Incoherent, spatially-mapped THz spectral analysis

Daniel Headland, Philipp Hillger, Robin Zatta, Ullrich R. Pfeiffer

This document is the accepted manuscript version that has been published in final form in:

2018 43rd International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz). https://doi.org/10.1109/IRMMW-THz.2018.8510246

Incoherent, spatially-mapped THz spectral analysis

Daniel Headland, Philipp Hillger, Robin Zatta, and Ullrich Pfeiffer,
Institute for High-frequency and Communications Technology, University of Wuppertal, Germany
Email: daniel.j.headland@gmail.com

***Abstract*—We employ a lens-coupled CMOS terahertz camera to measure the dispersion of an inexpensive reflective diffraction grating. Thus, although the terahertz camera was originally intended for terahertz imaging applications, we show that it can be re-purposed to perform spectral analysis. Two different experiments to determine the spectral content of a source under test are performed. These experiments target separate frequency bands, and hence they must make use of different sources and gratings. As such, we demonstrate a modular and low-cost technique for spectral analysis in the terahertz range.**

I. Introduction

IN recent years, silicon-based integrated circuits operating in the terahertz-range have gained momentum. The potential for low-cost fabrication and compact size is key for leveraging terahertz technology. For example, a fully-integrated 1 k-pixel CMOS terahertz camera for imaging applications was presented in [1]. This device consists of an array of square-law power detectors that are coupled directly to ring-antennas, and it exhibits usable sensitivity over a broad terahertz bandwidth. The backside of the chip is adhered to a hyper-hemispherical silicon lens that is 15 mm in diameter, and this results in a switched beam device that maps each pixel to a distinct angle of incidence in the far-field [2].

In this work, external optics expand the functionality of the aforementioned terahertz camera beyond imaging applications. Diffraction gratings are employed to engineer a predictable spectral dependence onto the camera readout. As a result, each pixel of the camera maps to a specific, narrow band of frequencies. This device is closely related to dispersive optical spectroscopy systems [3], which are well-understood in the visible and infrared regimes, but have not yet been reported in the terahertz range. Thus, we explore the possibility of using incoherent detection for spectral analysis, as a lower-cost alternative to heterodyne and time-domain techniques. It is noted that CMOS-based incoherent detection mechanisms have previously been demonstrated for on-chip spectral analysis of terahertz waves [4], but the reliable extraction of frequency required significant calibration and processing. By contrast, frequency estimation is made significantly simpler in the present work, as frequency can be read directly from pixel position with minimal processing.

II. Experiment

At the core of this demonstration is a diffraction grating, as it is one of the simplest and most well-known means to achieve spatially-mapped dispersion. Two gratings are manufactured for the purposes of this study, using an inexpensive PCB-manufacture process. Both are composed of periodic striplines of metal, in an even duty cycle, on a metal-backed dielectric laminate. The reflection-phase contrast between the striplines and the bare dielectric produces the desired diffraction-grating operation. One such grating, termed ”Grating 1”, has a period of 400 µm, and makes use of 76 µm-thick Rogers’ CLTE-MW laminate. The other, “Grating 2”, employs 130 µm-thick Rogers’ RO3003 laminate, with a 600 µm grating period. A micrograph of each grating is shown in Fig. 1(a,b). Full-wave simulations are performed in order to verify the functionality of the diffraction gratings. The efficiency with which energy is converted into the desired diffraction order—i.e. the diffraction efficiency—is given in Figs. 1(c,d). It can be seen that these gratings target 725 and 450 GHz, respectively, with peak diffraction efficiency of $\sim$80%.

As the gratings target different frequency bands, each must be excited by a different source. For Grating 1, a multi-band Philipp Goy source that spans a total of 0.6–1 THz with -21 dBm max power is employed. Grating 2 is excited by a 325–500 GHz VDI VNAX source with -10 dBm max power.

