Translation of a sample certificate

This document contains a translation of a sample certificate. The document is meant to help the reader understand the official calibration certificate in principal. But it is possible that there are differences with regard to contents between this translation of a sample certificate and the actual version of the official German calibration certificate, e.g. the description of the measurement object, measurement ranges, numbers, …

The sealed and duly signed German copy of the calibration certificate is the only binding format.

Physikalisch-Technische Bundesanstalt

Braunschweig und Berlin

Kalibrierschein

Calibration Certificate

Gegenstand: {Name of the device, short characterization}
Object:

Hersteller: {Name of the manufacturer, client}
Manufacturer:

Typ: {Type of the device}
Type:

Kennnummer: {Number of the investigated device, standard, preparations}
Serial number:

Auftraggeber: {Name of the client, street, head officez}
Applicant:

Anzahl der Seiten: 19
Number of pages:

Geschäftszeichen: {YYY-ZZZZZZZZ}
Reference No.:

Kalibrierzeichen: {YYY-XXXXXXX}
Calibration mark:

Datum der Kalibrierung: {Date or start until end of calibration}
Date of calibration:

Im Auftrag: Braunschweig, Bearbeiter:
By order: *Examiner:*

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1. Type of the calibration

The following is determined:

a) the value of the absolute differential spectral irradiance responsivity at a specific wavelength and a short-circuit current,

b) the function of the relative differential spectral irradiance responsivities at different short-circuit currents,

c) the function of the differential irradiance responsivity in accordance with AM1.5 as a function of the short-circuit current,

d) the value of the short-circuit current under standard test conditions,

e) the function of the absolute spectral irradiance responsivity under standard test conditions,

f) the function of the temperature coefficient of the spectral responsivity and

g) the value of the temperature coefficient of the short-circuit under standard test conditions

for a reference solar cell.

2. Measurement object

The object of the calibration is a reference solar cell in WPVS design, composed of the actual solar cell with a plane light entry surface of approx. 20 x 20 mm² and a Pt100 temperature sensor, installed in a metal housing. The calibration mark must be applied to its side. The electrical connections of the solar cell and of the temperature sensor are introduced at four points on socket connectors.

3. Measurement procedure

A constant irradiance responsivity $s = I_{\mathrm{sc}}(E)/E$ is determined from short-circuit current $I_{\mathrm{sc}}(E)$ and associated irradiance E. However, for a reference solar cell with non-linear behaviour, the differential irradiance responsivity $\tilde{s}(E_{\mathrm{b}})$ in the presence of a bias irradiance E_{b} must be taken into account.

$$\tilde{s}(E_{\mathrm{b}}) = \left.\frac{\partial I_{\mathrm{sc}}(E)}{\partial E}\right|_{E_{\mathrm{b}}}$$

Spectrally resolved (wavelength λ), the differential spectral irradiance responsivity $\tilde{s}(\lambda, E_{\mathrm{b}})$ provides the basis for the calculation of the quantities to be calibrated, taking prescribed standard test conditions (index STC) into account. It is determined by spectroradiometry in accordance with the DSR method (Differential Spectral Responsivity Method).

The DSR method is a two-beam procedure and makes simultaneous use of:

(i) a stationary **bias irradiation** with irradiances E_b which are not, however, explicitly measured. Its variation over more than 2 powers of ten causes short-circuit direct currents $I_{sc}(E_b)$ which are measured, as well as

(ii) a quasi-monochromatic **measurement radiation modulated with time.** Its irradiance is determined with reference radiometers (silicon photodiode or radiation thermopile as receiver, depending on the spectral range) whose functional values of the spectral radiant power responsivities as well as their diaphragm size have been traced back to national standards.

a) The **value of the absolute differential spectral irradiance responsivity** $\tilde{s}(\lambda_0, I_{sc}(E_0))$ is measured at the lowest bias irradiance E_0 which generates the short-circuit current $I_{sc}(E_0)$. As measurement radiation at the wavelength λ_o, a quasi-monochromatic homogeneous radiation field is used, and the reference radiometer (without bias radiation) and the reference solar cell (together with bias radiation) are irradiated alternately.

