Component-Level Photodiode Testing Procedure

Initial test setup and procedure for photodiodes

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1.0 Purpose

The purpose of this test is to verify that the photodiodes are functioning and evaluate their performance at a component level. The test will verify the directional sensitivity characteristics of the photodiodes as well as the change in output current related to the intensity of the light incident on the photodiode. This will verify the range of angles over which the photodiode behaves according to Lambert's Cosine Law, and determine whether the given half angle is reliable.

2.0 OSRAM SFH 2430 Silicon Photodiode Parameters

Table 1 below lists the key electrical characteristics of the SFH 2430 photodiode, and Figure 1 shows the directional sensitivity characteristics. All of this data was provided by the manufacturer.

Parameter	Symbol	Values	Unit
Operating Temperature Range	T_{op}	-40…100	°C
Reverse Voltage	V_R	6	V
Total Power Dissipation	P_{tot}	150	mW
Spectral Sensitivity	S	6.3 (≥ 5)	nA/Ix
Radiant Sensitive Area	A	7.02	mm^2
Half Angle	φ	+- 60	°
Dark Current	I_R	0.1 (≤ 5)	nA
Short-circuit Current	I_{SC}	6.1	µA
Rise and Fall Time	t_r, t_f	200	µs

Table 1: OSRAM SFH 2430 Photodiode Electrical Characteristics

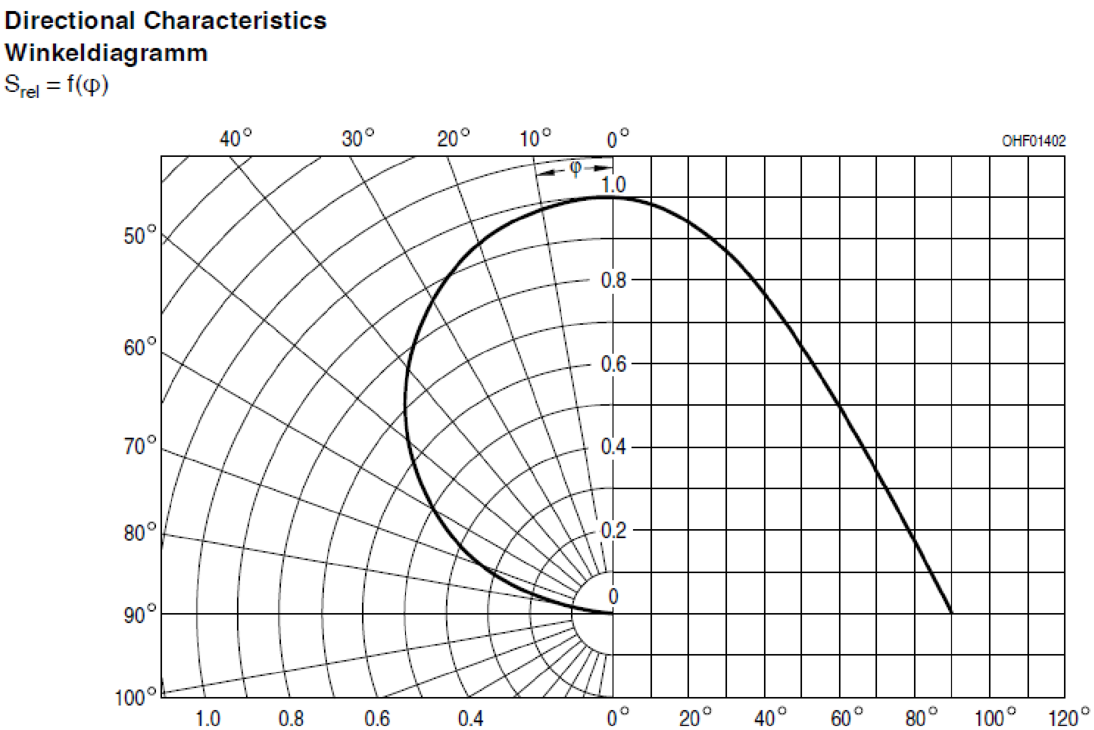


Figure 1: OSRAM SFH 2430 Photodiode Directional Sensitivity Characteristics

3.0 Equipment

3.1 Equipment List

The equipment required for the component-level test is as follows:

- SFH 2430 Photodiode
- Controlled Voltage Source
- 10 kΩ Resistor
- High Precision Voltmeter
- LED parabolic reflecting lamp
- Circuit Wiring Components
- Lens Mount with focus adjustor
- Light Box with Aperture
- Turntable
- Photodiode Mount
- Angular Measurement Mat

3.2 Resistor Selection

The output voltage of the photodiode is directly proportional to the generated photocurrent and also the load resistance. In this component test, the angular response depends on only relative values, so the load resistance does not need to be any certain value in particular, as long as it remains the same throughout the testing. However, it is important to make sure that the resistor value is not too large so that it does not impact the reverse bias on the diode. The resistor used in flight will depend on the method used in measuring voltage, since we need to ensure that the voltage does not exceed what the boards are capable of measuring. For the first attempt this component level test, a resistor of 10 kΩ was used.

