

Lowered uncertainty in estimation of spectral mismatch correction factor in solar cell and photovoltaic (PV) devices calibration

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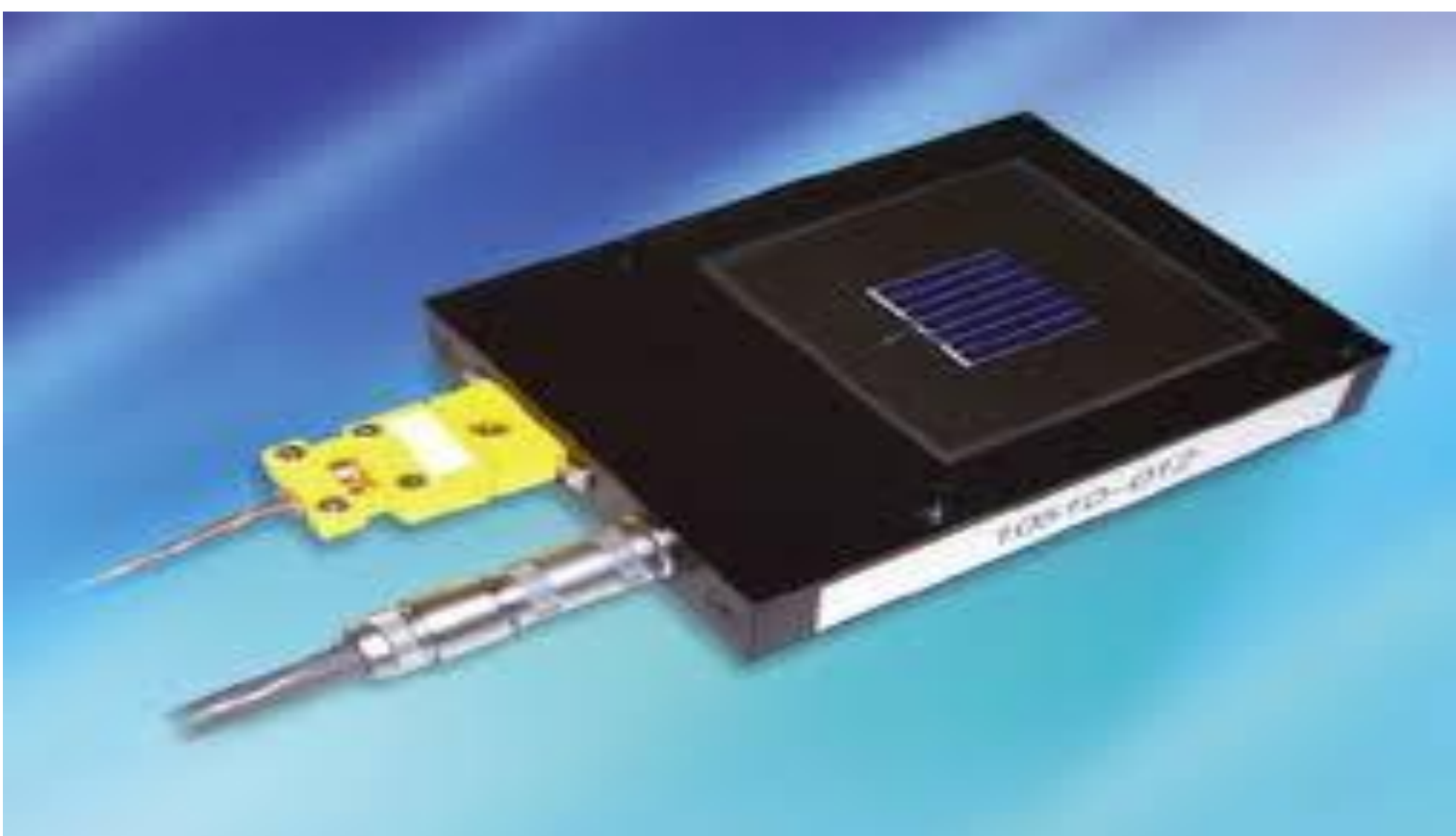
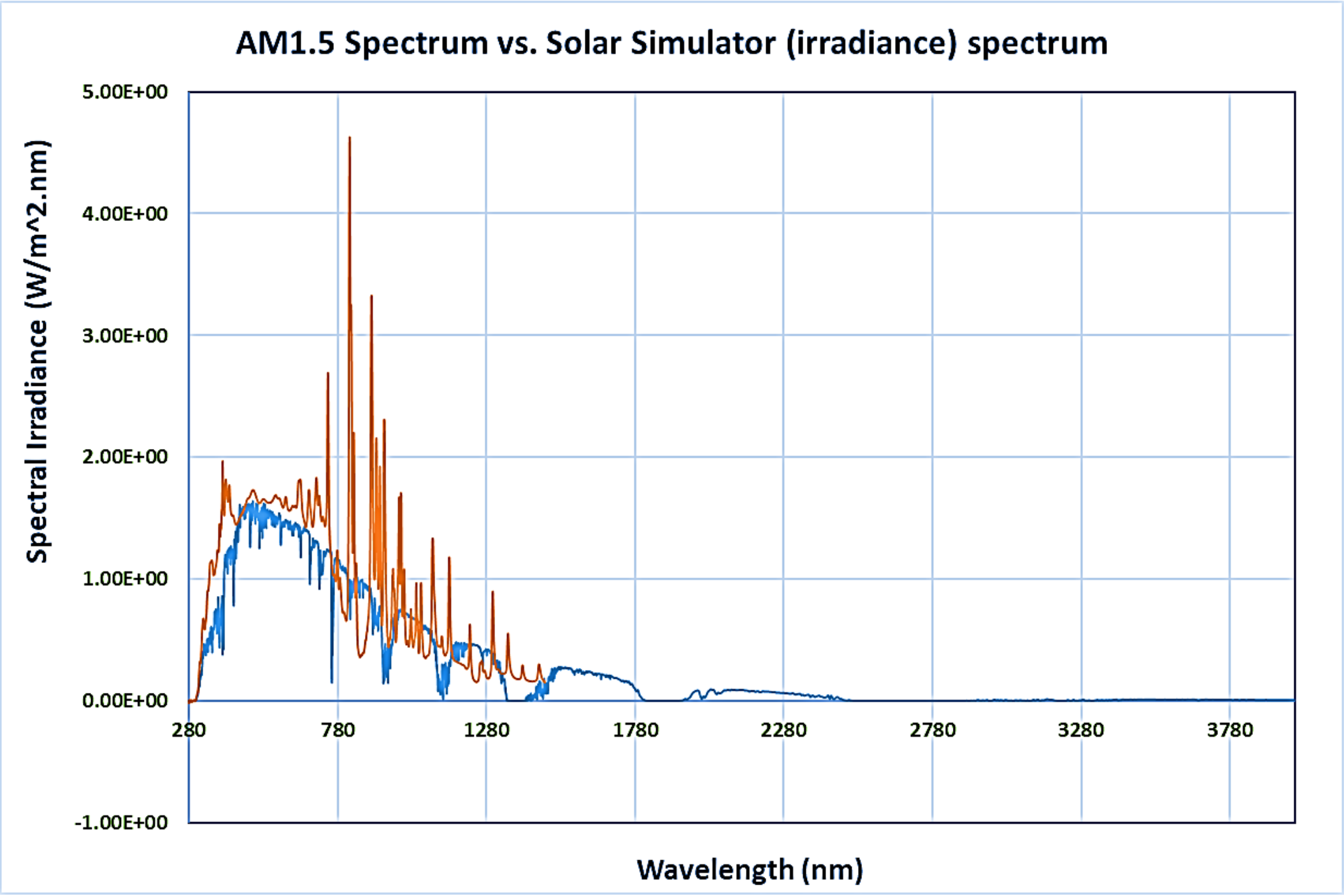
Motivation

The spectral mismatch correction factor (SMCF) is a crucial parameter in solar cell calibration, as it compensates for differences between the spectral irradiance of a reference source and the actual solar spectrum under standard test conditions (STC). This occurs when the spectral distribution of the irradiance from the reference source does not exactly match the spectral sensitivity of the solar cell being calibrated.

