

SMART Solar module angular response on a tracker

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Introduction

➤ In Concentrating Photovoltaic (CPV) systems, a large area of sunlight is focused onto a solar cell using an optical device. CPV technology has competitive industry advantages: it requires less photovoltaic (PV) material to capture the same sunlight as non-concentrating PV. Using less PV material mitigates the high cost of highly-efficient multi-junction III-V material, while reaching cell efficiencies of 44.7% [1].

➤ CPV devices can harvest only the direct beam of the sun, and thus must be mounted on dual-axis trackers. Increased optical concentration in the modules is desirable as it improves cell efficiency due to the $\ln(C)$ dependence of semiconductor PV cell voltage. However, increasing optical concentration will narrow the achievable angular acceptance which in turn requires better tracking precision. Widening the angular response of solar concentrating modules can compensate for the tracker system's accuracy.

➤ In this study, we assess the angular response and effects of tracking precision for three different prototypes composed of an input lens, a refractive secondary optic (2OE), and a triple-junction photovoltaic solar cell (3JPV). On-sun tracker and module measurements are compared with modeling that combines optical ray tracing with a simulation of multi-junction cell efficiency versus illumination spot uniformity.

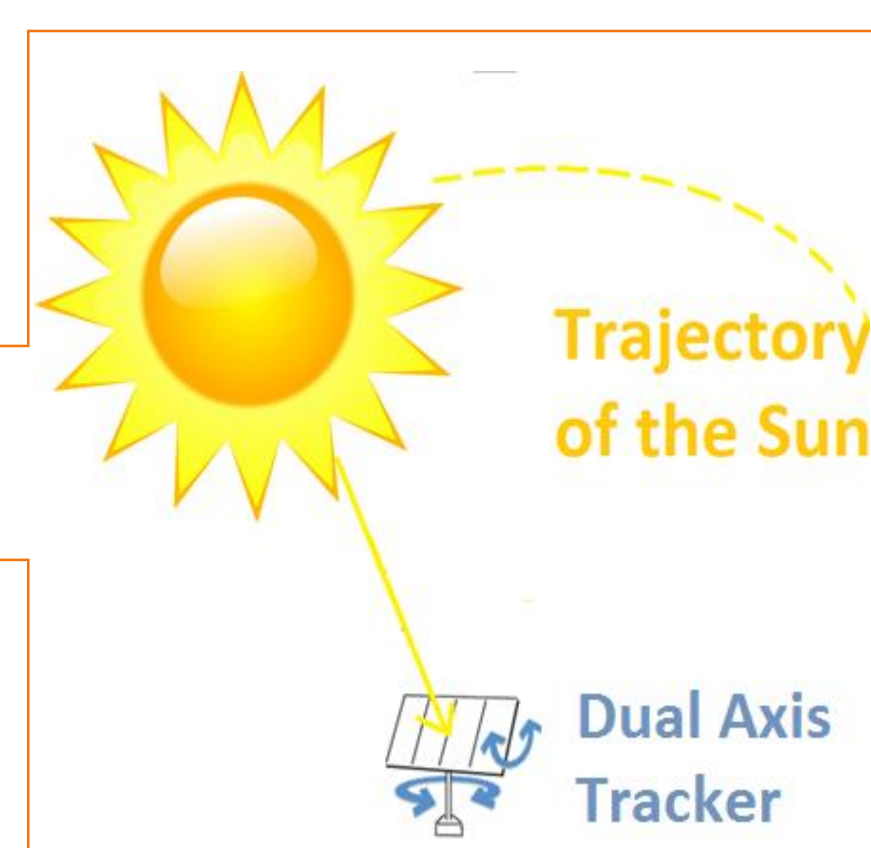
Methodology

Three industry partner prototype CPV modules with different refractive concentrator optics are mounted on a commercial dual-axis sun tracker at the university of Ottawa SUNLAB outdoor test site.

