Development of a pyroelectric detector-based method for low uncertainty irradiance and radiance calibrations in the short-wave infrared

Brian G. Alberding, John T. Woodward, Ping-Shine Shaw, Leonard M. Hanssen, Catherine C. Cooksey, and Joseph P. Rice

National Institute of Standards and Technology, Gaithersburg, MD, USA
brian.alberding@nist.gov

The uncertainty of detector-based radiance and irradiance responsivity calibrations in the short-wave infrared (SWIR) traditionally has been limited to around 1% or higher by the low spatial uniformity of detectors used to transfer the scale from radiant power. Pyroelectric detectors offer a solution that avoids the spatial uniformity uncertainty, but also introduces additional complications due to alternating current (AC) measurement techniques; there is additional uncertainty when using lock-in amplifiers. Herein, a new method for low uncertainty irradiance responsivity calibrations in the SWIR is presented. An absolute irradiance responsivity scale was placed on a pyro-electric detector with total combined uncertainty (k=1) of 0.5% without using a lock-in amplifier.

PYROELECTRIC IRRADIANCE SCALE

At the National Institute of Standards and Technology (NIST), a method for calibrating instruments directly in irradiance or radiance mode using high power, narrow bandwidth lasers has been in use for about 20 years [1,2]. Typically, low uncertainties are achieved by traceability to the NIST Primary Optical Watt Radiometer (POWR) [3] and the NIST Aperture Measurement Facility [4]. In short, a transfer standard detector equipped with a precision aperture is calibrated by POWR with a laser in an underfilled configuration. Irradiance responsivity is therefore determined but the uncertainty is limited by the uniformity of the transfer detector. This method works well in the silicon detector region, where highly uniform trap detectors are available. In the short-wave infrared (SWIR), current indium gallium arsenide (InGaAs) or extended InGaAs (ex-InGaAs) detectors, for example, do not have sufficient uniformity. Pyroelectric detectors offer a potential solution to this problem where an irradiance scale traceable to POWR in the SWIR can be achieved with uncertainties approaching those obtained in the silicon spectral region.

We use a pyroelectric detector with organic black coating as our transfer standard. The coating has low reflectance on the order of a few percent and the transmittance of the coated pyroelectric element is negligible. If the spectral reflectance, A(λ), of the detector can be measured independently over a desired wavelength range, then the spectral absorptance, A(λ), can be derived using Eq. (1). Because the power or irradiance responsivity of a pyroelectric detector is spectrally flat against absorptance [5], the responsivity of the detector over the entire wavelength range with measured reflectance can be determined by using a single tie point responsivity measured at a single wavelength in the silicon trap spectral range.

$$A(\lambda) = 1 - R(\lambda) \qquad (1)$$

ALTERNATING CURRENT SIGNAL PROCESSING

Using a pyroelectric detector also introduces other problems for radiometric calibrations resulting from the requirement that an AC signal is measured. A typical strategy is to modulate the light source by a chopper and process the induced quasi-square waveform detector signal with a lock-in amplifier. The signal output from the lock-in amplifier is derived from the amplitude of the first harmonic of the waveform, which introduces the requirement of calibrating the lock-in amplifier used for a correction factor to determine the DC response of a test detector. Additionally, transient regions in the quasi-square waveform could cause large errors in the resulting output signal (i.e. there is a settling time that must be considered).

In this work, we collected the AC waveform digitally using a modern high-sampling-rate analog-to-digital converter (avoiding the use of a lock-in amplifier) as shown in Fig. 1, and removed unwanted portions of the transient regions to determine the DC offset signal with higher accuracy. For irradiance response measurements, where the pyroelectric detector has a relatively low signal-to-noise, this method allowed us to maintain the main benefit of a lock-in amplifier, namely picking out modulated signals from high noise, without the added complications. At a chopping frequency of 10 Hz, we could also obtain a relatively large number of samples in a short amount of time (1-minute measurements yield 600 independent measurements) to yield better measurement standard deviation of the mean.

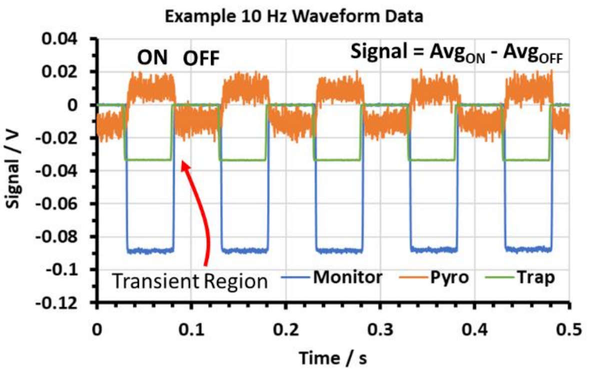

Figure 1: Representative 10 Hz waveform data for the silicon trap (green) pyroelectric (orange) and monitor (blue) detectors.

RESULTS

Using this method, we have performed the scale transfer from a POWR-calibrated Si trap irradiance detector to a pyroelectric irradiance detector as shown in Fig. 2. The reflectance spectrum of the black coating was measured from 834 nm to 3393 nm on a witness pyroelectric detector sample representative of the actual detector absorptance manufactured in such a way to provide complete hemispherical access to the front surface while maintaining optically identical design as a real detector without the electrical connections. The irradiance scale was transferred from the silicon trap irradiance detector at 849 nm yielding the absolute spectral *irradiance* responsivity with a combined standard uncertainty (k=1) of 0.5%, where the dominant uncertainty components were the irradiance measurement standard deviation (due to low signal-to-noise of the pyroelectric detector) and the witness sample absorptance.

SUMMARY

Herein, we detail our efforts to provide a low uncertainty absolute irradiance responsivity scale in the SWIR using a pyro-electric detector. We used an AC detection method without a lock-in amplifier that simplifies the overall calibration chain by digitally processing the data. Current state-of-the-art irradiance responsivity calibrations in the SWIR typically have uncertainties on the order of 1% or more. In this work we achieved 0.5% (k=1) uncertainty for absolute *irradiance* responsivity using a pyroelectric detector. It should be noted that there is still room for improvement with these methods as described. First, we have only averaged our measurements over timescales of ~ 1 minute. Further improvements could be made simply for averaging longer time to reduce the measurement standard deviations. Second, there is room for improvement in the design of the pyroelectric detectors. Fabrication with less reflective coatings (for example by adding carbon nanotubes) could yield improvement in the irradiance scale transfer, which is reliant on the absorptance of the detector black coating.

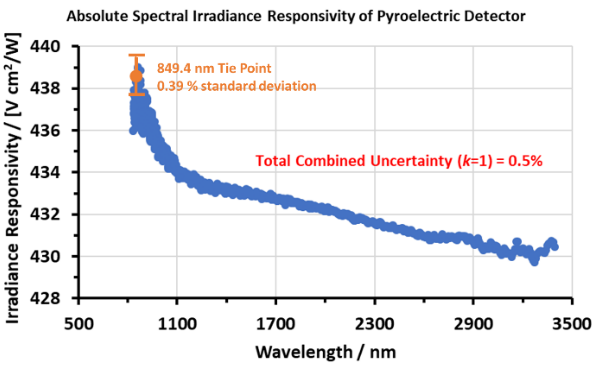

Figure 2: Absolute spectral irradiance responsivity of the pyroelectric detector determined from the witness sample reflectance and a tie point with the silicon trap detector at 849 nm.

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