Calibration Certificate

Kalibrierschein

issued by the calibration laboratory
erstellt durch das Kalibrierlaboratorium

Calibration and Test Center (CalTeC) Solar Cells
Institut für Solarenergieforschung GmbH
Am Ohrberg 1
31860 Emmerthal
GERMANY

http://caltec.isfh.de/
solarcells@caltec.isfh.de

Deutsche Akkreditierungsstelle
D-K-18657-01-00

Calibration mark *Kalibrierzeichen*	002647 D-K-18657-01-00 2022-07

Object *Gegenstand*	**Irradiance sensor**
Manufacturer *Hersteller*	**SEVEN SENSOR SOLUTIONS, Corum, TURKEY**
Type *Typ*	**3S-IS**
Serial number *Fabrikat/Serien-Nr.*	**ISFH22004**
Customer *Auftraggeber*	**SEVEN SENSOR SOLUTIONS, Corum, TURKEY**
Order No. *Auftragsnummer*	**02822SE_04**
Date of calibration *Datum der Kalibrierung*	**July 5th, 2022**
Place of calibration *Ort der Kalibrierung*	**ISFH CalTeC, 31860 Emmerthal, GERMANY**
Number of pages of the certificate *Anzahl der Seiten des Kalibrierscheins*	**6**

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Dieser Kalibrierschein dokumentiert die Rückführung auf nationale Normale zur Darstellung der Einheiten in Übereinstimmung mit dem Internationalen Einheitensystem (SI).
Die DAkkS ist Unterzeichner der multilateralen Übereinkommen der European co-operation for Accreditation (EA) und der International Laboratory Accreditation Cooperation (ILAC) zur gegenseitigen Anerkennung der Kalibrierscheine.
Für die Einhaltung einer angemessenen Frist zur Wiederholung der Kalibrierung ist der Benutzer verantwortlich.

Date of issue *Datum der Ausstellung*	Deputy head of the calibration laboratory *Stellvertretender Leiter des Kalibrierlaboratoriums*	Person in charge *Bearbeiter*
July 13, 2022	Dr. David Hinken	Tobias Gandy

1 Type of calibration

The irradiance sensitivity s(T) of the irradiance sensor is determined as a function of the temperature T of the sensor at an irradiance of $E_{\text{trgt}} = 1000\,\text{W/m}^2$ using a class A+AA+ sun simulator.

2 Calibration object

The calibration object with identifier *ISFH22004* (see Fig. 1) is an irradiance sensor consisting of an encapsulated solar cell electrically connected to a switch box. This sensor provides wires allowing a voltage measurement V_{irr} which is correlated to the incident irradiance.
In addition, the sensor provides wires for the internal temperature sensor.
The calibration object is shown in Fig. 1.

