# Beam Profile Investigation of an Optoelectronic Continuous-Wave Terahertz Emitter

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*Abstract*—**The beam profile of an optoelectronic continuous-wave terahertz emitter is investigated in the frequency range up to 200 GHz. The radiation pattern is measured by a calibrated pyroelectric power detector. As these frequencies are promising for terahertz communications, knowledge and predictability of radiation pattern are required for link budged estimation.**

## I. INTRODUCTION

In the last decade, the terahertz (THz) frequency range, and especially the frequencies below 1 THz, have attracted much interest for wireless communication. Optoelectronic continuous-wave (cw) emitters combine the benefits of compatibility with existing fiber-optical networks and the feasibility of highly integrated devices [1]. Since PIN photodiodes (PD) are an established type of emitter device in cw THz spectroscopy, they constitute a promising candidate for future communication links at THz carrier frequencies [2].

Whereas in spectroscopy setups the THz beam profile is commonly formed by lenses or mirrors, this is not an option for THz links. For these reasons, the radiation pattern and propagation of THz beams from the emitter into free-space is of major interest and merits investigation. The results of such studies can feed into link design parameters, specification of optical components, and link budget estimation.

## II. RESULTS

The emitter beam profiles were obtained by line-scanning a power meter at a constant distance from the emitter along axes (a) parallel (E-field) and (b) perpendicular (H-field) to the emitter polarization; then the scans were repeated at a different distance from the emitter. The power was measured by a calibrated pyroelectric detector (SLT, calibrated by PTB). Two emitters were examined. Both emitters, manufactured by HHI, are based on a waveguide-integrated PIN-PD. The PD is equipped with a substrate-integrated bow-tie antenna for broadband emission up to several THz. For radiation into free-space, the PD is mounted onto a silicon lens. The emitters are packaged into a fiber-coupled housing [3]. A pair of tunable DFB laser sources (Toptica Terascan) drives the emitter.

Fig. 1 shows the beam power profiles of Emitter A, measured at a distance of 8 mm from the edge of the emitter housing, as a function of displacement of the detector. In both planes the power drops to ½ within less than ± 10 mm. Due to the significant aperture of the detector (10 mm) and the setup geometry, this distribution indicates a narrow main lobe of the radiation pattern; as expected from the particular antenna type. For lower frequencies, the observed spatial power distribution is broader than expected. Also, as expected, the power drops with frequency. Notably, all beam profiles have distinct frequency- and polarization-dependent spatial features.

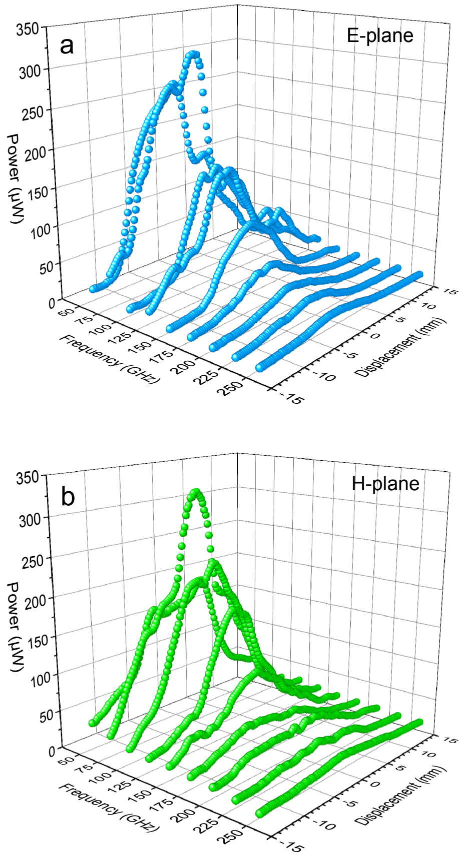

Fig. 1. Beam profiles of Emitter A at different frequencies, measured at a distance of 8 mm from the edge of emitter housing. a) E-plane; b) H-plane.

To clarify the variation of the beam profile with frequency, normalized E-plane profiles at 5 frequencies are plotted in Fig. 2. It is seen, as expected, that the beam profile features become less pronounced at higher frequencies.

Considerable differences in the features were observed between the beam profiles of the two emitters studied, although overall beam profiles and widths were similar. This is demonstrated in Fig. 3 where normalized beam profiles of both emitters are plotted at two frequencies.

In order to understand better the behavior of beam profiles and the relationship with emitter design parameters, simulations of the profiles were carried out. The model for simulations with HFSS consists of the photodiode-chip and the silicon lens. For comparison of the simulation with the measured beam profile, the angle-resolved radiation pattern has to be translated into particular measurement geometry employing linear displacement of the detector. The results at 100 GHz and 150 GHz are shown in Figs. 4 & 5 respectively, together with the measured normalized profile of Emitter A.

