

Spectral Responsivity Calibration of Infrared Detectors for Scientific Planetary Exploration Missions

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Reference detectors based on thermopile sensors have been developed for SI-traceable measurements in DLR's detector characterisation laboratory. These detectors have been calibrated in terms of their spectral responsivity in the wavelength range 2 μm to 17.7 μm against PTB's cryogenic electrical substitution radiometer, thus making these measurements SI-traceable. The relative standard measurement uncertainty lies between 1.6 % and 2.6 %. The results demonstrate PTB's first spectrally resolved detector characterisation in this broad infrared spectrum.

INTRODUCTION

Accurate and comparable measurement of infrared (IR) radiation is essential for advancing space research and its applications in planetary studies, Earth observation, and security. National Metrology Institutes (NMIs), such as the Physikalisch-Technische Bundesanstalt (PTB), achieve this by ensuring that measurements are traceable to the International System of Units (SI).

In a collaboration between PTB and the Institute of Space Research of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V., DLR) two new reference detectors have been developed and calibrated in view of their spectral responsivity in the wavelength range from 2 μm to 17.7 μm .

Calibration was performed using a cryogenic electrical substitution radiometer (CR), which is a primary detector standard for the measurement of optical radiation, and against calibrated transfer detectors at a detector comparator facility (DCF). This work will present spectrally resolved detector characterisation results obtained at PTB's facilities in this broad infrared spectrum for the first time.

THERMOPILE REFERENCE DETECTOR

The developed reference detectors utilise a TS-76 thermopile sensor fabricated by Leibniz Institute of Photonic Technology (IPHT), Jena. The detector design uses an aperture baffle to limit the field of view, as well as thermally decoupled outer and inner detector housings to reduce temperature fluctuations in the sensor base plate which serves as a heat sink [1] (compare Fig. **Error! Reference source not found.**).

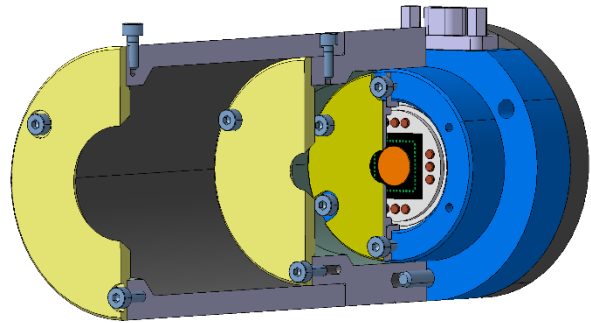


Figure 1. CAD model cut view of the reference detector (inner housing) showing (from left to right) the stray light baffles (light yellow) and the 5.8 mm diameter defining aperture (yellow), the detector (orange), heat sink (blue), and baseplate (gray).

SPECTRAL RESPONSIVITY CALIBRATION

Calibration was performed against a cryogenic electrical substitution radiometer. The CR facility uses various IR laser radiation sources [1] and has recently been expanded with additional quantum cascade lasers operating at 14 μm and 17.7 μm . The calibration results can be found in Figure 2 in blue.

Alongside with DLR's reference detectors, PTB transfer detectors have been calibrated against the CR. These transfer detectors are also based on thermopile detectors TS-76 [1]. A polynomial fit function is used for the spectral interpolation of the spectral responsivity between the laser calibration wavelengths. This fit function considers the

uncertainties of and correlations between the individual CR calibrations [2].

By this means, these transfer detectors can be used to disseminate the spectral responsivity at any wavelength within the calibrated range. This dissemination takes place at PTB's IR detector comparator facility [3], which utilises besides laser radiation sources also a broadband thermal emitter with a monochromator. The calibration results from the DCF are depicted in Fig. 2 in red.

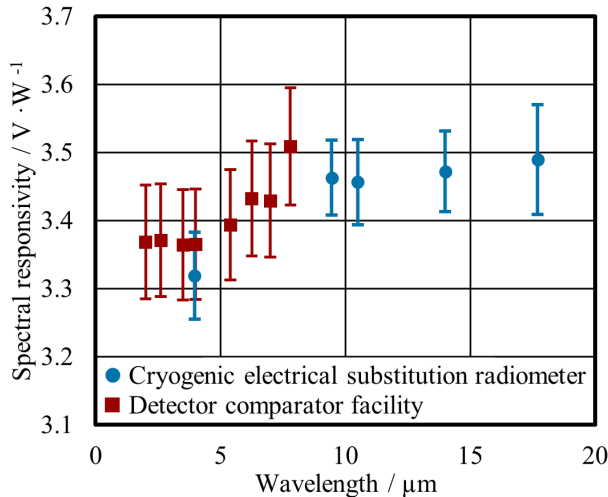


Figure 2. Spectral responsivity of one of DLR's reference detectors, calibrated against the cryogenic electrical substitution radiometer (blue) and against PTB's transfer detector at the IR detector comparator facility (red).

MEASUREMENT UNCERTAINTY AND COMPARISON

The relative standard measurement uncertainty of the CR calibration is in the range from 1.6 % to 2.3 %. A systematic non-uniformity of the responsivity over the TS-76 absorber has already been published [4] and is confirmed by PTB's measurements but not yet comprehensively studied. Consequently, spatial stray radiation and uncertainty in the geometrical positioning of the detector in the beam necessitate corrections. Due to the TS-76 uniformity not yet being fully quantified, these corrections lead to the dominant uncertainty contributions.

The relative standard measurement uncertainty of the DCF calibration is approximately 2.5 %, dominated by the uncertainty of the transfer standard from the CR calibration. Furthermore, a significant uncertainty contribution arises from the mentioned TS-76 non-uniformity due to corrections for positioning and stray radiation.

As Figure 2 shows, the two calibration approaches differ by about 1.4 %. This systematic

difference may also be caused by the non-uniformity of the TS-76: Different beam geometries between the two facilities - the relatively small diameter of the laser beam versus the larger monochromatised DCF radiation beam - lead to different results, if the detectors differ in terms of their non-uniformities. However, this difference is fully accounted for by the given measurement uncertainty.

APPLICATION AT DLR'S DETECTOR CHARACTERISATION LAB AND OUTLOOK

At DLR, the reference detectors will be employed to characterize future flight instruments on solar system exploration missions in a thermal vacuum environment. In particular, radiometric flux received at the detector inside a vacuum cryostat behind an infrared transparent window [5,6] will be quantified.

In addition, the aim is to examine the spatial uniformity of the responsivity over the sensitive areas of both DLR's reference detectors and PTB's transfer detectors. Consequently, the systematic difference and measurement uncertainty resulting from corrections when using the detectors with different beam geometries could be significantly reduced. First results will be presented.

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