b) The values of the two-dimensional **function of the relative differential spectral irradiance responsivity** $\tilde{s}_{rel}(\lambda, I_{sc}(E_b))$ are determined by

- variation of both the bias irradiance and the wavelength of the measurement radiation which is separated with the aid of a grating double monochromator, the wavelength range being covered by two radiation sources, i.e. a halogen lamp for $\lambda \geq 600\,\mathrm{nm}$ and an Xe arc lamp for $\lambda \leq 720\,\mathrm{nm}$ as well as
- standardization to 1 at the working point $(\lambda_0, I_{sc}(E_0))$ from 3a); thus, the following is valid: $\tilde{s}_{rel}(\lambda_0, I_{sc}(E_0)) = 1$.

The function of the **(absolute) differential spectral irradiance responsivity**

$$\tilde{s}(\lambda, I_{sc}(E_b)) = \tilde{s}(\lambda_0, I_{sc}(E_0)) \cdot \tilde{s}_{rel}(\lambda, I_{sc}(E_b))$$

is defined as the product of the absolute value according to 3a) and the relative function defined before. Interim values of the function are linearly interpolated.

c) The **function of the differential irradiance responsivity** $\tilde{s}_{AMx}(I_{sc}(E_b))$ **assessed in accordance with AMx** as a function of the short-circuit current is obtained after assessment of the differential spectral irradiance responsivity with a spectral irradiance $E_{\lambda,\,AMx}(\lambda)$ and integration over the whole wavelength range.

$$\tilde{s}_{\mathrm{AMx}}\left(I_{\mathrm{sc}}\left(E_{\mathrm{b}}\right)\right)=\tilde{s}\left(\lambda_0,I_{\mathrm{sc}}\left(E_0\right)\right)\cdot\frac{\int_0^\infty \tilde{s}_{\mathrm{rel}}\left(\lambda,I_{\mathrm{sc}}\left(E_{\mathrm{b}}\right)\right)\cdot E_{\lambda,\,\mathrm{AMx}}\left(\lambda\right)\,\mathrm{d}\lambda}{\int_0^\infty E_{\lambda,\,\mathrm{AMx}}\left(\lambda\right)\,\mathrm{d}\lambda}.$$

d) The values for the standard test condition are indicated in the measurement conditions (see 4.i)). The associated **value of the short-circuit current under standard test conditions** $I_{\mathrm{STC}}=I_{\mathrm{sc}}(E_{\mathrm{STC}})$ is obtained in accordance with the following formula by approximation of the upper integration limit I_{STC} so that the value of the integral furnishes the irradiance E_{STC}.

$$E_{\mathrm{STC}}=\int_0^{I_{\mathrm{STC}}}\frac{\mathrm{d}I_{\mathrm{sc}}}{\tilde{s}_{\mathrm{AM1.5}}\left(I_{\mathrm{sc}}\right)} \quad \text{with AMx = AM1.5}$$

Notes:

i) The irradiance responsivity of the solar cell under standard test conditions s_{STC} is now obtained by definition from the quotient from current and irradiance:

$$s_{\mathrm{STC}}=I_{\mathrm{STC}}/E_{\mathrm{STC}}$$

ii) An integration of the reciprocal of the function of the differential irradiance responsivity assessed in accordance with AMx $1/\tilde{s}_{\mathrm{AMx}}\left(I_{\mathrm{sc}}\right)$ via the short-circuit current I_{sc} up to the measured value of the short-circuit current $I_{\mathrm{sc}}\left(E_{\mathrm{b}}\right)$ as solid upper integration limit furnishes the value assessed in accordance with AMx of the associated bias irradiance

