NIST’s primary optical power responsivity scale realized using a supercontinuum source with automation from 480 nm to 1650 nm

Ping-Shine Shaw and Joseph P. Rice

Sensor Science Division
National Institute of Standards and Technology
Gaithersburg, MD 20899, USA
Corresponding e-mail address: shaw@nist.gov

Traditionally, the optical power responsivity scale at NIST was transferred from cryogenic radiometers using various quasi-CW tuneable lasers from the UV to IR. While this technique achieves very low measurement uncertainty, there are several drawbacks that make routine calibration difficult. For example, the complex laser system requires well-trained personnel to operate. Wavelength tuning often requires manual adjustment of laser optics which makes the optical power measurement over many wavelengths very time consuming and labor intensive. Here, we describe a newly-developed system based on the supercontinuum source. This is a truly turn-key system and is fully automated such that many wavelengths over a wide range can be measured without human intervention. Most importantly, the typical detector calibration uncertainty of 0.04 % (k=1) obtained in the visible spectral range is very comparable to those achieved with lasers and still better than usually required.

INTRODUCTION

In the last decade, NIST took advantage of the fast-evolving optical technology and used the Primary Optical Watt Radiometer (POWR) cryogenic radiometer [1] in conjunction with tuneable quasi-CW lasers to achieve measurement uncertainty in the 10^{-4} level on optical power responsivity measurements. This forms the primary optical power responsivity scale which has been disseminated to many other metrology measurements at NIST. In the beginning days of the use of lasers as light sources with cryogenic radiometers, the general practice was to measure a few wavelengths in the silicon wavelength range as tie points and rely on the responsivity model [2] to fill in other wavelengths. As measurement uncertainty dropped, the trend today is to use tuneable lasers to directly measure a wide wavelength range at a typical wavelength interval of 5 nm or 10 nm, thus eliminating uncertainties caused by spectral modelling. While this can be done [3], such fine-wavelength calibration requires months of effort with intensive labor. This is mainly caused by the frequent manual adjustment of the laser from wavelength to wavelength and the switching between several lasers in order to cover the entire wavelength range. An additional problem caused by using a narrow-band laser is the fringing effect which excludes calibration on windowed detectors.

To overcome these problems, we developed a new optical system that employs a broadband Supercontinuum (SC) source for detector optical power responsivity calibration while maintaining uncertainties comparable to those obtained by lasers.

MEASUREMENT SETUP AND RESULTS

Fig. 1 shows the basic schematic for POWR-based detector responsivity calibration using the SC. Our particular SC has a useable wavelength range from 480 nm to just under 2000 nm, and newer versions have broader spectral range. The SC output is fiber-coupled to a computer-controlled monochromator (labelled LLTF in Fig. 1). The output is a slightly divergent laser-like beam with about 1 nm bandwidth.

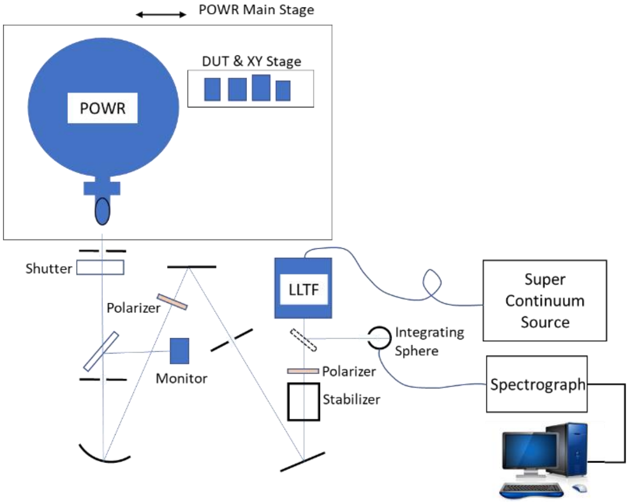

Figure 1. POWR based detector responsivity measurement setup.

The wavelength of the beam is calibrated by a spectrograph which, in turn, was calibrated by spectral lamps.

