Accurate, Low-cost Solar Irradiance Measurements from a New, Compact Thermopile Pyranometer

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Introduction

There are multiple pyranometer options available for global horizontal and plane of array shortwave irradiance measurements. Some solar power installations require ISO secondary standard pyranometers, but those that don't may use a first or second class pyranometer, or a silicon-cell pyranometer. The advantage of silicon-cell pyranometers is low cost, but they are not sensitive to all solar wavelengths. Silicon is only sensitive from 350 to 1100 nm, thus, silicon-cell pyranometers sub-sample the solar spectrum. This results in spectral errors when the solar spectrum changes. The advantage of first and second class pyranometers is sensitivity to all solar wavelengths, minimizing spectral errors, but they are higher cost.

Here, performance of a new, compact and low-cost blackbody thermopile pyranometer, the Apogee model SP-510, is detailed. Specifications of the new pyranometer compare favorably to ISO second class and first-class blackbody thermopile pyranometers, but price is similar to silicon-cell pyranometers. The new pyranometer and silicon-cell pyranometers were compared to secondary standard pyranometers for two years in Logan, Utah. Performance of the new thermopile pyranometer suggests it is an accurate and cost-effective alternative for solar irradiance measurements in applications that don't require a secondary standard.

Specifications and Prices

The International Standards Organization (ISO) and World Meteorological Organization (WMO) classify pyranometers according to a standard set of specifications. Specifications for the Apogee SP-510 pyranometer were compared to these specifications (Table 1), and some of the specifications for the SP-510 were evaluated by direct comparison of global shortwave irradiance measurements from seven replicate SP-510 pyranometers to mean global shortwave irradiance calculated from measurements from four secondary standard pyranometers.

Table 1: Specifications of the Apogee SP-510 thermopile pyranometer compared to ISO-9060 specifications for secondary standard, first class, and second class pyranometers (WMO classifications are also listed). Some of these specifications for the SP-510 were evaluated with field data (references to the table or figure are listed next to the specification).

ISO-9060	Secondary Standard	First Class	Second Class	SP-510 Thermopile Pyranometer
WMO	High Quality	Good Quality	Moderate Quality	
Response Time (95 %)	< 15 s	< 30 s	< 60 s	0.5 s
Zero Offset A due to 200 W/m² net thermal radiation (ventilated)	± 7 W m^{-2}	± 15 W m^{-2}	± 30 W m^{-2}	8 W m^{-2} (unheated)
Zero offset B response to 5 K/hr change in ambient temperature	± 2 W m^{-2}	± 4 W m^{-2}	± 8 W m^{-2}	± 5 W m^{-2}
Stability (Change per year, % full scale)	± 0.8 %	± 1.5 %	± 3 %	± 2 %
Linearity	± 0.5 %	± 1 %	± 3 %	± 1 %
Directional Response (up to 90°)	± 10 W m^{-2}	± 20 W m^{-2}	± 30 W m^{-2}	± 20 W m^{-2} (up to 80°)
Percent deviation due to temperature change within an interval of 50 K	2 %	4 %	8 %	5 % from -15° to 45° C
Tilt Response	0.5 %	2 %	5 %	1 %
Uncertainty (95 % confidence level) Hourly Totals	3 %	8 %	20 %	8 %
Uncertainty (95 % confidence level) Daily Totals	2 %	5 %	10 %	5 %
Spectral Range	300 to 3000 nm	300 to 3000 nm	300 to 3000 nm	385 to 2105 nm
Resolution	1 W/m²	5 W/m²	10 W/m²	1 W/m²

Table 2: Price ranges of pyranometer classes (ISO) compared to the SP-510

Pyranometer	Price Range
Silicon-cell	$200 - $500
SP-510	$325
Second Class	$500 - $1,000
First Class	$1,000 - $2,100
Secondary Standard	$2,000 - $4,000

Fig. 1 Apogee SP-510 thermopile pyranometer and SP-110 silicon-cell pyranometer. The SP-510 is similar to silicon-cell pyranometers in terms of size-shape and cost (Table 2), but has specifications comparable to first and second class pyranometers (Table 1).

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Thermal Offset

Nighttime thermal offset (Table 3) was determined by calculating the mean shortwave irradiance from an SP-510 pyranometer with the heater turned off and an SP-510 pyranometer with the heater turned on. It was considered nighttime when mean shortwave irradiance calculated from the four secondary standard pyranometers was less than 0 W m^{-2}.

Table 3: Nighttime thermal offset [W m^{-2}] for an SP-510 thermopile pyranometer with the heater turned off and an SP-510 with the heater turned on.

Heater Status	Nighttime Thermal Offset [W m^{-2}]
Off	-1.3 ± 2.5
On	-7.4 ± 3.4

Directional Response

Directional response was determined by direct comparison of an SP-510 thermopile pyranometer to the mean of the four secondary standard pyranometers on rooftop of the Apogee building (Fig. 2). All replicate SP-510 pyranometers performed similarly.

Temperature Response

Temperature response was determined by direct comparison of an SP-510 thermopile pyranometer to the mean of the four secondary standard pyranometers on rooftop of the Apogee building (Fig. 3). All replicate SP-510 pyranometers performed similarly.