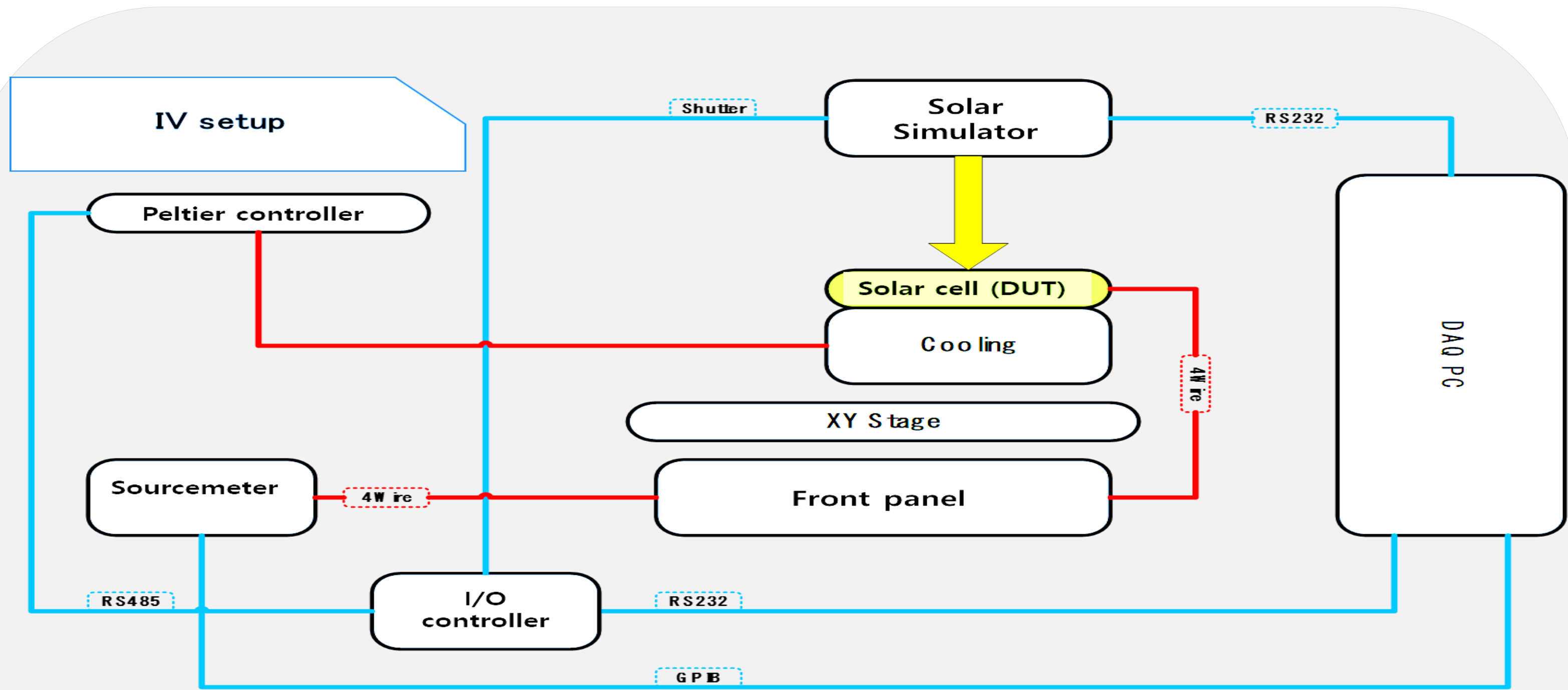
Estimating the SMCF involves a complex process, and the uncertainty in this estimation plays a crucial role in the accuracy of the solar cell calibration, which directly impacts the performance predictions of solar energy systems. Key concepts include spectral mismatch, SMCF, source spectral power distribution, solar spectrum variability, instrument calibration, and spectral sensitivity of the solar cell.

