

Fresnel Lens Concentrator Photovoltaic System for Deep Space Power

Generation at Asteroid 16 Psyche

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Sponsor: NASA Psyche Mission

Motivation

The NASA Psyche mission targets asteroid 16 Psyche in the main asteroid belt at approximately 2.5–3.3 AU from the Sun, where solar irradiance is greatly reduced compared to Earth. Traditional photovoltaic systems experience a significant drop in power output at these distances. A Fresnel lens concentrator offers a potential way to increase irradiance on a photovoltaic (PV) cell without substantially increasing system mass or area.

Objective

Design, build, and test a Fresnel lens based photovoltaic system that increases PV cell power output under reduced irradiance conditions representative of the 16 Psyche orbital range, and evaluate its potential for deep space solar power applications.

Experimental Setup

Constructed a laboratory test setup using:

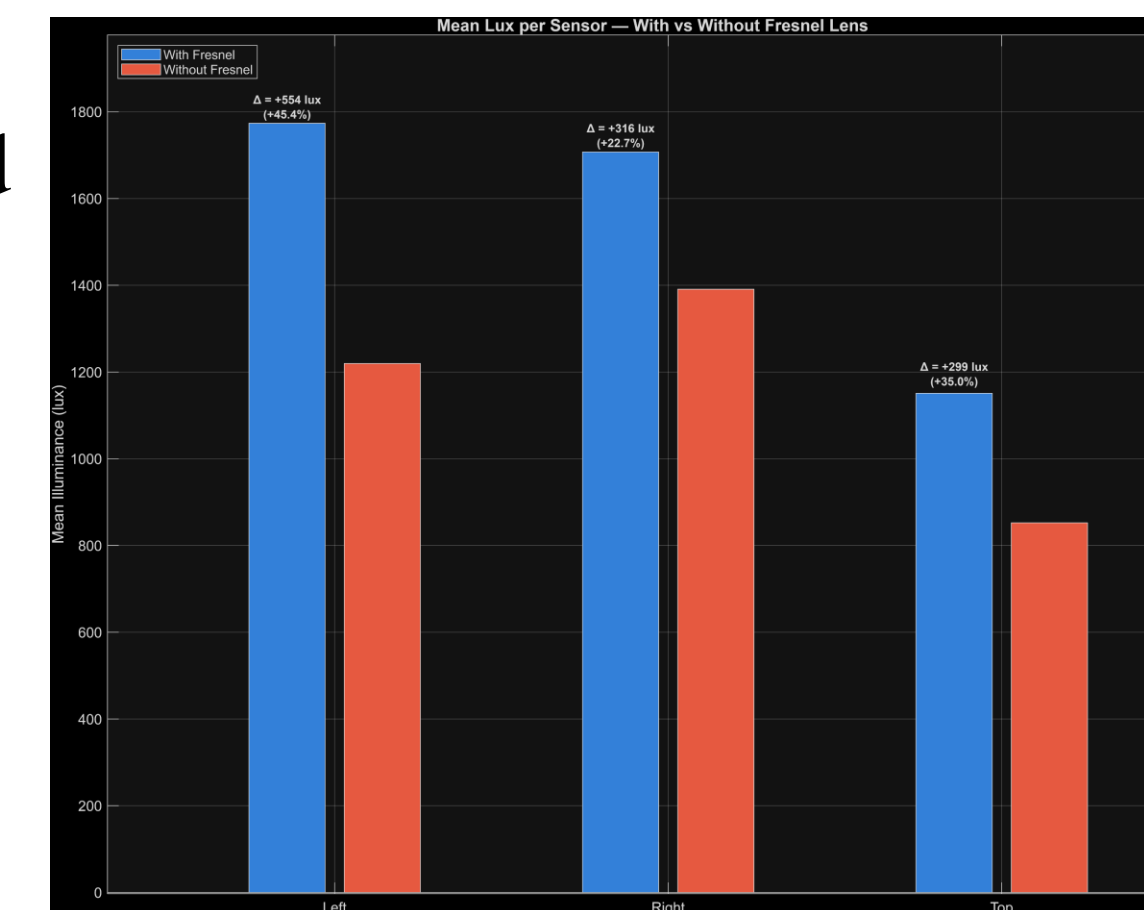
- Bridgelux COB LED light source
- Mean Well LDD-700L drivers
- Fresnel lens concentrator
- Photovoltaic cell

- Arduino based data acquisition system
- Light-tight enclosure with aperture/diffuser system
- Measured lux at multiple sensor positions (left, right, top) with and without the Fresnel lens.
- Swept PWM steps to evaluate stability and illumination behavior.
- Extrapolated results to heliocentric distances corresponding to 16 Psyche's orbit.

