IEC 60904-2

Edition 3.0 2015-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Photovoltaic devices –
Part 2: Requirements for photovoltaic reference devices

Dispositifs photovoltaïques –
Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.160

ISBN 978-2-8322-2184-6

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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International Standard IEC 60904-2 has been prepared by IEC Technical Committee 82: Solar photovoltaic energy systems.

This third edition cancels and replaces the second edition, published in 2007. It constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

– addition of a test procedure in simulated sunlight of subsequent measurement of primary and secondary reference device;
– definition of standard test conditions;
– reduction of allowed diffuse component for secondary reference cell calibration to 20 %.

The text of this standard is based on the following documents:

FDIS	Report on voting
82/893/FDIS	82/918/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60904 series, published under the general title *Photovoltaic devices*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

PHOTOVOLTAIC DEVICES –

Part 2: Requirements for photovoltaic reference devices

1 Scope

This part of IEC 60904 gives requirements for the classification, selection, packaging, marking, calibration and care of photovoltaic reference devices.

This standard covers photovoltaic reference devices used to determine the electrical performance of photovoltaic cells, modules and arrays under natural and simulated sunlight. It does not cover photovoltaic reference devices for use under concentrated sunlight.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60891, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

IEC 60904-1, *Photovoltaic devices – Part 1: Measurements of photovoltaic current-voltage characteristics*

IEC 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 60904-4, *Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability*

IEC 60904-5, *Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

IEC 60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

IEC 60904-8, *Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of linearity measurement*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and the following apply.

3.1
calibration traceability
traceability as defined in IEC 60904-4

Note 1 to entry: Photovoltaic reference devices are distinguished by their position in a chain of calibration traceability.

3.2
primary reference device
photovoltaic reference device whose calibration is based on a radiometer or standard detector or standard light source traceable to SI units as defined in IEC 60904-4

3.3
secondary reference device
photovoltaic reference device calibrated in natural or simulated sunlight against a primary reference device

3.4
working reference device
photovoltaic reference device calibrated in natural or simulated sunlight against a secondary reference device

3.5
reference devices
specially calibrated photovoltaic devices which are used to measure natural or simulated irradiance or to set simulator irradiance levels for measuring the performance of other photovoltaic devices

3.6
reference cell
single photovoltaic cell used primarily for transfer of calibration values

Note 1 to entry: For practical reasons, such cells are small in surface area, and are usually mounted on a fixture which ensures reproducibility in mounting, thermal control and electrical connections. A typical sample is sketched in Figure 1.