Downstream from the LLTF, the beam passes through a polarizer followed by an intensity stabilizer. Then it is spatially filtered, re-polarized, re-collimated, and directed into POWR or the test detectors. The incident light onto POWR and test detectors has a diameter of about 1 mm and a typical power on the order of 100 µW. Great care was taken to shape the light beam to ensure the beam underfills POWR and the test detectors with minimum stray light. The system is fully automated and controlled by a single computer which commands the wavelength of the LLTF, the stage or the placement of POWR and test detectors, and acquires all signals from POWR, monitor diode, and test detectors.

Fig. 2 shows the calibrated External Quantum Efficiency (EQE) of a 6-element trap detector T04 using the SC/LLTF from 480 nm to 1000 nm at a 5 nm interval.

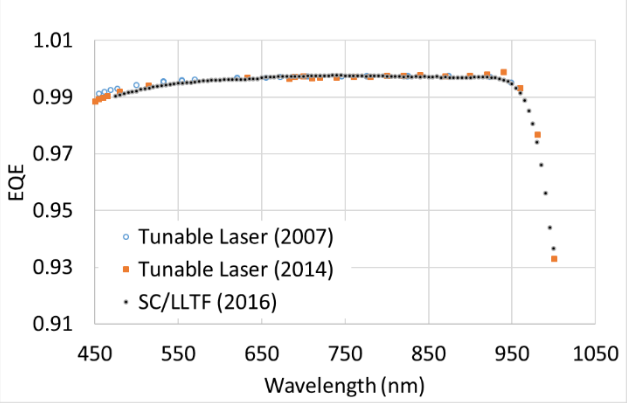

Figure 3. Power responsivity of trap detector T04 measured with tunable lasers and SC.

Also shown in Fig. 2 for comparison are the power responsivities of the same detector measured in previous years using tuneable lasers. Other than the short wavelength end, where the detector is known to degrade over the years, and the long wavelength end, where the detector is subject more to temperature variation, there is good agreement between calibrations using tuneable lasers and SC/LLTF and the variation is well within the measurement uncertainty. Notice the regular and high-density nature of the data for SC/LLFT calibration as compared to the more sparse and irregularly-spaced data points when tuneable lasers were used.

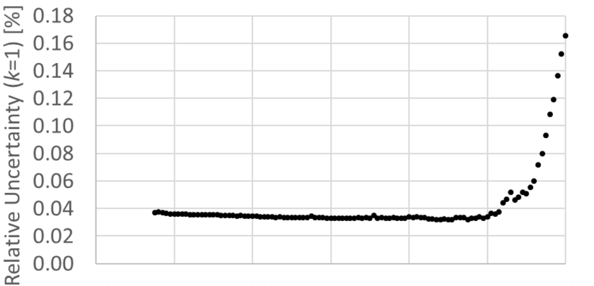

Figure 2. Estimated relative overall uncertainty on the trap responsivity at k=1.

Fig. 3 shows the estimated overall standard uncertainty of the trap detector responsivity using SC/LLTF. Other than the long end of the wavelength range, the uncertainty is generally under 0.04 %. This compares favourably with the 0.02 % to 0.03 % uncertainty obtained by calibration using tuneable lasers. The slight increase in overall uncertainty is mainly due to the increased wavelength uncertainty of the much wider bandwidth of ~ 1 nm of the SC/LLTF. In addition to the trap detector calibrations, we have also used this system for calibrating many single element photodiodes, both windowed and non-windowed, such as Si and InGaAs detectors, with satisfactory results.

CONCLUSION AND OUTLOOK

We have shown that SC/LLTF can be used as a light source for ACR-based power responsivity calibration with comparable uncertainty as using tuneable lasers. Without the complex laser system, this much simplified system is fully automated and can calibrate many wavelengths automatically. For calibrations involving a wide wavelength range with many wavelengths, this system can reduce the measurement time from months to days. At NIST, our current strategy for maintaining our power responsivity scale is to use the SC/LLTF system for routine calibration while operating our tuneable lasers only at a few selected wavelengths to serve as a validation of SC/LLTF calibration.

REFERENCES

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