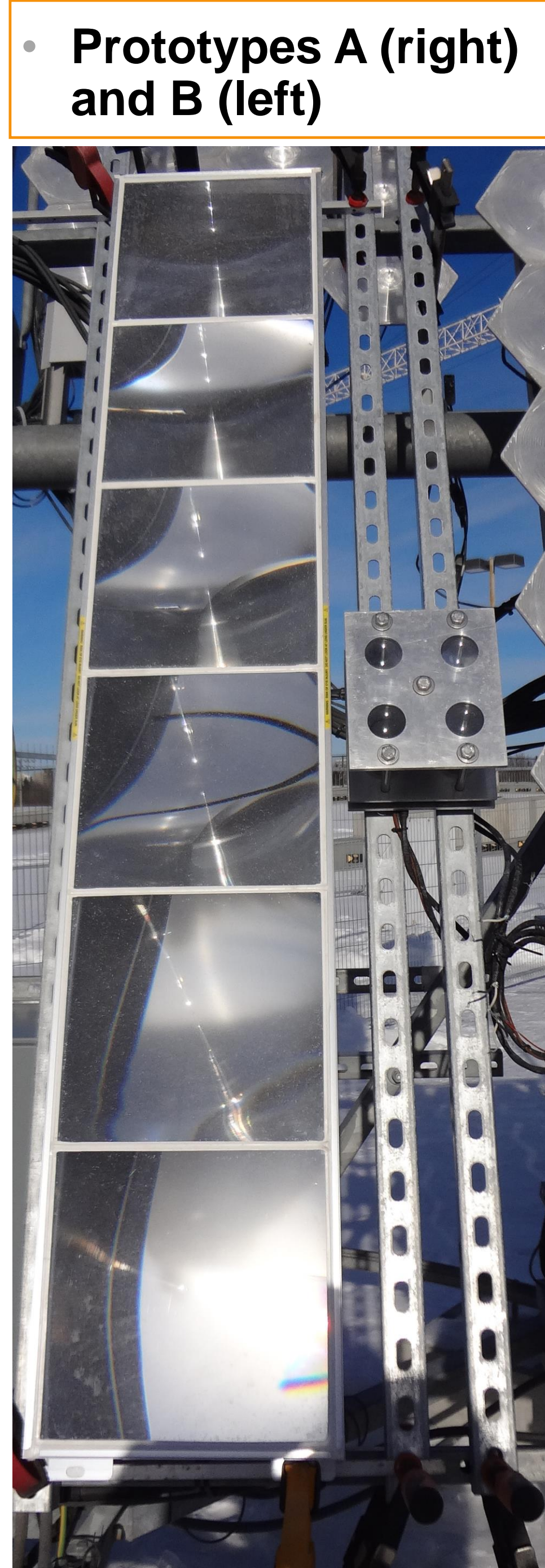
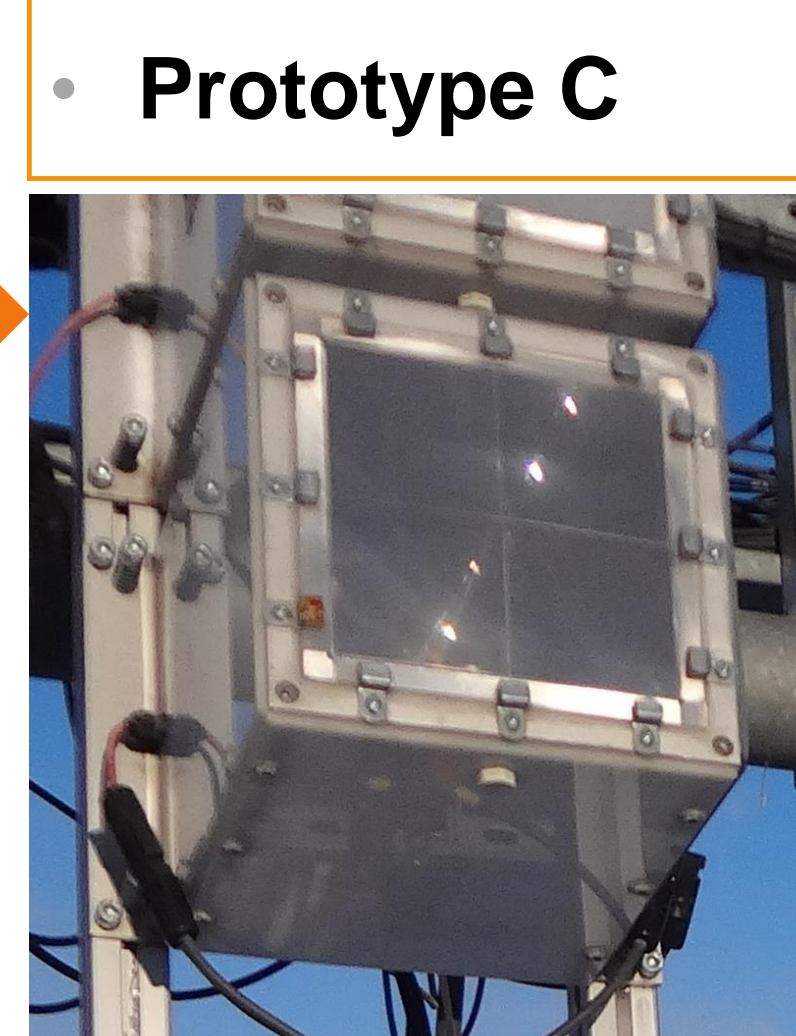
The tracker analog position signals are calibrated for known time of day (universal coordinated time, UTC) and known sun position from the NREL SOLPOS sun position calculator [2];