$$E_{\mathrm{b,\,AMx}}=\int_0^{I_{\mathrm{sc}}\left(E_{\mathrm{b}}\right)}\frac{\mathrm{d}I_{\mathrm{sc}}}{\tilde{s}_{\mathrm{AMx}}\left(I_{\mathrm{sc}}\right)}.$$

e) Accordingly, the **function of the absolute spectral irradiance responsivity is determined under standard test conditions** $s_{\mathrm{STC}}\left(\lambda\right)$ for each wavelength by integrating the reciprocal of the function of the differential spectral irradiance responsivity $\tilde{s}\left(\lambda,I_{\mathrm{sc}}\left(E_{\mathrm{b}}\right)\right)$ up to the short-circuit current calculated before under standard test conditions and subsequent formation of the quotient:

$$s_{\mathrm{STC}}(\lambda)=\frac{I_{\mathrm{STC}}}{\int_0^{I_{\mathrm{STC}}}\frac{\mathrm{d}I_{\mathrm{sc}}}{\tilde{s}\left(\lambda,I_{\mathrm{sc}}\right)}}.$$

For control purposes, the spectral irradiance responsivity can now be multiplied by the spectral irradiance $E_{\lambda,\mathrm{AM1.5}}\left(\lambda\right)$ and integrated over the whole wavelength range. The result is the short-circuit current under standard test conditions I_{STC}.

f) The **function of the temperature coefficient of the spectral responsivity** $T_C(\lambda)$ is determined from the spectral responsivity at solar cell temperatures of 20°C, 25°C and 30°C.

g) The **value of the temperature coefficient of the short-circuit current under standard test conditions** is calculated from the function of the temperature coefficient of the spectral responsivity obtained under f), the function of the absolute spectral responsivity under standard test conditions obtained under e) and the reference spectrum.

4. Measurement conditions

i) Standard test conditions according to CEI IEC 60904-3:2008:

- the spectral irradiance $E_{\lambda,\,\mathrm{AMx}}(\lambda)$ for assessment is given by the AM1.5 reference solar spectrum $E_{\lambda,\,\mathrm{AM1.5}}(\lambda)$
- the associated irradiance amounts to $E_{\mathrm{STC}} = 1000 \quad \mathrm{W \cdot m^{-2}}$
- the temperature of the reference solar cell amounts to 25°C

ii) The temperature of the solar cell is measured with the incorporated Pt100 measuring resistor and constantly controlled to values in the interval (25 ± 0.2) °C, whereby the nominal value of the Pt100 resistor of 100 Ohm at 0 °C is used as a basi s. During the assessment, the photo currents are corrected with the aid of the temperature coefficient to the value expected at 25°C. The ambient temperature lies between 24°C and 26°C.

iii) During the measurement, the bias radiation is constant with time, illuminates the reference solar cell homogeneously and has a spectral distribution similar to that of the sun.

iv) The measurement radiation illuminates the reference solar cell and is modulated by a chopper with 78.9 Hz. It is formed as a slightly divergent beam with an aperture angle between the marginal rays of maximally 5° and has a quasi-monoc hromatical spectral distribution which is adjusted in the spectral range $280\ \mathrm{nm} \le \lambda \le 1200\ \mathrm{nm}$ in steps of 5 nm, with a spectral bandwidth (half-value full width) of

$$\Delta\lambda = \begin{cases} 5 \ \ \mathrm{nm\ for\ 280\ nm} \le \lambda \le 680\ \mathrm{nm} \\ 10 \ \ \mathrm{nm\ for\ 680\ nm} \le \lambda \le 1200\ \mathrm{nm} \end{cases} .$$

v) Measurement geometry: The front face of the actual solar cell is the reference plane for the irradiance and the beam-alignment axis of the measuring radiation is aligned vertically and centrically to it.

vi) The short-circuit current is measured with a current-voltage converter which is connected with the four connections on the solar cell housing via two current and potential connections each (four-wire method) and keeps the terminal voltage smaller than $100\ \mu\mathrm{V}$.

