# Recent Progress on Calibration of Spectroradiometers using Tunable Lasers

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**To reduce calibration uncertainties of spectroradiometers, we developed a detector-based method for calibrating spectroradiometers directly (one-step) against transfer-standard trap detectors using a tunable laser. Recently, we conducted more research on spectroradiometer's wavelength calibration and the uncertainty was reduced to approximately 0.25 % (*k* = 2), which is much smaller than that using the conventional calibration method based on transfer-standard lamps. The calibrated spectroradiometer is also a new transfer-standard detector for spectral irradiance or radiance scale.**

## 1. INTRODUCTION

Traditionally, spectroradiometers have been calibrated using transfer-standard broadband light sources such as 1000 W FEL lamps (or deuterium lamps in the ultra-violet region). Using this source-based calibration method, the uncertainty of a spectroradiometer, dominated by the uncertainty of transfer-standard light sources [1], is typically about 1 % in the visible to infrared region and much larger in the ultra-violet region. Compared to transfer-standard detectors the transfer-standard light sources (which are mostly discontinued by the lamp manufacturers) have quite large uncertainties, mainly resulting from the long chain of calibrations to establish their traceability. For example, the spectral irradiance of a 1000 W FEL lamp is derived and transferred in sequence from (1) primary cryogenic radiometer, (2) transfer-standard trap detector, (3) reference field radiometer, (4) gold point blackbody, and (5) high temperature blackbody.

To reduce the calibration uncertainty, we developed a new detector-based method for calibrating spectroradiometers directly (one-step) against transfer-standard trap detectors using a fully automated tuneable laser [2]. This method was improved recently, mainly on spectroradiometer's wavelength calibration and the calibration uncertainty for a spectroradiometer's spectral irradiance responsivity was reduced to approximately 0.25 % (*k* = 2). A spectroradiometer calibrated using this low-uncertainty method can become a new transfer-standard detector for spectral irradiance or radiance scale which can then be transferred again to other detectors or even sources for further downstream dissemination.

## 2. THE NEW CALIBRATION METHOD

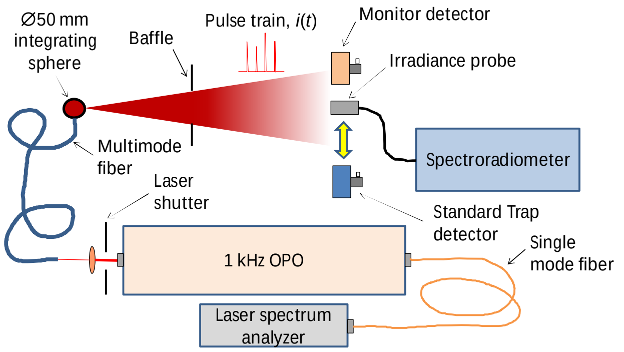


**Figure 1.** Schematic of the new calibration method

A schematic for calibration of an irradiance spectroradiometer is shown in Figure 1. A 1000 Hz, fully automated tunable (210 nm to 2400 nm) optical parametric oscillator (OPO) laser is used for this calibration. The bandwidth of the OPO laser is approximately 0.2 nm in the visible region. A laser spectrum analyser (LSA) is used for measurement of the wavelength of OPO laser. The wavelength scale of the spectroradiometer is calibrated against the LSA with a standard uncertainty on the order of a picometer [3].

The calibration is based on the measurement of the total energy of a pulsed OPO train. The length of the pulsed OPO train, controlled by a laser shutter, can vary from 1 s to 10 s depending on the laser power. A monitor detector is mounted near the test spectroradiometer or the transfer-standard trap detector to measure the relative total energy of an OPO pulse train. The calibration uses the substitution method where the transfer-standard trap detector and the irradiance probe of the test spectroradiometer are positioned, in turn, to the center of the optical beam. Two charge integrators (not shown in Figure 1) are used for simultaneous measurements of the total electric charge in unit of coulomb: one for the transfer-standard trap detector and the other for the monitor detector.

