Stable spectrally tunable source based on supercontinuum laser and monochromator for detectors radiometric calibration

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A stable spectrally tunable source for calibration of radiometric detectors in radiance or power mode has been developed and characterized. It consists of a supercontinuum laser with expander and focusing optics, subtractive monochromator, power stabilization feedback control scheme, and output coupling optics.
The commercial supercontinuum laser Fianium SC400-4 was used. It has wavelength range from 0.4 to 2.5 µm with full spectrum power of 4 W.
A power stabilization feedback control scheme has been incorporated that stabilizes the source to better than 0.02% for averaging times longer than 1200 s.

INTRODUCTION

When developing facilities for spectroradiometric instrument calibrations, including detectors, spectroradiometers, video spectrometers, etc., one of the main components of uncertainty budget of radiance or radiant power measurements is the instability of the radiation source used.

While radiant sources based on lamps and blackbodies provide sufficient measurement accuracy in the visible range of the spectrum, for example, for the detectors spectral responsivity, the radiant power level of these sources does not provide the required accuracy in the infrared. A partial solution to the problems of measurements in the infrared spectral range is to using lasers at fixed wavelengths.

Nowadays, lasers with a wide spectral range are available [1,2]. These lasers are called supercontinuum and covered the spectral range from 0.4 to 2.5 µm with full power up to 14 watts. Using of these lasers significantly expands the capabilities of the metrological assurance of spectroradiometric instruments calibrations, while the stability is certain.

This work is devoted to stabilization of supercontinuum laser power, while it used as a radiant source of detector spectral responsivity calibration facility based on a cryogenic radiometer.

STABLE SPECTRALLY TUNABLE MONOCHROMATIC SOURCE

Figure 1 shows the VNIIOFI stable spectrally tunable monochromatic source for the spectral range from 0.4 to 2.5 µm.

The main parts of the facility are: (i) radiation source unit with the optical system, which focuses the radiation on the input slit of the monochromator; (ii) subtractive double monochromator, (iii) laser feedback system, (iv) output coupling optics and (v) detector under test.

The facility includes powerful supercontinuum laser Fianium WhiteLase SC 400-4 for the spectral range from 0.4 µm to 2.5 µm. Special laser beam mirror expander with focusing unit are used to irradiate entrance slit of double monochromator and fill its f/4,8 aperture angle. This expander consists of 2 spherical mirrors with expansion ratio of 6^x. The focusing unit includes flat and off-axis parabolic mirrors. The spectral mercury lamp is used for monochromator wavelength calibration.

Radiation of source is directed to monochromator input slit, in front of which the order-sorting filter wheel is located. Subtractive double monochromator McPherson 2035D uses gratings of 600 grooves/mm for the spectral range from 0.4 to 2.5 µm. Monochromator technical characteristics allow selecting radiation with the spectral bandwidth of 6 nm in this spectral range.

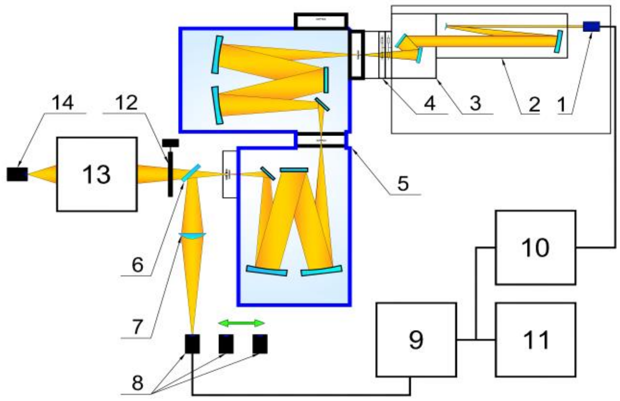

Figure 1. VNIIOFI stable spectrally tunable monochromatic source
1 – supercontinuum laser emitter, 2 – laser beam mirror expander, 3 – focusing unit, 4 – order-sorting filter wheel, 5 – subtractive double monochromator, 6 – quartz beamsplitter, 7 – quartz lens, 8 – feedback monitor detector, 9 – transimpedance amplifier, 10 – supercontinuum laser unit, 11 – digital voltmeter, 12 – shutter; 13 – output coupling optics; 14 – detectors under test (DUT).

For stabilization of monochromatic radiant power the feedback control is used. It consists of thin quartz plate beamsplitter (6), quartz lens (7), feedback monitor (8), transimpedance amplifier (9), supercontinuum laser unit (10) and digital voltmeter (11). Thin quartz plate beamsplitter is installed after output slit of monochromator. The reflected beam is directed to feedback monitor detector with focusing quartz lens. Silicon trap-detector is used as feedback monitor in the spectral range from 0.4 to 1.0 μm. InGaAs and Extended-InGaAs photodiodes are used as feedback monitor in the spectral range from 0.9 to 1.6 μm and from 1.6 to 2.5 μm respectively. Spectral responsivities of this feedback monitor detectors are presented in Figure 2.