3.3 Light Selection

In order to come up with a low cost light source which we will use to mimic the sun, a halogen flashlight, an LED lamp with a parabolic reflector, and a laser pointer were considered. Desirable features include a wavelength distribution that closely matches the sun, a light source with a solid angle of approximately 0.5 degrees, and light rays that are as straight as possible, and constant luminous intensity with respect to the angle. A xenon-arc lamp would best imitate solar light, but is prohibitively expensive for our purpose. A halogen lamp would have a continuous wavelength distribution, but parabolic reflectors are not commonly found. Flashlights of any variety were ruled out after initial tests revealed a slow decrease in power over time as the battery drained. The first testing attempt used an inexpensive laser that would not cover the surface of the photodiode in its entirety, and produced an inexplicable peak current at over 15 degrees from the normal plane. Finally, an LED lamp with a 20-degree parabolic reflector was chosen. By keeping the diffraction cap on and placing the lamp in a box, we were able to use an aperture of controlled size, which could be treated as a point source.

3.4 Lens Selection

The light housing provided a controlled light source, but did not provide collimated light. To collimate the light, a plano-convex lens or a bi-convex lens could be placed in such a way that the aperture point source would be at a distance equal to the focal length from the lens. This would produce straight light rays similar to a projector, with the focus at infinity. A plano-convex lens would be preferable to reduce chromatic aberration from the LED, which emits three peak wavelengths of light that combine to produce white light. These three wavelengths all have different indices of refraction, which separate the light into rings when passing through a lens. Since the light is effectively refracted twice as much in a bi-convex lens, the chromatic aberration would be exacerbated by its use. Nonetheless, a low grade bi-convex lens, normally used as a magnifier for soldering, was chosen as a collimator based exclusively upon its immediate availability.

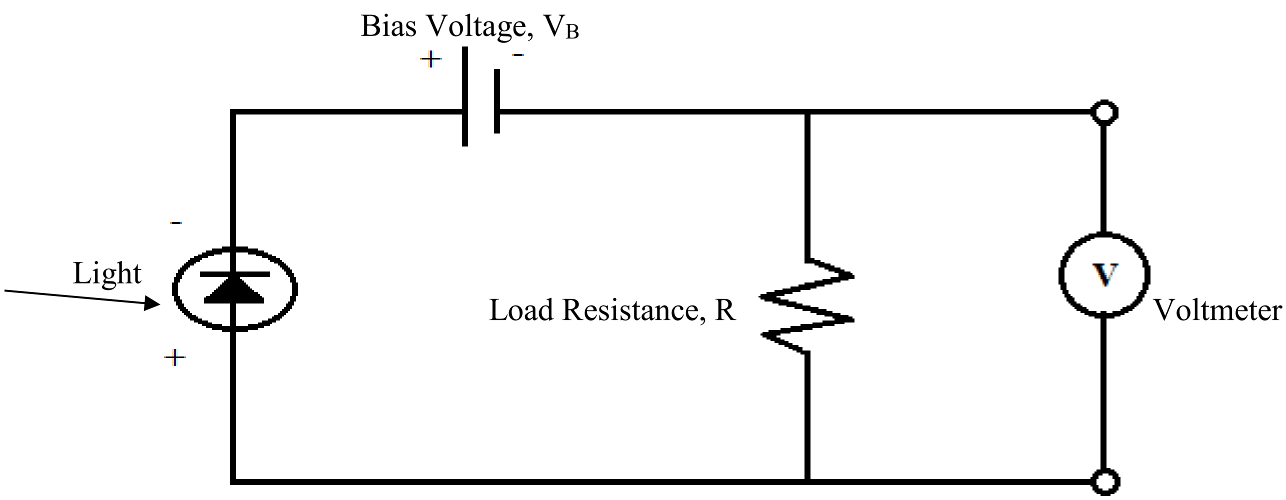
4.0 Test Procedures

4.1 Photodiode Circuit Setup

Figure 2 below shows the circuit setup for the photodiode component level test. To run the photodiode in photoconductive mode, a reverse bias voltage is applied. This ensures improves the linearity of response to varying intensity of light, and gives the fastest response time of the device. This circuit is a simplified version of how the photodiode will be applied on the spacecraft, with bias voltage coming from the internal power systems.

The original plan was to test the photodiode on a PCB with the same setup as the final flight setup, and read the voltage values off of the ADC. However, after ordering a receiving the photodiode PCBs, an error was discovered in the design. To save time, the board was modified so that it operated as a very simple circuit similar to that shown in figure 2, and the voltage measurements were taken with a high precision multimeter. A bias voltage of 5 Volts was applied to the circuit, and the resistor was 10 kΩ.

