Characterization of spectral irradiance system based on a filter radiometer

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Abstract. The spectral irradiance scale has been realized recently. It is based on a filter radiometer that was mounted and characterized. The optical system was assembled and the procedures of the methodology were defined, including the mounting of FEL lamp jig, alignment of the optical system, calibration of the instruments and optical devices used on the experimental system. The main uncertainty components were evaluated and the preliminary uncertainty budget of the spectral irradiance system is presented.

1. Introduction
At INMETRO, the realization of the spectral irradiance scale is based on detector. This methodology has been realized using filter radiometers. These devices are basically composed by an aperture, interference filters, and a trap detector [1, 2]. All these components should be characterized to give traceability in spectral irradiance measurements. For this the spectral responsivity of trap detector is linked to cryogenic radiometer [3]. The preliminary irradiance measurements were presented elsewhere [4, 5]. In this resume we describe the employed methodology and the uncertainty budget for the system.

2. Experimental Set-up
The experimental setup assembly consists of four main steps: definition of the optical axis with auxiliary lasers, alignment of the FEL lamp jig, of the FEL lamp, and of the filter radiometer. The Resin (Ceramcast 575-N powder) was used to fix the lamp jig and in its support, as depicted in Figure 1. The jig is a target used as a reference for the reproducible alignment of the lamp.
The laser was fixed to a support at a height of about 28 cm, corresponding in about to the lamp middle height. First, a target was used to align the laser on the optical table. The target was moved along the trail defining the optical axis. It was then removed and two apertures were used to finish the alignment and as markers.

The lamp holder is fixed in an adjustable support on the optical rail with several degrees of freedom. The height of this structure relative to the optical table was measured (~ 28 cm). The center of the lamp filament was aligned in relation to the optical axis. The FEL lamp was replaced by the jig. Angular alignment was completed by returning the reflected beam back on the incident laser beam, as shown in Figure 2.

The two apertures are displaced close to the radiometer, once the optical axis has already been marked with them. Another laser was added to the system – similar to the other laser used before – with a plane mirror to align the filter radiometer on the optical axis. The laser is aligned to the apertures, reaching the filter radiometer, which has its center aligned. The back-reflected beam is used for angular alignment (see Figure 3).
Figure 3 – A) Alignment of the second laser relative to the first. B) Filter radiometer alignment.

The Figure 4 shows the experimental system assembly. This system is composed by a filter radiometer with a thermally-controlled filter holder and a current-stabilized lamp.

Figure 4 – Schematics for the experimental setup

A trans-impedance amplifier and a digital voltmeter (DVM) are used to acquire the electrical signal of the filter radiometer. Additional DVMs are used to monitor the voltage and current (through a shunt resistor) applied to the FEL lamp and also the electrical signal of the temperature controller. Figure 5 shows a picture of the setup.

Figure 5 – The view of the irradiance system, A) by the side of the filter radiometer B) by the side of the FEL lamp jig.

3. Results and Discussions

The uncertainty components were evaluated and the uncertainty budget is presented in Table 1. In Table 1 are detailed some of the main uncertainty components related to spectral irradiance scale. The uncertainties analyzed are linked to the trap detector, the interferential filters, the apertures, and setup characterization. The dominant component comes from the calibration spectral responsivity of the trap detector. The second one comes from the calibration of interference filters.
Table 1. Uncertainty Budget

| Sources of uncertainty          | 394 | 420 | 450 | 500 | 550 | 600 | 694 | 800 | 905 | 940 |
|---------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Wavelength (nm)                 |     |     |     |     |     |     |     |     |     |     |
| Spectral Responsivity (%)       | 0.83| 0.77| 0.72| 0.65| 0.59| 0.54| 0.46| 0.40| 0.35| 0.34|
| Spectral transmittance (%)      | 0.40| 0.40| 0.41| 0.40| 0.40| 0.40| 0.40| 0.40| 0.23| 0.43|
| Filter temperature (%)          | 0.26| 0.00| 0.31| 0.25| 0.38| 0.12| 0.17| 0.14| 0.23| 0.26|
| Lamp current (%)                | 0.001| 0.001| 0.001| 0.001| 0.001| 0.001| 0.001| 0.001| 0.001| 0.001|
| Distance (%)                    | 0.06| 0.06| 0.06| 0.06| 0.06| 0.06| 0.06| 0.06| 0.06| 0.06|
| Aperture area (%)               | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Interreflection in filter (%)   | 0.10| 0.10| 0.10| 0.10| 0.10| 0.10| 0.10| 0.10| 0.10| 0.10|
| Combined uncertainty (%)        | 0.96| 0.88| 0.89| 0.81| 0.81| 0.69| 0.65| 0.59| 0.49| 0.62|
| Expanded uncertainty (%)        | 1.9 | 1.8 | 1.8 | 1.6 | 1.6 | 1.3 | 1.3 | 1.2 | 1.0 | 1.2 |

The detector responsivity was measured using a cryogenic radiometer as a primary standard at wavelengths of 457.8 nm, 476.0 nm, 488.0 nm, 501.0 nm, 514.5 nm, and 632.8 nm. The data was interpolated and extrapolated (provided the linear behavior of this kind of detector) in the visible and near infra-red spectral ranges. The uncertainty component due to linear adjust of the data dominates the total uncertainty (see Table 2).

