THz Corrugated Horn Antennas as TEM Mode-Convertor for Power Measurement and Material Characterization in Free-Space

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Abstract

In-waveguide measurements are usually challenging at THz frequencies because of dimensional restrictions. Corrugated horn antenna is studied to show its capabilities (and limits) as WG to free-space mode convertor. Results are presented in terms of energy transfer to an open-surface detector and TEM propagation-mode on-and-near the antenna aperture. This paper shows the feasibility of using such antennas in 75-110GHz and 500-750GHz bands for power measurement and material characterization with the estimation of systematic and random errors.

1. Introduction

In recent years, 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 reliable measurements.

For material characterization, Vector Network Analyzer (VNA) can be used with quasi-optical associated devices to set the free-space non-contact measurements up [1]. The setup should be adequately calibrated and S-parameters derived on the material-under-test (MUT). Based on the measured S-parameters and the MUT thickness and positioning, permittivity and permeability can be extracted. A well-designed corrugated horn antenna can replace classic quasi-optical devices (pyramid horn plus lenses or parabolic mirrors) [2, 3]. However, probable systematic errors relevant to non-perfect TEM/free-space mode on the antenna aperture should be known and quantified, in advance.

For power measurement, open-surface classic optical detectors like pyroelectric and photo-acoustic devices can be characterized and used in THz domain, as well [4]. The main challenge is to suit a waveguide THz source to the open surface of the detector. Here again, a corrugated horn antenna is an appropriate choice if the scattering parameters of the antenna WG-input, aperture and the air-gap between the antenna and detector are characterized adequately.

2. Discussion and results

A long-body aperture-matched corrugated horn antenna can convert waveguide TE and TM modes to the hybrid HE_{11} mode with "quasi"-TEM electromagnetic fields on the antenna aperture (Fig.1)

A set of two corrugated horn antennas, head-to-head, with high surface aperture quality can be used as a compact material characterization device [3].

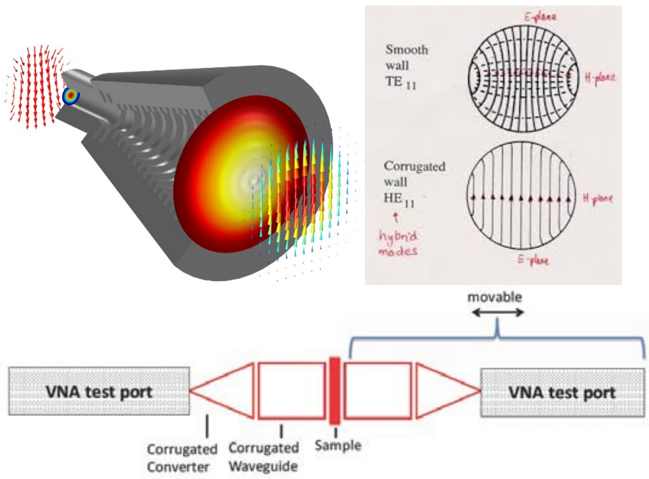

Figure 1: Schematic of mode conversion in corrugated horn antenna, and a set of two (aligned) antennas connected to the VNA test-ports for material characterization.

As the MUT is placed and measured in the air-gap between two apertures, this small space should be characterized and compared with the "real" free-space conditions. The method we use here is to assume an arbitrary air-gap as MUT and measure its permittivity. Deviations from ε_r = 1+j0 can demonstrate propagation mode conditions in the air-gap. Measurement results are presented (Fig.2) for the frequency-ranges 75-110GHz (3mm air-gap) and 500-750GHz (1mm air-gap). As shown, a slight rising slope (~ 0.5%) is observed around "ε_r (Re) = 1" for both frequency ranges. This should be taken into account for further assessment of errors and uncertainties. Measurements are based on transmission-only method [5] and have been performed for different air-gap distances, the tendency seems consistent for all cases.