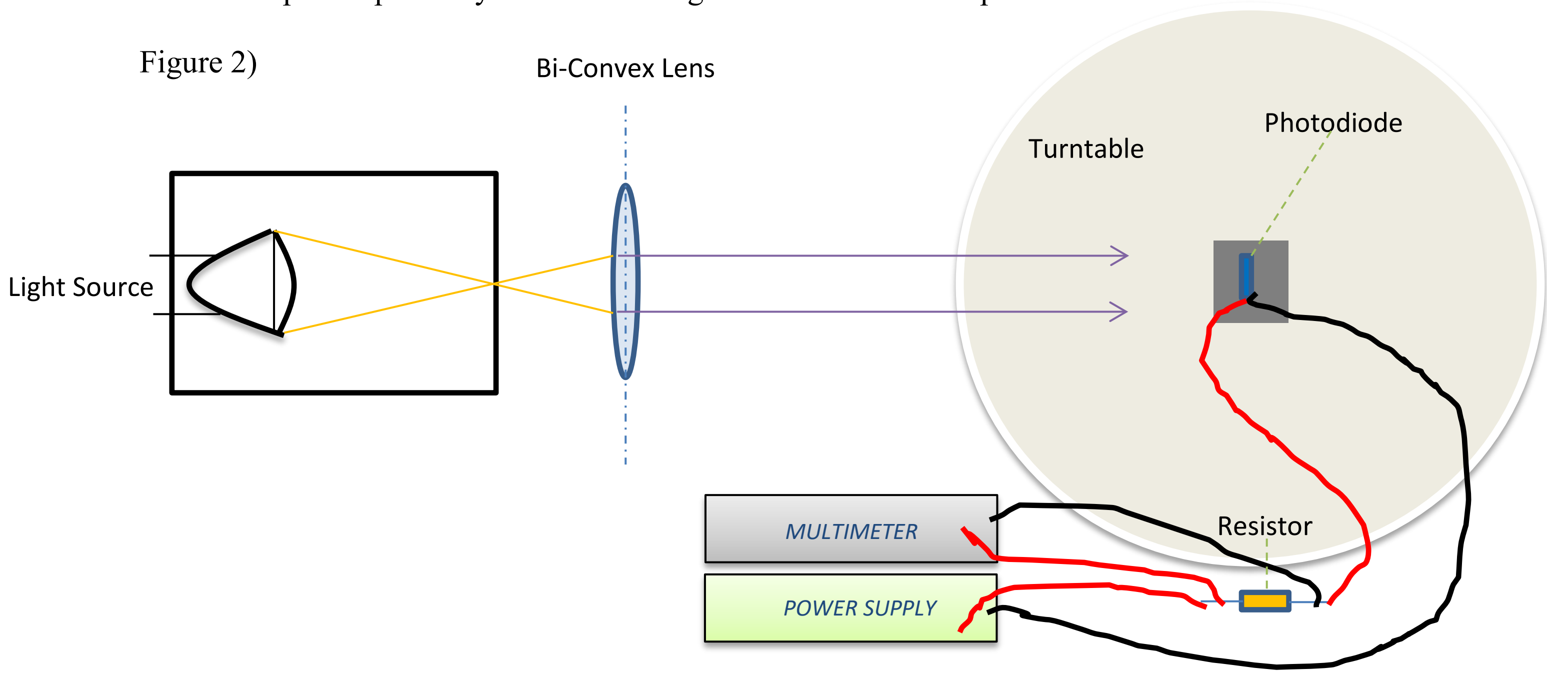
Figure 1)



4.2 Testing Environment Setup

The photodiode board was clamped to a stand which was carefully designed from metal pieces from the S3FL Lab. This setup requires some patience since the photodiode needs to be centered by hand. However, once in place it is very sturdy and it is screwed down to the turntable so it stays in place. This stand, harnessed to the turntable, is shown below in figure 3. Underneath the turntable is a sheet of paper with angles labeled from 0 to 180 degrees in increments of 5 degrees. The turntable was placed an arbitrary distance of approximately 18 inches from the lens, which was placed precisely at the focal length distance from the aperture.

Figure 2)



The center point of the lamp, the box aperture, the center of the lens, and the photodiode were all placed at the same height to produce a symmetrical distribution of light passing through the lens onto the photodiode. Before the photodiode was placed on the angular measurement mat, the lens had to be focused to project the light. The diameter of the projected light was measures at a distance of 6 inches from the lens, and again at 10 feet from the lens. Both distances were arbitrary, but the purpose was to ensure the circular pattern was not expanding or contracting with distance from the lens. Once the lens was focused, the turntable was placed on the angular measurement mat and the circuit was setup as depicted in Figure 2 below. The room was blacked out, and there was a barrier placed in front of the multimeter and power supply to limit the interference of ambient light coming from the digital display.