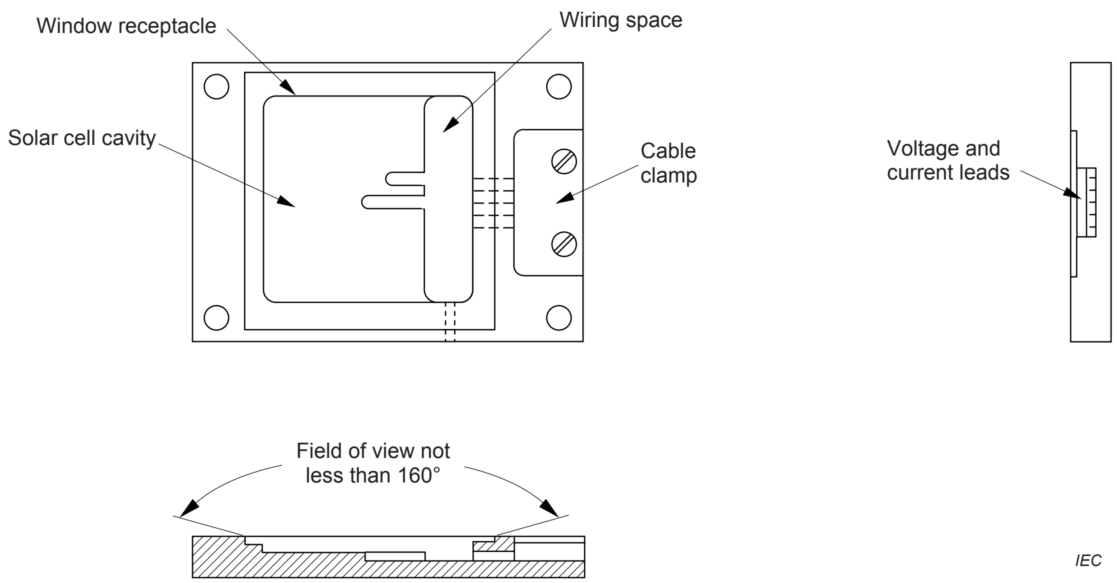

Figure 1 – Single-cell package

3.6.1
reference cell with protective cover but without encapsulant
photovoltaic reference cell similar to 3.6, but provided with a protective cover

Note 1 to entry: Recommended use: as a laboratory primary, secondary and working reference, in particular when measuring the performance of other photovoltaic devices using solar simulators or natural sunlight with direct beam only.

3.6.2
encapsulated reference cell
photovoltaic reference cell similar to 3.6, but encapsulated in a protective assembly so as to withstand short-term outdoor exposure

Note 1 to entry: Recommended use: as a laboratory primary, secondary and working reference, in particular when measurements of the performance of other photovoltaic devices under natural sunlight are performed.

Note 2 to entry: If the encapsulation system has been demonstrated to withstand long-term outdoor exposure, applying test levels according to IEC 61215, such reference cells may also be suitable to be used as a monitoring device for long-term assessment of operational photovoltaic arrays.

3.7
multi-cell reference devices
photovoltaic device consisting of several photovoltaic cells

Note 1 to entry: Recommended use: as the diffuse component of natural sunlight and non-normal incidence of simulated sunlight interact with encapsulants and back sheets of a module and influence the amount of irradiance which a particular cell receives, it is recommended that reference devices used for measuring sub-assemblies of modules and arrays be encapsulated in a multi-cell package, matching the mechanical and optical features of the test specimen (module, sub-assemblies of modules, arrays) so as to respond to variations in the geometrical distribution of the incident radiation in the same way as the test specimen.

3.8
single reference cell in a multi-cell package
single photovoltaic cell mounted in such a package that frame, encapsulation system, shape, size and spacing of the cells surrounding it are the same as in the module to be tested

Note 1 to entry: The surrounding cells may be real or dummies that have the same optical properties.

3.9
reference module
photovoltaic module consisting of the encapsulation of a series and/or parallel connection of photovoltaic cells

Note 1 to entry: Recommended use: for measuring other modules in order to achieve correspondence of dimensions, mechanical construction, optical properties and electrical circuitry of the reference module and test module, so as to minimize discrepancies due to simulator non-uniformity, internal reflections or temperature distribution.

3.10 built-in shunt resistors
resistor connected across the output terminals of photovoltaic devices

Note 1 to entry: The resistor shunts the output of the photovoltaic device providing an output voltage to be measured and avoiding user-provided means of establishing short circuit condition.

4 Selection of reference device

4.1 General requirements

Depending on their intended use, reference devices need to meet different requirements in terms of their spectral responsivity, mechanical construction, optical properties, dimensions and electrical circuit. The spectral responsivity of the reference device, for example, is determined by the transmission of any protective cover in front of the device and the spectral responsivity of the device itself. Therefore the overall spectral responsivity can be adapted by using suitable filters as or in addition to the protective cover.

A reference device shall meet the following requirements:

a) photovoltaic characteristics shall be stable according to the requirements in Clause 11;

b) the output signal of the reference device shall vary linearly with irradiance, as defined in IEC 60904-10, over the range of interest.

4.2 Additional requirements for single reference cell in a multi-cell package

The dotted line in Figure 2 indicates the minimum acceptable size of a multi-cell package.

