SPS Chapter Research Award Proposal

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<th>Finding the sun: developing a Sun Sensor for use on a 1U CubeSat satellite</th>
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<td>$2000</td>
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Abstract

Rhodes college is getting closer to space. RHOK-SAT, a 1U CubeSat satellite, is about 18 months from launch. The project is currently focused on payload integration. A critical aspect of our payload is creating a sun sensor to help track the angle of the sun relative to the satellite.
Proposal Statement

Overview of Proposed Project

The scientific mission of the Rhodes College CubeSat is to test the impacts of radiation on novel solar cell technology in conjunction with the Photovoltaics and Materials Devices research group at the University of Oklahoma. The cells being developed, called perovskites, have shown increased efficiencies and incredible potential when compared with traditional types of solar cells. Perovskites show great promise for use in long-term and deep space missions due to their self-annealing properties. Their increased efficiency becomes important because they are able to generate power in darker conditions, like those in deep space. RHOK-SAT will be one of the first missions to test the performance of perovskites in a space environment, as well as one of the first to conduct in-orbit measurements on the cells.

An important component of the payload is a sun sensor. The sun sensor consists of a quad photodiode, aperture plate, and baffle tube. The baffle tube is used to restrict the field of view of the sensor to 35° in each direction from the normal axis of the diode to limit the amount of excess light and reflections from other objects. The aperture plate only allows light to pass through the center of the diode window creating an illuminated area smaller than the total active area of the four quadrants. As the position of the sun changes, the light spot will move across the quadrants. Both the baffle tube and the aperture plate need to be anodized and dyed black so that they do not reflect any stray light that would interfere with measurements. Given the differences between the voltages read by each quadrant, a measurement of the angle of the sun relative to the satellite can be found. Having this angle ensures that measurements of the cells are only taken when there is enough light to give useful data.

The RHOK-SAT team has worked to design a sun sensor using the photodiode, aperture plate, and baffle tube as well as designing a procedure to calibrate the sun sensor. The current laboratory setup has an OPR5911 quad photodiode sitting on a 2-axis calibration table and is hooked up to an Arduino with an LCD screen which displays the voltage read by each quadrant. The next step is to order blackened metal foils from a photo-etching company to use as aperture plates. An aluminum baffle tube has been designed but also needs to be manufactured. The current photodiode is not suitable for use in space, so TO-5 diodes will need to be purchased. Once the sun sensor has been assembled it can be exposed to a light source comparable to what it is expected to experience in orbit (AM0) and the calibration process can begin. The calibration process involves taking a series of voltage measurements at approximately every degree of vision the sensor assembly will experience. The voltage measurements will be taken from each quadrant (labelled A-D), and this will provide a framework for the significance of measurements taken in orbit.

This project aims to answer the question: What is the angle of the sun relative to the payload face of the RHOK-SAT satellite? It will provide the RHOK-SAT with a functioning and calibrated sun sensor. The goal of this project is to fully assemble and execute the design and procedure which have been developed by the RHOK-SAT team.

The CubeSat project is closely connected to the Rhodes chapter of SPS. Nearly all of the students involved in the RHOK-SAT team are members of SPS and several of the faculty act as advisors to the Rhodes chapter. SPS's mission of increasing accessibility and interest in physics is at the core of the RHOK-SAT project. Rhodes is a small liberal arts school without a formal engineering program, and RHOK-SAT is an undertaking by undergraduate students from a variety of majors.
Background for Proposed Project

This CubeSat will be ready for launch in June of 2023 with a scientific mission to test novel photovoltaic cells called perovskites. RHOK-SAT is a collaboration between RHodes College and the University of OKlahoma, who are developing and researching novel perovskite photovoltaic technology. Once in orbit, RHOK-SAT will study the effects of radiation on the degradation of perovskite cells as well as monitoring the impact of thermal cycling on the cells. RHOK-SAT will have a solar diode which functions as a sun sensor to measure the angle of the sun relative to the payload face of the satellite. The angle measurement will provide insight on illumination of the test cells and will help control when solar cell measurements are taken. The RHOK-SAT team has also done research into the process of calibration by reading an article from another collaborator. (1) This article detailed the process of using a TO-5 diode as a sun sensor and provided an idea of how to build the calibration table. There are also schematics on successful aperture plates and baffle tubes which helped the RHOK-SAT team develop designs. This article was integral to increasing team understanding of the sensor set up and function. The knowledge that RHOK-SAT gathers from this calibration will be what the photodiode measurements in space are based on.

Expected Results

The project aims to calibrate a TO-5 quad photodiode for use as a sun sensor. The setup includes a platform that can accurately change the angle of the diode relative to a stable light source. The setup currently has an Arduino microcontroller to take the measurements, and will have the baffle tube and aperture plate mounted onto the TO-5 diode. The tilting table and light source will calibrate the sun sensor to find the angle of the sun to the nearest 2 degrees, which is plenty for the RHOK-SAT’s needs. By using an Arduino microcontroller, code can be written and diode readings can be converted into voltage measurements. The LCD screen displays these voltage measurements so that they are easy to record.