Before recording measurements every 5 degrees, the position of the photodiode was adjusted though the photodiode mount such that the peak current was produced at 0 degrees from the light source. This was done to limit the offset error produced in the data, since the peak current should theoretically be produced when normal to the light source.

Image 1: Indoor Testing setup without blocking ambient light

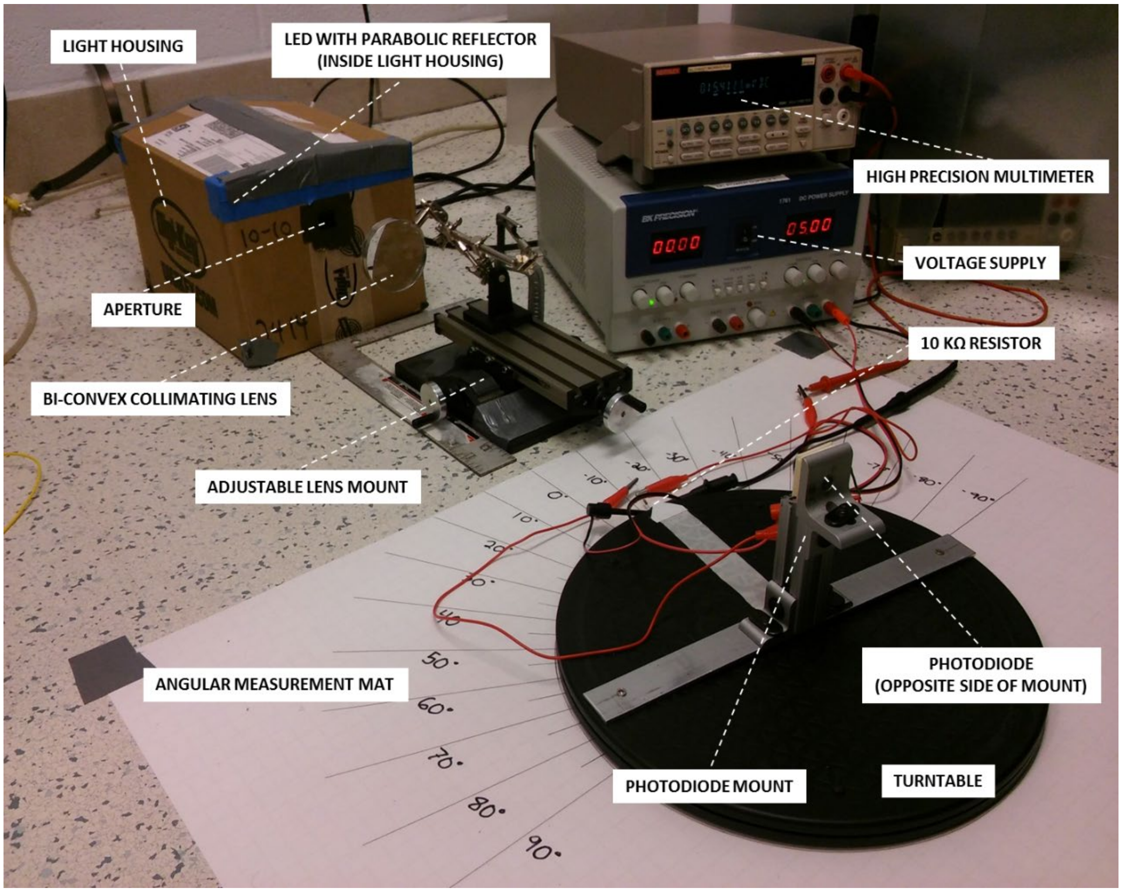
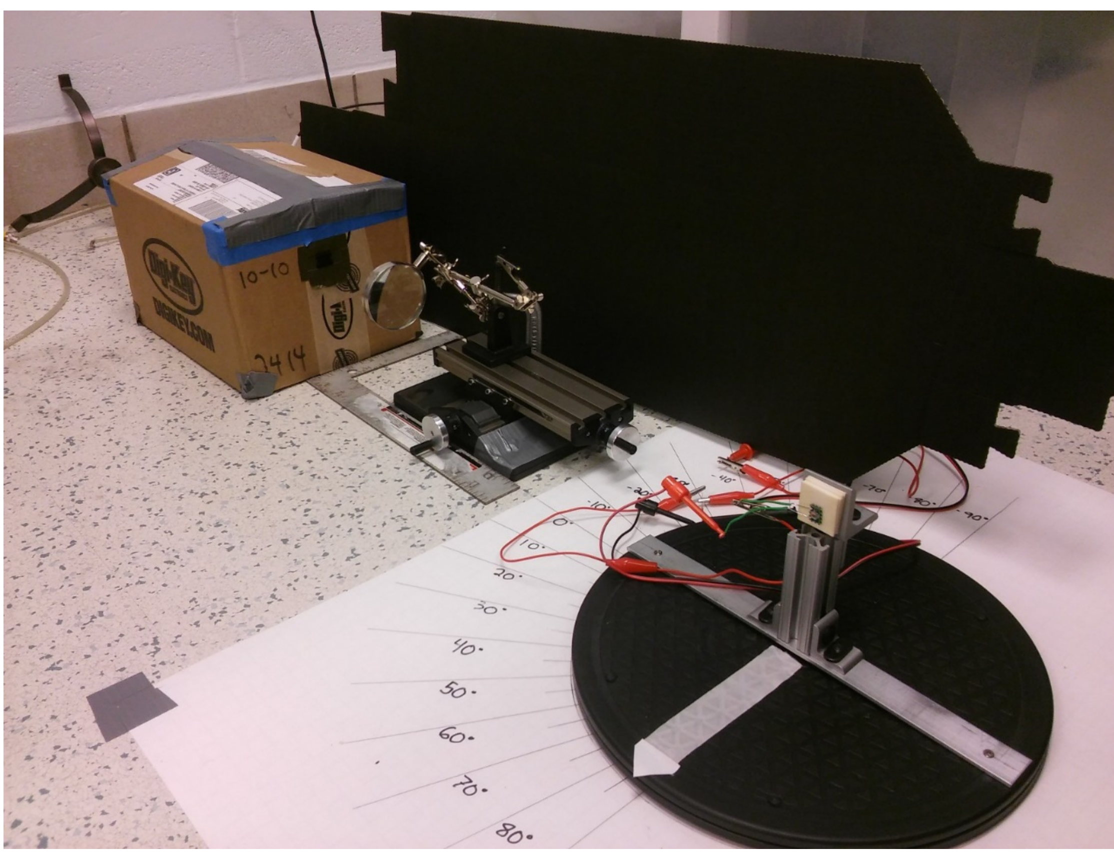


