



Designation: E 973 – 02

Standard Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell¹

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1. Scope

1.1 This test method covers a procedure for the determination of a spectral mismatch parameter used in performance testing of photovoltaic devices.

1.2 The spectral mismatch parameter is a measure of the error, introduced in the testing of a photovoltaic device, caused by mismatch between the spectral responses of the photovoltaic device and the photovoltaic reference cell, as well as mismatch between the test light source and the reference spectral irradiance distribution to which the photovoltaic reference cell was calibrated. Examples of reference spectral irradiance distributions are Tables E 490 or G 159.

1.3 The spectral mismatch parameter can be used to correct photovoltaic performance data for spectral mismatch error.

1.4 This test method is intended for use with linear photovoltaic devices.

1.5 There is no similar or equivalent ISO Standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 The values stated in SI units are to be regarded as the standard.

2. Referenced Documents

2.1 ASTM Standards:

E 490 Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables²

E 772 Terminology Relating to Solar Energy Conversion³

E 948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight³

E 1021 Test Methods for Measuring Spectral Response of Photovoltaic Cells³

¹ This test method is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal, and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

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² Annual Book of ASTM Standards, Vol 15.03.

³ Annual Book of ASTM Standards, Vol 12.02.

E 1036 Test Methods for Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Modules and Arrays using Reference Cells³

E 1039 Test Method for Calibration of Silicon Non-Concentrator Photovoltaic Primary Reference Cells Under Global Irradiation³

E 1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum³

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion³

E 1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells³

G 138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance⁴

G 159 Tables for References Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface⁴

SI 10 Standard for Use of the International System of Units (SI): The Modern Metric System⁴

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminology E 772 and Terminology E 1328.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *test light source, n*—a source of illumination whose spectral irradiance will be used for the spectral mismatch calculation.

3.3 *Symbols*—The following symbols and units are used in this test method:

M —spectral mismatch parameter,

ϵ —measurement error in short-circuit current,

λ —wavelength, μm or nm ,

$R_r(\lambda)$ —spectral response of reference cell, AW^{-1} ,

$R_d(\lambda)$ —spectral response of photovoltaic device, AW^{-1} ,

E —irradiance, Wm^{-2} ,

$E(\lambda)$ —spectral irradiance, $\text{Wm}^{-2}\mu\text{m}^{-1}$ or $\text{Wm}^{-2}\text{nm}^{-1}$, and

$E_o(\lambda)$ —reference spectral irradiance, $\text{Wm}^{-2}\mu\text{m}^{-1}$ or $\text{Wm}^{-2}\text{nm}^{-1}$.

⁴ Annual Book of ASTM Standards, Vol 14.04.



NOTE 1—Following normal SI rules for compound units (see Practice SI 10), the units for spectral irradiance, the derivative of irradiance with respect to wavelength $dE/d(\lambda)$, would be Wm^{-3} . However, to avoid possible confusion with a volumetric power density unit and for convenience in numerical calculations, it is common practice to separate the wavelength in the compound unit. This compound unit is also used in Tables G 159.

4. Summary of Test Method

4.1 Determination of the spectral mismatch parameter M requires the spectral response characteristics of the photovoltaic device and the spectral irradiance distribution of the test light source, along with the spectral response and the reference spectral irradiance distribution used for the reference cell calibration.

4.2 Because all four spectral quantities appear in both the numerator and the denominator in the calculation of the spectral mismatch parameter (see 8.1), multiplicative calibration errors cancel, and therefore only relative quantities are needed, although absolute spectral quantities may be used if available.

5. Significance and Use

5.1 The calculated error in the photovoltaic device current determined from the spectral mismatch parameter can be used to determine if a measurement will be within specified limits before the actual measurement is performed.

5.2 The spectral mismatch parameter also provides a means of correcting the error in the measured device current due to spectral mismatch.