The experimental setup is shown in Fig 2(a), including a ray-tracing diagram. Radiation from a terahertz source is collimated by Lens 1, and it falls on the reflective diffraction grating. Oblique incidence at 60° is employed to minimize unwanted diffraction orders. As the grating assigns distinct angles of departure to different frequencies, Lenses 2 and 3 subsequently convert the frequency-dependent angles of

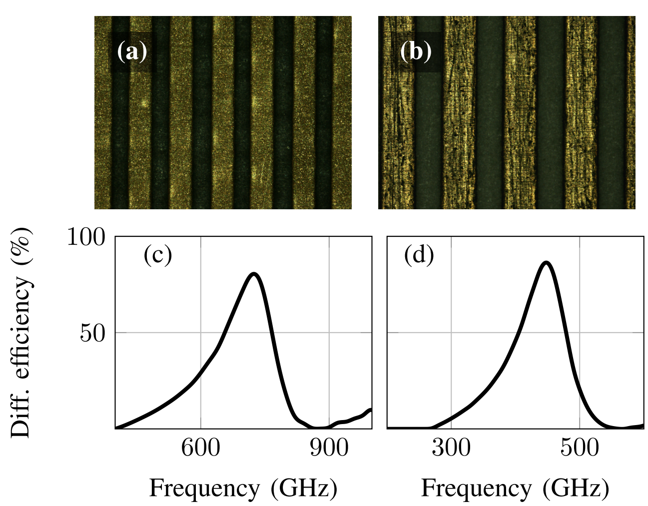

Fig. 1. Diffraction gratings (a,b) micrographs of the periodic structures, and (c,d) simulated diffraction efficiency in the desired order, when excited with terahertz waves at a 60° angle of incidence.

