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CALIBRATION OF SPECTRAL RADIANCE STANDARDS**

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STUDY OF THE SIZE-OF-SOURCE EFFECT (SSE) ON THE CALIBRATION OF SPECTRAL RADIANCE STANDARDS

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Abstract

Standards and Calibration Laboratory of Hong Kong SAR, China has set up calibration service for spectral radiance light sources in the wavelength range from 300 nm to 1800 nm. The calibration is performed by direct comparison with reference spectral radiance light sources. A series of evaluation, including the study of the size of source effect, were conducted to validate the performance of the calibration system. In this paper, the evaluation of the size of source effect of the system is presented. The size of source effect was estimated as an uncertainty component of less than 0.1 %. This is a relatively small contribution to the overall expanded measurement uncertainty of the system, which was estimated as 2.4 % for the wavelength range between 400 nm to 1000 nm.

Keywords: Size of Source Effect (SSE), Spectral Radiance, Radiometry

1 Introduction

The Standards and Calibration Laboratory (SCL) of Hong Kong SAR, China has a spectral radiometric system for the calibration of spectral responsivity of photodetectors, spectral irradiance of standard light sources and spectral radiance of standard light sources in the wavelength range from 300 nm to 1800 nm. Size of source effect (SSE) is an important parameter in the validation of precision radiation measurement, which is associated with the variation in measured signal due to the change in the size of source. This parameter characterizes the contribution from the surroundings to the measured signal from the target, and the dependence of the radiometer on the area around the target. In the lowest uncertainty optical measurements, it is necessary to evaluate the SSE of the system and to minimize this effect as far as possible. At the SCL, the evaluation of the SSE of the spectral radiance calibration system was conducted. In this paper, the measurement setup, evaluation results and associated uncertainty are presented and discussed.

1.1 Spectral radiance and related parameters

Spectral radiance, $L_{e,\lambda}$, is the ratio of the amount of electromagnetic radiant flux per unit solid angle to the projected area of the source element at a particular wavelength as given by equation (1).

$$L_{e,\lambda} = \frac{dI_{e,\lambda}}{dA \cdot \cos \theta} \quad (1)$$

where

$I_{e,\lambda}$ is the spectral radiant intensity; and

$A \cdot \cos \theta$ is the projected area of the source.

The unit of spectral radiance is $\text{W} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$, which steradian (sr) is the unit of the solid angle. Equation (1) contains the parameter of spectral radiant intensity, $I_{e,\lambda}$, which is equal to the spectral radiant flux from a source emitted per unit solid angle in a given direction at a particular wavelength, as given by equation (2).

$$I_{e,\lambda} = \frac{d\phi_{e,\lambda}}{d\Omega} \quad (2)$$

where

$\Phi_{e,\lambda}$ is the spectral radiant flux; and

Ω is the solid angle containing the given direction.

The spectral radiant flux, $\phi_{e,\lambda}$, is the spectral energy Q_λ radiated by a source at a particular wavelength per unit of time with the unit of watt per wavelength ($\text{W}\cdot\text{nm}^{-1}$) as given by equation (3).

$$\Phi_{e,\lambda} = \frac{dQ_\lambda}{dt} \quad (3)$$

At the SCL, source-based method is used in the calibration of spectral radiance light sources. The spectral distribution of the optical radiation emitted from the test light source is calibrated by direct comparison with the laboratory reference radiance standards through a high precision double monochromator and a series of detectors.

1.2 Size of source effect

Size of source effect is an important parameter in photometry, radiometry and radiation thermometry. It is associated with the variation in measured signal due to the change in the size of source. It characterizes the contribution of surrounding radiation to the measured signal of the target. SSE usually comes from homochromatic stray light and scatter from optics.

In general, two techniques were commonly employed in the evaluation of SSE, namely: the direct technique and the indirect technique. For the direct technique, a radiometer is focused on a uniform radiance source whose aperture diameter can be varied, then the SSE can be calculated by measuring the signal with respect to the diameter of the source. For the indirect technique, a radiometer is focused to a uniform source with a small light block that is slightly larger than the target size. The SSE at each wavelength can be calculated by the ratio between the blocked and unblocked signal at various aperture diameters as given by equation (4):

$$SSE(\lambda, d) = \frac{L(\lambda, d)_{\text{Blocked}} - L_{\text{dark}}}{L(\lambda, d)_{\text{Unblocked}} - L_{\text{dark}}} \quad (4)$$

where

$L(\lambda, d)_{\text{Blocked}}$ is the measured signal with the light block mounted on the integrating sphere;

$L(\lambda, d)_{\text{Unblocked}}$ is the measured signal without the light block mounted on the integrating sphere; and

L_{dark} is the measured dark signal with the sphere port blocked by a shutter.

The indirect method was used by SCL to evaluate the SSE performance of the spectral radiance measurement system. Details of the measurement setup and results are presented and discussed in the sections below.