5.2.1 The spectral mismatch parameter is formulated as the fractional error in the short-circuit current due to spectral differences.^{5,6}

5.2.2 Error due to spectral mismatch can be corrected by dividing the measured photovoltaic cell current by M , a procedure used in Test Methods E 948 and E 1036

6. Apparatus

6.1 In addition to the apparatus required by Test Methods E 1021, the following apparatus is required.

6.1.1 *Spectral Irradiance Measurement Instrument*—A spectroradiometer, defined in Test Method G 138, calibrated according to Test Method G 138.

6.1.1.1 The wavelength resolution shall be no greater than 10 nm.

6.1.1.2 The wavelength pass-bandwidth shall be no greater than 6 nm.

6.1.1.3 The wavelength range shall be wide enough to include the spectral response of the photovoltaic device and the photovoltaic reference cell.

6.1.1.4 The spectral irradiance measurement instrument must be able to scan the required wavelength range in a time period short enough such that the spectral irradiance at any wavelength does not vary more than $\pm 5\%$ during the entire scan.

⁵ Seaman, C., "Calibration of Solar Cells by the Reference Cell Method—The Spectral Mismatch Problem," *Solar Energy*, Vol 29, 1982, pp. 291–298.

⁶ Osterwald, C. R., "Translation of Device Performance Measurements to Reference Conditions," *Solar Cells*, Vol 18, 1986, pp. 269–279.

7. Procedure

7.1 Determine the spectral response $R_f(\lambda)$ of the photovoltaic device using Test Methods E 1021.

7.2 Obtain the spectral response $R_r(\lambda)$ of the photovoltaic reference cell.

NOTE 2—Test Methods E 1039, E 1125, and E 1362 require the spectral response to be provided as part of the reference cell calibration certificate.

7.3 Measure the spectral irradiance $E(\lambda)$ of the test light source, using the spectral irradiance measurement instrument (see 6.1.1).

7.4 Obtain the reference spectral irradiance distribution $E_o(\lambda)$ that corresponds to the calibration of the photovoltaic reference cell, such as Tables E 490 or G 159.

8. Calculation of Results

8.1 Calculate the spectral mismatch parameter with:^{5,6}

$$M = \frac{\int_{\lambda_1}^{\lambda_2} E(\lambda) R_f(\lambda) d\lambda}{\int_{\lambda_3}^{\lambda_4} E(\lambda) R_r(\lambda) d\lambda} \times \frac{\int_{\lambda_3}^{\lambda_4} E_o(\lambda) R_r(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} E_o(\lambda) R_f(\lambda) d\lambda} \quad (1)$$

using a suitable numerical integration scheme such as those described in Tables G 159.

8.1.1 The wavelength integration limits λ_1 and λ_2 shall correspond to the spectral response limits of the photovoltaic device.

8.1.2 The wavelength integration limits λ_3 and λ_4 shall correspond to the spectral response limits of the photovoltaic reference cell.

8.2 Calculate the measurement error due to spectral mismatch using:

$$\epsilon = |M - 1| \quad (2)$$

9. Precision and Bias

9.1 *Precision*—Imprecision in the spectral irradiance and the spectral response measurements will introduce errors in the calculated spectral mismatch parameter.

9.1.1 It is not practicable to specify the precision of the spectral mismatch test method using results of an interlaboratory study, because such a study would require circulating at least six stable test light sources between all participating laboratories.

9.1.2 Monte-Carlo perturbation simulations⁷ using precision errors as large as 5 % in the spectral measurements have shown that the imprecision associated with the calculated spectral mismatch parameter is no more than 1 %.

TABLE 1 Estimated Limits of Imprecision in Spectral Measurements

Source of Imprecision	Estimated Limit, %
Spectral response measurement	2.0
Spectral irradiance measurement	5.0

⁷ Emery, K. A., Osterwald, C. R., and Wells, C. V., "Uncertainty Analysis of Photovoltaic Efficiency Measurements," *Proceedings of the 19th IEEE Photovoltaics Specialists Conference—1987*, pp. 153–159, Institute of Electrical and Electronics Engineers, New York, NY, 1987.