

Stray light correction for array spectroradiometers

This application note describes the possibilities of stray light correction for array spectroradiometers of the CAS 140 series and highlights the advantages of application of the stray light matrix for different measurements. Application of the stray light correction matrix suppresses the stray light by an order of magnitude down to 10^{-5} . All users benefit from this by achieving more precise calibration, in particular in the UV range. 3-4% higher radiometric precision is obtained in UV sources and up to 0.0005 more accurate determination of colour coordinates in visible LEDs.

APPLICATION
NOTE

\ 1. INTRODUCTION

A major limitation in the capabilities of array spectroradiometers in photometry and radiometry is the occurrence of stray light in the device. This means that a certain element of the array detector is contaminated by radiation other than that of the given spectral range. The reason for the occurrence of stray light can be found in various mechanisms:

- » Stray light from the diffraction grating due to manufacturing inaccuracies in the shape and spacing of lines, or roughness of the surface of the grating,
- » Higher diffraction orders, particularly for detectors with a broad spectral range,
- » Double diffraction of the back-reflected light on the grating,
- » Interreflection between the detector and other optical components,
- » Reflexion and scattering of surfaces, in particular of the inner wall of the spectrograph,
- » Fluoreszenz von optischen Elementen,
- » Way in which the light is coupled in the spectroradiometer.

The total amount of measured radiant power thus contains a portion of stray light that causes an error. The main objective of the improvement of radiometric performance of the spectroradiometer is to avoid, or at least largely suppress, the stray light by design measures. Thereafter, residual stray light can be effectively corrected by a suitable method of measuring and calibration, e.g. by the NIST method [1], as outlined in the following.

\ 2. CREATION AND APPLICATION OF THE STRAY LIGHT MATRIX

The calculation of correction functions requires a precise knowledge of the stray light behaviour of the spectroradiometer used for measurements over the full detectable spectral range. The complex stray light behaviour of an array spectrometer can, as shown in [1], be determined with the aid of tunable laser sources. The idea is that monochromatic radiation can be attributed for the most part to a certain pixel of the detector. The entire light that is measured outside the bandpass function for this wavelength is the stray light contribution of pixel i that is seen from all other pixels j in the detector.

In practical implementation, wavelengths are tuned within the measurement range of the spectrometer in 10 nm increments with the aid of OPO (optical parametric oscillator) laser excitation and one spectrum recorded in each case. The entirety of all detected spectra over all excitation wavelengths and suitable interpolation results in a device-specific matrix. If the bandpass function of the real signal is subtracted, the result is a stray light matrix, as for example shown in Fig. 1. This is already numerically applied in the calibration of the spectrometer with the accessory. The user must only load the appropriate calibration for the stray light corrected measurements and the stray light matrix is automatically applied to the measured spectrum by the SpecWin Pro software from Version 3.1 upwards. For the user there is practically no additional measuring time or effort. Depending on the application, lamp type and observed spectral range, a stray light correction of array spectrometers provides lesser or greater advantages.

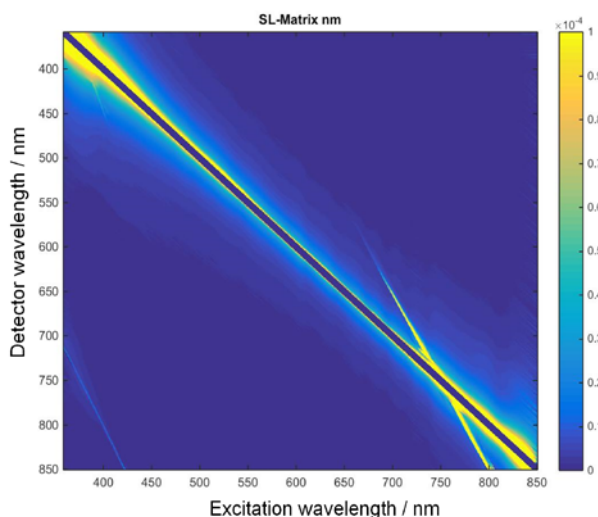


Fig. 1: Typical stray light matrix using the example of a CAS 140CT (Model VIS).