Uncertainty in the estimation of SMCF arises from several factors, including spectral measurement uncertainty, solar spectrum difference, instrument calibration, and spectral sensitivity of the solar cell. Key components in this uncertainty include spectral measurement uncertainty, solar spectrum variability, instrument calibration, and spectral sensitivity of the solar cell.

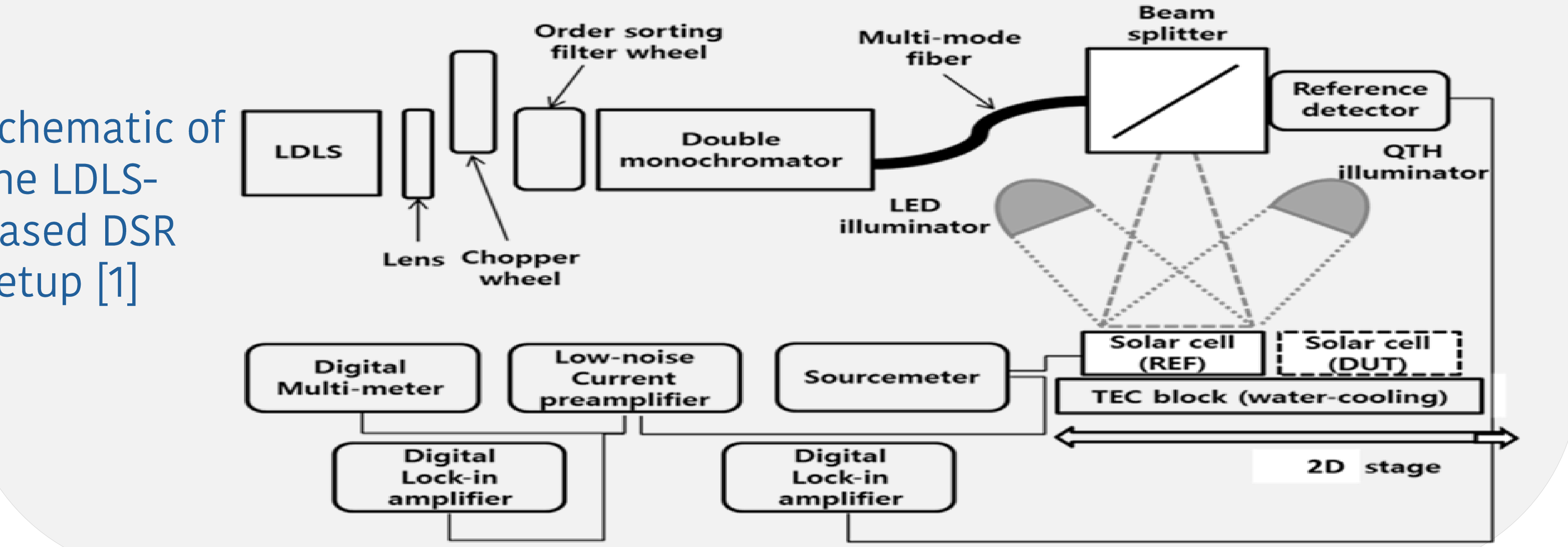
To estimate and reduce uncertainty in SMCF, steps for estimating and reducing uncertainty include ensuring proper calibration of spectral instruments, accounting for light source stability, using high-precision solar spectrum models, modeling and simulations, repeatability and consistency in measurements, standardizing measurement protocols across laboratories, and regularly testing and calibrating the solar cell's spectral response using precise instrumentation as well as robust automation.



