

Correcting for bandwidth effects in monochromator measurements

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The problem

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 is performed at a single wavelength, corresponding to the central wavelength of the monochromator bandwidth. However, this assumption is often invalid, particularly when the two sources (detectors) have spectral irradiances (responsivities) that vary rapidly with wavelength in different ways.

The solution for perfect slits

If there were no optical aberrations within a monochromator, the bandpass function would be a perfect triangle, and indeed for good monochromators the bandpass is often nearly triangular (as in Figure 1). Therefore corrections suitable for such monochromators have been developed for triangular bandpass functions [1,2].

Given a triangular bandpass function of full width $2\Delta\lambda$ and unit area, and given the measured signal $\tilde{V}$, the 'perfect' signal V that would be obtained with a monochromator with an infinitely narrow bandpass is given by the formula

$$V(\lambda_0) = \tilde{V}(\lambda_0) - \frac{1}{12}(\Delta\lambda)^2 \tilde{V}''(\lambda_0) + \frac{1}{240}(\Delta\lambda)^4 \tilde{V}^{iv}(\lambda_0) + \dots \quad (1)$$

The above result is used to apply a correction to the measured signal by truncating the expansion and approximating the derivatives in the expansion in terms of measurements of the signal. The measured data can be at any arbitrary step size. Figure 2 shows the results for simulated data. The 2nd derivative term is sufficient to correct for 'rounded' peaks, but the 4th derivative term is also required for sharp spectral features.

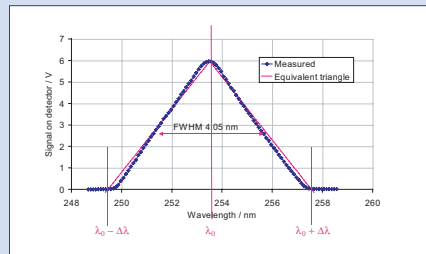


Figure 1. Measured bandpass of a real double Czerny-Turner monochromator and the triangular bandpass function with the same area.

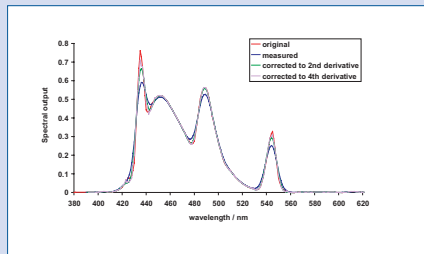


Figure 2. Correcting for the bandwidth effect with a triangular bandpass – the effect of truncating at the 2nd and 4th derivative terms in the Taylor Expansion. The bandwidth is 5 nm and the measurements were simulated at 1 nm steps.

Experimental Results

Measurements were made at 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 a wide slit the half-width $\Delta\lambda$ was 4.05 nm and with a narrow slit it was 1.49 nm. The two sources were spectrally very different (Figure 3), and both changed rapidly with wavelength. This meant that large corrections (around 15 % at the shortest wavelengths for the wide slit) were predicted by the 2nd derivative term in formula (1).

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 between the two ratios of the order of the measurement uncertainty (blue curve in Figure 4). 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 (pink curve in Figure 4).

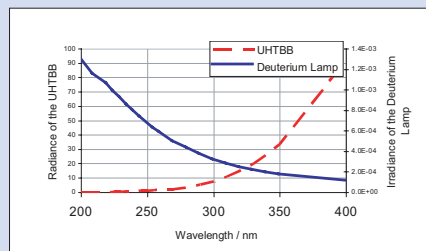


Figure 3. Spectral shape of deuterium lamp and blackbody outputs.

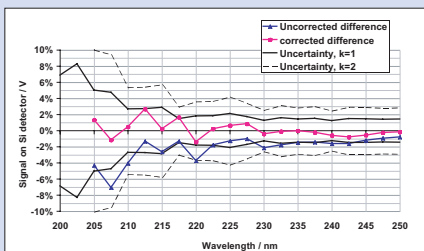


Figure 4. The effect of applying the correction on the difference between the ratio lamp to blackbody with 4.05 nm and 1.49 nm monochromator bandwidths.

The solution for imperfect slits

A method has been proposed to correct for the effect of non-triangular bandpass functions [3], which is an extension of the Stearns and Stearns approach [1]. Here we describe an alternative method. A new formula was derived to correct for the effect of non-triangular bandpass functions. This formula assumes the bandpass function is described by a piecewise linear function defined on a uniform subdivision of the bandwidth of the function (as exemplified by Figure 5).

This formula has a more complicated form than formula (1), and additionally includes derivative terms of odd order:

$$V(\lambda_0) = \tilde{V}(\lambda_0) - \beta \Delta\lambda \tilde{V}'(\lambda_0) + (\beta^2 - \gamma)(\Delta\lambda)^2 \tilde{V}''(\lambda_0) + \dots \quad (2)$$

where

$$\beta = \frac{\Delta\lambda}{N^2} \sum_{r=1-N}^{N-1} r s_r$$

$$\gamma = \frac{1}{12N^2} + \frac{\Delta\lambda}{N^3} \sum_{r=1-N}^{N-1} r^2 s_r \quad (3)$$

In the case of symmetrical bandpass functions the 1st derivative term in formula (2) vanishes since $\beta = 0$. To test this correction, the extreme (and unrealistic) bandpass function shown in Figure 5 was applied to simulated data. This resulting data was then corrected using formula (2) as shown in Figure 6.

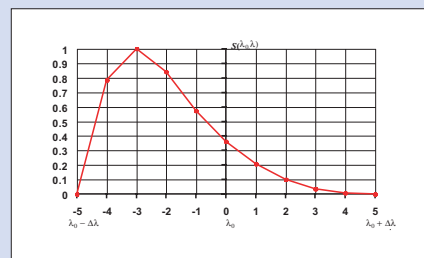


Figure 5. A piecewise linear function describing the bandpass of the monochromator. Here $N = 5$.

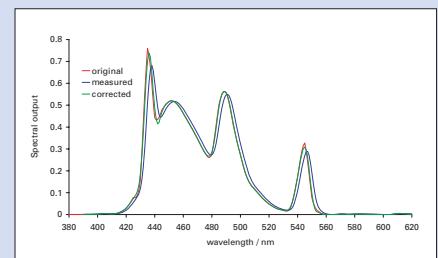


Figure 6. Correcting for an extreme non-triangular bandpass function.

Conclusions

Formulae have been given to correct for bandpass effects in monochromators both in the case of a triangular bandpass and non-triangular bandpass. These corrections have been applied to simulated data and, in the case of a triangular bandpass, to experimental data. To apply the corrections, the derivatives of the functions describing the measurements must adequately be approximated. This means that the measurements must be made at a sufficiently small wavelength step, more closely spaced than the bandwidth. The formulae given here constitute truncations of a Taylor expansion. If necessary additional terms in the expansion can be used to improve the accuracy of the approach, provided sufficient experimental data exists to approximate high order derivatives satisfactorily.

References

- [1] E. I. Stearns and R. E. Stearns, 'An example of a method for correcting radiance data for bandpass error'. *Color Res. Appl.*, 1988. **13**(4), pp. 257-259.
- [2] M. G. Cox, P. M. Harris, P. D. Kenward and E. R. Woolliams. 'Spectral Characteristic Modelling'. 2003. *NPL Report CMSC 27/03*.
- [3] Y. Ohno. 'A flexible bandpass correction method for spectrometers'. in *10th Congress of the International Colour Association*. 2005. Grenada, Spain.