978-1-5386-3809-5/18/$31.00 ©2018 IEEE

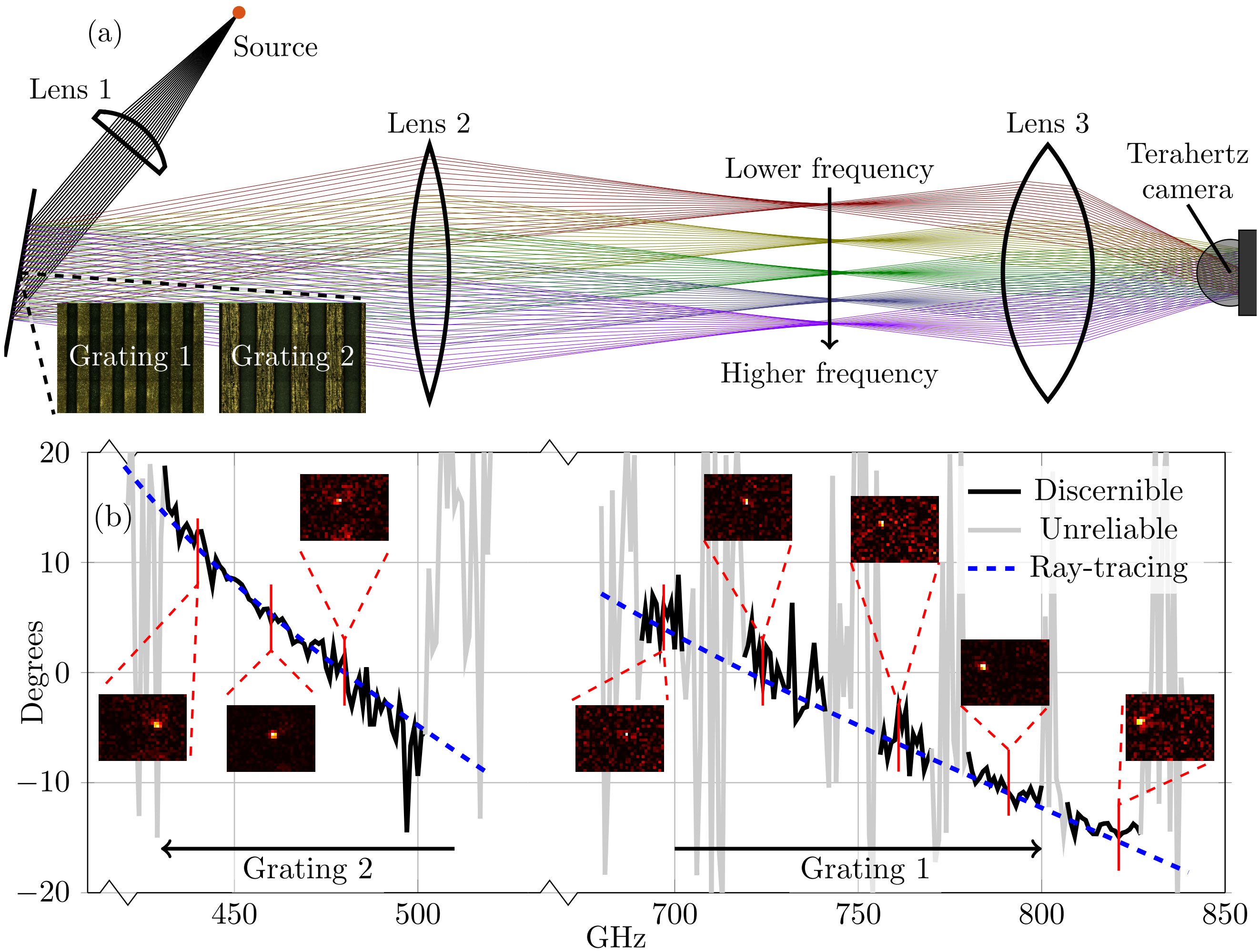

Fig. 2. Spectrum analyzer experiment, showing (a) experimental setup and ray-tracing diagram, and (b) results of measurement and ray-tracing.

departure into angles of incidence upon the terahertz camera.

III. Results

For both gratings, camera readout is extracted over the relevant frequency range. For each frequency, the position of maximum field intensity on the camera surface is mapped to the angle of incidence via a geometric argument [2]. The results of this procedure are shown in Fig 2(b), along with the results of the ray-tracing diagram in Fig 2(a), and a selection of camera readouts are given as insets. The frequencies for which the incident field is discernible on the camera readout are plotted in black. Results at other frequencies are unreliable due to factors including diffraction efficiency, camera sensitivity, and source power, and hence they are plotted in gray. It can be seen that, when discernible, the measured results are in reasonably close agreement with the ray-tracing diagram.

IV. Conclusion

The viability of inexpensive diffraction gratings as a means to perform spectral analysis is demonstrated experimentally. Crucially, this is achieved with an all-passive optical system combined with a terahertz camera—a wholly incoherent detection mechanism. This principle may be exploited for a new generation of low-cost terahertz spectrum analyzers. Furthermore, with calibration it may be possible to extract a quantitative measure of the power in each frequency band, and achieve real-time monitoring of multiple spectral components.

Acknowledgement

This work was partially funded by the DFG project C04, TRR 196 “MARIE.”

References

[1] R. Al Hadi, H. Sherry, J. Grzyb, Y. Zhao, W. Förster, H. M. Keller, A. Cathelin, A. Kaiser, and U. R. Pfeiffer, “A 1 k-pixel video camera for 0.7–1.1 terahertz imaging applications in 65-nm CMOS,” *IEEE J. Solid-State Circuits*, vol. 47, no. 12, pp. 2999–3012, 2012.

[2] R. Jain, J. Grzyb, and U. R. Pfeiffer, “Terahertz light-field imaging,” *IEEE Trans. THz Sci. Technol.*, vol. 6, no. 5, pp. 649–657, 2016.

[3] W. Neumann, *Fundamentals of dispersive optical spectroscopy systems*. SPIE Press, 2014.

[4] X. Wu and K. Sengupta, “On-chip THz spectroscope exploiting electromagnetic scattering with multi-port antenna,” *IEEE J. Solid-State Circuits*, vol. 51, no. 12, pp. 3049–3062, 2016.