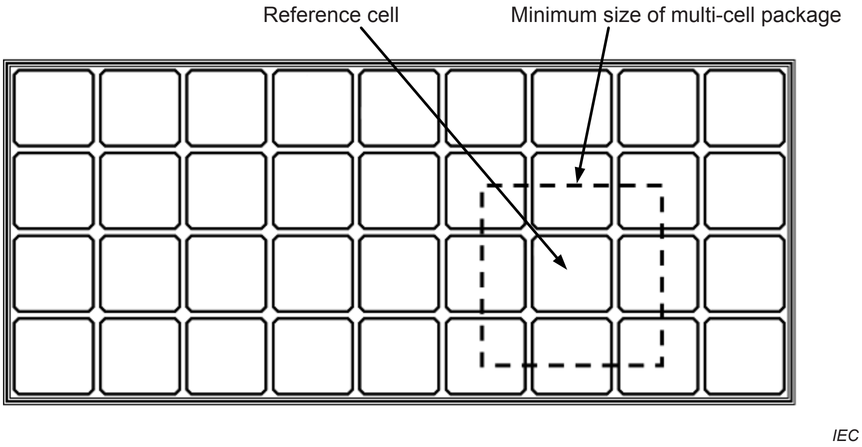

Figure 2 – Single reference cell in a multi-cell package

4.3 Additional requirements for reference modules

Additional requirements apply to reference modules:

a) Bypass diodes:
   - general reference modules, that are used to measure a range of module types and geometries, should not contain bypass diodes. The presence or absence of bypass diodes shall be noted and considered in conjunction with the measurement conditions, in particular spatial non-uniformity of the irradiance on the module during measurement;
   - for reference modules, that are intended to be matched to the module under test, the number, type and connection of bypass diodes (if present) shall match those in the module under test.

b) If they are made from discrete cells, these shall be matched as follows depending on the intended use of the reference module:
   - if only the short circuit current of the reference module will be used the short circuit current of the individual cells shall be matched to within ± 1 %;
   - if other parameters (such as maximum power) are used additionally or exclusively, both the short circuit current and the fill factor of the individual cells shall be matched to within ± 1 %.

   The matching of the individual cells is the responsibility of the manufacturer of the reference module, bearing in mind that matching may also be influenced by encapsulation or lamination. The cell matching needs not be checked by the calibration laboratory. However, if I-V curves of the reference module indicate inconsistent response (i.e. steps are noted in the I-V curve), the I-V curve should be measured under light that is known to be uniform (e.g. natural sunlight) to determine whether there is evidence that the cells within the module are matched within 1 %. If the module exhibits evidence of > 1 % mismatch between cells, the module shall not be used as reference module.

4.4 Requirements for built-in shunt resistors

The resistor shall be chosen such as to ensure that the reference device operates sufficiently near to short-circuit condition, meeting the requirement:

$$I_{SC} \times R_{CAL} < 0{,}03 \times V_{OC} \quad (1)$$

where

R_{CAL} is the shunt resistor;

I_{SC} is the short circuit current of the reference device at reference conditions;

V_{OC} is the open circuit voltage at reference conditions.

If a shunted reference cell does not meet the requirement of formula (1), it shall only be used at irradiances (± 5 %) and temperatures (± 2 ºC) at which it was calibrated.

The long-term stability of such resistors shall also meet the stability requirements of the reference device. Calibration values of such reference devices shall be measured as the voltage drop across the shunt resistor and stated with the dimension [V] at standard test conditions (see Clause 7). The temperature coefficient of the built-in shunt resistor is part of the temperature coefficient of the calibration value of the reference device. As the uncertainty in the calibration may be strongly dependent on the shunt resistor stability and temperature coefficient, respective values should be provided with the reference cell data sheet.

If a shunted reference cell is to be used for low irradiance measurements, either a dedicated cell can be constructed with the restriction of formula (1), where the short circuit current is considered at the desired low irradiance rather than at STC. Alternatively a shunted cell can have a larger shunt resistor, but requires a separate calibration for each irradiance and temperature it is to be used at.