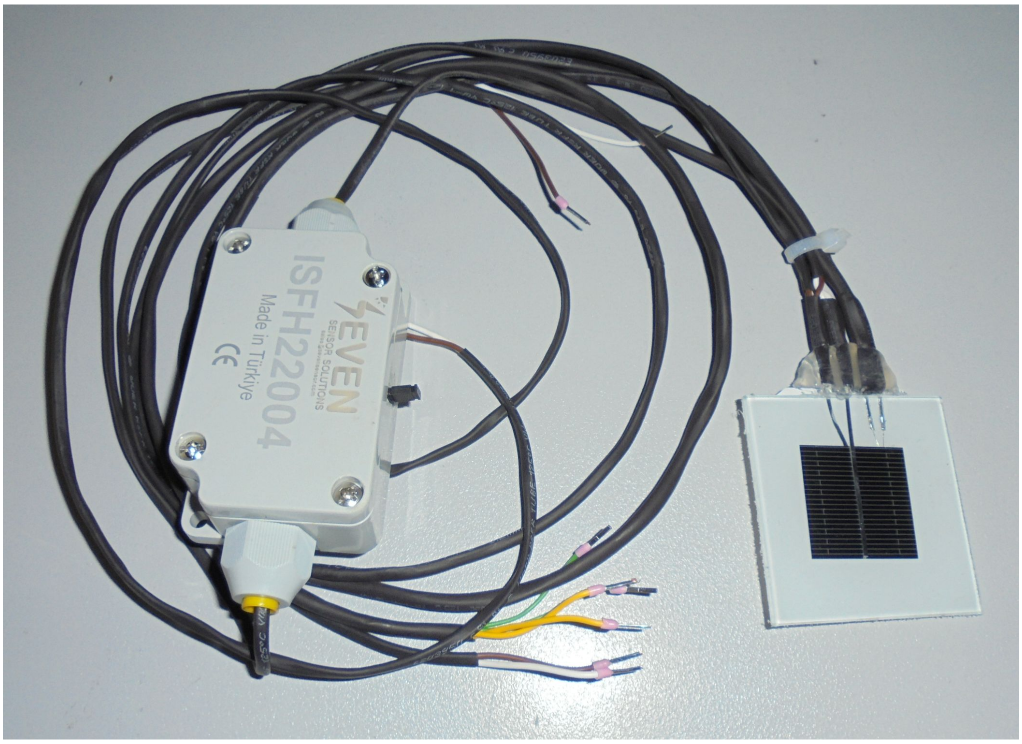

Fig. 1: Picture of the irradiance sensor with identifier *ISFH22004*.

Condition of calibration object

The visual examination of the calibration object did not detect any visible damage.

3 Mounting

The encapsulated solar cell is fixed to the measurement stage using hold-down clamps. The front glass is adjusted to be perpendicular and centrical to the optical axis.
According to manufacturer specifications the position of the solar cell is at a height of 0.95 mm (distance from position of solar cell to bottom side).

4 Electrical contacting

Irradiance signal

The electrical contacting of the irradiance signal V_{irr} is carried out via the wires of the calibration object.

Temperature signal

The electrical contacting of the temperature sensor is carried out via the wires of the irradiance sensor. Here, the resistance of the built-in PT1000-sensor is measured using four-wire technique and converted into a temperature value using the IEC 60751:2008 standard.

5 Irradiance

5.1 Classification

The used steady-state IV tester is classified as A+AA+ (spectrum, inhomogeneity of the light field and instability in time) according to the IEC 60904-9:2020 standard. This classification in all three areas is tested on a regular basis:

- The spectrum is tested before each measurement of the calibration object using a spectroradiometer. The spectroradiometer is traceable to reference lamps which were calibrated at the Physikalisch-Technische Bundesanstalt PTB (Braunschweig).
- The inhomogeneity of the light field is measured on a regular basis by scanning the light field with a reference solar cell.
- The instability in time of the light field is tested on a regular basis using a monitor diode.

The divergence of the light is smaller than 3°. The stability of the irradiance over time is controlled with a monitor diode during the whole measurement.

5.2 Adjustment

The irradiance of the sun simulator is adjusted using a WPVS reference cell (primary standard “IV”, see section 7). The short circuit current of this reference cell was calibrated under standard test conditions (1000 W/m^2, AM1.5G reference spectrum and 25 °C). For the adjustment of the irradiance the spectral mismatch correction factor *MM* was considered. Three measurement curves are required for the determination of *MM*:

- The spectral responsivity of the calibration object. This measurement is traceable to the spectral responsivity of a primary calibrated WPVS reference solar cell (primary standard “DSR”, see section 7).
- The spectral responsivity of the primary calibrated WPVS reference cell of the IV tester (primary standard “IV”, see section 7).
- The spectral irradiance of the sun simulator which is determined using a spectroradiometer in the wavelength range from 250 nm to 1700 nm.

With these curves the factor *MM* is calculated as described in the IEC 60904-7:2019 standard using the reference spectrum of the IEC 60904-3:2019 standard. It follows to

$$MM = 1.00867. \tag{1}$$

Fig. 2 shows the normalized spectral responsivities of the calibration object (yellow) and the primary calibrated WPVS reference solar cell (red) as well as the spectral irradiance of the sun simulator (blue) and the reference spectrum (black).