Figure 1 – Layout of the SCL’s Spectral Radiance System for SSE study

2 Measurement Setup

The layout of the SCL's spectral radiance system is shown in Figure 1. The calibration of spectral radiance light sources is conducted by comparison with the laboratory's 6-inch diameter reference radiance standards, which has an output port diameter of 38 mm. Owing to the fixed output port size of the reference radiance standards, it is necessary to evaluate the SSE of the system, such that the range of output port size of test radiance sources can be evaluated. The system uses a double monochromator for the selection of specific monochromatic optical signal from the source. Photomultiplier tube detectors, silicon detectors and InGaAs detectors are used as the detectors for measuring optical signal in the wavelength ranges of 300 nm to 400 nm, 400 nm to 950 nm and 950 nm to 1800 nm respectively.

To evaluate the SSE of the system, a 12-inch diameter integrating sphere with a 100 mm diameter output port as shown at the top of Figure 1 was used as the radiance source. The integrating sphere was illuminated by two 35 W tungsten filament lamps. The integrating sphere is kept slightly away from the stray light shield. This could minimize the reflected light from the shield to the sphere which could minimize the reflected light from re-entering the monochromator.

A blocking ring, which has a small light block of 10 mm high by 2.5 mm wide was hanged at the center of the output port to block the main light signal, is shown in Figure 2. A 100 mm diameter variable aperture was placed in front of the integrating sphere and the blocking ring for varying the size of the aperture. Setup photos of the integrating sphere, the blocking ring and the variable aperture are shown in Figure 3. The radiance source was aligned such that the image of the input slit of the double monochromator was focused onto the light block as shown in Figure 4.

Figure 2 – The blocking ring with a small light block at the center.

Figure 3 – The blocking ring is mounted at the output port of the integrating sphere. A variable aperture is located at the front of the integrating sphere.

Figure 4 – The radiance source setup was aligned such that the image of the input slit of the double monochromator was focused on the black light block.

3 Measurement results

A series of measurement were performed at 11 aperture diameters, including: 25 mm, 29 mm, 35 mm, 38 mm, 45 mm, 48 mm, 50 mm, 60 mm, 70 mm, 80 mm and 90 mm. At each aperture diameter, measurement was performed at wavelengths from 300 nm to 1000 nm at a 50 nm interval, and from 1000 nm to 1800 nm at a 200 nm interval.

Measurement results in the 300 nm – 1000 nm and 1000 nm – 1800 nm wavelength ranges are presented in Figure 5 and Figure 6 respectively. Since the diameter of the SCL's reference radiance standards is 38 mm, the measured results presented in the figures are referenced to

38 mm by the equation: $SSE(\lambda, d) - SSE(\lambda, 38)$. Overall, the SSE difference was in the order of less than 0.1%, and it was less than 0.05 % in the wavelength range from 400 nm to 1000 nm. The SSE contribution has been applied to the overall uncertainty budget of the system. This order of contribution is relatively small when comparing with other uncertainty components. Details of the uncertain components of SSE are presented in the next section.

Figure 5 – Measurement results in the ultra violet (UV) and visible wavelength ranges.

Figure 6 – Measurement results in the infrared (IR) wavelength range.

4 Measurement uncertainty

Based on equation 4, the measurement model for uncertainty estimation can be written with measurement parameters as shown in equation (5).

$$SSE = \frac{\frac{V_b - V_{d_1}}{G_1(1 + \delta G_1)}}{\frac{V_{ub} - V_{d_2}}{G_2(1 + \delta G_2)}} + C_{stb} \quad (5)$$

where

- V_b is the measured voltage from the current amplifier at blocked condition;
- V_{d_1} is the measured dark voltage at blocked condition;
- G_1 is the calibrated gain of the amplifier at measuring blocked signal;
- δG_1 is the gain deviation (linearity error) from calibration current level of the amplifier at measuring blocked signal;
- V_{ub} is the measured voltage from the current amplifier at unblocked condition;
- V_{d_2} is the measured dark voltage at unblocked condition;
- G_2 is the calibrated gain of the amplifier at measuring unblocked signal;
- δG_2 is the gain deviation (linearity error) from calibration current level of the amplifier at measuring unblocked signal; and
- C_{stb} is the corrected for instability and repeatability of the measurement.

The above components were considered in the SSE uncertainty estimation budget. The uncertainty due to instability and repeatability in the blocked condition is the dominant factor in this estimation, which was in the order of about 0.04 %. The uncertainty contribution due to SSE at different wavelength ranges is summarized in Table 1. It was estimated as less than 0.1 % for wavelength from 300 nm to 1800 nm, and less than 0.05 % for wavelength from 400 nm to 1000 nm.

Table 1 – Uncertainty contribution due to SSE

Wavelength	Uncertainty Contribution (Rectangular distribution with infinite degrees of freedom)
300 nm to 400 nm	0.1 %
400 nm to 1000 nm	0.05 %
1000 nm to 1800 nm	0.1 %

5 Conclusions

The SCL has evaluated the SSE of the spectral radiance measurement system. Although it was predicted that more scattered light could be measured when the source diameter increased, measurement results did not show clear relationship between the SSE and the aperture size. The SSE contributes to a very small fraction of measurement uncertainty of the system. The measurement results can ensure that the system is suitable for radiance light sources calibration with a wide range of output diameters.

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