Then the NREL calculator is used to determine sun position 20 minutes in advance of a "center time" and the tracker is advanced to that position and stopped;

As the sun moves along its arc the short-circuit current is manually recorded for each module on a 1-minute timebase. Sun positions in the sun align jig are noted.



Prototype B contains six nominally identical channels, connected electrically in series, while prototypes A and C each comprise a single channel (optics + cell).



Results

In assessing angular acceptance [3] we define the incident angle at 90% of the maximum obtainable efficiency (FW90%M) (full-width acceptance angle). Firstly, we measured and modeled FW90%M values for three prototypes, given in Table 1 and Fig. 1. Secondly, we modeled a typical CPV refractive optical train with a geometric concentration of 625 suns (1 sun = 1000Wm^{-2}), consisting of a Fresnel lens primary optical element (1OE) and the truncated pyramid secondary optical element (2OE), similar to Prototype B. Thirdly, instantaneous mistracking data was extracted from a logging database.

	Prototype	C_g	FW90%M	FWHM
Measured	A	400×	3.0°	3.4°
Measured	B	600×	2.1°	4.6°
Measured	C	1000×	1.8°	2.5°
Modeled	B with 2OE	625×	2.6°	4.0°
Modeled	B no 2OE	625×	1.3°	2.0°
Extracted	Tracker (az × el)		0.3° × 0.2°	2.0° × 0.9°

Table 1. Summary of results. Geometric concentration factors (C_g), Full Width at half maximum (FWHM), full width at 90% maximum (FW90%M)

