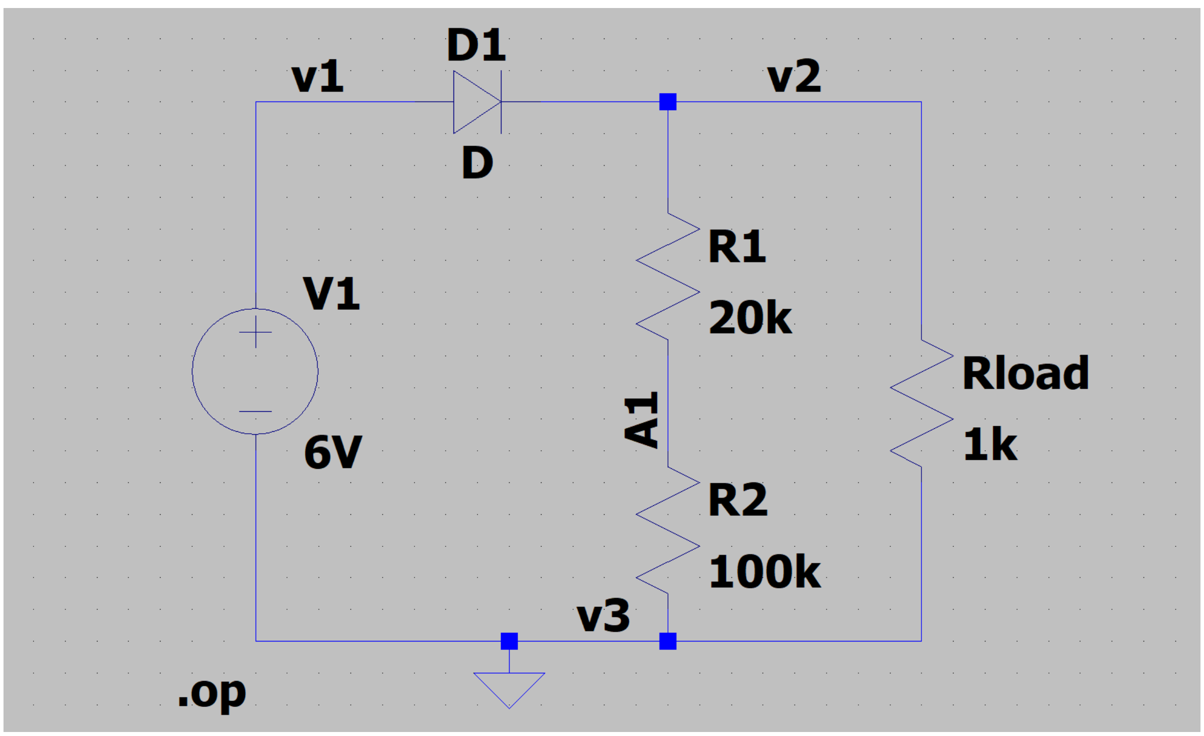
Solar Panel Monitoring System
Project Report

