Investigation of an Alternative Method for Measuring the Spectral Irradiance of a High-Powered Focused Light Source

Speaker / Author: I. Kruger*
Co-author: R. Sieberhagen**

National Metrology Institute of South Africa
Private Bag X34, Lynnwood Ridge, Pretoria, 0040, South Africa
*Phone: 012 841 3047 Fax: 012 841 2131
**Phone: 012 841 2729 Fax: 012 841 2131

Abstract

An alternative method was developed to measure the spectral irradiance of a high-powered focused light source, since the existing measurement procedure for spectral irradiance does not make provision for a focused light source. The alternative measurement setup makes use of a spectroradiometer combined with a diffuse reflectance standard. The results obtained from this method were verified with an illuminance meter in the visible wavelength region, i.e. 380 to 780 nm and with a UVA filter radiometer in the ultraviolet wavelength region of 330 to 450 nm.

1. Introduction

The aim was to develop a procedure to measure the spectral irradiance of a high-powered focused light source. The existing measurement procedure for spectral irradiance [1] dictates that the unit under test and the irradiance standard should both have a small filament and should be without focussing optics. The prescribed instrumentation to be used is a monochromator with an integrating sphere or diffuser at the entrance slit of the monochromator. In this scenario, alignment of the standard and the unit under test to the monochromator system is fairly simple and can be done accurately using a laser alignment setup. This ensures repeatability between measurements.

Initial measurements were performed according to this procedure. However, it was discovered that the results were not repeatable. Since the source of light is very directional, the alignment of the source has a great influence on the amount of light that enters the monochromator system and will therefore influence the measurement result dramatically. It became clear that an alternative procedure had to be developed that is not influenced by the alignment of the source with the detector.

It was therefore decided to use a different measurement setup that relies on using a spectroradiometer combined with a diffuse reflectance standard. The results obtained with this setup were verified with an illuminance meter in the visible wavelength region, i.e. 380 to 780 nm and with an UVA filter radiometer in the ultraviolet wavelength region of 330 to 450 nm.
2. Method

2.1 Existing measurement procedure

The spectral irradiance of the high-powered focused Xenon arc light source was determined using the existing measurement procedure. With this procedure the spectral irradiance of the source was measured against a spectral irradiance standard lamp, traceable to the national measuring standards of spectral irradiance.

The light emitted by the source was measured spectrally on two double grating monochromators. One monochromator was set up with an integrating sphere at the entrance slit and a photomultiplier as the detector. The measurements were performed over the wavelength range of 250 to 750 nm with increments of 5 nm. The monochromatic bandwidth was 2 nm. The second monochromator was set up with a diffuser plate at the entrance slit. Measurements were performed in the wavelength range of 700 to 1 000 nm with 25 nm increments, using a Silicon photodiode detector and in the range of 950 to 1 600 nm with 50 nm increments, using an Indium Gallium Arsenide photodiode detector. The monochromatic bandwidth was 4 nm. [2]

The high-powered focused Xenon arc light source was positioned horizontally, with the centre of the source aligned along the optical axis of each of the monochromators’ entrance optics. It has to be noted that due to the physical construction of the source, it was not possible to use a laser alignment system and therefore proper alignment could not be guaranteed. The distance between the source reference plane and the receiving aperture of the first monochromator was ~4,0 m, and ~6,4 m for the second monochromator. The reference plane of the source was defined by the front of the lens fitted in the front of the housing. The high-powered focused light source was replaced by the spectral irradiance standard lamp, placed at a distance of ~0,5 m from the monochromator reference plane, and the measurement was repeated. [2]

2.2 Alternative measurement procedure

A measurement setup was constructed on a 50 m bench used for dimensional measurements. A diffuse reflector standard and a spectroradiometer, aligned at ~45° to the reflector standard, were set up on the one end of the bench. The high-powered focused Xenon arc light source was set up at the opposite end of the bench. In order to reduce stray light, a baffle tube with an ~45° extension tube was placed between the spectroradiometer and diffuse reflector standard as well as baffles along the optical path. All the components were aligned in one horizontal plane.

The diffuse reflector standard was positioned in the area where the light source produced maximum irradiance. The area of maximum irradiance was determined with an illuminance meter by measuring the illuminance at certain points in a grid at approximately 50 m from the light source.

Measurements were performed with the spectroradiometer from 380 to 1 080 nm in 2 nm increments. The bandwidth of the spectroradiometer was 14 nm and the aperture size used was 0,5°. A sandwich measurement was made with the spectroradiometer and an illuminance meter. Figure 1 shows the measurement setup.
3. Results and Discussion

3.1 Results from existing measurement procedure

Figure 2 shows the absolute spectral irradiance values obtained using the existing measurement procedure. The measurement ranges for the two monochromators were chosen to overlap between 700 and 750 nm as a check to determine whether this procedure would yield repeatable results. As seen from this overlapping area in Figure 2 it is clear that the results did not correspond with each other.
3.2 Results from the alternative measurement procedure

Figure 3 shows the absolute spectral irradiance values of the high-powered focused Xenon arc light source. Comparing the measured values with a typical 150 W Xenon arc lamp, it was found that the spectral characteristics were similar [3].

![Spectral Irradiance Graph](image)

Figure 3: Spectral irradiance obtained from the alternative measurement procedure.

3.3 Verification of results in the visible region

An illuminance meter was used to verify the results obtained from the spectroradiometer in the visible region of the electromagnetic spectrum. The first step was to convert the absolute spectral radiance values measured with the spectroradiometer to absolute spectral irradiance values. Radiance is converted to irradiance using the following formula: [4]

\[ E(\lambda) = \frac{L(\lambda)}{\rho(\lambda)} \pi \]  

where \( E(\lambda) \) is spectral irradiance, \( L(\lambda) \) is spectral radiance and \( \rho(\lambda) \) is the spectral reflectance of the diffuse reflectance standard [5].

