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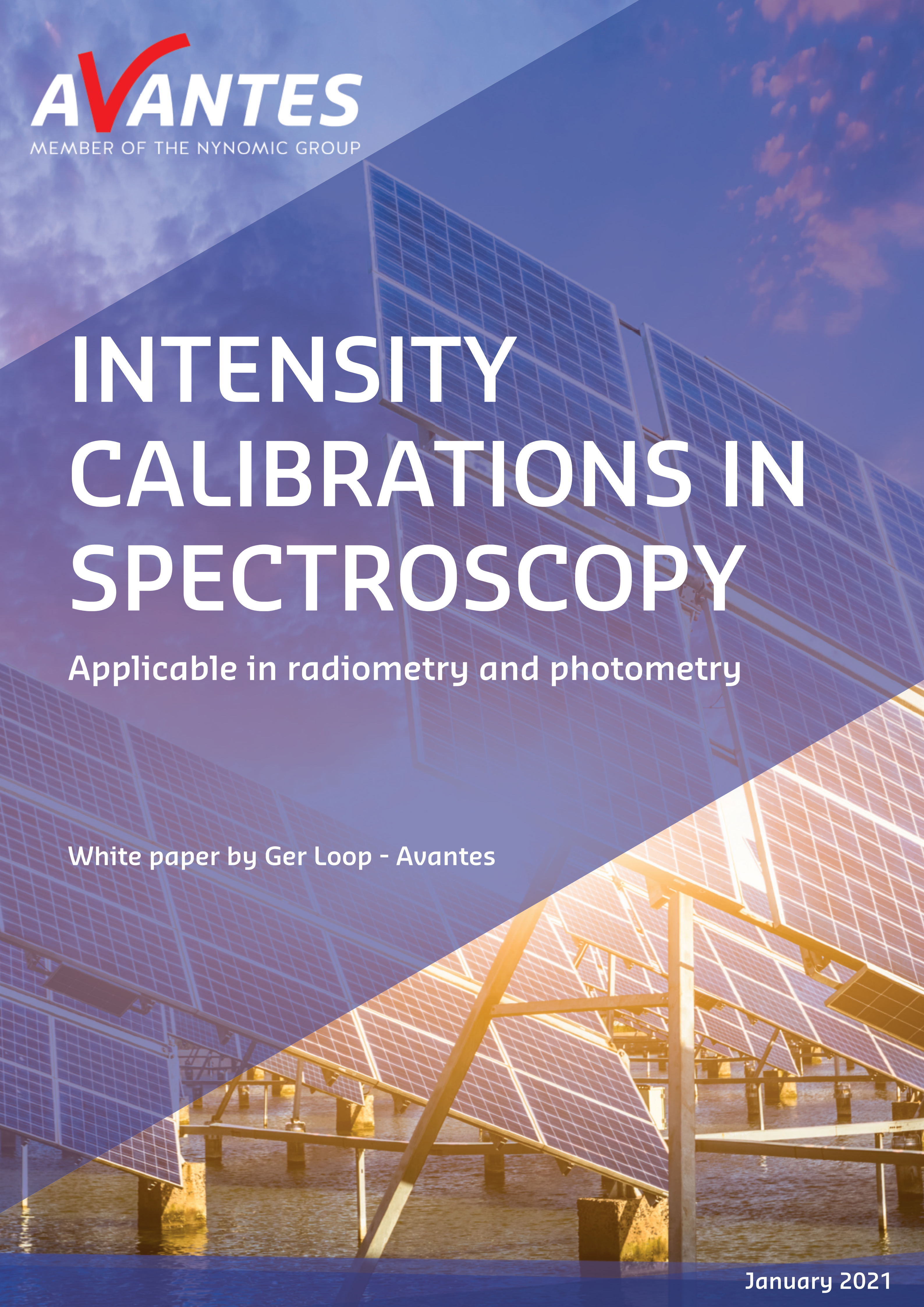

INTENSITY CALIBRATIONS IN SPECTROSCOPY

Applicable in radiometry and photometry

White paper by Ger Loop - Avantes

January 2021

Content

Introduction

Systems based on compact fiber-coupled spectrometers offer great flexibility and are able to obtain accurate spectral wavelength information. To perform measurements on light-emitting examples or objects, however, it is important to know how to interpret the intensity information provided by the spectrometer. In characterizing light sources (e.g. LEDs, Tungsten lamps and sunlight), understanding the differences in parameters is key. This white paper describes the above aspects and shows how an intensity calibration impacts them.