3. ADVANTAGES OF STRAY LIGHT CORRECTION FOR THE CALIBRATION OF SPECTRORADIOMETERS

3.1 More precise measurement of spectral lines

In order to investigate the impact of stray light correction on a linear lamp for the calibration of spectrometers, an HgAr lamp was measured with and without stray light correction, as shown in the logarithmic display in Fig. 2. Overall, a lower stray light level was determined due to the stray light correction, particularly around the peaks in the range above 700 nm. As anticipated, no effect of stray light correction on the peak wavelength of the respective spectral line is recognizable. On individual lines the shoulder on the left side of the peak is eliminated by the correction, causing the centroid wavelength to shift by up to 0.1 nm, in particular in the red range of the spectrum. Due to stray light correction the centroid wavelength can be more accurately determined and is almost identical to the peak wavelength. Because linear lamps are normally used for the wavelength calibration of spectroradiometers, wavelength precision is accordingly increased.

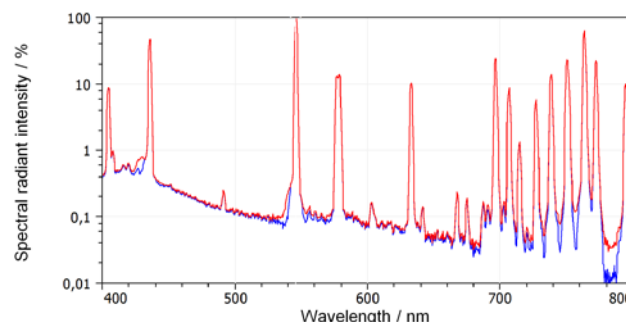


Fig. 2: Spectrum of a HgAr linear lamp without (red) and with stray light correction (blue)

3.2 Impact of stray light correction on broadband sources for spectral calibration

Broadband sources such as halogen lamps and deuterium lamps are normally used for the spectral calibration of spectroradiometers. The impact of stray light correction on the spectrum of a broadband source is particularly distinct in the UV and IR spectral range, because the detector of an array spectroradiometer has only a very low sensitivity at the edges. Stray light correction of the spectrum used for calibration is particularly meaningful, as in particular errors in the areas of lower sensitivity are intensified due to the division of the measured spectrum by the reference spectrum.

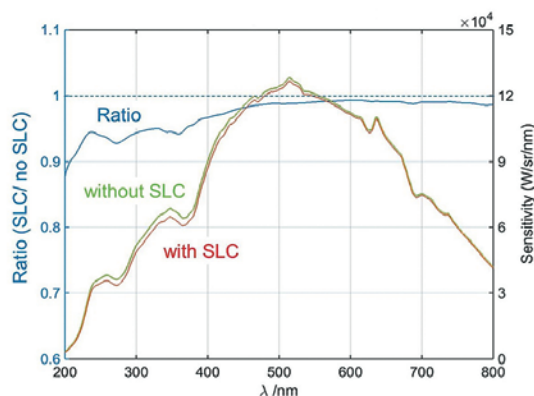


Fig. 3: Sensitivity curves with and without stray light correction and the relationship between them.

If we compare the relationship of sensitivities with and without stray light correction after calibration, we can recognize a stray light portion of about 10% in the range below 400 nm (Fig. 3). A 10% increase in sensitivity in this range of the already low sensitivity, has a direct effect on the absolute precision. In particular applications based on UV radiometry thus profit from stray light correction, e.g. measurement of UV LEDs, sun simulators or halogen lamps with a high portion of UV radiation.

4. STRAY LIGHT CORRECTION IN THE UV RANGE

The ultraviolet range is normally subdivided into UVA (320-400 nm), UVB (280-320 nm) and UVC (200-280 nm). UVA radiation is used, e.g. for curing of printing inks, adhesives and coatings. UVC radiation is used, e.g. for disinfection and water purification.

Fig. 4 shows by way of example the spectra of a UVA LED with and without stray light correction in logarithmic presentation. The suppression of stray light in the spectral course by somewhat more than an order of magnitude in the UV range to almost 10^{-5} is clearly recognizable. Beyond this, we measure about 3% more precise radiant intensity in this example with the use of stray light correction. The impact of stray light correction is somewhat greater in UVC LEDs. It almost reaches the stray light level of a double monochromator and about 4% more precise radiant intensity (Fig. 5). While the peak wavelength (257 nm) does not change at all with the stray light correction, the centroid wavelength shifts by about 0.8 nm in the direction of the peak wavelength.