The second step is the conversion of absolute spectral irradiance to illuminance, \( E_v \), since this is the output quantity given by the illuminance meter. To convert to illuminance, the absolute spectral irradiance is weighted by the normalised photopic response, \( V(\lambda) \) [6]. The weighted curve is integrated over the visible wavelength region (380 to 780 nm) and the result is multiplied by a constant, \( K_m \), known as the maximum spectral luminous efficacy (of radiation) for photopic vision:

\[ E_v = K_m \int_{380}^{780} E(\lambda)V(\lambda)d\lambda \]  

where \( K_m = 683 \) lumen/watt.
Figure 4 shows the absolute spectral irradiance obtained from the alternative measurement procedure in the range of 380 nm to 780 nm, the ideal photopic response, \( V(\lambda) \), and the weighted curve. All curves are normalised on the graph for the sake of comparison.

![Graph of absolute spectral irradiance, ideal photopic response, and weighted curve](image)

Figure 4: Absolute spectral irradiance obtained from the alternative measurement procedure, ideal photopic response, \( V(\lambda) \), and the weighted curve.

Table 1 shows the calculated illuminance and the illuminance measured with the illuminance meter. The deviation of the calculated value from the measured value could be ascribed to the fact that an ideal photopic response was assumed and not the actual response of the illuminance meter, but this will have to be verified.

<table>
<thead>
<tr>
<th>Calculated [lux]</th>
<th>Measured with illuminance meter [lux]</th>
<th>Deviation [%]</th>
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</thead>
<tbody>
<tr>
<td>881,2</td>
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<td>6,5</td>
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</table>

### 3.4 Verification of results in the ultraviolet region

The first step was to extend the absolute spectral irradiance values down to 330 nm. This was done by treating the spectral irradiance values measured with the existing measurement procedure in the 330 to 380 nm region as relative spectral values and scaling these values to match the absolute values obtained from the alternative measurement procedure. Figure 5 shows the spectral irradiance obtained from the existing and the alternative measurement procedures and the extended spectral irradiance.
The second step was to weigh the absolute spectral irradiance values in the ultraviolet region with the corresponding normalized relative responsivity of the UVA filter radiometer (obtained from its calibration certificate [7]). Figure 6 shows the spectral responsivity of the UVA filter radiometer, extended spectral irradiance and the weighted spectral irradiance. All curves are normalised on the graph for the sake of comparison.

Figure 5: Spectral irradiance obtained from the existing and the alternative measurement procedures and the extended spectral irradiance.

Figure 6: Spectral responsivity of the UVA filter radiometer, the extended spectral irradiance and the weighted spectral irradiance.
A distance correction was performed using the following equation:

\[ E_1 d_1^2 = E_2 d_2^2 \]  

(3)

where \( E \) is the spectral irradiance and \( d \) is the measurement distance.

Table 2 shows the results of the calculated spectral irradiance and the spectral irradiance measured with the UVA filter radiometer.

Table 2: Calculated and measured spectral irradiance.

<table>
<thead>
<tr>
<th></th>
<th>Calculated [W/m²]</th>
<th>Measured with UVA filter radiometer [W/m²]</th>
<th>Deviation [%]</th>
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<tr>
<td>UVA (330-450 nm)</td>
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There is a significant deviation of the calculated spectral irradiance and the spectral irradiance measured with the UVA filter radiometer. The cause of this deviation is unclear and requires further investigation.

3.5 Uncertainty budget

See Annexure 1 for the uncertainty budget.

4. Conclusion

An alternative procedure was developed to measure the spectral irradiance of a high-powered focused light source. This procedure makes use of a spectroradiometer combined with a diffuse reflectance standard. The results obtained from this method were verified with an illuminance meter in the visible wavelength region, \( i.e. \) 380 to 780 nm. The illuminance calculated from the alternative measurement procedure corresponds well with the values measured directly with the illuminance meter.

Measurements were also made with a UVA filter radiometer to verify the results in the ultraviolet wavelength region of 330 to 450 nm. However, these results were not satisfactory and further experimentation is necessary to investigate the effect of \( e.g. \) bandwidth, aperture size and stray light on the measurements.

A final conclusion regarding the suitability of the alternative measurement procedure can only be made once the deviation in the UVA region can be explained and is within the uncertainty of the measurement.

5. Future Work

In order to gain more confidence in the results of the visual region it would be necessary to determine the actual responsivity of the illuminance meter. Instead of weighing the spectral irradiance with the ideal photopic response, it will be weighted with the actual response of the sensor, yielding a more accurate result.

The deviation between the measured and calculated values in the UVA region is of great concern. Further experimentation is required to investigate the cause of this. Factors that should be considered include, amongst others, the bandwidth and aperture size of the measuring instruments (\( i.e. \) monochromator and spectroradiometer) and effects such as stray light.
light. In addition, the claimed spectral responsivity of the UVA filter radiometer will have to be verified, especially in the out-of-band wavelength regions.

Consideration will also be given to the verification of the absolute spectral irradiance in the wavelength range of 780 to 1600 nm.

The uncertainty budget will be revised accordingly.

6. References


Annexure 1: Uncertainty Budget

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<th>Symbol</th>
<th>Input Quantity</th>
<th>Estimated Uncertainty</th>
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<th>Standard Uncertainty Contribution (U)</th>
<th>Sensitivity Coefficient (C)</th>
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