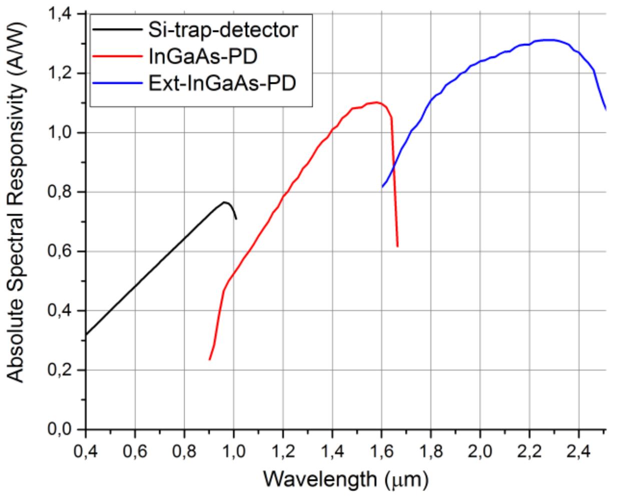

Figure 2. Spectral responsivities of feedback monitor detectors

Feedback monitor detectors are connected to transimpedance amplifier that outputs feedback DC voltage in the range from 0 to +5V. Adjusting DC Voltage of feedback is provided by changing the gain of transimpedance amplifier. Output of amplifier is connected to supercontinuum laser unit that has own internal feedback interface. A PID (Proportional-Integral-Differential) control loop is used to adjust the drive levels to the laser.

Optionally optical program-controlled shutter is placed after feedback beamsplitter in transmitted beam.

Developed monochromatic laser-based source has been established at VNIIOFI Primary Standard for Optical Radiant Power based on Absolute Cryogenic Radiometer (ACR) [3]. Output coupling optics (13) is provided by using two off-axis parabolic mirrors to the entrance window of the vacuum chamber, which forms a common vacuum volume for the ACR and detectors under test.

Spectral responsivity scale realization consists in measuring the radiant power absorbed by the receiving cavity of the radiometer, irradiating the photodetector with this flux, measuring its signal and calculating its spectral responsivity by the formulas:

$$S_I(\lambda) = \frac{I(\lambda)}{P_o(\lambda)}; \quad S_U(\lambda) = \frac{U(\lambda)}{P_o(\lambda)},$$

Where $S_I(\lambda)$, $S_U(\lambda)$ - current and voltage spectral responsivities of calibrating detector, $I(\lambda)$, $U(\lambda)$ - current and voltage of calibrating detector, $P_o(\lambda)$ - spectral radiant power.

The measured spectral radiant power of developed monochromatic laser-based source in the spectral band of 6 nm is presented in Figure 3.

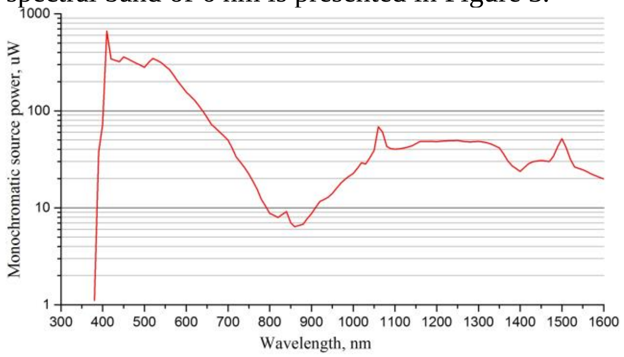

Figure 3. Spectral radiant power of developed monochromatic laser-based source in the spectral band of 6 nm

A power stabilization feedback control scheme has been incorporated and it stabilizes the monochromatic radiant power better than 0.02% for time interval longer about 1200 s. Spectral radiant power stability is presented in Figure 4.

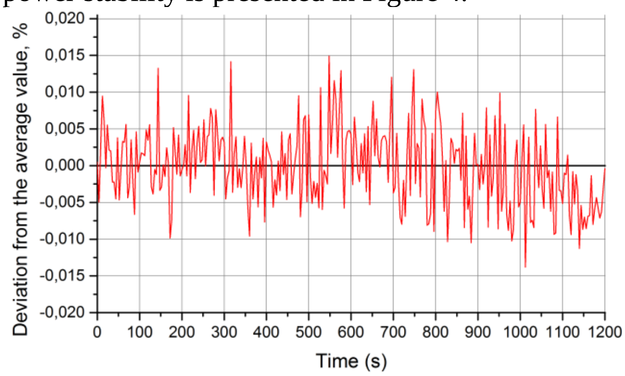

Figure 4. Temporary stability of spectral radiant power

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2. Andrew P. Levick et al., Spectral radiance source based on supercontinuum laser and wavelength tunable bandpass filter: the spectrally tunable absolute irradiance and radiance source, APPLIED OPTICS / Vol. 53, No. 16 / 1 June 2014.
3. Gavrilov V.R. et al., National Primary Standard for the Units of Absolute and Relative Spectral Sensitivity at Wavelengths from 0.25 to 14.00 μm Get 213–2014, Measurement Techniques, February 2016, Volume 58, Issue 11, pp 1200-120.