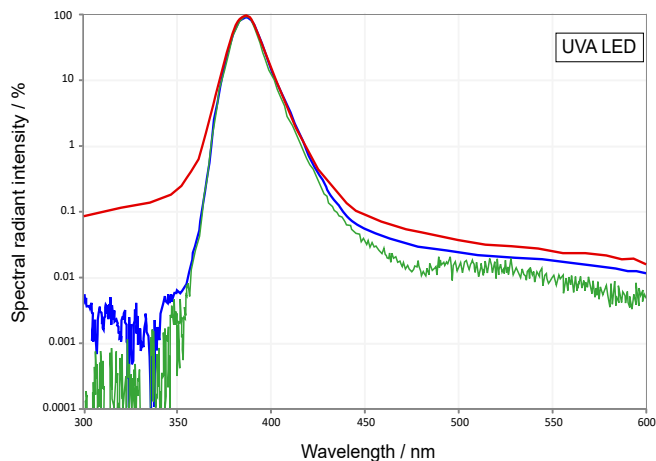


Fig. 4: Logarithmic display of the spectra of a UVA LED without (red) and with stray light correction (blue) and measured with a double monochromator (green).

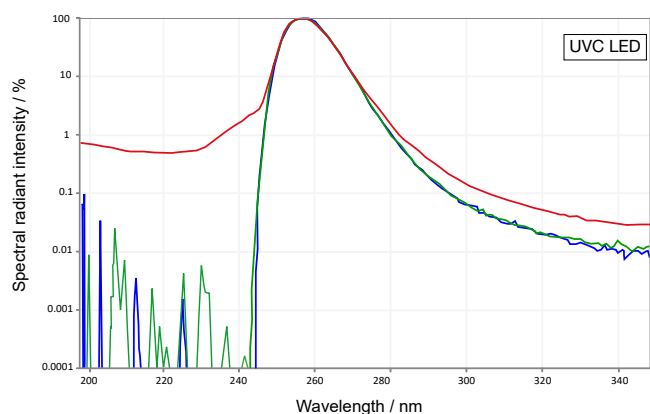


Fig. 5: Logarithmic display of the spectra of a UVC LED without (red) and with stray light correction (blue) and measured with a double monochromator (green).

In the measurement of UV LEDs considerable errors are made in the determination of the absolute value alone by reason of stray light contaminated calibration. As a direct consequence stray light correction thus has a higher precision in radiometric evaluation. All applications based on UV LEDs profit from this, e.g. curing of adhesives and coatings, lithography, scanning heads, horticulture lighting, biomedical devices, combatting of hospital infections, etc.

\ \ 5. INFLUENCE OF STRAY LIGHT CORRECTION ON LED MEASUREMENTS

Fig. 6 shows an example of the spectra of LED standards in the colours white, blue, green and red, in each case with and without stray light correction. The LED standards refer to stabilized and temperature-controlled LEDs. These were measured in a luminous intensity measuring adapter in the I-LED-B configuration with an array-spectral radiometer CAS140 CT (UV-VIS-NIR) with and without application of the stray light correction matrix.

The logarithmic presentation of the spectra clearly shows the impact of stray light correction in the marginal zone

and the signal around zero. In ranges with a generally low signal, particularly in the blue and UV range, the stray light level is corrected up to one order of magnitude and reaches a level of 10^{-4} to $5 \cdot 10^{-5}$.

The impact of stray light correction on the x, y colour coordinates with up to 0.0005 is not to be neglected, if we bear in mind that high-quality array spectral radiometers exhibit measurement uncertainties of ± 0.002 to ± 0.0015 and the LED industry strives for an ambitious tolerance of ± 0.001 . Any increase in measurement accuracy is thus extremely welcome.

