Correcting for bandwidth effects in monochromator measurements

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Abstract. In radiometric calibrations of detectors and sources it is common to use a monochromator-based system to compare the spectral response of an unknown detector with that of a known detector or the spectral irradiance of an unknown source with that of a known source. It is often assumed that this calibration can be considered to correspond to the central wavelength of the monochromator bandwidth. This paper considers when such an assumption is valid and how a correction can be made to convert integrated measurements into point values. It includes experimental verification of the methods described.

Introduction

The bandpass of monochromators can cause significant errors when calibrating sources or detectors that change rapidly with wavelength, particularly when the calibration is performed relative to a source or detector that has a very different spectral response [1]. Methods for correcting this for the case of a perfectly triangular slit [2,3] and for an arbitrary bandpass function [4] have been previously described.

This paper describes a method for correcting the measured data to obtain an estimate of the result that would have been obtained for an infinitely narrow bandpass. The method makes no assumptions about the shape of the bandpass function, nor does it require the measured data to be modelled. The method applies for arbitrary measurement spacings that may be greater or less than the bandwidth of the monochromator. It does however assume that the function representing the measured values is continuously differentiable with respect to wavelength to a degree appropriate to the spectral shape of interest.

The technique can be applied to any spectrally varying quantity measured using a monochromator. However, this paper considers the special case of the calibration of a deuterium lamp with respect to a blackbody source in the UV spectral region. Since the spectral irradiance of the deuterium lamp rapidly decreases with wavelength, while the blackbody's spectral irradiance rapidly increases, this represents a "worst case scenario" and as such experimental results could be obtained showing noticeable differences between a wide and narrow bandwidth. Such differences have been corrected using the method described here.

Measurement equation

The signal of a PMT detector on the exit port of a double monochromator was recorded first when a blackbody of known temperature illuminated a diffuser on the input port of the monochromator and then again when a deuterium lamp illuminated the same diffuser.

The signal obtained when using the blackbody is given by

$$\tilde{V}_{\mathrm{BB}}(\lambda_0) = \pi g \int_{\lambda_{-1}}^{\lambda_{+1}} L_{\mathrm{BB}}(\lambda,T)R(\lambda)S(\lambda)\,d\lambda \qquad (1)$$

where $\tilde{V}_{\mathrm{BB}}(\lambda_0)$ is the measured signal, g a geometric constant, $L_{\mathrm{BB}}(\lambda,T)$ the radiance of the blackbody, $R(\lambda)$ the detector responsivity and $S(\lambda)$ the bandpass function of the monochromator. Similarly, the signal obtained when measuring the lamp is given by

$$\tilde{V}_{\mathrm{lamp}}(\lambda_0) = A \int_{\lambda_{-1}}^{\lambda_{+1}} E_{\mathrm{lamp}}(\lambda)R(\lambda)S(\lambda)\,d\lambda \qquad (2)$$

where A is a geometric constant and $E_{\mathrm{lamp}}(\lambda)$ is the irradiance of the lamp.

If the bandpass function of the monochromator were infinitely narrow, the 'perfect' measured signals would be

$$V_{\mathrm{BB}}(\lambda_0) = \pi g L_{\mathrm{BB}}(\lambda_0,T)R(\lambda_0) \qquad (3)$$

and

$$V_{\mathrm{lamp}}(\lambda_0) = A E_{\mathrm{lamp}}(\lambda_0)R(\lambda_0). \qquad (4)$$

Without the integrations, the irradiance of the lamp can easily be determined by dividing the signal obtained using the lamp by that using the blackbody. It is important to understand whether the ratio for real signals is a close approximation to that for 'perfect' signals, i.e. whether, $\tilde{V}_{\mathrm{lamp}} / \tilde{V}_{\mathrm{BB}} \approx V_{\mathrm{lamp}} / V_{\mathrm{BB}}$, and the extent to which it is possible to estimate the 'perfect' signals given the real signals.