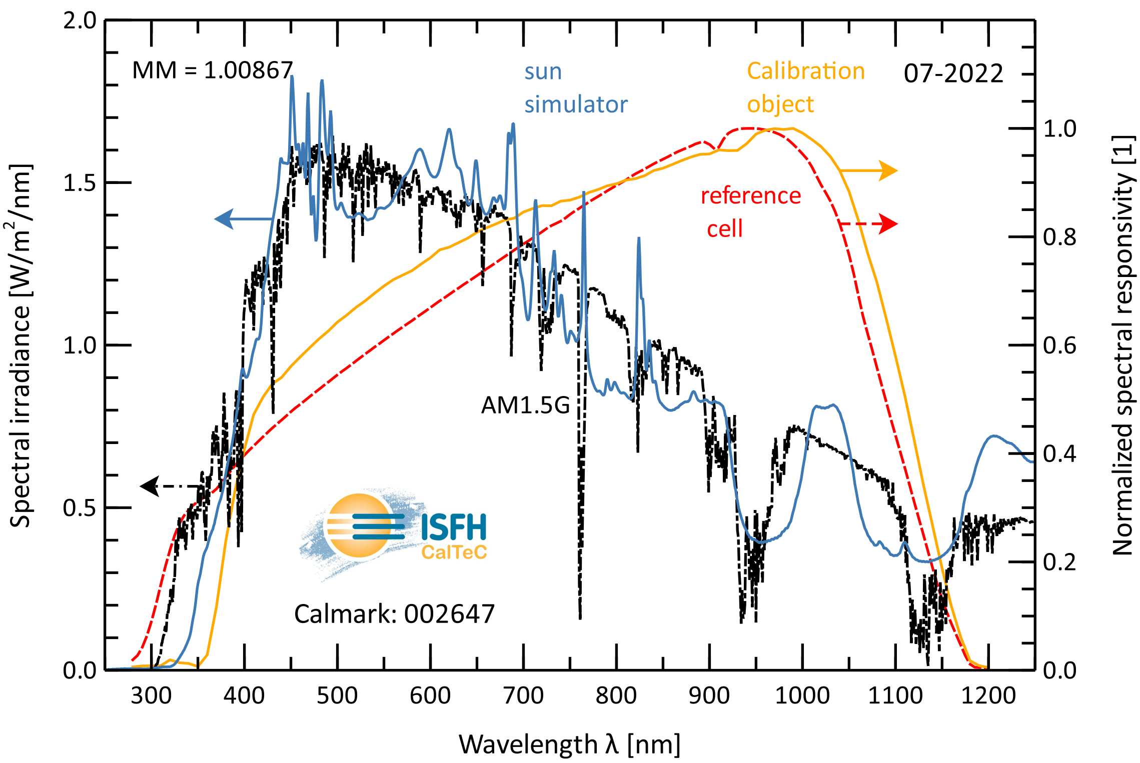

Fig. 2: Plot of the normalized spectral responsivities and spectral irradiances for the calculation of the spectral mismatch factor.

6 Measurement conditions

The temperature of the ambient during measurement is

$$T_{\text{room}} = (26.9 \pm 1.0)\,°\text{C}. \tag{2}$$

The relative humidity of the ambient during measurement is

$$H_{\text{room}} = (32.4 \pm 5.0)\,\%. \tag{3}$$

7 Used primary standards

The following WPVS reference solar cells, calibrated at the national metrology institute Physikalisch-Technische Bundesanstalt PTB (Braunschweig, Germany), were used as primary standards:

DSR: 47051-PTB-20 (RD009),

IV: 47086-PTB-21 (RD001).

8 Measurement procedure

8.1 Conditioning

The irradiance sensor is conditioned for at least 24 hours in the conditioning storage or in the laboratory.

8.2 Warm-up phase

The shutter of the sun simulator is opened to warm up the irradiance sensor. The irradiance signal $V_{\mathrm{irr.A}}(T)$ and the temperature T of the sensor are measured continuously. If the heating of the sensor changes by less than 1 K/min or reaches a pre-defined maximum temperature the warm-up phase is completed.

8.3 Cool-down phase

The shutter of the sun simulator is closed. This causes the sensor to cool down again. At defined temperatures (usually all 2 °C) the shutter is briefly opened and the irradiance signal $V_{\mathrm{irr.B}}(T)$ of the sensor is recorded.

8.4 Data analysis

A second degree polynomial,

$$V_{\mathrm{irr}}(T) = c_0 + c_1 \cdot T + c_2 \cdot T^2, \tag{4}$$

is fitted to the measured data of the warm-up process $V_{\mathrm{irr.A}}(T)$. It is checked that the fit describes the entire measuring range well and that there are no hysteresis effects between the warm-up and cool-down phases. The irradiance sensitivity is calculated using the formula

$$\mathrm{s}(T) = \frac{V_{\mathrm{irr}}(T)}{E_{\mathrm{trgt}}} = \frac{c_0 + c_1 \cdot T + c_2 \cdot T^2}{E_{\mathrm{trgt}}}. \tag{5}$$

9 Measurement result

The following results are obtained:

Irradiance sensitivity s(T) at $T = 25.0$ °C:	(41.64 ± 0.50) µV/(W/m^2)

Temperature-dependent measurement data are printed in table 1. These results are plotted in Figure 3.