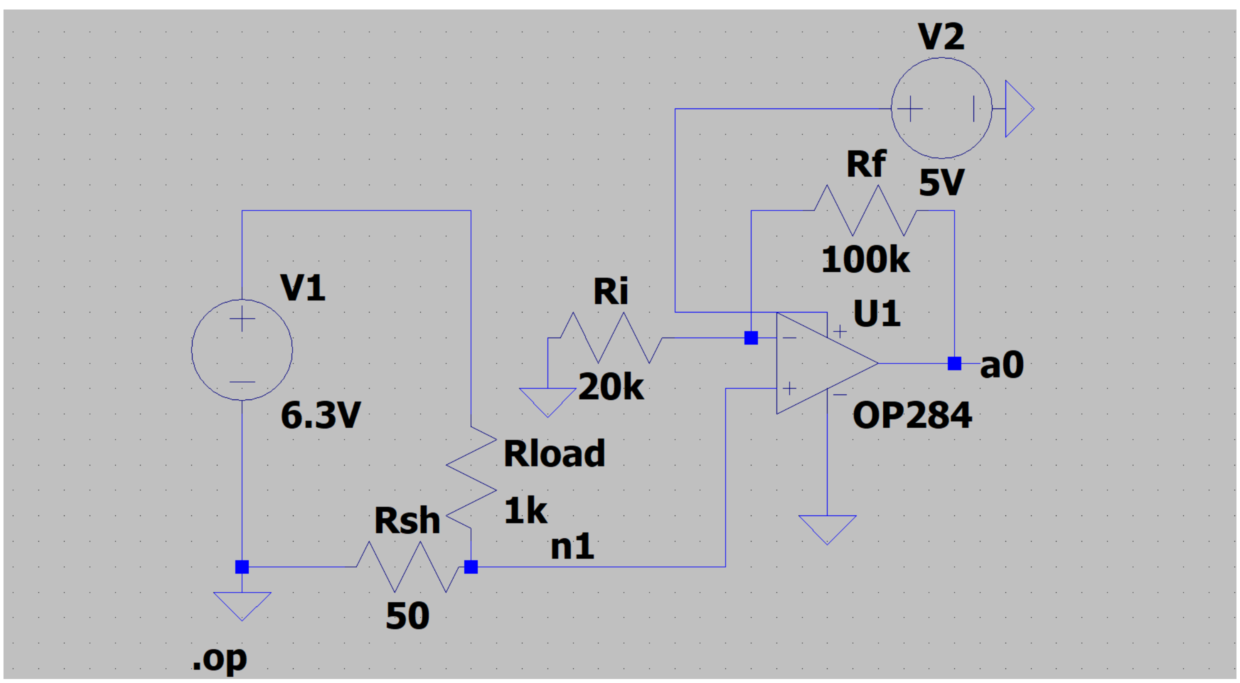
For the final project, an automated solar panel power meter was designed. The purpose of this project was to create a portable, user-friendly, and accurate device capable of providing digital readouts of voltage, current, and power output from solar panels. This project aimed to enhance the user experience by automating measurements, hence minimizing calculation errors. Criteria such as portability, ease of use and accuracy were kept in mind while designing this project. This project was made for mainly homeowners as well as technicians using Sparky Solar Panels. Portability was a key concern to ensure users could carry their devices around and operate them in various conditions. Furthermore, ease of use was important to ensure that anyone using the device could get the necessary measurements without having prior knowledge of the subject.

This project consisted of a voltage divider circuit and an operational amplifier (Op-Amp) circuit which were later combined. The voltage divider circuit consisted of a diode, three resistors namely R1, R2 and a load resistance. The purpose of this voltage divider circuit was to get two such resistor values that reduced the voltage received at pin A1 to be less than 5V.



This pin A1 was the analog pin in the arduino and was used to measure the Solar Panel voltage. Along with the constraint of voltage at A1 being less than 5V; cost, size and availability had to be considered as well. Through trial and error, we arrived at two resistor values: R1 = 20k ohms and R2= 100k ohms. The Arduino would read the analog voltage at pin A1, convert this analog value to a digital signal using its built-in ADC, and then multiply it by the voltage divider ratio. The code was used to calculate the value of voltage it was receiving, namely the Solar Panel Voltage. Furthermore, the circuit consisted of a single diode connected in series with the Solar Panel in order to prevent backflow of current.