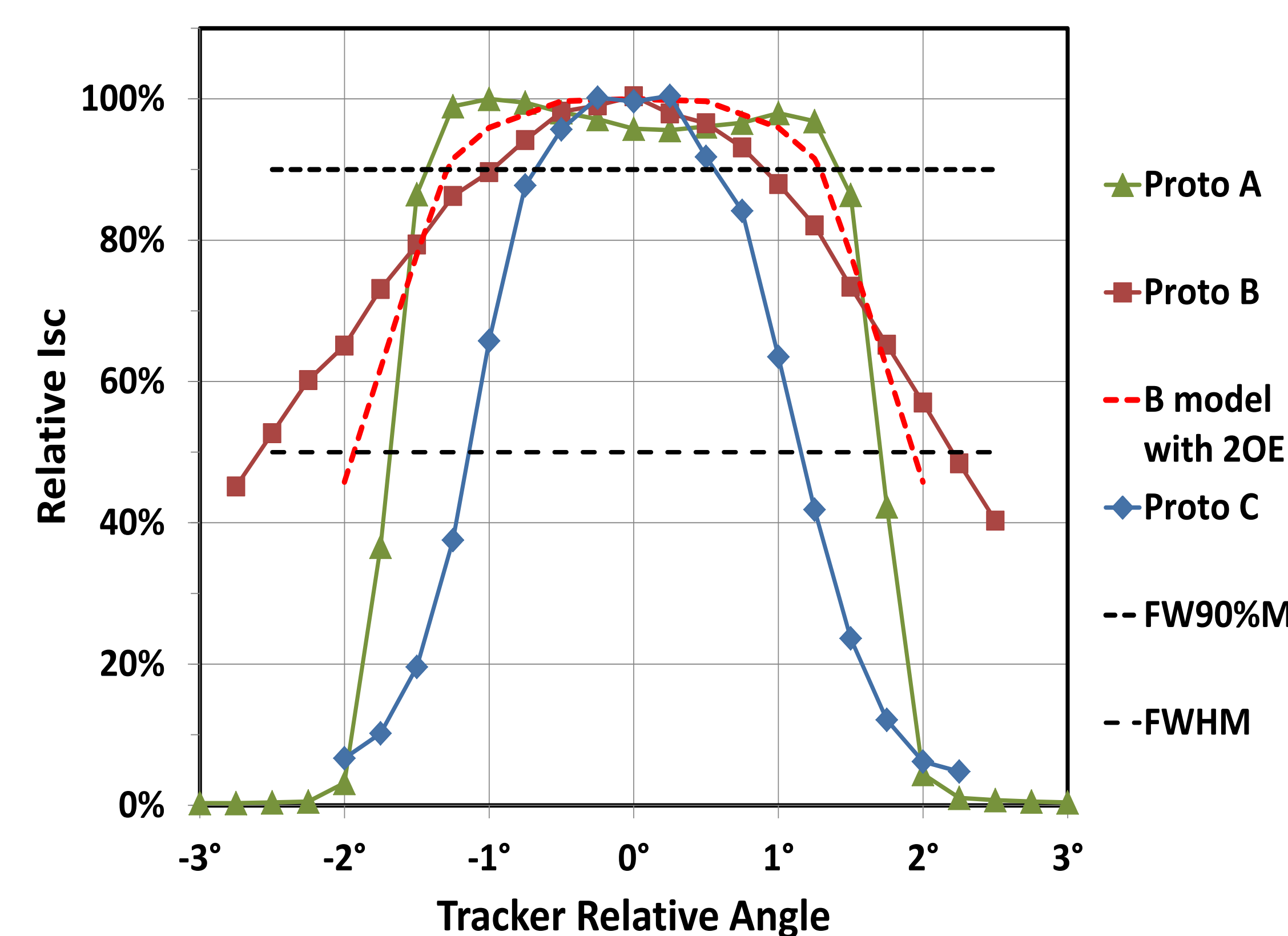


Fig. 1. Measured and modeled angular responses of three prototype CPV module architectures.

