Spectral Radiance Scale Traceability Chain by Using Monte Carlo Application

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This work aims to determine the radiance responsivity to be used in the calibration of polychromatic radiation sources with low uncertainty using GUM and GUM Suplement-1. The spectral radiance values of the polychromatic lamps are obtained using the radiance responsivity of the system. The study aims to develop the derivation and better understand traceability of the other radiometric and photometric quantities with low uncertainty from the fundamental radiometric radiance unit. Measurement results obtained in the extended measurement uncertainty scale are determined using both classical and Monte Carlo methods.

INTRODUCTION

In this research, laser-based high-resolution spectra radiometric systems were established. The proposed system calculates the basic radiometric unit radiance with low uncertainty and meets the needs of instrument characterization, which may occur in scientific research activities using other radiometric and photometric quantities. A monochromator that is used for the spectral radiance measurement was first characterized in terms of the wavelength accuracy [1]. Secondly, a reflection-type Si-based trap detector, which is used in the NMIs laboratory as a radiometric transfer standard [2,3] comparatively characterized against an electrical substitution cryogenic radiometry (ESCR) system [4,5]. Thirdly, by using an integrated sphere and laser, the Lambertian distributed radiance beam was determined [6]. In the specific laser wavelength region, radiance values were obtained using a He-Ne tunable (543, 594, 604, 612 and 632.8nm), Argon-Ion (457, 477, 488, and 514 nm), and Nd-Yag (1064 nm) lasers.

MEASUREMENT SETUP

Laser-based measurement system was established, as shown in Fig. 1. First, spectral radiance values were obtained at the laser wavelength using a silicon-based trap detector [7] Then, the same system was transferred to the double monochromator system, and the spectral transfer function of the system was obtained. Thus, the spectral radiance values of the unknown polychromatic radiator source were derived using a transfer function obtained with low uncertainty measurements using both the classical and Monte Carlo approaches.

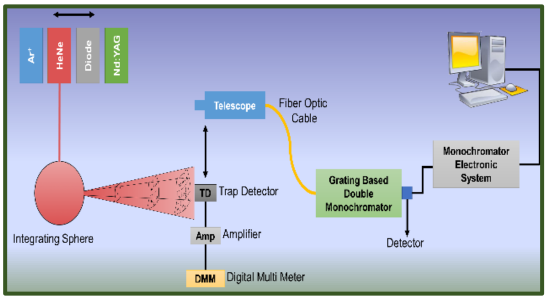

Figure 1: Spectral radiance measurement system.

$$L_\lambda(\lambda) = \frac{\mathbf{I}^s(\lambda)}{R_s^*(\lambda)} \frac{D^2}{A_s A_d(1+\delta)} \quad (1)$$

Where $\delta = r_s^2 r_d^2 / D^4$ and $D^2 = r_s^2 + d^2 + r_d^2$ in Eq. 1, and A_s and A_d are the active area of the radiation source and detector, respectively. d represents the distance between the radius of source r_s and detector r_d. In addition, $\mathrm{I}^s(\lambda)$ is the measured spectral current, $L_\lambda(\lambda)$ is the spectral radiance, and $R_s^*(\lambda)$ is the spectral power responsivity of the detector.

SYSTEM CHARTERIZATION AND CORRECTION FACTORS

The spectral radiance formula defined in Eq. 1 should include some uncertainty and correction factors caused by the measurement setup in Fig. 1. These are the wavelength accuracy of the monochromator system; trap detector characterization, geometric correction factor owing to the conservation of radiance, the monochromator wavelength shift, and the bandwidth. If the spectral radiance distribution formula of an unknown radiation defined as in Eq. 1 is redefined, it is given as in Eq. 2.

$$L_\lambda^U(\lambda) = \frac{\mathrm{I}^U(\lambda_M)\ \mathrm{I}^s}{\mathrm{I}^M(\lambda_M)\ R_s^*(\lambda_L)\ \Delta\lambda\ \Delta C}\mathrm{CorFac} \qquad (2)$$

Where $\mathrm{I}^U(\lambda_M)$ and $\mathrm{I}^M(\lambda_M)$ monochromator output signal of the unknown and known radiation source respectively. $\Delta\lambda$ is the full width at half maximum (FWHM), which is the spectral band-pass value of the monochromator.

RESULTS

The GUM Suplement-1 (Monte Carlo) [8] method is a relatively new method, and is a useful and practical alternative to the Gum method. Here, the probability density function (PDF) is defined for each measured output quantity, and defines the system and includes pseudo random numbers.

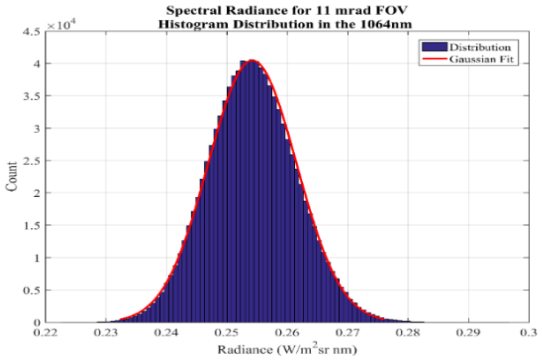

Figure 2: Plot showing 1064-nm spectral radiance histogram distribution and associated Gaussian fit function. The mean value of the function is the spectral radiance value 0.25424 ($Wm^{-2}sr^{-1}nm^{-1}$), and one sigma value of it is 0.007315 ($Wm^{-2}sr^{-1}nm^{-1}$).

Table 1: k=2 Extended standard uncertainty for 11-mrad FOV in terms of both GUM and GUM Suplement-1.

λ (nm)	GUM		Monte Carlo		Ratio
	Radiance (W/m^2sr nm)	k=2 Extended uncer. (W/m^2sr nm)	Radiance (W/m^2sr nm)	k=2 Extended uncer. (W/m^2sr nm)	
457	0.11952	0.0058	0.11953	0.0057	1.0229
477	0.14892	0.0072	0.14887	0.0071	1.0198
488	0.16825	0.0119	0.16819	0.0108	1.0998
514	0.19524	0.0094	0.19483	0.0093	1.0086
543	0.24632	0.0122	0.24708	0.0121	1.0099
594	0.32095	0.0153	0.32041	0.0153	1.0033
604	0.33359	0.0165	0.33469	0.0162	1.0204
612	0.32635	0.0155	0.32543	0.0155	0.9980
633	0.34347	0.0163	0.34237	0.0163	0.9993
1064	0.25589	0.0150	0.25424	0.0146	1.0253

When the function that defines the measurement system is linear, the Gum method offers an easy solution, but when the function that defines the system is not linear, the Monte Carlo [32] method is more practical because the partial derivation of the output quantities according to each input quantity makes the calculations difficult.

For different mrad FOV, a Monte Carlo operation was performed, and the uncertainties corresponding to spectral radiance values were calculated.

CONCLUSION

The spectral radiance traceability chain was created, and the radiance value of any radiation source or the surface of an unknown radiance value can be described with ease. In this study, to find a spectral transfer function, uncertainty values were defined by a 95% confidence level by both the classical method and Monte Carlo method.

This study is a guide towards the derivation of radiometric and photometric measurement units. In addition, the Monte Carlo uncertainty, which is often preferred by many national metrology laboratories in recent days, is a guide for calculations.

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