Results

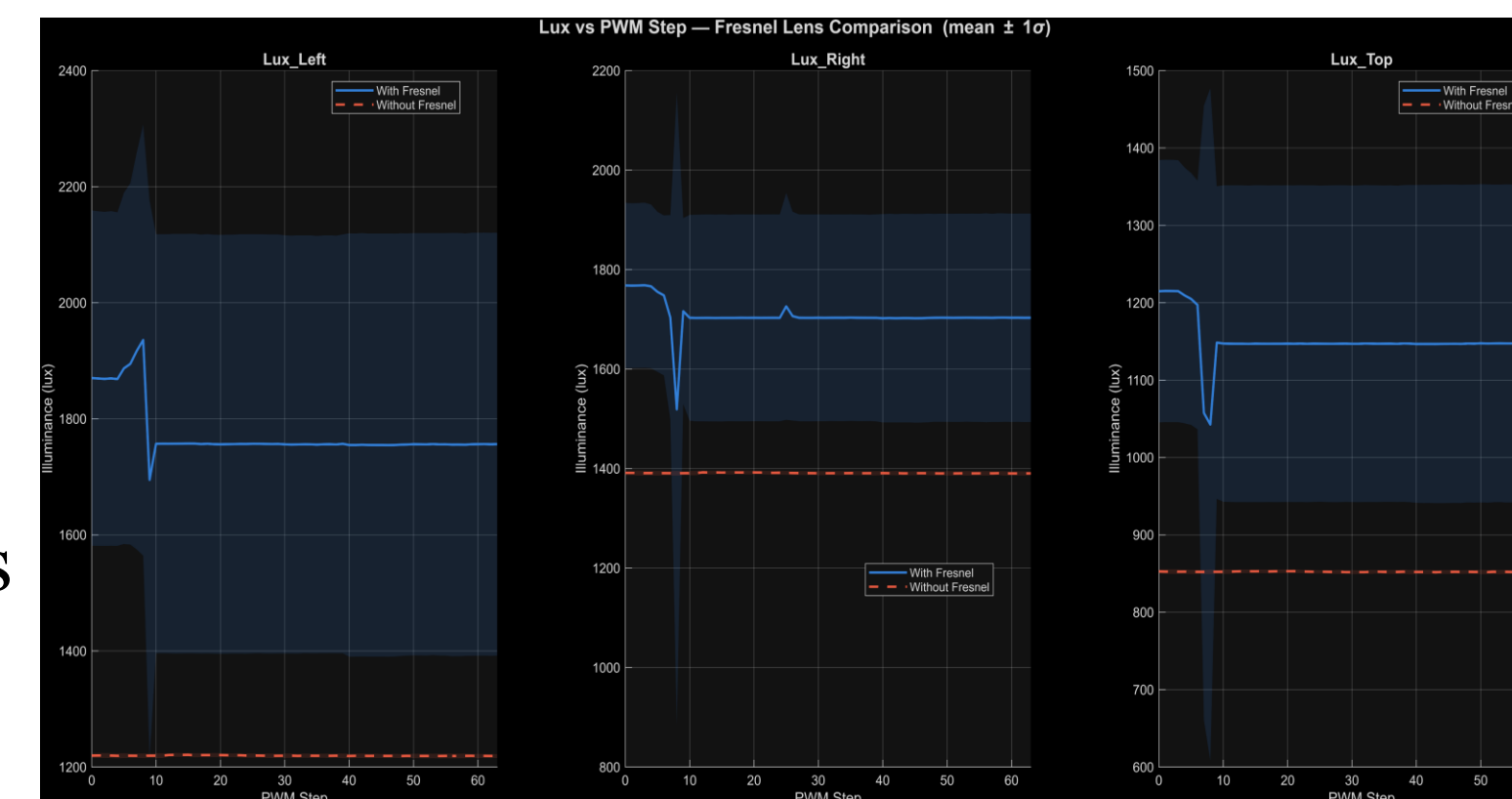
Mean Lux per Sensor (With vs Without Fresnel):

- The largest gain was measured at the left sensor with an increase of about 554 lux (+45.4%).
- The right and top sensors also showed strong improvement, with gains of about 316 lux (+22.7%) and 299 lux (+35.0%).