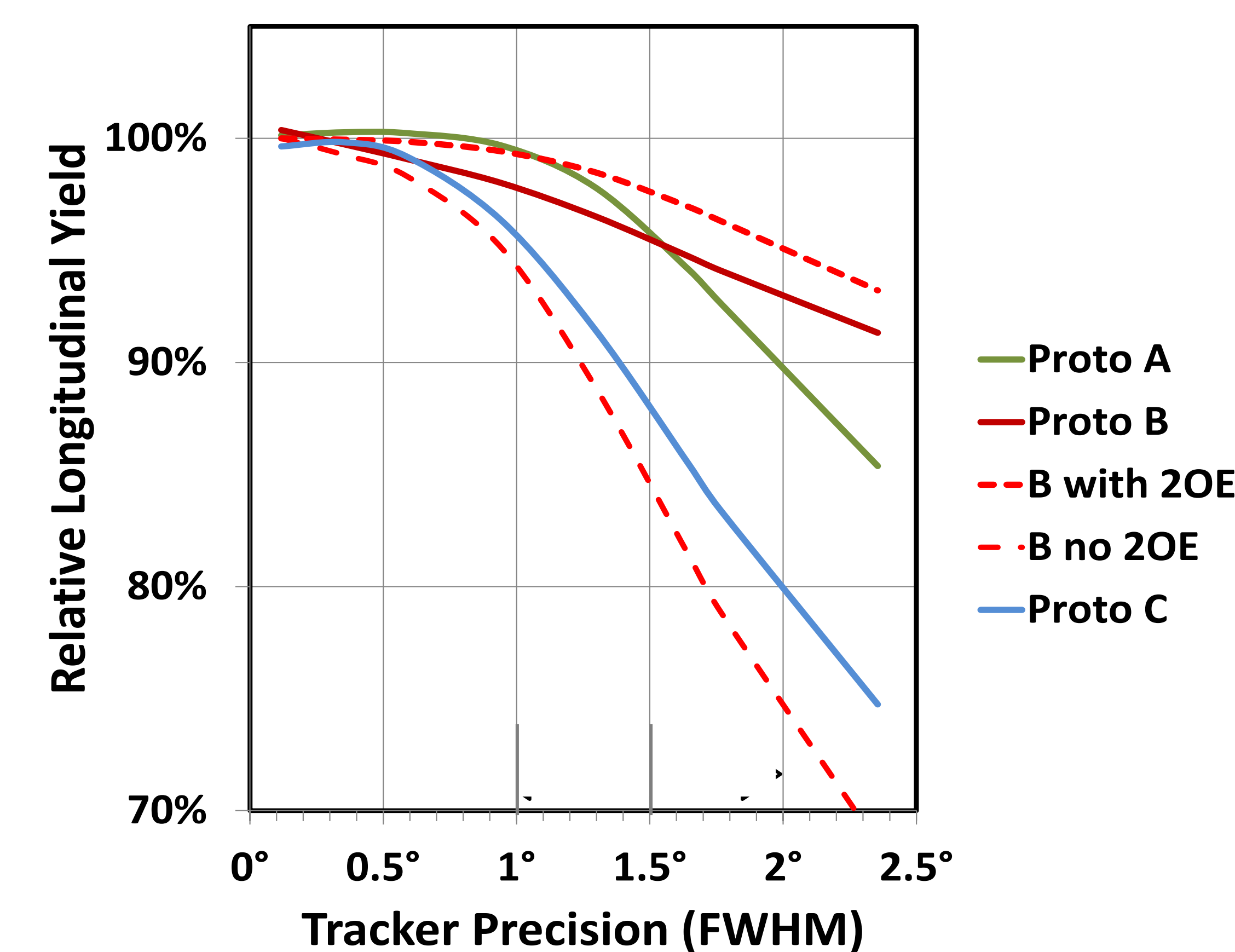


Fig. 2. Calculated degradation of cumulative energy harvest arising from tracker pointing variability, using angular responses from Fig. 1, and modeling the tracker error locus as a normal distribution.