Spectroscopy - Raw Data vs. Intensity Calibrated Data

A spectrometer-based system analyses light received by the measurement head (in the applications described in this white paper, the setups mostly consist of a spectrometer, fiber-optic cable and an integrating sphere that serves as a measurement head). As light travels through the system, all optical properties of the components inside (fiber-optics, grating, detector, mirrors etc.) affect the raw data signal a spectrometer provides.
When looking at the light coming from a Tungsten halogen light bulb, the output of a spectrometer does not resemble the spectrum found in literature, but a more distorted signal like the one depicted below in Figure 1.

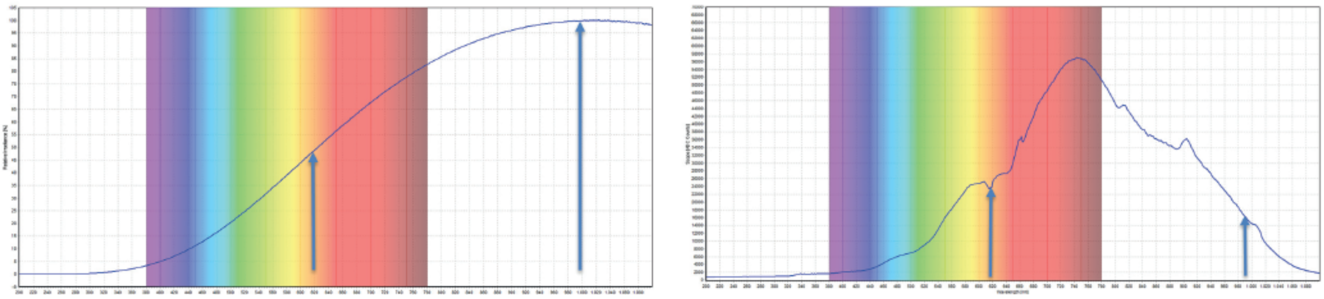

Figure 1. Left is a typical halogen spectrum, right is the raw data signal provided by a spectrometer

To compare the intensity (e.g. height) of the signals at 620 nm and 1000 nm, based on the raw data, it could be stated that the signal is lower at 1000 nm. However, in reality the signal is about twice as high. To compensate for this, the spectrometer can be calibrated for intensity.

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Relative and Absolute Calibration

There are two situations in which a calibration is necessary: when an absolute value of intensity is needed (to qualify the output of a light source, for instance), or when the ratio of intensities is needed (for instance in plasma, LIBS and Raman measurements). For the latter, a relative intensity calibration can be performed.

With a relative calibration the shape of the spectrum is corrected by comparing it to the shape of a known light source (halogen light bulb with 2850K color temperature). This way, the intensity values at different wavelengths can be compared, but not the power in absolute terms.

AvaSoft 8 offers this functionality in the Relative Irradiance Mode (RI). The calibration can be performed quickly by taking a dark reference (a measurement with the light source turned off) and a white reference (a measurement of a halogen light source). After this, the calibration is completed and the measurements will be scaled accordingly to allow for a true intensity comparison.

When absolute intensity values are needed, the spectrum needs to be converted to not only compare it to the shape of a lamp, but to measure the power levels of the lamp as well. This can be done by calibrating the system against a NIST-calibrated light source, as shown in Figure 2.