Table 2. Spectral responsivity uncertainties of Trap detector

| λ (nm) | s (A/W) | u (A/W) | u_r (A/W) |
|--------|---------|---------|-----------|
| 400.0  | 0.3167  | 8.5E-05 | 2.6E-03   |
| 420.0  | 0.3331  | 8.5E-05 | 2.6E-03   |
| 450.0  | 0.3577  | 8.5E-05 | 2.6E-03   |
| 457.9  | 0.3642  | 8.5E-05 | 2.6E-03   |
The interferential filters are linked to the reference spectrophotometer; as shown in Table 3. The main characterization steps of the instrument include evaluation of the stray light, photometric noise, linearity, temporal drift of the standard, FWHM, scan rate, among others. The total uncertainties of the filters are determined measuring the peak transmittance, wavelength scale and wavelength setting repeatability. The temperature uncertainty is analyzed with the temperature controller attached to the interferential filters during the transmittance measurement.

Table 3. Uncertainties of Transmittance, Δλ, and Temperature of Interferential Filters

| λ (nm) | T (%) | U (%) | u (%) | Δλ (nm) (FWHM) | u (nm) | θ (°C) | u_c (°C) |
|--------|-------|-------|-------|----------------|--------|--------|----------|
| 340    | 89.61 | 0.74  | 0.40  | 9.7            | 1.7    | 24.97  | 0.01     |
| 365    | 92.00 | 0.74  | 0.41  | 8.9            | 1.5    | 24.98  | 0.28     |
| 394    | 95.31 | 0.76  | 0.40  | 7.8            | 1.4    | 24.99  | 0.26     |
| 420    | 96.78 | 0.77  | 0.40  | 9.5            | 1.6    | 24.93  | 0.00     |
| 450    | 88.32 | 0.73  | 0.41  | 8.6            | 1.5    | 24.94  | 0.31     |
| (445)  |       |       |       |                |        |        |          |
| 500    | 96.42 | 0.74  | 0.40  | 8.9            | 1.5    | 24.94  | 0.25     |
| (502)  |       |       |       |                |        |        |          |
| 550    | 95.68 | 0.76  | 0.40  | 8.5            | 1.5    | 24.93  | 0.38     |
| 600    | 95.42 | 0.76  | 0.40  | 8.2            | 1.4    | 24.94  | 0.12     |
| (695)  |       |       |       |                |        |        |          |
| 694    | 96.29 | 0.76  | 0.40  | 8.5            | 1.5    | 24.95  | 0.17     |
| (695)  |       |       |       |                |        |        |          |
| 800    | 95.98 | 0.75  | 0.40  | 8.7            | 1.5    | 24.95  | 0.14     |
| (798.35)|    |       |       |                |        |        |          |
| 905    | 89.79 | 0.38  | 0.23  | 10.9           | 1.9    | 24.95  | 0.23     |
| (907)  |       |       |       |                |        |        |          |
| 940    | 90.32 | 0.73  | 0.43  | 10.1           | 1.8    | 24.96  | 0.26     |
| (943)  |       |       |       |                |        |        |          |

The other components are connected to spectral irradiance measurement where the uncertainties of lamp current, distance between lamp and detector, and repeatability are analyzed. The interreflections of the filter radiometer have been evaluated too. The components related to electronics of the system...
are linked to electrical standards. The aperture area of the filter radiometer is determined at INMETRO with a non-contact method [6], which is based on the image analysis of the aperture area with a microscope. The final value is calculated based on a mean radius, so the circularity of the aperture is important. The calibrated area is 7.051 mm$^2$ with uncertainty 0.004 mm$^2$. Additionally, studies on the stability and detection limits of spectral irradiance system are being made to characterize it better. Figure 6 shows the electrical signal detected by the filter radiometer during a period of exposure to radiation emitted by a FEL lamp. It can be seen that the data oscillate around a mean straight line and the amplitude of this oscillation does not exceed too much 0.05%.

![Figure 6 – Temporal stability of the irradiance system](image)

4. Conclusions
This work described the definition of the alignment methodology and the uncertainty budget for the spectral irradiance scale developed in Brazil, which covers the spectral range of visible and near infrared. The preliminary spectral irradiance measurements show results compatible with the literature. The spectral responsivity of trap detector was measured by direct comparison with the cryogenic radiometer using Ar$^+$ and HeNe laser lines as radiation sources. The uncertainty component due to the linear adjust of this data dominates the total uncertainty. A characterized commercial spectrophotometer was used to measure the spectral transmittance of the interferential filters. The analysis was also performed as a function of the temperature of the filters. The measurement corresponds to the second dominant uncertainty contribution. Other uncertainty sources as detector nonlinearity, out-of-band filter peaks, and diffraction will be determined in the near future.

5. References

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