It is recommended that the shunt resistor be a removable 4-wire resistor, to allow for periodic checking of the reference device stability by taking an I-V curve per IEC 60904-1.

Formula (1) means that the measured output voltage of a shunted reference cell shall be less than 3 % of its open circuit voltage. For typical crystalline Silicon this equates to about 20 mV output.

5 Temperature measurement

Means shall be provided for determining the reference cell temperature or, for reference modules, the equivalent cell temperature (ECT), according to IEC 60904-5. The required uncertainty for temperature measurements shall be less than ± 2,0 °C for all reference devices. A minimum accuracy of ±1,0 °C for the temperature sensor is suggested to achieve this uncertainty in the temperature measurement.

6 Electrical connections

The electrical connections to reference cells shall consist of a four-wire contact system (Kelvin probe). Care shall be taken to avoid measurement errors due to voltage drops along the cell’s contact bars and the package wiring.

The electrical connections to the reference module shall be designed to meet the requirements of IEC 60904-1.

7 Calibration

Each reference device shall be calibrated in terms of its calibration value at the desired reference conditions, normally standard test conditions (STC) (1 000 W·m^{-2}, 25 ºC device temperature with the reference spectral irradiance distribution as defined in IEC 60904-3).

Methods for calibrating primary reference devices are included in IEC 60904-4. A method of calibrating secondary reference devices is described in Clause 12. The calibration of working reference devices is treated in Clause 13.

The spectral responsivity at short-circuit current conditions of each reference device shall be measured in accordance with IEC 60904-8. If for reference modules this cannot be measured directly, it shall be deduced from measurements made on representative encapsulated photovoltaic cells.

The temperature coefficient of each reference device shall be measured in accordance with IEC 60891.

8 Report

Each time a reference device is calibrated, the following information shall be recorded on a data sheet:

- Identification number
- Type (primary reference cell; secondary reference device, working reference device)
- Cell manufacturer
- Material type
- Type of package
- Type and dimension of cell(s)
- Circuit diagram, in particular of any connectors
- Calibration organization
- Site and date of calibration
- Method of calibration (refer to standard)
- Radiometer or standard lamp characteristics (where applicable)
- Primary reference cell identification (where applicable)
- Simulator characteristics (where applicable)
- Type of temperature sensor (where applicable)
- Spectral responsivity
- Temperature coefficient of calibration value
- Calibration value at reference conditions
- Reference conditions
- Estimated uncertainty
- Shunt resistor nominal resistance and temperature coefficient (where applicable)
- Either the mismatch correction value used in the measurement or an estimate of the uncertainty introduced by using the mismatched reference device.

For reference cells without fixed electrical connection to the cell, the following information shall be recorded on the data sheet:

- Illustration of type, shape and location of electrical contacts during calibration.

For reference modules, the following information shall be recorded in addition on the data sheet:

- manufacturer
- model designation
- serial number

– cell technology
– construction and dimensions of module
– electrical circuit layout
– presence or absence of bypass diodes and if present their number and type.

9 Marking

The reference device shall carry a clear, indelible serial or identification number for cross-reference to its data sheet.

10 Packaging

10.1 Recommended packaging for use in natural sunlight

The reference device used for measurement in natural sunlight should respond to variations in the geometrical distribution of the incident radiation in the same way as the test specimens (cells, sub-assemblies of cells, modules). As encapsulants and back sheets respond to the diffuse component of natural sunlight, it is recommended that reference cells used for measuring modules be enclosed in a multi-cell package (see Figure 2), simulating the neighbouring optical parameters of a module.

In this case, the frame, the encapsulation system, the shape, and the size and spacing of the cells surrounding the reference cell shall be the same as in the module to be tested. The surrounding cells may be real or dummies that have the same optical properties. The dotted line in Figure 2 indicates the minimum acceptable size of the multi-cell package for outdoor testing.