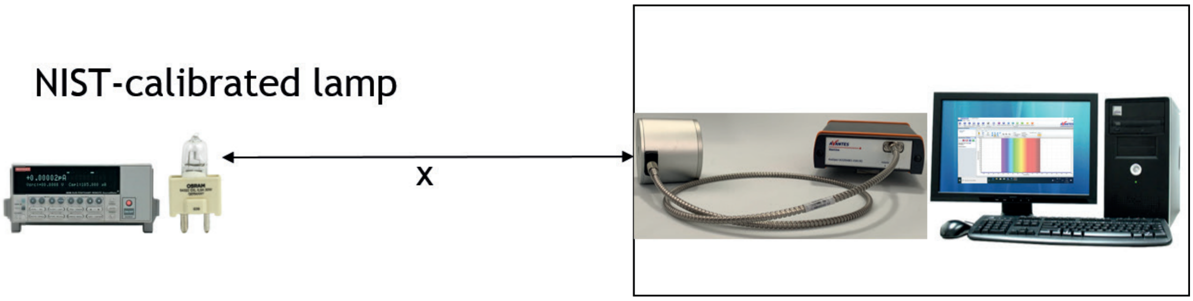


Figure 2. A NIST-calibrated light source setup

The intensity calibration contains the data transfer function for each pixel. The data transfer function is used to convert the raw data (A/D counts) into irradiance data (in μWatt/cm²). To calculate the transfer function, a calibrated light source with known output (in μWatt/cm²/nm) is necessary.

When saving the A/D counts with the reference light source turned on and off, the relation between the A/D counts and μWatt/cm² is as follows:

$$\left(\frac{Caldata_n}{refcal_n - darkcal_n}\right)$$

$Caldata_n$ = Intensity of the calibrated light source at pixel n (in μWatt/cm²) from lamp file
$refcal_n$ = A/D Counts at pixel n that were saved with the reference light source on
$darkcal_n$ = A/D Counts at pixel n that were saved with the reference light source off

This relation can be used to measure the intensity at every pixel (in µWatt/cm²) when measuring the A/D counts received from a light source different from the calibrated light source. If $sample_n$ is the measured A/D counts at $pixel_n$ when looking at the sample light source , and $dark_n$ is the measured A/D counts with the sample light source turned off, the equation for intensity (In), displayed in µWatt/cm² becomes:

$$I_n = Caldata_n * \left(\frac{sample_n - dark_n}{refcal_n - darkcal_n} \right)$$

If an integration time (e.g. 100 ms) was used during the intensity calibration that differs from the integration time during the sample measurements (e.g. 2 ms), a factor needs to be added to the equation to compensate for this difference. In the example the factor is 100/2=50.
The intensity (in µWatt/cm²) from the measured sample spectrum (in A/D counts) can then be calculated using the following equation:

$$I_n = Caldata_n * \left(\frac{sample_n - dark_n}{refcal_n - darkcal_n} \right) * factor$$

After performing this calibration, the conversion data will be stored in EEPROM on the spectrometer to enable correct conversion of the raw data into true radiometric values.

In AvaSoft 8, these absolute values can be displayed in the Absolute Irradiance Mode (AI).

The aforementioned calibration is suitable for a complete measurement setup, including a spectrometer, fiber-optic cable and sphere or cosine corrector.

For customers who need more flexibility and have to recalibrate their system on a regular basis, a field calibration source, like the AvaLight-HAL-CAL-Mini-ISP50 is available. This source can be used by customers to perform an intensity calibration themselves, though it is less accurate than our in-house calibration service.

Various light output parameters can be calculated using the irradiance spectrum (in µWatt/cm²). For a better understanding of this topic, the following sections of this white paper explain the differences between radiometry and photometry and provide a more detailed explanation of several often-used parameters.

Radiometry and Photometry - Finding Your Way

When measuring light sources like LEDs, different parameters can be used to describe the object in question. The following section clarifies and differentiates these terms.

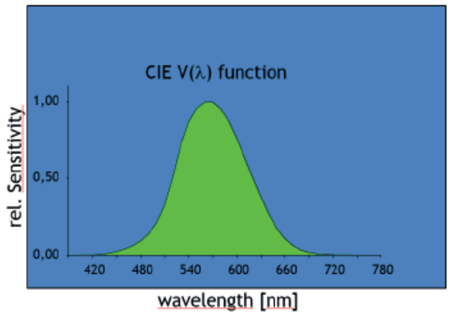
Radiometry vs. Photometry

Radiometry measures all electromagnetic (optical) radiation in the ultraviolet, visible and near-infrared ranges.

Photometry is used to measure visible optical radiation as perceived by the human eye.

Since the human eye responds to light following the V(λ) curve, the photometric counterpart of a radiometric value can be obtained by filtering it through the V(λ) curve, as described in Figure 3.

Radiometry >



> Photometry

Figure 3. Obtaining photometric values using radiometric values

Characterizing a light source

There are several parameters used to characterize the output of a light source.