Reference solar cell [1]



Block diagram of Solar Simulator (IV Setup) & C++ Home-made Automation [1]



Uncertainty in the Spectral Mismatch Correction Factor (SMF)

To calculate the uncertainty of M , we assume that there are no significant spectral correlations between the data points in spectral responsivity measurements of the cells or the spectral irradiance measurements of the solar simulator. Therefore, using the calculus chain rule, we calculate the uncertainty of M for each of the four spectral functions, E_r , E_s , S_r , and S_t and finally add these in quadrature. The uncertainty of M with respect to E_r or $UM_{Er} = 0$ since that is the reference spectrum. Below, we only show this calculation for the UM_{Es} term and the final two terms, UM_{Sr} , and UM_{St} are similarly calculated.

$$UM^{Es} = \frac{1}{\left(\int E_s(\lambda) S_r(\lambda) d\lambda \times \int E_r(\lambda) S_r(\lambda) d\lambda \right)^2} \times \left(\left(\int E_r(\lambda) S_r(\lambda) d\lambda \int \frac{1}{100} UE_s(\lambda) E_s(\lambda) S_r(\lambda) d\lambda \right) \int E_s(\lambda) S_r(\lambda) d\lambda \times \int E_r(\lambda) S_r(\lambda) d\lambda - \left(\int \frac{1}{100} UE_s(\lambda) E_s(\lambda) S_r(\lambda) d\lambda \right) \int E_r(\lambda) S_r(\lambda) d\lambda \times \int E_r(\lambda) S_r(\lambda) d\lambda \right) \times \frac{100}{M} \quad (2)$$

In (2), $UE_s(\lambda)$ is the uncertainty associated with the solar simulator's spectral irradiance measurements. Also note that in (2), UM_{Es} is the relative uncertainty. The total uncertainty associated with M , or UM is therefore given by:

$$UM = \sqrt{(UM^{Er})^2 + (UM^{Es})^2 + (UM^{Sr})^2 + (UM^{St})^2} \quad (3)$$

We performed the above calculations for cases 1 and 2 respectively and we report the following outcomes: Case 1: $M = 0.9994$, $UM = 0.036 \%$ for $k=2$ & Case 2: $M = 0.9452$, $UM = 0.042 \%$ for $k=2$

Principle

The spectral mismatch parameter (M) and its total uncertainty UM was calculated for two different cases. Case 1 consisted of a silicon-based reference solar cell and another silicon based test cell, measured under a xenon based solar simulator at NIST. Case 2 consisted of the same reference cell and a GaAs-based test cell, also measured under the xenon solar simulator. In both cases, the reference reporting condition is the air mass 1.5 global illumination condition with spectral irradiance given by the IEC 60904-3 standard. The spectral mismatch parameter, M , is given by:

