Beam profile Measurement of THz pulses in a TDS system

Yang Zeng[1], Andre Sarker Andy[1], Theo Kreouzis[2], Xiaodong Chen[1]. Robert S. Donnan[1]

[1]School of Electronic Engineering and Computer Science, Queen Mary University of London, London E1 4NS, United Kingdom

[2]School of Physics and Astronomy, Queen Mary, University of London, London, E1 4NS, United Kingdom

***Abstract*— Beam profile measurement of broadband THz pulses in a TDS system are carried out by analyzing the spatial distribution of the pulse. Beam-waists of different frequency components are calculated. Overall the waist decreases with the increasing frequency with higher order modes being observed.**

I. INTRODUCTION

TERAHERTZ time-domain spectroscopy (TDS) provides both amplitude and phase information in the THz spectral domain. This makes it one of the most popular methodologies in THz spectroscopic research as well as in remote/stand-off sensing and imaging applications [1].

Understanding the beam profile of a THz pulse in a TDS system is of great significant to high spatial resolution measurement and detection. The spatial distribution of the THz pulse is generally measured with a THz camera based on a bolometer array [2]. However, by this method, only the amplitude of the THz beam is measured; phase information is lost.

Here we present the measurement of the spatial distribution of a THz beam field within a THz-TDS system that preserves phase information.

II. RESULTS

The layout employed for TDS is outlined by McIntosh et al [3]. In our experiment, an iris is placed in the focal plane. The diameter of the iris is variable from 8.0 mm to 1.5 mm. A full scan is made for each aperture setting. The measurement process is repeated as the iris is translated along the beam axis either side of the focal plane in order to compensate for alignment error. The results are shown in Figure 1.

As indicated in Figure 1, the decreasing rate of power with the decreasing iris aperture is dependent on frequency. At frequencies below 1 THz, the power spectrum decreases rapidly with the decreasing iris aperture. Over 10 dB of attenuation is observed when the diameter of the iris reduced from 1.5 mm to 0.8 mm. In contrast, the power at frequencies above 1.5 THz only experiences visible attenuation when the aperture reduces below 3.0 mm. The change above 2.5 THz is even less. This result suggests that different frequency components of the broadband THz pulse spread at the focal plane in the TDS system, having different waist. The waists decrease with increasing frequency.

The insert of Figure 1 illustrates the relative spectrum amplitude of the THz wave with respect to the background. To our surprise, the power spectrum of the THz wave above 0.7 THz is enhanced comparing to the background signal when the aperture of the iris varies between 5.0 mm and 3.0 mm. The reason for this is unclear. A possible explanation is that the iris helps reducing the standing wave in the system, which leads to an enhancement in dynamic range of detection.

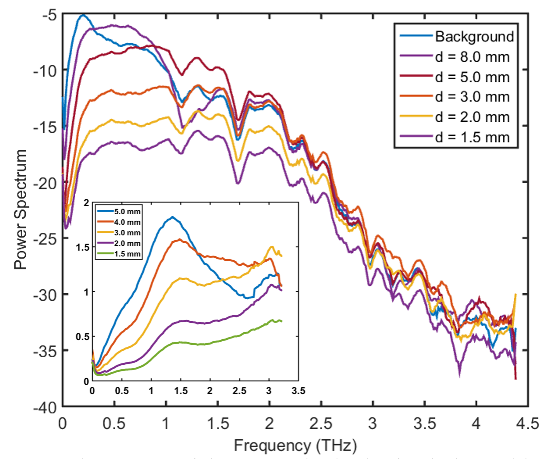
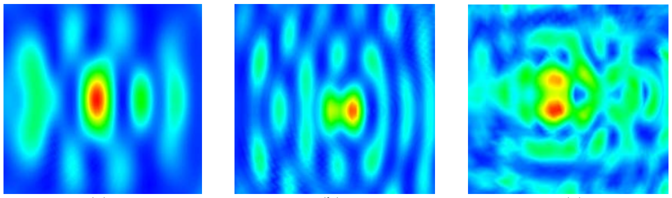


