IDR300-PSL Uncertainty Budget

BENTHAM

Overview

In the consideration of measurement uncertainty, there are two types of component to consider; type A statistical and type B systematic uncertainties.

The starting point is to determine the measurement equation. For the calibration and the measurement of the lamp under test, the photocurrent as a function of wavelength is recorded by the system detectors before relating the two using the calibration data to determine the irradiance/ radiance of the test lamp.

Measurement of Spectral Irradiance

The measurement of spectral irradiance involves the use of a D7 cosine corrected input optic to couple light to the IDR300-PSL for spectral analysis.
The system is initially calibrated with respect to a standard of spectral irradiance for which the uncertainty is provided, at the correct measurement distance and correct operation current.
The device under test is then placed at the correct measurement distance, aligned and operated at the correct current.

The following equation describes theoretically the recorded photocurrent during calibration in the above configuration:-

$$\mathrm{I_c}(\lambda) = \alpha \int_{\lambda-\delta\lambda}^{\lambda+\delta\lambda} \mathrm{E_c}(\lambda).\,\delta_c(\lambda).\,\varepsilon_c(\lambda).\,\mathrm{d_c}(\lambda).\,\mathrm{a_c}(\lambda).\,\mathrm{t_c}(\lambda).\,\mathrm{s_c}(\lambda).\,\mathrm{r_c}(\lambda).\,\Gamma_c(\lambda)$$

Where:-

$\mathrm{I_c}(\lambda)$ is the theoretical photocurrent
α is the area of the input optic
$\mathrm{E_c}(\lambda)$is the certificate irradiance of the calibrated lamp
$\delta_c(\lambda)$ is a factor taking into account ageing of the calibration lamp
$\varepsilon_c(\lambda)$ is a factor taking into account deviation in lamp irradiance due to operation conditions
$\mathrm{d_c}(\lambda)$ is a factor taking into account measurement distance
$\mathrm{a_c}(\lambda)$ is a factor taking into account lamp alignment
$\mathrm{t_c}(\lambda)$ is the transfer function of the monochromator including wavelength calibration
$\mathrm{s_c}(\lambda)$ is the slit function of the monochromator centred on nominal wavelength, λ
$\mathrm{r_c}(\lambda)$ is a factor taking into account the responsivity of system detectors, including linearity
$\Gamma_c(\lambda)$ is a factor taking into account the gain of transimpedance amplifier, including inter-range linearity and ADC conversion

Similarly, for the measurement of the device under test:-

$$\mathrm{I_t}(\lambda) = \alpha \int_{\lambda-\delta\lambda}^{\lambda+\delta\lambda} \mathrm{E_t}(\lambda).\,\varepsilon_t(\lambda).\,\mathrm{d_t}(\lambda).\,\mathrm{a_t}(\lambda).\,\mathrm{t_t}(\lambda).\,\mathrm{s_t}(\lambda).\,\mathrm{r_t}(\lambda).\,\Gamma_t(\lambda)$$

Where:-

$\mathrm{I_t}(\lambda)$ is the theoretical photocurrent
α is the area of the input optic
$\mathrm{E_t}(\lambda)$is the certificate irradiance of the calibrated lamp
$\varepsilon_t(\lambda)$ is a factor taking into account deviation in lamp irradiance due to operation conditions
$\mathrm{d_t}(\lambda)$ is a factor taking into account measurement distance
$\mathrm{a_t}(\lambda)$is a factor taking into account lamp alignment
$\mathrm{t_t}(\lambda)$ is the transfer function of the monochromator including wavelength calibration
$\mathrm{s_t}(\lambda)$ is the slit function of the monochromator centred on nominal wavelength, λ_0
$\mathrm{r_t}(\lambda)$ is a factor taking into account the responsivity of system detectors, including linearity
$\Gamma_t(\lambda)$ is a factor taking into account the gain of transimpedance amplifier, including inter-range linearity and ADC conversion

Where the measurement is performed over an infinitesimal bandwidth, the integrals can be ignored, and the component representing the slit function converted to a fixed component in the first analysis, which shall therefore include a component to account for the difference between $\mathrm{I_t}(\lambda)$ and the measured $\widetilde{\mathrm{I_t}}(\lambda)$ and $\mathrm{I_c}(\lambda)$ and the measured $\widetilde{\mathrm{I_c}}(\lambda)$.

This leads to the reduced expression for the irradiance of the device under test as:-

$$\mathrm{E_t}(\lambda) = \mathrm{E_c}(\lambda).\frac{\widetilde{\mathrm{I_t}}(\lambda)}{\widetilde{\mathrm{I_c}}(\lambda)}.\frac{\varepsilon_c(\lambda).\,\delta_c(\lambda).\,\mathrm{d_c}(\lambda).\,\mathrm{a_c}.\,\mathrm{t_c}(\lambda).\,\mathrm{s_c}(\lambda).\,\mathrm{r_c}(\lambda).\,\Gamma_c(\lambda)}{\varepsilon_t(\lambda).\,d_t(\lambda).\,a_t.\,\mathrm{t_t}(\lambda).\,s_t(\lambda).\,\mathrm{r_t}(\lambda).\,\Gamma_t(\lambda)}.$$

All factors other than the measurands, $\mathrm{E_c}(\lambda)$, $\mathrm{E_t}(\lambda)$, $\widetilde{\mathrm{I_c}}(\lambda)$ and $\widetilde{\mathrm{I_t}}(\lambda)$ are taken as having nominal value of unity with an associated uncertainty.