The simulations show an offset in displacement axes, which might arise from deviation in packaging or be due to the measurement geometry. Furthermore, the profile of the center portion of the beam differs between simulation and measurement. Since the distance between the emitter and detector is short, cross-reflections and standing waves between emitter and detector might lead to uncertainties, especially at the beam center and at maximum power. However, the overall beam width as well as the position of the side lobes of the E-plane at 150 GHz are modeled very well. Note that the influences of the metallic emitter housing and any reflections from the setup environment are not taken into account in the simulations.

## III. CONCLUSION

We investigated the beam profile of a photodiode-based optoelectronic continuous-wave THz emitter using linear displacement of a calibrated power detector. In addition, we compared the results with simulations performed with HFSS. In employing this type of emitter in wireless communication links, the demonstrated results may be utilized for link budget estimation and for designing suitable THz optics. Furthermore, the comparison with the simulations makes it possible to develop a more precise HFSS model of the emitter, aiding the design of future optoelectronic THz emitters.

## IV. ACKNOWLEDGEMENT

This project has received funding from Horizon 2020, the European Union's Framework Programme for Research and Innovation, under grant agreement No. 761579 "TERAPOD".

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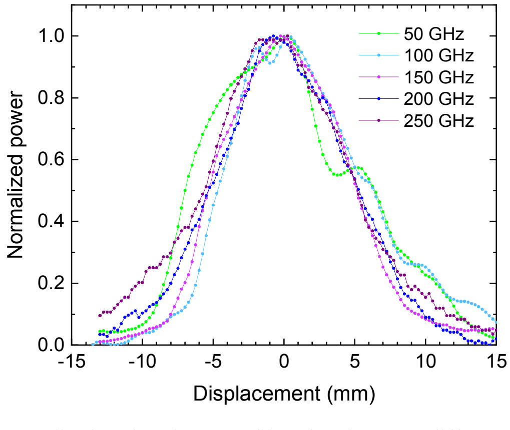

Fig. 2. Normalized E-plane beam profiles of Emitter A at different frequencies (measured at a distance of 8 mm from the edge of emitter housing).

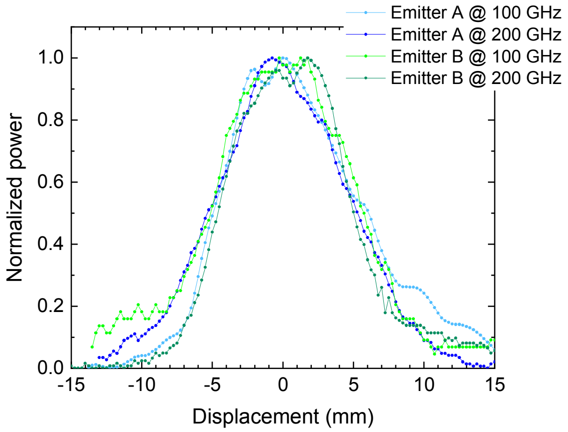

Fig. 3. Normalized E-plane beam profiles of Emitter A and Emitter B at 100 & 200 GHz (both measured at a distance of 8 mm from the edge of emitter housing).

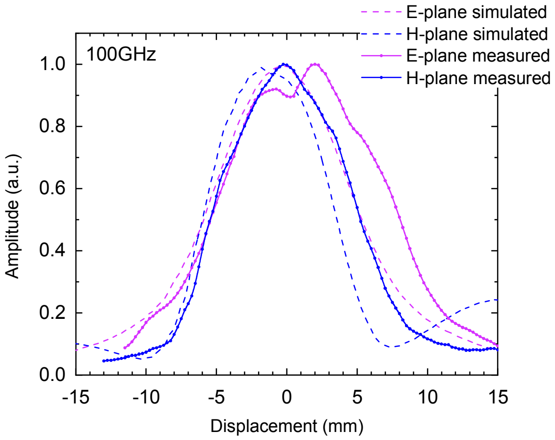

Fig. 4. Simulated beam profiles of the emitter (dashed lines) at 100 GHz in E-plane and H-plane together with normalized measured beam profiles of Emitter B (solid line). The detector is placed at a distance of 8 mm from the edge of emitter housing.

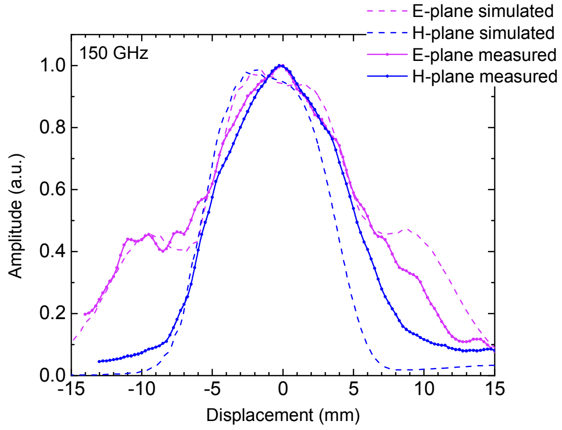

Fig. 5. Simulated beam profiles of the emitter (dashed lines) at 150 GHz in E-plane and H-plane together with normalized measured beam profiles of Emitter B (solid line). The detector is placed at a distance of 8 mm from the edge of emitter housing.