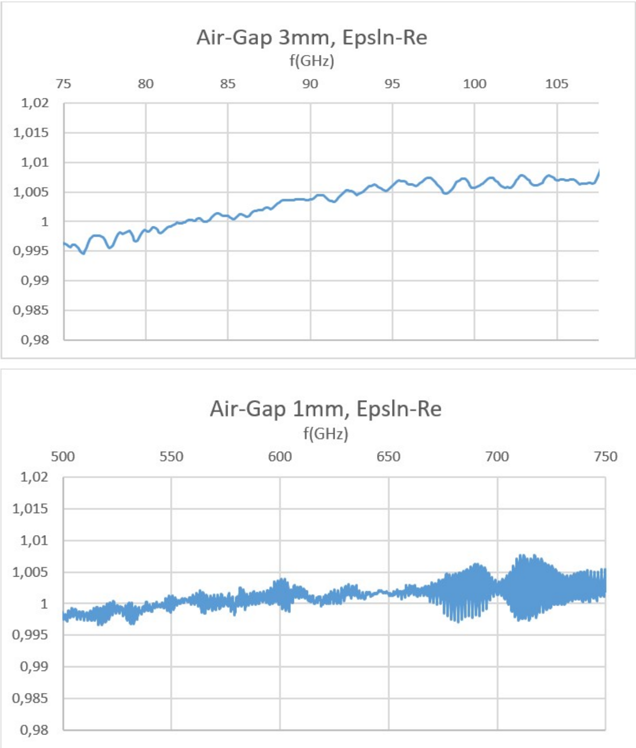

Figure 2: Propagation-mode characterization of the air-gap for 75-110GHz (top) and 500-750GHz (bottom) bands. Raw results are presented without time-gating or smoothening.

In terms of energy leakage, the air-gap can be characterized by S_{21} parameter normalized to the closed-gap case (Fig.3). This parameter is very important for the RF/THz power measurement in free-space. As shown, for the gaps up to 5mm, power transfer is well performed with losses less than 0.4dB in the 75-110GHz range.

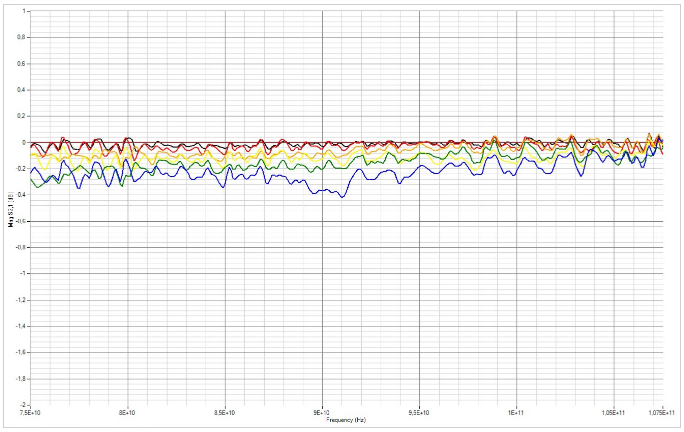

Figure 3: Power transfer via the air-gap (0.5, 1, 2, 3, 4 and 5mm) for 75-110GHz band. Raw results are presented without time-gating or smoothening.

Very low (and precisely measurable) energy leakage of the air-gap may make the corrugated horn antenna suitable for power measurement in free-space (Fig.4). The whole system should be characterized in terms of: antenna to WG-source matching, antenna input-to-aperture losses, air-gap and detector scattering, and standing-wave phenomena.

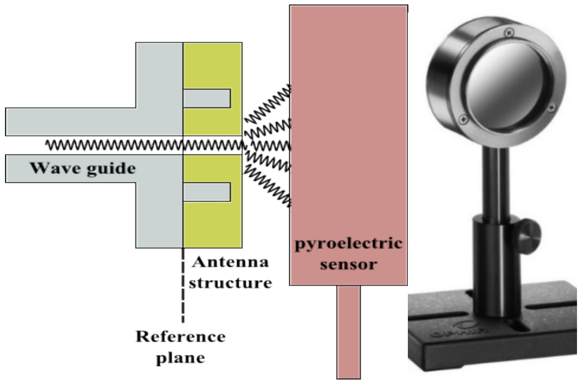

Figure 4: Schematic of THz waveguide source, antenna structure and power transfer to the open-surface sensor.

However, even the air-gap radiation and small losses make it necessary to reconsider the measurement conditions of low-refractive & low-loss materials like TPX, Teflon etc.

3. Conclusions

It is shown that the corrugated horn antenna can be characterized as TEM-mode convertor for various free-space measurements. Results are presented at 75-110GHz and 500-750GHz frequency ranges to show the propagation conditions and power transfer capability. Further works are in progress to improve the measurement system in terms of matching and multiple-reflection phenomena controlling.

Acknowledgements

This work was supported by the European Metrology Programme for Innovation and Research (EMPIR), under 18SIB09-TEMMT project. EMPIR programme is co-financed by the Participating States and from the European Union's Horizon 2020 Research and Innovation Programme.

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