5. Measurement results:

a) The value of the absolute differential spectral irradiance responsivity according to section 3a) amounts to:

$$\tilde{s}(\lambda_0, I_{sc}(E_0)) = \text{X}\ \text{mA} \cdot \text{W}^{-1} \cdot \text{m}^2 \quad \text{with} \quad \lambda_0 = 546.1\ \text{nm}$$

$$I_{sc}(E_0) = \text{X mA}$$

The associated expanded measurement uncertainty amounts to:

$$U(\tilde{s}(\lambda_0, I_{sc}(E_0))) = \text{X}\ \text{mA} \cdot \text{W}^{-1} \cdot \text{m}^2$$

b) In the following table, the function of the relative differential spectral irradiance responsivity is indicated $\tilde{s}_{rel}(\lambda, I_{sc}(E_b))$ according to 3b) and the associated expanded measurement uncertainty is stated for different short-circuit currents.

Wave length λ/nm	Relative differential spectral irradiance responsivity $\tilde{s}_{rel}(\lambda, I_{sc}(E_b))/1$ and $U(\tilde{s}_{rel}(\lambda, I_{sc}(E_b)))/1$							
	$I_{sc}(E_b)$ = 0. mA		$I_{sc}(E_b)$ = , mA		$I_{sc}(E_b)$ = , mA		$I_{sc}(E_b)$ = , mA	
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Wave length $\lambda/_{\text{nm}}$	Relative differential spectral irradiance responsivity $\tilde{s}_{\text{rel}}\left(\lambda, I_{\text{sc}}\left(E_{\text{b}}\right)\right)\big/1$ and $U\left(\tilde{s}_{\text{rel}}\left(\lambda, I_{\text{sc}}\left(E_{\text{b}}\right)\right)\right)\big/1$							
	$I_{\text{sc}}(E_{\text{b}})$ = , mA		$I_{\text{sc}}(E_{\text{b}})$ = , mA		$I_{\text{sc}}(E_{\text{b}})$ = , mA		$I_{\text{sc}}(E_{\text{b}})$ = , mA	
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Note:

The function of the absolute differential spectral irradiance responsivity according to section 3b) is calculated in accordance with the formula

$$\tilde{s}(\lambda, I_{\mathrm{sc}}(E_{\mathrm{b}})) = \tilde{s}(\lambda_0, I_{\mathrm{sc}}(E_0)) \cdot \tilde{s}_{\mathrm{rel}}(\lambda, I_{\mathrm{sc}}(E_{\mathrm{b}}))$$

For the associated expanded measurment uncertainty, the following formula is valid:

$$U(\tilde{s}(\lambda)) = k \cdot \sqrt{u^2\left(\tilde{s}\left(\lambda_0, I_{\mathrm{sc}}(E_0)\right)\right) \cdot \tilde{s}_{\mathrm{rel}}{}^2\left(\lambda, I_{\mathrm{sc}}(E_{\mathrm{b}})\right) + u^2\left(\tilde{s}_{\mathrm{rel}}\left(\lambda, I_{\mathrm{sc}}(E_{\mathrm{b}})\right)\right) \cdot \tilde{s}^2\left(\lambda_0, I_{\mathrm{sc}}(E_0)\right)} \quad ; \text{with } k=2 .$$

It must be taken into account that, due to the joint measuring set-up for all measurement points, and due to the spectral bandwidth used, the measurement uncertainties of all values - and especially of neighboured values - are correlated.

c) Function of the differential irradiance responsivity assessed in accordance with AM1.5 $\tilde{s}_{\mathrm{AM1.5}}(I_{\mathrm{sc}}(E_{\mathrm{b}}))$ as a function of the short-circuit current $I_{\mathrm{sc}}(E_{\mathrm{b}})$ generated by the bias irradiance E_{b} according to section 3c):