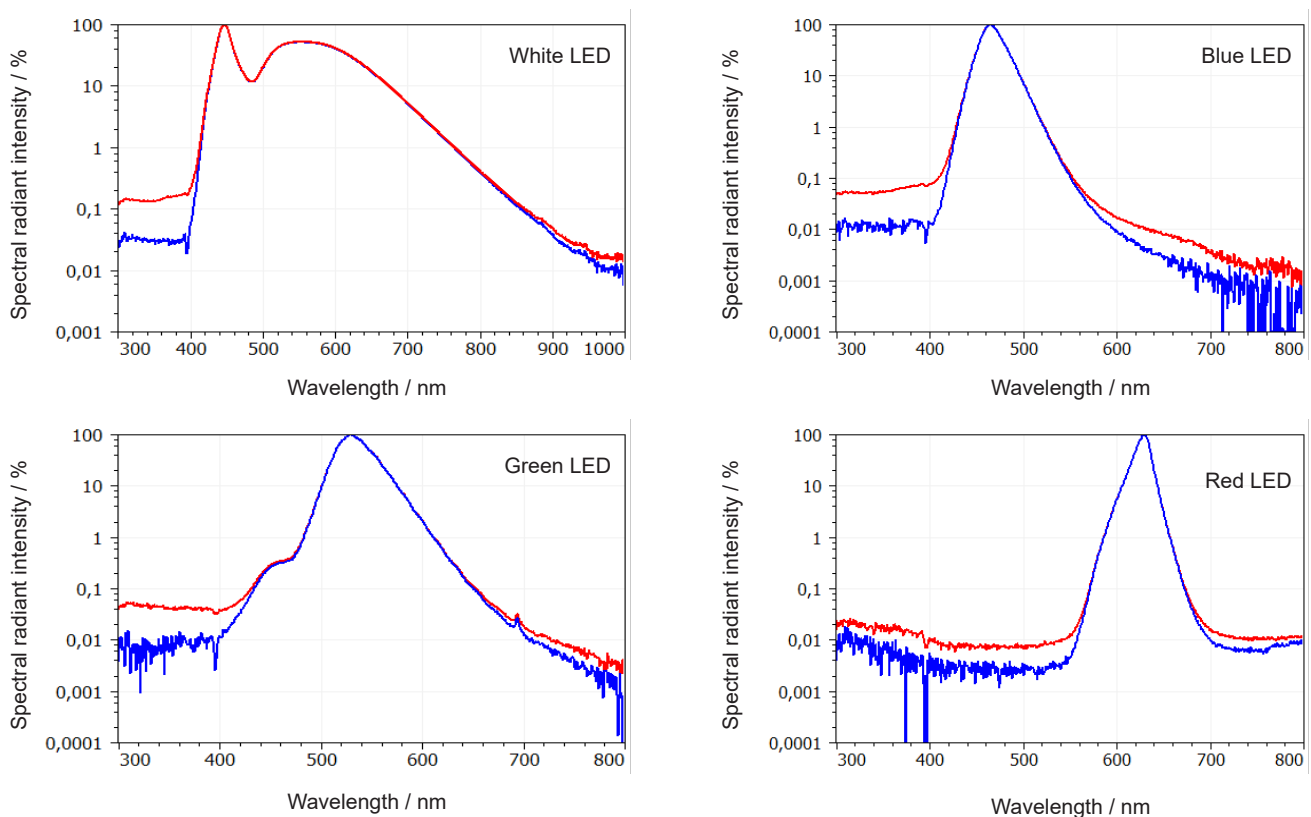


Fig. 6: Logarithmic display of the spectra of white, blue, green and red LED without (red) and with stray light correction (blue).

\ 6. PHOTOBIOLOGICAL SAFETY

One application that could particularly benefit from stray light correction is the assessment of the photobiological hazard by optical radiation, in particular the blue light hazard to the human eye. By blue light hazard we mean the potential risk of photochemical damage to the retina, caused by radiation in the wavelength range 300-700 nm, with the greatest impact in the range between 400 and 500 nm. Hitherto, complex and expensive double monochromators were recommended as measuring instruments in Standard EN 62471, in particular due to the extremely low stray light level. The higher stray light level in the area of greatest impact in the blue and UV range can simulate a non-existent hazard. With the correction of the stray light a greater measurement accuracy and measurement dynamics can be achieved in this range. Due to stray light correction the array spectroradiometer could become a more convenient and lower-cost alternative to the monochromator for determining the blue light hazard.

\ BIBLIOGRAPHY

- [1] Yuqin Zong et al., *Simple spectral stray light correction method for array spectroradiometers*, *Appl. Opt.* 45, 1111-1119 (2006).



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