Image 2: Testing setup with ambient light blocking



5.0 Collected Data

5.1 Indoor Testing of Photodiode 2

The indoor photodiode testing produced results which conflicted with the data sheet provided by the manufacturer. The testing data for photodiode number 2 and 3 is shown below in figures U and U2, along with the theoretical data from Lambert's Cosine Law and the data sheet provided by the manufacturer.

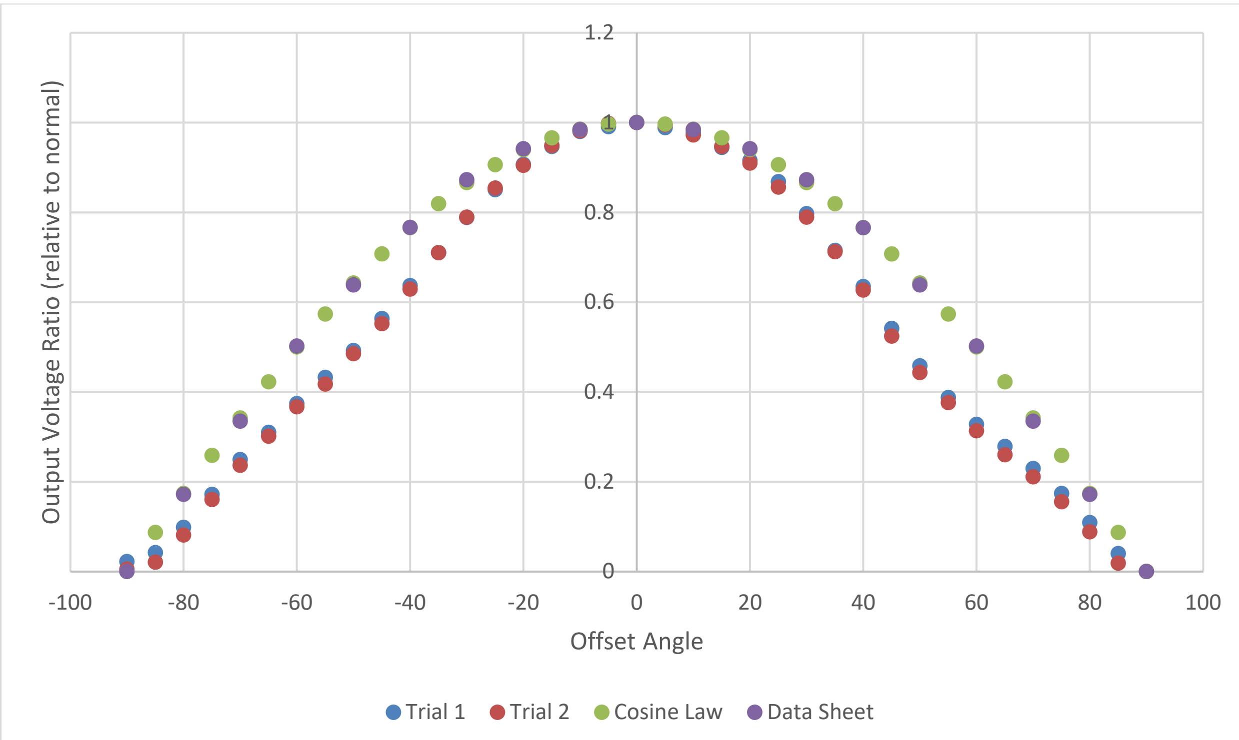


Figure U: Indoor Aperture Box Testing Data for Photodiode 2

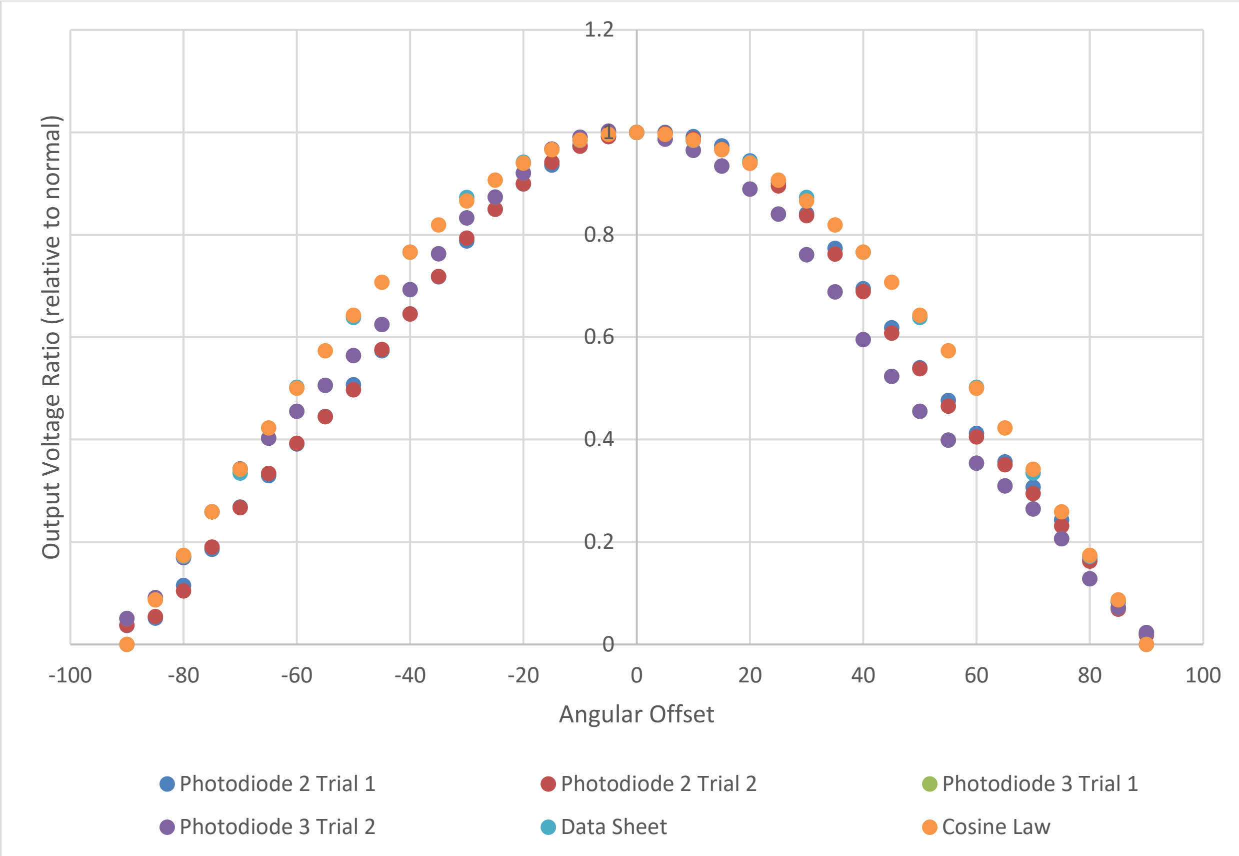


Figure U2: Indoor Aperture Box Testing for Photodiodes 2 and 3

It is clear in the data that there is a large discrepancy in the range of offset angles from about 20 to 60 degrees especially. This is true in both rotation directions. The theoretical data and the data collected do not match, and are offset by as much as nearly 15 degrees at times, which would be detrimental to our attitude determination if carried through. The tests of photodiode 1 and 3 yield almost identical data. Although it would be possible to find a fit for this data and use it in our attitude determination scheme, the discrepancy between manufacturer specifications and data collected is, at best, very concerning.