Triangular bandpass function

A solution has previously been proposed for a triangular bandpass function [3]. Given a triangular bandpass function of full width $2\Delta\lambda$ and unit area, as shown in Figure 1, and given the measured signal $\tilde{V}$, the 'perfect' signal V that would be obtained without the bandpass is given by the formula

$$V(\lambda_0) = \tilde{V}(\lambda_0) - \frac{1}{12}\left(\Delta\lambda\right)^2 \tilde{V}''(\lambda_0) + \frac{1}{240}\left(\Delta\lambda\right)^4 \tilde{V}^{\mathrm{iv}}(\lambda_0) + \cdots. \qquad (5)$$

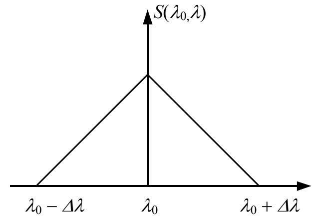

Figure 1 Defined triangular bandpass function.

This correction can be performed for any data set given enough measurements to estimate the derivatives. The measured data can be at any arbitrary step size. In practice, the second term, containing the second derivative, can be determined as the correction and the third term, containing the fourth derivative, measures the effect of truncating the correction at the second term. If this effect is too large, the second and third terms can be used as the correction and the next term, containing the sixth derivative, used to measure the effect of truncation.

Experimental data

Measurements were made in 2.5 nm steps of a deuterium lamp and a blackbody with a monochromator set with two different slit widths. In both cases the bandpass could be realistically modelled as a triangle. With wide slits the half-width $\Delta\lambda$ was 4.05 nm and with narrow slits it was 1.49 nm. The wider bandpass is shown in Figure 2.

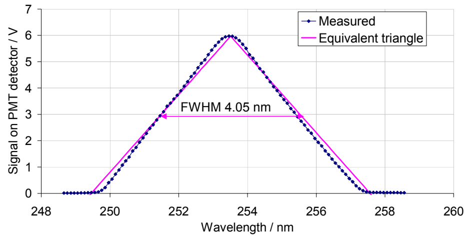

Figure 2 Monochromator bandpass with wide slits

The ratio $\tilde{V}_{\text{lamp}} / \tilde{V}_{\text{BB}}$ was compared for the wide slit and narrow slit case and there was a noticeable difference of the order of the measurement uncertainty between them (broken curve in Figure 3). Large corrections (around 15 % at the shortest wavelengths for the wide slits) were predicted by the second derivative term in Equation (5). However once these corrections were applied, the ratio $\tilde{V}_{\text{lamp}} / \tilde{V}_{\text{BB}}$ with wide slits agreed with that for the narrow slits (solid curve in Figure 3).

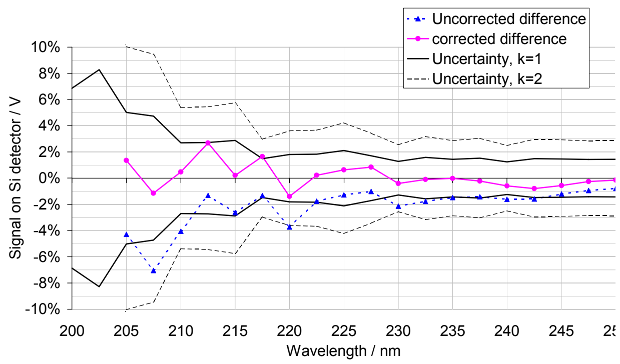

Figure 3 The effect of applying the correction on the difference between the ratio lamp to blackbody with 4.05 nm and 1.49 nm monochromator bandwidths

Generic bandpass

An approach has been developed to extend Formula (5) for an arbitrary bandpass function. The bandpass function is represented by a piecewise linear function, that is by sufficient straight-line segments to describe it. The approach provides an expression similar to Formula (5), but containing all derivatives (odd and even). The fractions in front of each term are replaced by algebraic expressions involving the terms defining the segments. For a symmetrical bandpass function, the multipliers of all odd derivates are zero.

This technique will be theoretically and experimentally investigated prior to the NEWRAD conference and will be presented along with the more straightforward case of a triangular slit function.

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