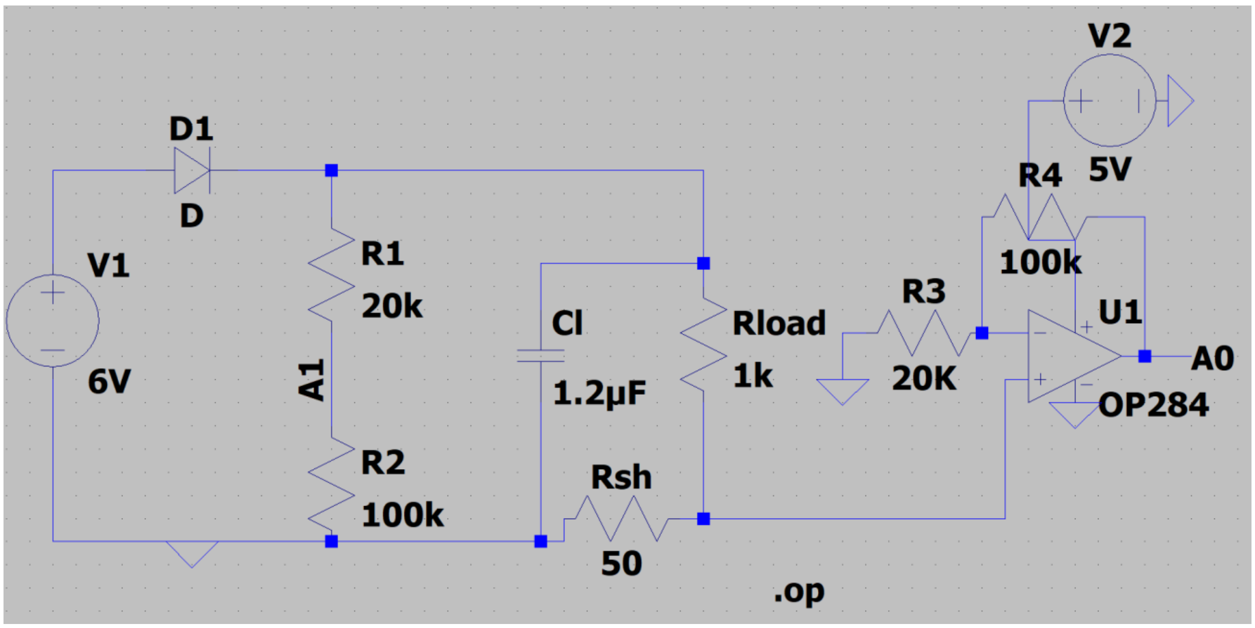
To further enhance the accuracy and reliability of voltage measurements, an operational amplifier (Op-Amp) circuit was integrated with the voltage divider. The Op-Amp was configured as a buffer, providing high input impedance and low output impedance. This setup ensured that the voltage divider's output was accurately transferred to the ADC without loading effects, preserving the integrity of the scaled voltage signal. By combining the voltage divider with the Op-Amp buffer, the design achieved precise and stable voltage measurements, which were crucial for the accurate calculation of the solar panel's power output.



The Op-Amp circuit was used to amplify the small voltage drop across a 50Ω shunt resistor, which was proportional to the current flowing through the solar panel.

Configured in a non-inverting mode, the Op-Amp provided a gain of G=1+Rf/Ri, where Rf=100k ohms and Ri=20k ohms, resulting in a gain of 6. This amplified voltage was read by the Arduino's ADC, which converted it into a digital value. The code accounted for the Op-Amp gain and shunt resistance to calculate the current. The calculated current, converted to milliamps, was then displayed on the LCD and printed to the serial monitor, enabling accurate and real-time current measurement.

Operationally, the Automated Solar Panel Power Meter functioned through a coordinated interaction of its components. Voltage and current sensors continuously monitored the solar panel's output, with the Arduino receiving analog signals from these sensors and converting them to digital data via the ADCs. The Arduino then calculated the power output using the formula P=V×I and sent the results to the LCD display, where users could view real-time measurements.



For this project the team had to determine the values of resistors for the Op-Amp and voltage divider circuits. For the voltage divider circuit, the criteria for choosing the resistors were as follows:

1) Voltage at pin A1 had to be less than 5V
2) Sooner Availability
3) Lower Cost
4) Smaller physical size

Three sets were given each consisting of resistors within different ranges.

Resistors	Cost	Physical Size	Max Operating Temp	Availability
Set 1 (1Ω-100Ω)	$1.00/each	3mm x 1 mm	155˚C	2-week delay
Set 2 (1kΩ - 100kΩ)	$1.00/each	4mm x 3mm	155˚C	Available now
Set 3 (200kΩ - 10MΩ)	$1.50/each	2mm x 2mm	135˚C	Available now

Set 2 was chosen for the voltage divider from which the values of R1 and R2 were determined (20k ohms and 100k ohms). Set 2 was chosen due it being available early and having a lower cost. However, it also consisted of physically bigger resistors. This criteria was traded off for the lower cost and sooner availability of the product. Furthermore, during the design of the Op-Amp circuit.