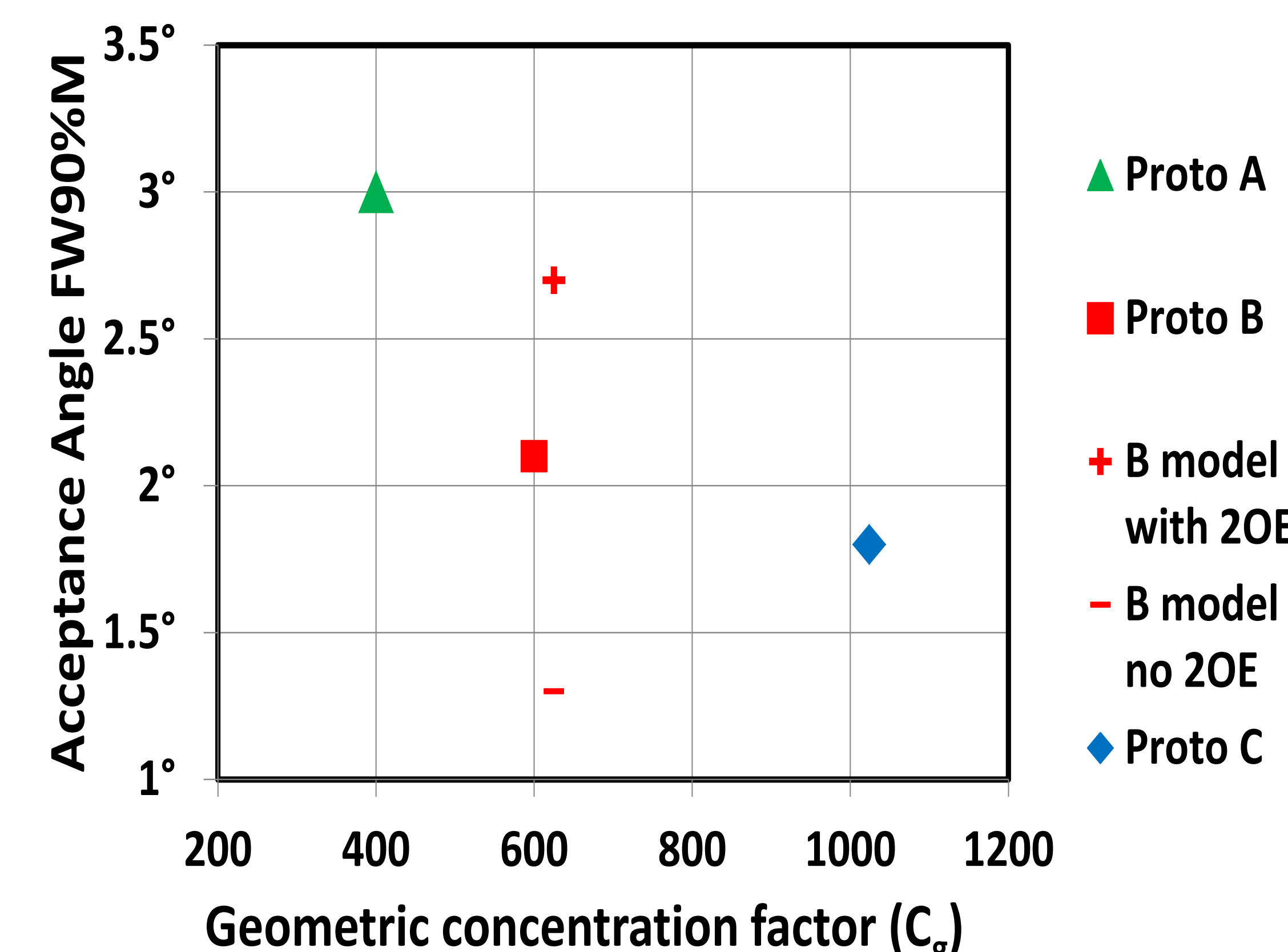


Fig. 3. Measured and modeled angular response, as a function of geometric concentration. C_g is defined as the ratio between the aperture area [5].

Discussion

Losses due to non-uniform illumination and chromatic aberrations across the very broad 3JPV wavelength range [4], are possible causes accounting for the difference in angular response of the three prototypes. Imprecise tracking may also cause spectral changes and hence current mismatch changes between the sub-cells of a multi-junction cell.

The tracker precision in this work was found to be $\sigma_{\text{azimuth}} \sim 0.83^\circ$ and $\sigma_{\text{elevation}} \sim 0.39^\circ$ (FWHM 2.0° and 0.9° respectively, approximating the response with a Gaussian function). Examining Fig. 2, it is suggested the level of precision of the tracker decreases the long term energy yield of all three CPV modules studied. The angular response of prototypes A and B is promising and would be able to maintain roughly 95% of nominal module yield. However, prototype C with the highest concentration factor needs a more precise platform. The substantial effect of the 2OE in improving angular response is evident in prototype B.

Conclusion

This study used a simple, low-cost method to determine the angular acceptance of three different CPV modules and assess their performance robustness against imperfect tracking. Following this study, measuring long term energy harvest, module orientation anisotropy, scaffold flatness, alignment to sun sensor, and wind effects would provide more insight into CPV module angular performance on a tracker system.

References

- [1] F. Dimroth, M. Grave, P. Beutel, U. Fiedeler, C. Karcher, T. N. D. Tibbits, E. Oliva, G. Siefer, M. Schachtner, A. Wekkeli, A. W. Bett, R. Krause, M. Piccin, N. Blanc, C. Drazek, E. Guiot, B. Ghyselen, T. Salvatet, T. Signamarcheix, A. Dobrich, T. Hannappel, K. Schwarzburg, "Wafer bonded 4-junction GaInP/GaAs//GaInAsP/GaInAs concentrator solar cells with 44.7% efficiency," Prog. Photovolt: Res. Appl., vol. 22, pp. 277-282, 2014.
- [2] NREL SOLPOS sun position calculator, website <http://www.nrel.gov/midc/solpos/solpos.html> as downloaded on Jan. 10, 2015.
- [3] Y.Ota, K. Nishioka, "Three-dimensional simulating of concentrator photovoltaic modules using ray trace and equivalent circuit simulators," Solar Energy, vol. 86, pp. 476-481, 2012.
- [4] H. Baig, K. C. Heasman and T. K. Mallick, "Non-uniform illumination in concentrating solar cells," Renewable and Sustainable Energy Reviews, vol. 16, pp. 5890-5909, 2012.
- [5] O'Gallagher, J. (2008). Synthesis lectures on energy and the environment Volume 2 of Synthesis lectures on energy and the environment, technology, science, and society. Morgan & Claypool.

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