Short-circuit current	Differential irradiance responsivity	
$I_{\mathrm{sc}}(E_{\mathrm{b}}) / \mathrm{mA}$	$\tilde{s}_{\mathrm{AM1.5}}(I_{\mathrm{sc}}(E_{\mathrm{b}})) / \mu\mathrm{A}\cdot\mathrm{W}^{-1}\cdot\mathrm{m}^2$	$U(\tilde{s}_{\mathrm{AM1.5}}(I_{\mathrm{sc}}(E_{\mathrm{b}}))) / \mu\mathrm{A}\cdot\mathrm{W}^{-1}\cdot\mathrm{m}^2$

d) The value of the short-circuit current under standard test conditions I_{STC} according to section 3d) amounts to

I_{STC} = X mA

The associated expanded measurement uncertainty amounts to:

$U(I_{\mathrm{STC}})$ = X mA

Only for comparison: According to the obsolete standard IEC 60904-3:1989, the value of the short-circuit current under standard test conditions amounts to $I_{\mathrm{STC:1989}}$ = X mA ± X mA.

e) The **function of the absolute spectral irradiance responsivity** $s_{\mathrm{STC}}(\lambda)$ under standard test conditions according to section 3e), related to an irradiance $E_{\mathrm{STC}} = 1000\,\mathrm{W}\cdot\mathrm{m}^{-2}$ is:

Wavelength	Absolute spectral irradiance responsivity	
λ / nm	$\frac{s_{\mathrm{STC}}(\lambda)}{\mathrm{mA} \cdot \mathrm{W}^{-1} \cdot \mathrm{m}^2}$	$\frac{U(s_{\mathrm{STC}}(\lambda))}{\mathrm{mA} \cdot \mathrm{W}^{-1} \cdot \mathrm{m}^2}$
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f) The **function of the temperature coefficient of the spectral responsivity** $T_C(\lambda)$ is stated in the following table.

Wavelength	Temperature coefficient	
λ / nm	$\frac{T_C}{\%\mathrm{K}^{-1}}$	$\frac{U(T_C)}{\%\mathrm{K}^{-1}}$
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g) **The value of the temperature coefficient of the short-circuit under standard test conditions**

The temperature coefficient of the short-circuit current under standard test conditions according to section 3g) amounts to:

$T_C(I_{STC})$ = X ppm/K

The associated expanded measurement uncertainty amounts to:

$U(T_C(I_{STC}))$ = X ppm/K

The uncertainty stated is the expanded uncertainty of measurement obtained by multiplying the standard uncertainty by the coverage factor k = 2. It has been determined in accordance with the "Guide to the Expression of Uncertainty in Measurement" (ISO, 1995). In the case of a normal distribution of the deviations from the measurement value, it corresponds to a coverage probability of 95%.

Die Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig und Berlin ist das nationale Metrologieinstitut und die technische Oberbehörde der Bundesrepublik Deutschland für das Messwesen und Teile der Sicherheitstechnik. Die PTB gehört zum Dienstbereich des Bundesministeriums für Wirtschaft und Technologie. Sie erfüllt die Anforderungen an Kalibrier- und Prüflaboratorien auf der Grundlage der DIN EN ISO/IEC 17025.

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Zur Sicherstellung der weltweiten Einheitlichkeit der Maße arbeitet die PTB mit anderen nationalen metrologischen Instituten auf regionaler europäischer Ebene in EURAMET und auf internationaler Ebene im Rahmen der Meterkonvention zusammen. Das Ziel wird durch einen intensiven Austausch von Forschungsergebnissen und durch umfangreiche internationale Vergleichsmessungen erreicht.

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It is fundamental task of the PTB to realize and maintain the legal units in compliance with the International System of Units (SI) and to disseminate them, above all within the framework of legal and industrial metrology. The PTB thus is on top of the metrological hierarchy in Germany. Calibration certificates issued by it document that the object calibrated is traceable to national standards.

To ensure worldwide coherence of measures, the PTB cooperates with other national metrology institutes within EURAMET on the regional European level and on the international level within the framework of the Metre Convention. The aim is achieved by an intensive exchange of results of research work carried out and by comprehensive international comparison measurements.