THz Detector Calibration Based on Microwave Power Standards

Abstract—This paper describes the calibration process of a THz pyroelectric detector, to be traceable to a standard thermocouple sensor in WR10 waveguide-range (75-110GHz). Setup consists of a suitable waveguide-to-free-space adaptor (antenna) with relevant positioners to analyze and characterize the standing-wave ratio. The results are presented together with a preliminary error analysis and uncertainties.

Keywords—Terahertz, THz detector, power measurement, traceability, RF metrology, corrugated horn antenna

I. INTRODUCTION

During the last decades, the utilisation of the mm-Wave/THz range has significantly increased in a wide range of applications. Environmental studies, space technology, remote sensing, spectroscopy, wireless communications, automotive radar, security scanners and biomedical applications are among many other examples. The development and approval of high quality and safe products and systems depends on the availability of traceable measurement capabilities. Present RF-power standards are generally coaxial and waveguide thermal detectors for frequencies up to 110GHz [1]. Calorimetric methods are often used to calibrate the sensors at primary-level directly traceable to International System of Units (SI). A few calculable calorimeters in sub-THz range are available (at research level only), yet there is not any established power-standard in THz-range, to our knowledge [2].

Pyroelectric detectors are traditionally characterized and used in higher THz range for the frequencies beyond 300GHz [3]. Here, we show the functionality of these detectors in a lower frequency band and try to establish a reliable calibration method.

II. MEASUREMENT SETUP AND CALIBRATION PROCESS

The main challenge is to suit a microwave waveguide source to the sensitive open-surface of the optical/THz power detector. Horn antennas in general (classic pyramid, conical, corrugated …) or modified open-waveguide apertures could be suitable solutions to launch electromagnetic power from the waveguide source and direct it to the detector. In this case, the calibration process must include the evaluation of the entire scattering parameters of the antenna and the air-gap (Fig.1).

The setup consists of a corrugated horn antenna in 75-110GHz range and a modulated RF signal source with 23Hz rectangular pulse-shape (necessary for the pyro-detection). The horn antenna can be modeled as a Gaussian source [4] with calculable beam-size on its aperture and in the near-field region. The antenna and the air-gap have been characterized and modeled by relevant S-parameters i.e. waveguide-port reflection, transmission losses, aperture scattering and standing-waves (Fig. 1). The incident wave to the detector b2 can be determined as a function of the incident wave to the system a1 and the S-parameters, as follow:

\[ b_2 / a_1 = S_{21} / (1 - \Gamma_1 S_{22}) \]  

(1)

Therefore, the calibration reliability depends on the precise evaluation of \( \Gamma_1 S_{22} \) (source-match factor), \( S_{21} \) (antenna & air-gap insertion losses) and \( a_1 \) (waveguide power-standard).
Based on the precise power measurement at the waveguide port (with WR10:75-110GHz power-standard, available at National Metrology Institutes NMIs) and S-parameter matrix, incident power to the Detector's surface is derived with the associated uncertainties. The antenna can be characterized as a 1-port device in aperture-Short configuration or as 2-port device with two similar antennas in back-to-back configuration. A commercial Vector Network Analyzer (VNA) is used to determine the S-parameters of the antenna. Measurements show S_{11} and S_{22} are less than 0.15 for all exploited frequencies and S_{21} better than 0.85. Meanwhile, [$\Gamma_{12}$S_{22}] can be evaluated by short-range scanning of the standing-wave near the antenna aperture.

$$[\Gamma_{12}\text{S}_{22}] = (\sqrt{V_{\text{max}}} - \sqrt{V_{\text{min}}}) / (\sqrt{V_{\text{max}}} + \sqrt{V_{\text{min}}}) \quad (2)$$

(here V is the readout voltage of the pyroelectric detector and thus proportional to the power)

With a couple repetitive Max. and Min. recorded for each frequency, the amplitude of the "source-match factor" [$\Gamma_{12}\text{S}_{22}$] is calculated, and its value is found smaller than 0.07.

The calibration factor of the detector is therefore called "Responsivity (V/W)" which is the ratio of the output voltage (pulse height readout by the oscilloscope) to the known incident power.

III. RESULTS

Two pyroelectric detectors with 20mm (Small) and 30mm (Large) diameter have been calibrated (Fig.2).

![Fig. 2. Calibration results (Responsivity V/W) of two pyroelectric detectors in the frequency-range 75-110GHz. As shown, the responsivity is in the range of 150(V/W) for the small detector and 70(V/W) for the large one, in the frequency range 75-110GHz.](image)

The S-parameters of the corrugated horn antenna and the air-gap have been evaluated with estimated uncertainties (k=2) less than 7%. As for the thermocouple waveguide standard detector, the overall uncertainty is less than 5%.

Once the detectors are calibrated and the responsivity known, they can be used to measure the power at higher frequencies with high accuracy. In this case, the absolute power absorption-rate of the pyroelectric detector sensitive surface must be determined by the available S-parameters standards in RF/THz metrology.

The nominal power absorption-rate of the pyroelectric detector is 50% and likely frequency-independent [5] with 25% transmission and 25% power reflection from the pyroelectric surface. Yet, material characterization techniques [6] can be used to evaluate the absorption behavior of the sensitive surface (and the housing / frame), quantitatively. Our observations show up to 5% variation of the measured absorption-rate around its nominal value at the exploited frequencies.

ACKNOWLEDGMENT

The authors wish to acknowledge funding within the research project 18SIB09 TEMMT (Traceability for electrical measurement at millimeter-wave and terahertz frequencies for communications and electronics technologies). This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme.

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