Voltage measurements will be taken from each of the four quadrants, marked “A”, “B”, “C”, and “D” at every two degrees of rotation. Taking the proportion of each quadrant to one another and knowing the angle will provide an understanding for what the diode’s voltage measurements will mean once the satellite is in orbit.
Design:
The desired sun sensor consists of a TO-5 quad photodiode, a circular aperture plate with a square hole in the center, and a baffle tube to restrict the field of view of the diode. The aperture plate is made from blackened photo-etched metal foil and is bonded to the top glass of the diode restricting sunlight to pass only through the square hole.

The calibration table is constructed using Thorlabs optical table equipment. The pitch and roll axes are each measured by a 2° manual rotation stage. The rotation stages have laser-engraved segments incremented at 2°. A light source sits fixed directly above the photodiode to illuminate the active areas.

Methods:
As light shines on the diode, it will illuminate the quadrants in a square shape. By controlling the angle at which the light shines on the diode and comparing the voltages produced by the quadrants, the satellite can be programmed to recognize these specific measurements to calculate sun angle while in flight. The computer can then decide when the satellite is pointing at the sun and can trigger a test on the solar cells.

The angle the light source makes with the diode can be determined by comparing the relative outputs from each of the quadrants. The horizontal and vertical positions of the light spot on the diode can be determined by equations (1) and (2) respectively.  

\[
x = \frac{V(a) + V(d)}{V(b) + V(c)} - x_0 \quad (1)
\]

\[
y = \frac{V(a) + V(b)}{V(c) + V(d)} - y_0 \quad (2)
\]

The ratios, x and y, are calculated by comparing the voltages, V, of quadrants a, b, c, and d. The ratios are adjusted by the offset correction values, h and g, determined through the calibration process.

Each diode will vary slightly due to small variations in aperture placement and quadrant manufacturing. This can be accounted for by calibrating the diode. Setting the exact angle of light shining on the diode will give baseline measurements, which can be set as baselines for the computer’s in-orbit calculations. Calibration is also useful for finding the sensor’s maximum field of view. The baffle tube is designed to restrict the field of view to 35° in each direction to limit the number of low light and low angle measurements. This will allow the computer to be programmed to recognize when the sun has entered the field of view.

Procedure:
- Assemble the sun sensor.
  - Using a microscope, center the aperture plate over the top of the TO-5 photodiode and bond the two with a small amount of Scotch-Weld 2216 epoxy.
  - Place the baffle tube over the can and bond it in place.
  - Solder the photodiode to its PCB.
  - Mount the diode-PCB assembly to the base payload board. This is how the diode will sit in the satellite.
- Level the calibration table using a digital level.
- Secure the sun sensor assembly to the table ensuring that the photodiode is centered under the light source.
• The first calibration measurement will be taken with the light source perpendicular to the diode face.
• Record voltage measurements from each quadrant and calculate the center \((x, y)\) of the illuminated section using:
  \[ x_0 = \frac{V(a) + V(d)}{V(b) + V(c)} \]  \(3\)
  \[ y_0 = \frac{V(a) + V(b)}{V(c) + V(d)} \]  \(4\)
• \(x_0\) and \(y_0\) will be set as \(h\) and \(g\) respectively.
• Using these values and equations (1) and (2), the computer can be programmed to account for the aperture plate offset and accurately determine the angle of illumination.
• Take voltage measurements at varying pitch and roll values to confirm calculations are correct.
• Take voltage measurements at the edges of the field of view as well as just past it.

![Figure [3]; Sun sensor assembly mounted to the payload board](image)

Plan for Carrying Out Proposed Project

The plan for the proposed project spans approximately a semester and a summer. The required equipment is in stock or can be shipped from the manufacturer with minimal lead time. The project involves SPS members with oversight from physics department faculty and staff.

SPS students leading sun sensor calibration are as follows:

• Ben Wilson, a fourth-year physics and computer science major. Ben is a student Co-Leader of the RHOK-SAT project and the team lead for mechanical integration and design. He is also the co-founder of the Aerospace Engineering Club at Rhodes College. Ben’s work on the project has contributed to the design and implementation of the RHOK-SAT custom payload, the programming of the Arduino microcontroller for the calibration of the photodiode, and the construction of the calibration table.
• Olivia Kaufmann, a third-year physics major and SPS Vice President. Olivia is the team lead for the characterization of experimental photovoltaic technology using a dedicated microcontroller. Her work includes the integration of payload microcontrollers with RHOK-SAT’s on-board computer. Olivia, previously the SPS On Campus Programmer, has organized panels of professionals in the aerospace industry for students at Rhodes.
• Jess Hamer, a third-year physics major and SPS Demo Officer. Jess is the team lead for the design and implementation of electronic hardware. Jess’s work includes the design of all custom circuit boards for the project.
• Giuliana Hofheins, a fourth-year physics major and SPS President. Giuliana is a student Co-Leader of the RHOK-SAT project and co-founder of the Aerospace Engineering Club at Rhodes. Her work on the project includes the programming of Arduino and Raspberry Pi microcontrollers for payload development and radio communications.
• Other SPS members working on the RHOK-SAT project include Jo Boff (Neuroscience ‘22), Jose Pastrana (Computer Science ’20), Damian Nguyen (Physics ’25), Kairos Wong (Physics ’24), Anas Matar (Computer Science ’25), and Aditya Pudaruth (Computer Science ’24) along with a growing interest amongst first year students.