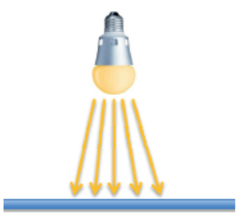
1. Radiometric/photometric flux power

The total amount of radiation emitted by a light source.

Radiometry	Photometry
Radiant power	*Luminous flux*
$Ø_e$ *(W)*	$Ø_v$ *(lm)*

2. Irradiance/illuminance

The amount of radiant power impinging upon a surface per unit area.



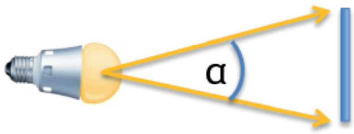
Radiometry	Photometry
Irradiance	*Illuminance*
E_e *(W/m²)*	E_v *(lm/m² = lx)*

Note: with irradiance, the Inverse Square Law and Cosine Law apply.
The inverse square law describes the relationship between irradiance and distance to the object. In equation: $E_1 d_1^2 = E_2 d_2^2$ (i.e. intensity per unit area varies in inverse proportion to the square of the distance).

The Cosine Law describes the nature of reception of an irradiance measurement head. The field of view of the detection area is 180º, yet the contribution follows a cosine curve. This means the irradiance will vary with respect to the cosine of the angle between the optical axis and normal to the detector.

3. Radiant/luminous intensity

The radiant power of a source emitted in a certain direction.



Radiometry	Photometry
Radiant intensity	*Luminous intensity*
I_e *(W/sr)*	I_v *lm/sr = cd*

All these parameters can be measured using one setup consisting of a spectrometer, fiber-optic cable and integrating sphere, as shown in Figure 4. Only the geometry (the position of the light source) changes per parameter. To correctly calculate these values, the right settings in the software need to be applied.

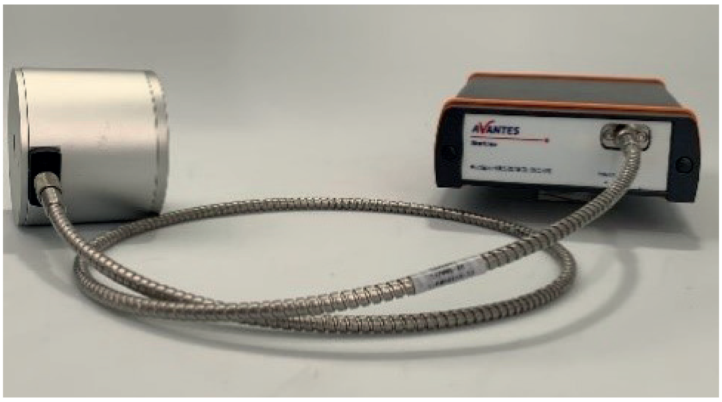


Figure 4. Setup with AvaSpec spectrometer, fiber-optic cable and integrating sphere

To determine flux/power, the light source needs to be positioned inside of the sphere to ensure all emitting light is captured and measured.

To determine irradiance/illuminance, the light source needs to be positioned outside of the sphere to enable measurement of energy per unit area.

To determine radiant/luminous intensity, the setup should be the same as for irradiance/illuminance, but the distance between the light source and the sphere and the diameter of the measurement port needs to be entered in the software in order to calculate the solid angle of the emitting source.

Conclusion

Measurement setups based on compact fiber-optic spectrometers are versatile and can be used in various applications. Some applications however, require not only accurate wavelength information, but also the possibility to compare intensities. To enable this, the spectrometer system needs to be intensity calibrated to convert the shape provided by the raw data into the actual spectral shape of the measured object.

Depending on whether a comparison of intensities or absolute values are needed, a relative or absolute calibration is necessary. An absolute intensity calibrated system can be used to measure both radiometric and photometric parameters.

About Avantes

Avantes is the leading innovator in the development of fiber-optic spectroscopy instruments and systems with over 25 years of experience developing customer-defined configurations. With a long history of consulting with clients across diverse industries and applications, Avantes is an experienced partner, equipped to guide customers who want a solution tailored to their application and research needs. Avantes reassures customers that the solutions they purchase will meet and exceed their expectations.

Please contact us or visit our website for more information on our products and services. We will gladly help you find the right measurement setup for your application!

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