Tab. 1: Irradiance sensitivity s(T) and measurement uncertainty U(s(T)) of the examined irradiance sensor.

T [°C]	s(T) [µV/(W/m^2)]	$U(\mathrm{s}(T))$ [µV/(W/m^2)]	$U_{\%}(\mathrm{s}(T))$ [%]	T [°C]	s(T) [µV/(W/m^2)]	$U(\mathrm{s}(T))$ [µV/(W/m^2)]	$U_{\%}(\mathrm{s}(T))$ [%]
23	41.61	0.50	1.2	41	41.86	0.5	1.20
25	41.64	0.50	1.2	43	41.89	0.5	1.20
27	41.67	0.50	1.2	45	41.91	0.5	1.20
29	41.70	0.50	1.2	47	41.94	0.5	1.20
31	41.72	0.50	1.2	49	41.97	0.5	1.20
33	41.75	0.50	1.2	51	41.99	0.5	1.20
35	41.78	0.50	1.2	53	42.02	0.5	1.20
37	41.81	0.50	1.2	55	42.05	0.5	1.20
39	41.83	0.50	1.2	-	–	–	–

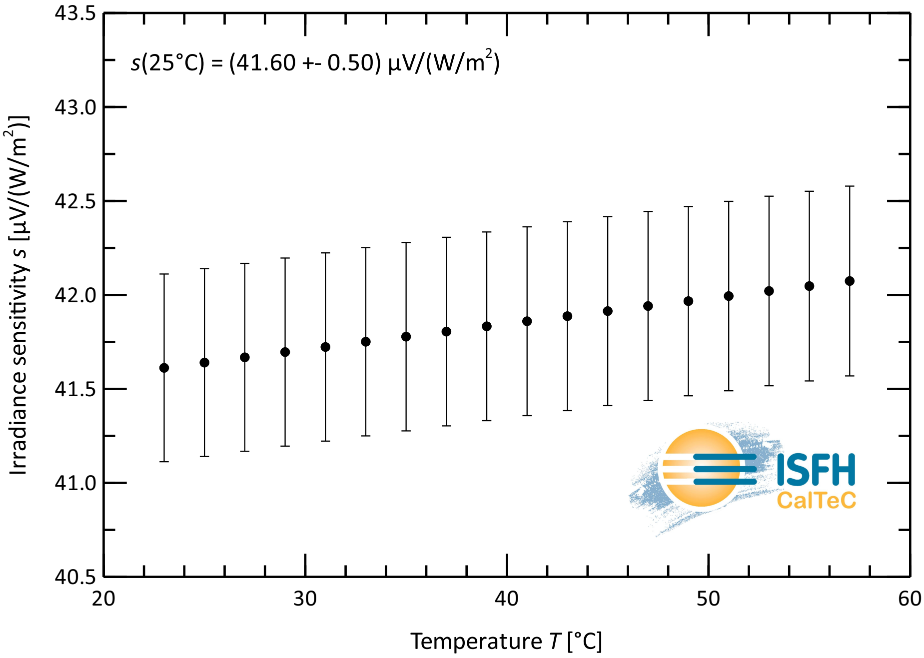

Fig. 3: Graphical representation of the data (printed in Tab. 1) of the irradiance sensitivity of the examined irradiance sensor.

As given in Eq. 5, the irradiance sensitivity $s(T)$ can be transformed into a voltage signal $V_{irr}(T)$ by multiplication with the irradiance E_{trgt}, i.e. $V_{irr}(T) = s(T) \cdot E_{trgt}$.

The uncertainty stated is the expanded uncertainty obtained by multiplying the standard uncertainty by the coverage faktor $k = 2$. The uncertainty analysis was carried out as described in the document EA-4/02 M:2013. The value of the measurand lies with a probability of 95% whithin the assigned interval.

10 Remarks

- The ISFH additionally provides the data in machine-readable format for further digital processing. However, only the data printed within this document are valid. It is up to the customer to carefully examine the electronic data before using them.
- The determined irradiance sensitivity of the irradiance sensor under examination applies only to the irradiance specified in section 1. The linearity of the sensor has to be ensured before applying the value to other irradiances. Methods of linear dependence and linearity measurements are given in the IEC60904-10 standard.
- The stability in time of the determined values was not tested.
- Throughout the document a dot is used as decimal separator.

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End of calibration certificate