10.2 Recommended packaging for use under solar simulators

In some simulators which allow multiple reflections of light to and from the test specimen, the irradiance in the test plane may change depending on whether or not the test specimen is present. Therefore, in order to measure accurately the irradiance that will be present when the test specimen is in place, the reference devices used in such simulators shall be packaged in the same way as the test specimen, so that the change in irradiance due to multiple reflections is the same for both the reference device and the test specimen.

Reference cells used for measurements in simulators designed to minimize any error from multi-reflected light may be packaged singly or, if not intended for day-to-day use, mounted in the unpackaged state on a temperature controlled block.

Alternatively, the requirements given for reference cells for use in natural sunlight may be followed.

10.3 Single cell package

If a single cell package is used, the following recommendations are made:

a) The field of view should be at least 160°.
b) All surfaces in the package within the cell’s field of view should be non-reflective, with an absorption of at least 0,95 in the cell’s wavelength responsivity band.
c) The material used for bonding the cell to the holder should be resistant to degradation, either electrically or optically. Its physical characteristics should remain stable over the entire period of intended use.
d) The use of a protective window is recommended. If encapsulated, the space between the window and the cell should be filled with a stable encapsulant. Both the protective window and the encapsulant should be transparent over the wavelength range in which the PV

reference device has a non-zero spectral responsivity. The refractive index of the encapsulant should be similar (within 10 %) to that of the window to minimize errors due to the internal reflection of light. The transparency, homogeneity and adhesion of the encapsulant should not be adversely affected by ultra-violet light and operational temperatures.

e) The protective window may embody a filter to match the spectral responsivity of the reference cell to that of the test specimen, provided that the other requirements of d) are met.

Figure 1 shows an example of a suitable single cell package. Other suitable single cell packages can be found in JIS C8910 or the World Photovoltaic Scale (see Bibliography).

11 Care of reference devices

It is recommended that reference devices be recalibrated on an annual basis.

The window of a packaged reference device shall be kept clean and scratch-free.

Uncovered reference cells shall be preserved against damage, contamination and degradation.

A reference device exhibiting any defect which might impair its function shall not be used.

The calibration value of a reference device might change systematically as a function of time for successive calibrations. If the calibration value of a reference device has changed by more than 1 % with respect to its previous calibration or by more than 5 % of its initial calibration, it shall not be used as a reference device.

12 Calibration of secondary reference devices against a primary reference cell

12.1 General

This Clause describes a procedure for calibrating a secondary reference device in natural or simulated sunlight against a primary reference cell whose calibration is traceable to SI units according to IEC 60904-4. The spectral responsivity mismatch between the primary reference cell and that of the secondary reference device under the illumination used for the calibration shall be determined according to IEC 60904-7. If the spectral mismatch correction is less than 1 %, the mismatch correction may be omitted.

The procedure can be applied using both natural and simulated sunlight according to the requirements in IEC 60904-1 with the following restrictions.

12.2 Natural sunlight

Calibration in natural sunlight shall be carried out under the following conditions:

a) Clear, sunny weather, with the diffuse irradiance not greater than 20 % of the global irradiance.

b) No observable cloud formations.

c) Total irradiance (sun + sky + ground reflection) not less than 800 $W \cdot m^{-2}$, as measured by the primary reference cell.

d) Air mass between AM1 and AM2.

e) Radiation sufficiently stable so that the variation in reference cell output signal is less than ± 0,5 % over the time taken for a measurement.

12.3 Simulated sunlight

The simulated sunlight for calibration can either be continuous or pulsed. Normally the primary reference cell and the secondary reference device are positioned side by side and measured simultaneously. In this case the simulator shall be of Class AAA in accordance with IEC 60904-9 with the additional requirement that the non-uniformity of irradiance is less than ± 1 % within the surface that includes the device to be calibrated and the primary reference device. The requirement of class A with respect to temporal instability as defined in IEC 60904-9 needs only be met for the short term instability (STI) as the long term instability (LTI) is not relevant in this case. In case that the primary and secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0), an additional measurement shall be taken exchanging their positions. A valid result is only obtained if both measurements agree within the measurement uncertainty.