5.2 Outdoor Testing

In addition to the indoor dark room testing with the light box and aperture, the photodiode was tested outside on a clear day in order to test general behavior in an environment with the same light source the spacecraft will encounter in flight. Even with some vast differences in setting from LEO, this test helped us understand how the photodiode acts in the face of the actual sun, as opposed to much weaker light sources. In order to do an angular test, the photodiode, attached on the turntable and mount, was moved into the sun. The turntable was then adjusted so that the 0˚ reading occurred at the maximum possible output voltage. Once this was set, the turntable was rotated from -90˚ to 90˚ for trial 1, and from 90˚ to -90˚ for trial 2. The voltage drop over the resistor during this testing was from 0.4V to 4.2V, which is a very nice and large range compared to what we experienced in the indoor testing. The photodiode outdoor testing setup is essentially the same as the indoor setup, but placed on a cart and using the sun as the light source as supposed to the box with aperture. The cart with setup is show in figure V and W below.

Figure V: Outdoor Photodiode Testing Setup, Including Sun in Distance

Figure W: Outdoor Testing Cart in Sun

Clearly, this testing environment was lacking a lot of control. The testing was done on a sunny day, but any impact of the atmosphere on the light was neglected, as well as any impact of surroundings on the ground which could potentially be reflecting light. The sun was also at an angle to the photodiode during the testing, since the mount holds the photodiode normal to the ground, and the testing was performed at 2:30 PM. Additionally, the testing was carried out over a span of around 30 minutes, which is sufficient time for the sun to move, likely accounting for the constant leftward shift from trial 1 to trial 2 on the graph of the data shown below in figure X. Despite the lack of control in this test, the data did show that with the sun as a light source, there is no longer the deterioration of the output voltage ratio in the range of 20-60˚ of offset which was found in the indoor testing.