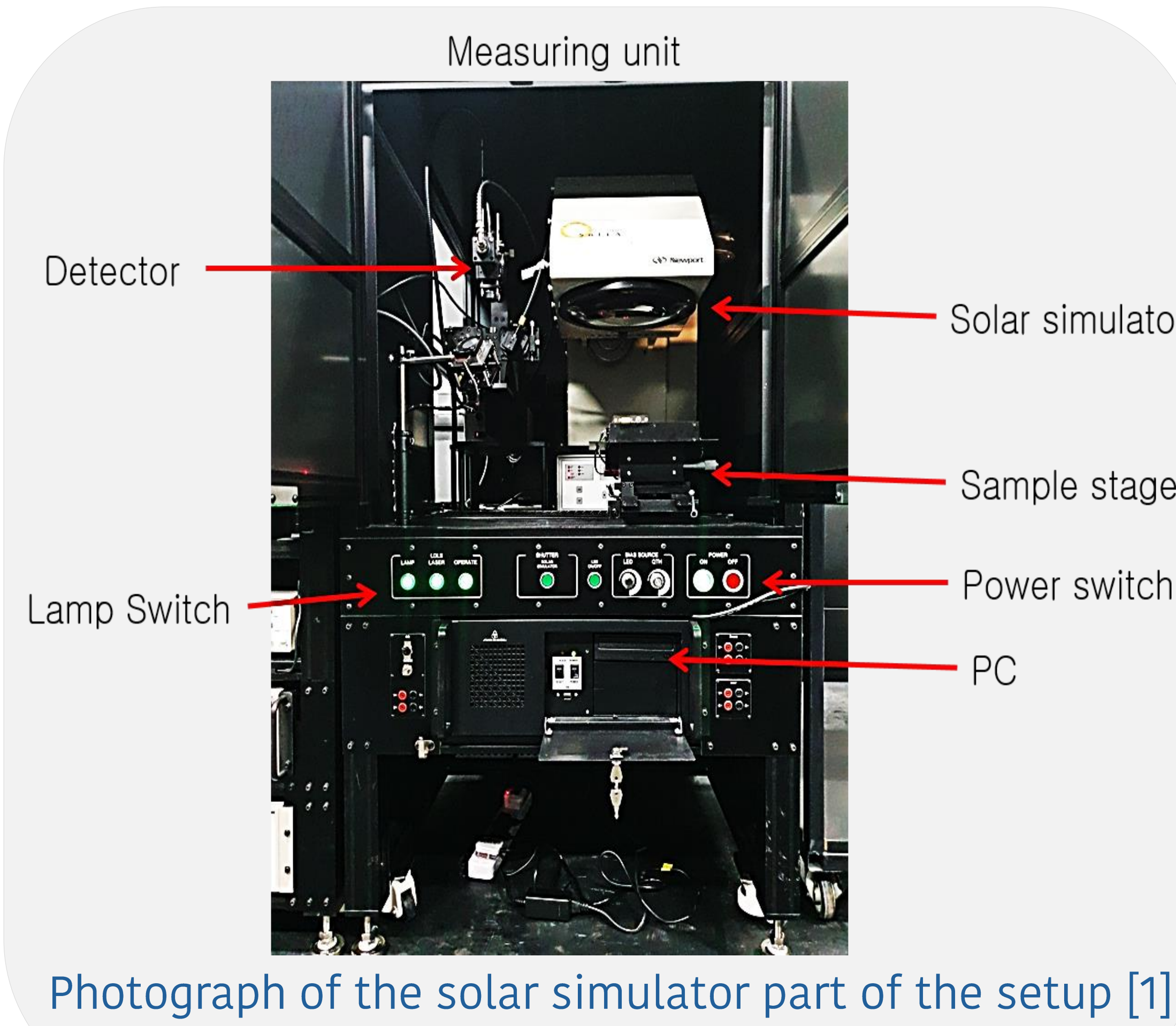
$$M = \frac{\int_{\lambda_1}^{\lambda_2} E_s(\lambda) S_r(\lambda) d\lambda}{\int_{\lambda_3}^{\lambda_4} E_s(\lambda) S_r(\lambda) d\lambda} \times \frac{\int_{\lambda_3}^{\lambda_4} E_r(\lambda) S_r(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} E_r(\lambda) S_r(\lambda) d\lambda} \quad (1)$$

where $E_s(\lambda)$ is the spectral irradiance of the source, $E_r(\lambda)$ is the reference spectral irradiance, $S_t(\lambda)$ is the spectral responsivity of the test cell, and $S_s(\lambda)$ is the spectral responsivity of the reference cell.

The spectroradiometric measurements of the solar simulator spectrum are traceable to the NIST FEL lamp.

Acknowledgment:

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Photograph of the solar simulator part of the setup [1]

[1] Khaled Mahmoud et al., New facility for primary calibration of differential spectral responsivity of solar cells using LDLS-based monochromatic source, J. Phys.: Conf. Ser. 2149 012003, 2022

[2] Hamadani, B. H.; Dougherty, B. Solar Cell Characterization. In Semiconductor Materials for Solar Photovoltaic Cells; 2016; pp 229–245. https://doi.org/10.1007/978-3-319-20331-7_8.

[3] Roller, J.; Hamadani, B. H. Reconciling LED and Monochromator-Based Measurements of Spectral Responsivity in Solar Cells. Appl. Opt. 2019, 58 (22), 6173. <https://doi.org/10.1364/AO.58.006173>.