Before the calibration, the stray light of the spectroradiometer is characterized such that all ensuing measurements are corrected [4] for out-of-band contribution.

For this calibration, we measured both line spread functions (LSFs) and slit scattering functions (SSFs) of the spectroradiometer under test. An LSF describes the response as a function the pixel for a given wavelength, while an SSF is the response of a pixel as a function of the wavelength for a given pixel. The LSF calibration does not require fine tuning of the laser wavelength to obtain the responsivity at a wavelength. Therefore, fixed wavelength lasers can be used to calibrate or check the responsivities of the spectroradiometer.

## 3. RESULTS OF CALIBRATION

Several CCD-array spectroradiometers were calibrated to validate the new calibration method. Figure 2 shows a measurement repeatability when

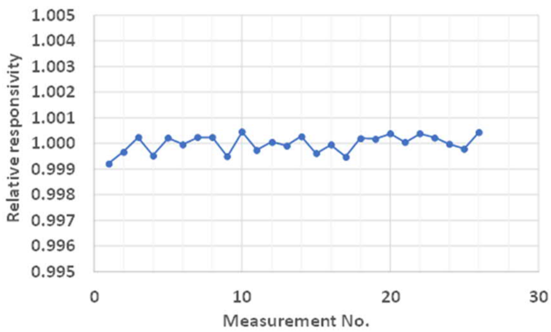


**Figure 2.** Measurement repeatability

using the LSF method. Also, both LSF method and SSF method were used for calibrating a spectroradiometer. The agreement of the calibration results for this spectroradiometer is shown in Figure 3,

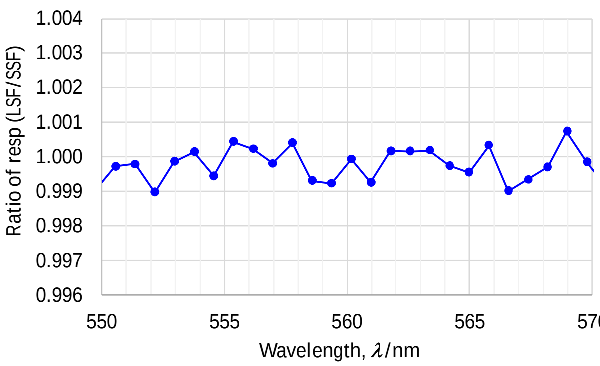


**Figure 3.** Comparison of LSF method and SSF method

which is approximately 0.1 %. The calibration result using the LSF method is also compared with that obtained using a transfer-standard FEL lamp and the agreement is within the combined expanded uncertainty ($k$ = 2) of the two methods (Figure 4).

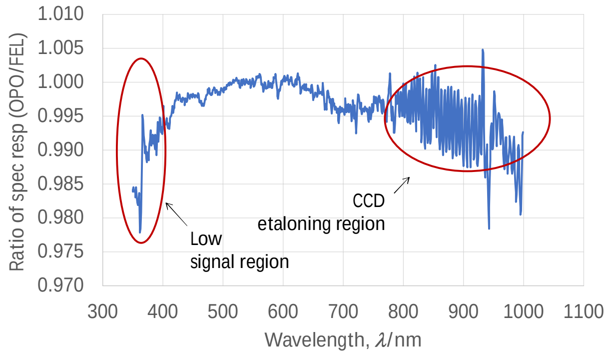


**Figure 4.** Comparison of spectral irradiance responsivities

## 4. SUMMARY

A fully automated method was developed for calibrating spectroradiometers directly (one-step) against transfer-standard trap detectors using a tunable laser. This new calibration method not only reduces spectroradiometer's calibration uncertainties but also enables a new approach to realize spectral irradiance or radiance scale. Each calibrated spectroradiometer is, in fact, a new detector-based transfer standard that can further calibrate secondary transfer-standard instruments and even transfer-standard sources for disseminating spectral irradiance and radiance scales with small uncertainties.


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