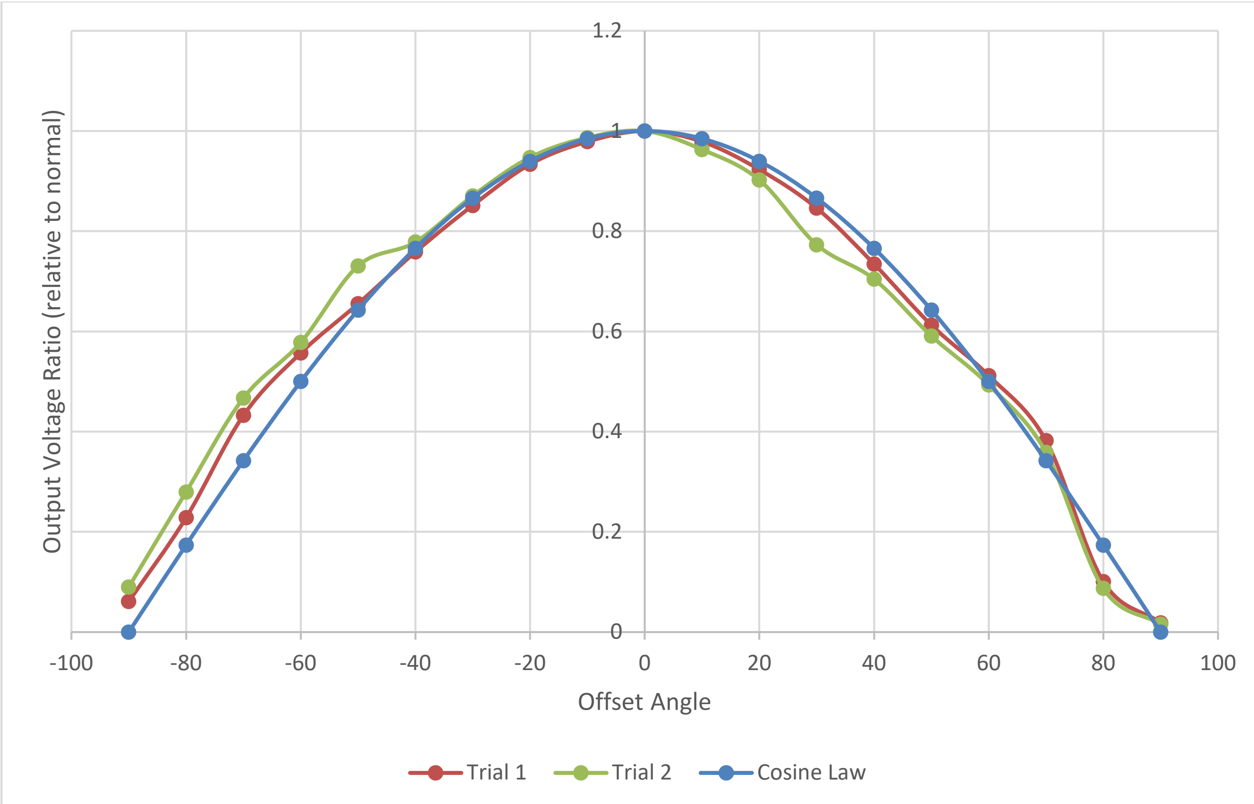


Figure X: Outdoor Testing Data for Photodiode 3

Figure 5

5.3 Indoor Testing Using Oriel 150W Solar Simulator

The University of Michigan has a solar simulator located in EECS 1322, and we were able to get access to it for about 90 minutes by reaching out to the MSE department who was using it at the time. We were able to replicate the same experiment that we had done for the previous indoor experiment with a few major differences to mitigate error. Firstly, the light source was an arc-xenon lamp that was designed to mimic the wavelength distribution, and therefore energy, of solar light. The lens used to collimate the light was a spherical, plano-convex lens which was clamped to an optics table at the same height as the clamped fiber optic cable coming from the solar simulator. The turntable and the circuit setup remained identical, as was the testing procedure. This was by far the most controlled of the four experiments, but