One obtains the uncertainty from

$$u_c^2(y) = \sum_{i=1}^{N} \left(\frac{\partial f}{\partial x_i} \right)^2 u^2(x_i)$$

For this simple case, the combined uncertainty is the square root of the sum of the relative uncertainty of the components squared.

The following uncertainties, which apply to both calibration and test measurement values, are assumed.

Uncertainty in the measured photocurrent, $u^2(\widetilde{\mathbf{I}_c})$

Evaluated by a type A uncertainty based on N observations, the standard uncertainty being evaluated by experimental standard deviation divided by √(N)

Uncertainty in the certificate irradiance, $\boldsymbol{u^2}(\mathbf{E_c})$

Obtained from calibration certificate, assuming a rectangular distribution, divisor √3.

Uncertainty in calibration lamp irradiance due to ageing, $\boldsymbol{u^2}(\boldsymbol{\delta_c})$

Estimated as 0.005, assuming a normal distribution, divisor 3.

Uncertainty in the calibration/ test lamp irradiance due to operation conditions, $\boldsymbol{u^2}(\boldsymbol{\varepsilon}_\mathbf{c})$

There are two cases considered, incandescent and all other lamps.

Based on the nominal colour temperature of the lamp, through the Stefan Boltzmann law, $(P = A\varepsilon\sigma T^4)$, the temperature of the lamp is proportional to the fourth root of the power put into the lamp, which is in turn proportional to the square root of the current, $(P = I^2R)$.

From Planck's law, $E = \frac{2h\nu^3}{c^2}.\frac{1}{e^{\frac{hc}{\lambda kT}}-1}, \frac{\partial E}{\partial I} = \frac{\partial E}{\partial T}\frac{\partial T}{\partial I}$ and re-arranging the expressions for P above, one obtains an expression for the relative uncertainty in the source output based on the relative uncertainty of the lamp operating current.

$$\frac{\Delta E}{E} = \frac{\Delta I}{I}\frac{hc}{2k\lambda T}.\frac{1}{1 - e^{-\frac{hc}{\lambda kT}}}$$

Presuming that the lamp current is stable to within ±0.005A with a rectangular probability distribution, the standard uncertainty is determined to be 0.005/√3 which is input to the determination of standard uncertainty of lamp output.

For all other lamps, an uncertainty, constant at all wavelength of 0.01 is assumed, with a rectangular distribution, divisor √3.

Uncertainty in measurement distance, $\boldsymbol{u^2}(\mathbf{d_c})$

Estimated as 1mm, assuming a normal distribution, divisor 3.

Uncertainty in alignment, $\boldsymbol{u^2}(\mathbf{a_c})$

Estimated as 0.005, assuming a rectangular distribution, divisor √3.

Uncertainty in the monochromator transfer function, $\boldsymbol{u^2}(\mathbf{t_c})$

The transfer function is presumed stable but consider that the wavelength calibration be to within ±0.2nm.

The signal at such points for the measurement results are determined and the uncertainty determined based on a rectangular probability distribution (divisor √3). The reported uncertainty is the maximum error caused by a deviation by +0.2nm or -0.2nm.

Uncertainty in the slit function, $\boldsymbol{u^2}(\mathbf{s_c})$

Estimated as 0.005, assuming a rectangular distribution, divisor √3.

Uncertainty in the responsivity of system detectors, including linearity $\boldsymbol{u^2}(\mathbf{r_c})$

This component is considered negligible.

Uncertainty in detection electronics linearity and ADC conversion, $\boldsymbol{u^2}(\boldsymbol{\Gamma_c})$

The current amplifier is a six-decade trans-impedance amplifier with inter-range calibration ±0.1% with rectangular distribution (divisor √3).

Measurement of Spectral Radiance

The uncertainty budget for the measurement of radiance yields a similar measurement equation, differing in that the factors for distance and alignment are taken into one parameter.

$$\mathrm{L_t}(\lambda) = \mathrm{L_c}(\lambda).\frac{\widetilde{\mathrm{I_t}}(\lambda)}{\widetilde{\mathrm{I_c}}(\lambda)}.\frac{\varepsilon_c(\lambda).\delta_c(\lambda).\mathrm{a_c}.\mathrm{t_c}(\lambda).\mathrm{s_c}(\lambda).\mathrm{r_c}(\lambda).\Gamma_c(\lambda)}{\varepsilon_t(\lambda).\mathrm{a}_t(\lambda).\mathrm{t}_t(\lambda).s_t(\lambda).\mathrm{r}_t(\lambda).\Gamma_t(\lambda)}.$$

The assignment of uncertainties above apply save for the following:-

Uncertainty in alignment, $\boldsymbol{u^2}(\mathbf{a_c})$

Estimated as 0.10 based on measurement fields of view employed by the standard, assuming a rectangular distribution, divisor √3.