Measurements Under Variable Sky Conditions

Shortwave irradiance measurements from an SP-510 and an SP-110 pyranometer were compared to the mean of the four secondary standard pyranometers under variable sky conditions to provide an indication of spectral error (Fig. 4 and Fig. 5).

Summary and Additional Features

- Specifications for the SP-510 pyranometer compare favorably to ISO first class and second class specifications.
- Evaluation of SP-510 by direct comparison the mean of four secondary standard pyranometers indicates the SP-510 performs similar to ISO first class and second class pyranometers.
- The SP-510 is a cost effective option for shortwave irradiance measurement applications that do not required an ISO classified pyranometer.
- Silicon-cell pyranometers are also cost effective options for shortwave irradiance measurements, but they sub-sample the shortwave spectrum, resulting in errors when the spectrum changes with cloudiness

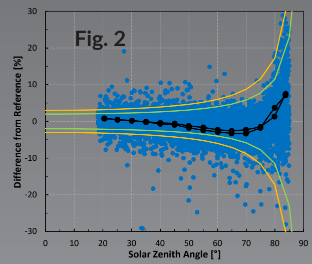

Fig. 2 Differences [%] of an SP-510 thermopile from the mean of four secondary standard (reference) pyranometers as a function of solar zenith angle. Black lines are bin averages for AM and PM. The green and orange lines are estimates of the specifications for first class (± 20 W m-2) and second class (± 30 W m-2) pyranometers, respectively, as a function of solar zenith angle.

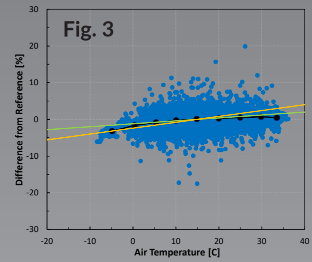

Fig. 3 Differences [%] of an SP-510 thermopile from the mean of four secondary standard (reference) pyranometers as a function of air temperature. Black line is a bin average. The green and orange lines are estimates of the specifications for first class (4 % over a 50 C interval) and second class (8 % over a 50 C interval) pyranometers, respectively, as a function of air temperature.

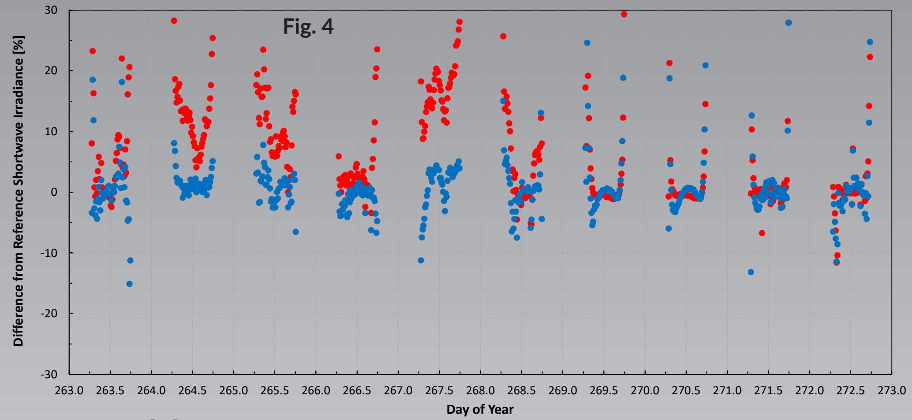

Fig. 4 Differences [%] of the SP-510 thermopile and SP-110 silicon-cell from the mean of four secondary standard (reference) pyranometers. While the errors shown for cloudy and overcast conditions were from an SP-110 silicon-cell pyranometer, they are common to all silicon-cell pyranometers.

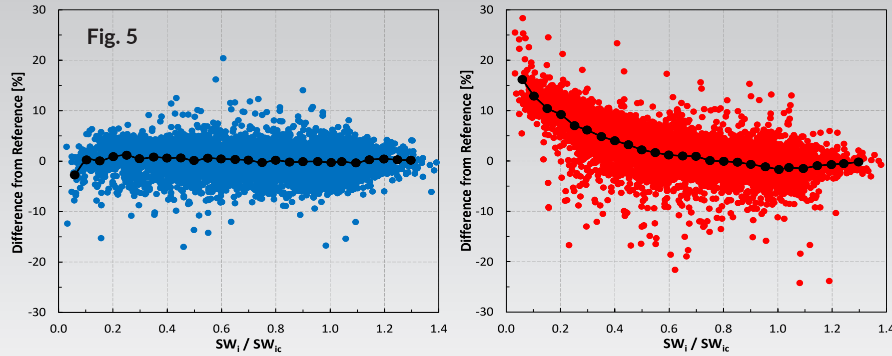

Fig. 5 Differences [%] of an SP-510 thermopile pyranometer and an SP-110 silicon-cell from the mean of the four secondary standard (reference) pyranometers as a function of cloudiness. Black lines are bin averages. The variable SWi / SWic is the ratio of measured global shortwave irradiance [W m^{-2}] to clear sky global shortwave irradiance [W m^{-2}] calculated from a model, and serves as a cloudiness index. Values of SWi / SWic near one indicate clear sky and values near zero indicate overcast sky. The predicted error values listed on each graph were calculated from the spectral response for each sensor and a solar spectrum for overcast conditions, assuming the pyranometers were calibrated under clear sky conditions.