If the requirement of non-uniformity of less than ± 1 % cannot be met for calibrating reference modules made from a series connection of cells, the simulator shall be class A for spatial non-uniformity and a detailed uncertainty analysis shall be provided taking into account mismatch in short-circuit current of the individual cells.

In the special case that the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and that the continuous simulated sunlight is stable, the two devices can be placed in the same position one after the other and measured consecutively. In this case the simulator shall be of Class AAA in accordance with IEC 60904-9 with the additional requirement that the LTI of irradiance is less than ± 1 %, where the LTI is with respect to the total time period needed for the measurements. A pulsed solar simulator may also be suitable if the repeatability of each pulse is better than 1 %. This shall be recorded using a suitable monitor cell.

In any case a detailed measurement uncertainty analysis considering both, spatial and temporal non-uniformity of the simulated sunlight needs to be provided, considering the specifics of the chosen measurement strategy.

12.4 Test procedure

12.4.1 Before the intial calibration, measure the spectral responsivity and temperature coefficient of short circuit current of the secondary reference device, using the procedures specified in IEC 60904-8 and IEC 60891, respectively. Whenever a change in the calibration value at the reference conditions of more than 2 % with respect to this initial calibration is detected, the measurements of spectral responsivity and temperature coefficient shall be repeated.

12.4.2 Adjust the mount so that the devices are normal to the light source within ± 5°.

– Mount the primary reference cell and the secondary reference device co-planar within ± 1° and in close proximity on the same mount (for simultaneous measurement).
– Mount the primary reference cell in the designated position (for consecutive measurement).

12.4.3 Control the cell temperature of both the primary reference cell and the secondary reference device at (25 ± 2) °C. Where this is not practical, readings of output signal shall be subsequently corrected to 25 °C in accordance with IEC 60891.

12.4.4 The spectral mismatch shall be corrected according to IEC 60904-7. Appropriate measurements of the specral irradiance shall be recorded.

12.4.5 Record simultaneous readings of the output signal and temperature:

– of both primary reference cell and secondary reference device (for simultaneous measurement),
– of the primary reference cell, (for consecutive measurement).

12.4.6 Repeat step 12.4.5 until five successive sets of readings are obtained in which:

– the ratio of the output signals (corrected to 25 °C and for spectral mismatch as required) does not vary by more than ± 0,5 % (for simultaneous measurement),

– the output signals for the primary reference cell (corrected to 25 °C and for spectral mismatch as required) do not vary by more than ± 0,5 %; then remove primary reference cell and mount the secondary reference device in the same position and repeat step 12.4.5 with the same constraints as for the primary reference cell (for consecutive measurement).

12.4.7 If the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and are measured simultaneously, exchange the position between the primary reference cell and the secondary reference device and repeat steps 12.4.5 and 12.4.6.

12.4.8 When calibrating in natural sunlight, steps 12.4.2 to 12.4.6, inclusive, shall be performed at least twice a day on at least three separate days.

12.4.9 From the acceptable data, calculate the ratio:

$$\frac{\text{Output signal of secondary reference device at 25 °C}}{\text{Output signal of primary reference cell at 25 °C}}$$

12.4.10 Multiply the calibration value of the primary reference cell by the calculated:

– mean of the ratios (for simultaneous measurement);

– ratio of the means of the output signals (for consecutive measurement),

to obtain the calibration value of the secondary reference device. If measurements have been taken with the positions of the primary reference cell and the secondary reference device exchanged, calculate the calibration value for both cases. The results are only valid if both agree within the measurement uncertainty. Both values are to be reported and their geometric average is to be used as the calibration value.

13 Calibration of working reference device against a secondary reference device

For calibration of a working reference device against secondary reference device the above procedure may be applied, omitting the spectral mismatch correction if the secondary and working reference are of the same material and construction, otherwise the same procedure as described in Clause 12 should be applied.

Bibliography

JIS C8910, *Primary reference solar cells*

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