was limited by the small window of time we had access to the equipment. Ideally, we would have liked to test at least three photodiodes under these conditions to verify the results. The results are shown below.

Oriel 150W Solar Simulator

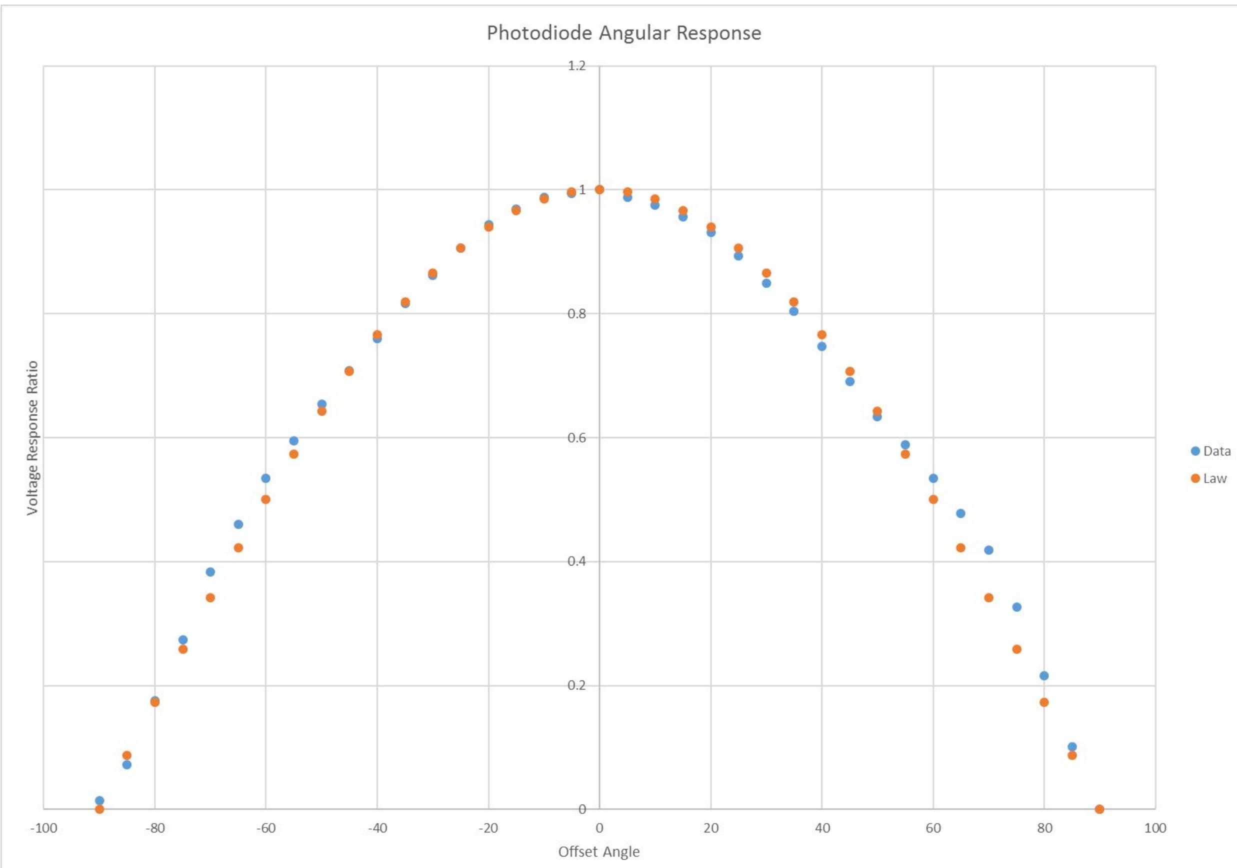


Figure Y: Solar Simulator Testing for Photodiode 2

6.0 Results and Observations

The testing done using the Oriel 150W Solar Simulator and plano-convex spherical lens shows a very close correlation to Lambert's Cosine Law between -60 degrees and 60 degrees, matching the manufacturer's specifications. This was the result of a single test of a single photodiode, but it was performed under a far more controlled circumstance than the previous attempts. NASA tested this model of photodiode at the Glenn Research Center and found it to follow Lambert's Cosine Law from -70 to 70 degrees, however we were not able to replicate those results.

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