For this project, the team selected resistors for the op-amp circuit based on the criteria of high operating temperature, sooner availability, and lower cost. Three sets of resistors were provided, each with varying ranges and specifications.

Resistors	Cost	Physical Size	Max Operating Temp	Availability
Set 1 (1Ω-100Ω)	$1.00/each	3mm x 1 mm	155˚C	2-week delay
Set 2 (1kΩ - 100kΩ)	$2.00/each	4mm x 3mm	155˚C	Available now
Set 3 (200kΩ - 10MΩ)	$2.00/each	2mm x 2mm	135˚C	Available now

Set 2 (Ri=20k ohms and Rf=100k ohms) was chosen because it offered immediate availability and supported a higher maximum operating temperature. Although the resistors were slightly larger in physical size compared to Set 3, this was an acceptable trade-off given the importance of availability and temperature reliability for the product's performance. The chosen resistors ensured the op-amp circuit operated effectively within the required 0–5V range for the Arduino's ADC.

In the EEE 202 lab, the key lesson learned was that theoretical design does not yield the same results as physical design most of the time. Theoretical design helps in building the concept; however, the results are mostly ideal and do not account for real-world challenges. Physical design introduces these challenges, which in this lab ranged from thermal energy losses, damaged breadboards or Arduino's, as well as components being labeled incorrectly. This was one challenge encountered in almost every lab. Most of the time, components like resistors, capacitors, inductors etc. were labeled incorrectly. Due to this a habit of measuring everything before building a circuit was developed. Adding on, theoretical design serves as a reference for physical design and makes troubleshooting less time-consuming by providing a baseline for expected behavior. While theoretical design often yields immediate and precise results in simulations, physical design requires iterative testing and adjustments to address unforeseen issues. A few issues encountered were multimeters connected incorrectly, incorrect series/parallel connections, component overheating, shorting and diodes connected incorrectly. Encountering such errors lead to the development of a habit of meticulously reviewing every detail to minimize these errors.

There were quite a few things that went wrong during the building process of this project. While designing the voltage divider circuit, due to low knowledge of diodes, the diode was connected incorrectly and hence was blocking all inflow of current. Hence wrong results were obtained. Connecting the diode correctly gave the correct results. Furthermore, while simulating the circuit on TinkerCAD, few wrong connections were made due to TinkerCAD being different from LTSpice hence wrong results were obtained. Remaking and asking for assistance helped solve this issue. Additionally, due to the large number of components, incorrect connections were made quite a few times before the correct circuit was obtained. Checking the circuit thoroughly helped fix this issue.

If this design were scaled up for large solar panel systems, there are a few important environmental, technological, societal, and financial considerations to think about. Environmentally, larger systems would need a lot more space, which could mean clearing land. The panels and equipment would also need to handle extreme weather like high winds, rain, or heat, so durable, weatherproof materials would be necessary. Technologically, managing the increased energy from multiple panels would require better components and equipment so as to not cause damage. Additionally, integration to the power grid would also need to be foolproof. The system would also need to meet grid standards and support energy flow back to the grid. Societally, large-scale solar projects could possibly face pushback from people unaware about these technologies. Furthermore, its efficiency could also be questioned. Financially, scaling up would cost a large sum, but things like generating funds from investors and selling excess energy back to the grid could help make it more affordable.

Working on this project helped me develop several valuable skills that'll be very handy in the future. It enabled me to work with a team to design a product which gave me an experience similar to working professionally. This project helped me learn how to collaborate with the team, divide tasks to finish work quickly and also helped me learn how to describe everything I did in a report. I feel like my knowledge of how circuits work has increased by a lot due to this project. At the start, the circuit given in the manual and the code did not make any sense to me. I was in charge of simulating circuits on TinkerCAD and LTSpice, however not being able to understand the code led to me messing up quite a lot of times. However, spending time after the lab and asking my teammates and the TA cleared all the doubts I had. I slowly started realizing how each component worked as well as the code behind the simulations. Furthermore it increased my understanding of Op-Amps greatly since they hadn't been taught in class properly. Overall, working on this project was an invaluable experience and I feel like it would help me in the future.