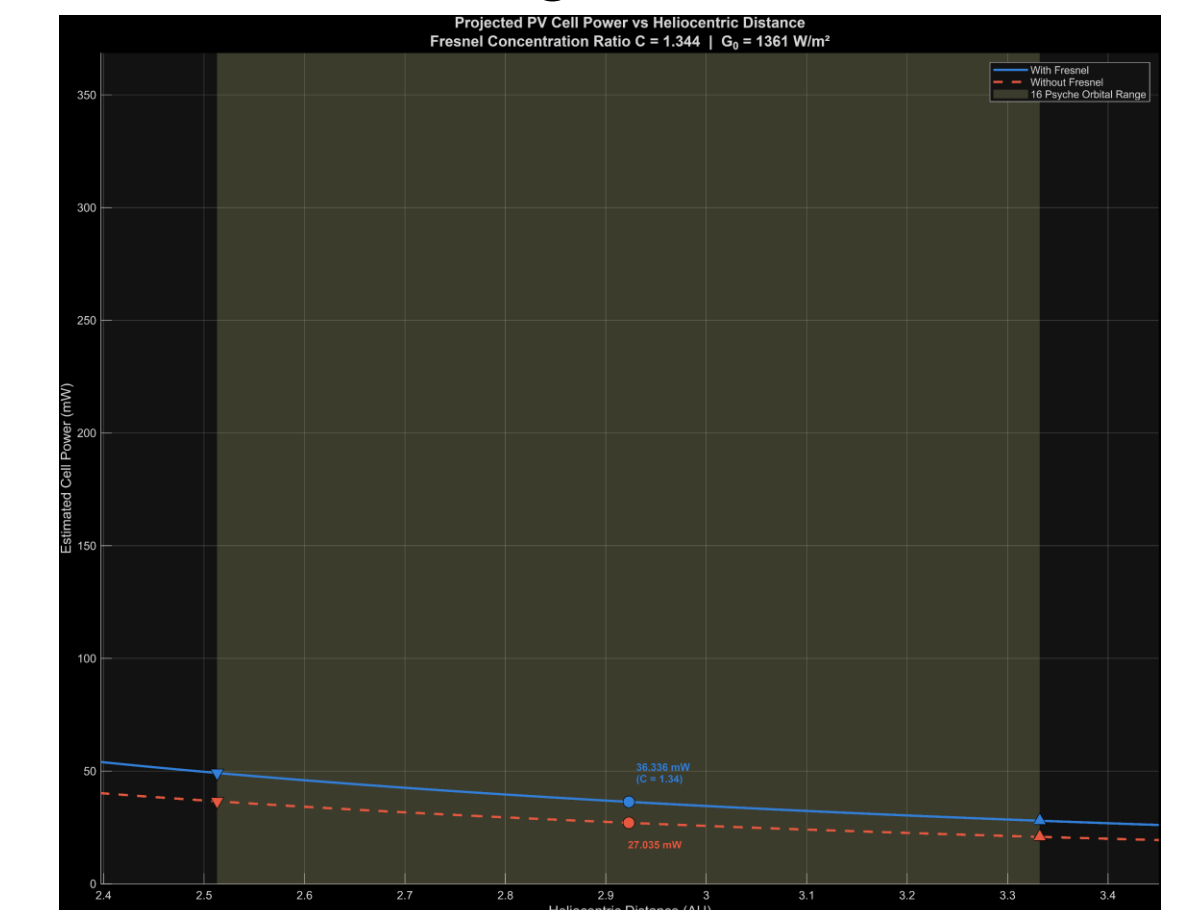
Lux vs PWM Step (Fresnel Lens Comparison):

- Across the tested PWM range, the system with the Fresnel lens consistently produced higher lux values than the baseline configuration.



Projected PV Cell Power vs Heliocentric Distance:

- The Fresnel lens produced a projected power increase across the full Psyche orbital range.
- At the mean orbit (~2.92 AU), projected PV cell power increased from about 27.0 mW without the lens to about 36.3 mW with the lens.
- At perihelion and aphelion, the gain remained close to 1.3 \times , indicating a consistent power benefit throughout the orbit.



Conclusion

- A Fresnel lens increased illuminance at all measured sensor locations.
- The system demonstrated consistent improvement in PV cell input irradiance and projected power output.
- At 16 Psyche's mean orbital distance, projected cell power increased from approximately 27.0 mW to 36.3 mW.
- Results support the use of Fresnel concentrators as a promising technique for improving solar power generation in deep-space environments.