Fig. 1 Measured spectrum of the THz pulse in the focal plane with aperture settings of the iris. The insert illustrates the relative value of the spectrum with respect to the background for iris aperture settings between 1.5 mm and 5.0 mm

Calculation of the beam waist is made assuming a fundamental Gaussian beam distribution. The calculated beam waists at 1.0, 2.0 and 3.0 THz are respectively, 2.8, 2.1 and 1.3 mm. The trend is as predicted. However, it does not follow the 1/f relation between the waist and frequency in a quasi-optic system [4]. This suggests that high order modes exist in the TDS system. The modes of different frequency components of the broadband THz pulse are not unique.

Further analysis of the beam profile of the broadband THz pulse is made in simulation with FEKO. Physical Optics (PO) propagation model is selected in order to shorten time consumption for calculation while preserving diffraction of the beam during propagation. The choice of geometric parameters of simulation of the Quasi-Optic (QO) system corresponds to the setup used in our measurement. The EM wave is collimated by the first parabolic mirror and then refocused by the second parabolic mirror. The distribution of electric field at the focal plane of the second parabolic mirror is then monitored, corresponding to the measurement in our experiment.

A uniformed plane wave is first used to feed the second parabolic mirror. As expected, 1/f relation between the waist and frequency is realized. This suggests that our model is valid and reliable. Then, the radiation pattern of the emitter over the frequency range of the radiated THz pulse (200 GHz ~ 2.5 THz) is calculated using Method of Momentum (MoM) solver. The field radiated from the emitter is used to feed the parabolic mirrors in the QO system. The emitter is placed at the focus of the first parabolic mirror. The distribution of electric field at focal plane at selected frequencies is illustrated in Figure 2.



(a) (b) (c)

Fig. 2 Electric field at focal plane of second parabolic mirror at (a) 300 GHz; (b) 600 GHz and (c) 1.2 THz

As in Figure 2, the distribution of the electric field at focal plane in the QO system is related to frequency. At 300 GHz, the electric field is focused at the center of the focal plane. At 600 GHz, in comparison, the distribution of the electric field splits at the focal plane. At 1.2 THz, the electric field splits as well, but in an orthogonal direction. Further analysis suggests that the mode of the electric field is in correspondent with the radiation pattern of the emitter. Nevertheless, the observation of splitting of electric field verifies the existence of high order modes in TDS system.

III. Summary

In this paper, a new method of THz beam profile measurement in TDS system is introduced. Spatial distribution of the THz pulse is measured. Beam waists of different frequency components are calculated. Low frequency components are found out to be distributed more dispersed around the focal. High order modes of THz wave are also observed in the measurement. Simulations are carried out to study this phenomenon. Splitting of electric field distribution at focal plane is observed, which is in agreement with our measurements. The origin of high order modes is discussed. Further studies are to carry out, including the influence of misalignment and cross polarization to the system. This work is of great significance for high accuracy and high spatial resolution measurement with TDS technique.

References

[1]. P. U. Jepsen, D. G. Cooke, and M. Koch, "*Terahertz spectroscopy and imaging - Modern techniques and applications*," Laser & Photonics Reviews, vol. 5, pp. 124-166, Jan 2011.

[2]. W. Tianwu, P. Klarskov, and P. U. Jepsen, "*Ultrabroadband THz Time-Domain Spectroscopy of a Free-Flowing Water Film*," Terahertz Science and Technology, IEEE Transactions on, vol. 4, pp. 425-431, 2014.

[3]. A. I. McIntosh, B. Yang, S. M. Goldup, M. Watkinson, and R. S. Donnan, *"Terahertz spectroscopy: a powerful new tool for the chemical sciences?*," Chemical Society Reviews, vol. 41, pp. 2072-2082, 2012.

[4]. P. F. Goldsmith, I. o. Electrical, E. Engineers, M. Theory, and T. Society, *Quasioptical systems: Gaussian beam quasioptical propagation and applications*: IEEE press New York, 1998.