Physics faculty members involved with the project include:
• Dr. Bentley Burnham, Assistant Professor of Physics and RHOK-SAT project manager. Dr. Burnham oversees the progression of the project and handles administrative communications between the Rhodes team, the University of Oklahoma, NASA and outside collaborators.
• Dr. Ann Viano, Sigma Pi Sigma (SPS) chapter advisor and Physics faculty member. Dr. Viano oversees the design and integration of electronics for the project as well as the educational outreach portion of the project.
• Dr. Brent Hoffmeister, SPS chapter advisor and Physics faculty member.

RHOK-SAT payload development has a dedicated laboratory on the fifth floor of Rhodes Tower. Calibration of the sun sensor will take place in the optics laboratory of Rhodes Tower. These spaces have all necessary equipment, computers, and resources to effectively carry out the proposed project.

Project Timeline

• Jan 2022: We will place orders for all the required materials, acquire the appropriate light source, and finish writing code for the Arduino board.
• Feb 2022: Once all materials have arrived, we will finish the assembly of the calibration system, make preliminary measurements using an Arduino microcontroller, and begin translating code into language for use with a dedicated microcontroller while in flight.
• March 2022: We will integrate custom designed printed circuit boards (PCBs), a dedicated microcontroller, and the assembled TO-5 sensor into calibration set up. We will then take measurements every two degrees for the entire field of view of the sun sensor.
• April 2022: We will perform calculations to determine what voltage values correspond to what angles and understand the offset of the aperture plate.
• May 2022: Integrating this information, we will update our flight software and write the interim report.
• June 2022: We will update microcontroller code for the dedicated sun sensor microcontroller, and continue integration into flight software.
• July 2022: Primary summer work will include the assembly of a fully integrated flight model, ready for space. To accomplish this, we will begin integrating the sun sensor set up into the flight model of the CubeSat.
• August 2022: During the summer we will finish integrating the sun sensor and payload into the flight model.
September 2022: As the semester begins, we will make the final touches before sending the flight model for environmental engineering.

October 2022 - Dec 2022: The CubeSat will undergo Environmental testing and we will write the SPS final report.

**Budget Justification**

Each component of the sun sensor assembly needs to be bought or manufactured, and then assembled. Despite the satellite only having one sun sensor, it is important to have multiple calibrated sensors for testing and integration into both the engineering model and flight model of the satellite. Once a sun sensor is assembled individual parts cannot be interchanged. A whole new assembly must be mounted and calibrated if something fails. Before launch the satellite will undergo extensive testing to ensure it can survive space. The team must be prepared for parts to fail during testing and have replacement sun sensor assemblies readily on hand.

Each component of the assembly must be adjusted in some manner. The baffle tube needs to be dyed black and anodized to ensure no stray light gets reflected into the tube and impacts the measurements made. The aperture plate must be attached to the top of the TO-5 with epoxy (Scotch-Weld 2216). The PCB holding the diode must be mounted to the calibration table and levelled with precision. To level the top of the sensor with the face of the CubeSat, it must be on a raised PCB which requires ordering its own board, board-to-board connectors, and PCB standoffs. All assembly will be completed by students involved in the project, and involve a degree of trial and error. To account for the uncertain nature of the assembly, it is important to have several sets of components on hand. In addition to the complexity and precision required to assemble the components, many of them are quite fragile (Aperture foils are 0.005” thick) so being prepared for error when attaching them is critical. Aperture plates have a minimum order of one sheet (100 foils).

In addition to the complexity that comes with the nature of a calibration project, there are more stringent requirements which must be met because this is being assembled for use in space. All of the materials involved in the assembly must meet the NASA outgassing requirements and pass vacuum pressure tests. These extra requirements make every step of the process more expensive than a normal calibration.

Any additional costs associated with the calibration process will be covered by the Rhodes College Department of Physics and the CubeSat program budget.
Bibliography


-(3) Faizullin, Dmytro. “Improvement of Analog Sun Sensor Accuracy and Data Processing For Sun Vector Determination.” Space Dynamics Laboratory, Department of Mechanical and Control Engineering, Kyushu Institute of Technology, August 2018, https://core.ac.uk/download/pdf/160822684.pdf