Characterization of widefield THz optics using phase shifting interferometry

Nicolás Reyes[1], Ivan Cámara-Mayorga[1], Gerrit Grutzeck[1], Stephen Yates[2], Andrey Baryshev[1], Bernd Klein[1]

***Abstract*—Characterization of wide-field optics in the Terahertz regime imposes new and demanding requirements for testing systems. From basic characterization using scalar sources or thermal sources located in the instrument focal plane, basic beam measurements can be determined, whereas important features, such as coupling to the antenna system or the effect of curved focal planes, cannot be determined by such approaches. These limitations can be overcome by performing phase and amplitude measurements of the beam. From its complete optical information of the system is obtained, allowing the estimation of all relevant optic parameters. In this work we present and demonstrate a technique to perform such measurement based on the use of photonic sources. The system was implemented to fully characterize the A-MKID instrument, a wide-field camera based on kinetic inductance detector (KID) technology to be deployed at the APEX Telescope in Chile.**

I. Introduction

The characterization of wide-field optics operating in the terahertz regime is a major challenge as it involves very demanding requirements many of which are hard to meet with the available testing systems technology. Whilst scalar or thermal sources placed in the focal plane allow basic characterization, important features such as spillover efficiency, wave front error, or aperture efficiency cannot be determined by such approaches. In addition, when instruments have a curved focal plane, designed to match the Petzval surface of the hosting telescope, even basic parameters are difficult to extract from scalar planar measurements. By contrast, from complex planar (amplitude and phase) measurements, the complete information of the optical system can be obtained, allowing the estimation of all relevant optical parameters [1][2]. The present paper reports on our work to implement a broad frequency tunable testing system capable of performing amplitude and phase measurements based on two interfering photonic sources of coherent terahertz radiation [3][4]. The described testing system allowed to characterize the wide-field optics of the A-MKID instrument, which will be shortly installed in the Atacama Pathfinder Experiment telescope (APEX) in Chile [5]. The A-MKID instrument is a wide-field, dual-color, bolometer camera. It is based on kinetic inductance detectors [6][7] and operates at 350 GHz and 850 GHz. The instrument optics consists of six reflective mirrors, possessing complex extended polynomial shapes optimized to achieve a diffraction limited performance and Strehl ratio better than 0.8 over the complete field of view [8].

This work presents a characterization system which consists of tunable terahertz photonic sources to perform amplitude and phase measurements by phase shifting interferometry. The experimental setup involved two terahertz sources located at the instrument focal plane, radiating at the same frequency but with the relative phase controlled using optical fiber stretchers. The use of fiber stretchers allows for electronical control of the phase shift, eliminating the need for mechanical delay lines, traditionally required by the phase shifting interferometry technique.

The interference between both sources -reference and signal source- is used to measure the complex beam pattern for every pixel in the detector. The signal source is mounted on an XY translation stage, whereas the reference source is static and couples to the detectors via reflection on a polarization grid.

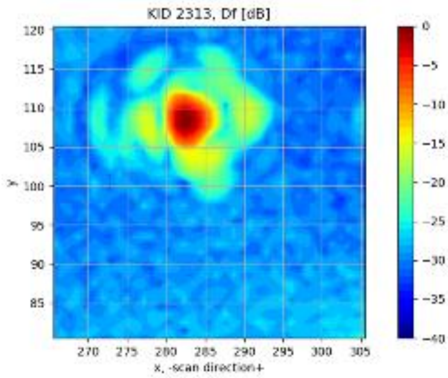

Figure 1: AMKID measured amplitude beam at 850GHz band. Sidelobe level is around -13 dB, in agreement with simulations, no pedestal response is observed down to -40 dB.

Nicolas Reyes, Ivan Camara Mayorga, Gerrit Grutzeck and Bernd Klein are with the Max Planck Institute for Radio-Astronomy, Auf dem Hugel 69, 53121, Bonn.
Stephen Yates is with SRON, Netherland Institute for Space Research, Groningen, The Netherlands.
Andrey Baryshev is with the Kapteyn Astronomical Institute, University of Groningen, The Netherlands and with the Max Planck Institute for Radio-Astronomy, Bonn.

NOTES:

Both terahertz signals propagate through the AMKID optical system and reach the detector array, where they interfere. The detected signal by the KID readout is proportional to the squared electric field at the detector, corresponding to the addition of the fields generated by the two photonic sources. As the phase of the sources, reference, and signal, was swept by a saw-tooth signal, the extraction of the amplitude and phase of the beam pattern is straightforward.

II. Conclusion

The setup probed to show an excellent terahertz signal phase stability of few degrees over several hours and allowed to characterize the optics of the instrument in two frequency bands: 350GHz and 850 GHz. The measured phase and amplitude beam maps yielded typically a signal to noise ratio of more than 40 dB, Figure 1, and allowed the extraction of aperture efficiency, spill-over efficiency, wavefront distorsion, beam ellipticity etc.

The system achieved a high level of accuracy and demonstrated a reliable method for measuring amplitude and phase in the terahertz regime.

References

[1] K.K. Davis, et al., “Complex Field Mapping of Large Direct Detector Focal Plane Arrays”, IEEE Transactions on Terahertz science and technology, Vol 9, No 1, January 2019.

[2] S.J.C. Yates et al., “Complex beam mapping and Fourier optics analysis of a wide-field Microwave Kinetic Inductance detector camera” Journal of Low Temperature Physics. 199:156-163, 2020.

[3] I. Cámara Mayorga, et al. “Terahertz photonic mixers as local oscillators for hot electron bolometer and superconductor-insulator-superconductor astronomical receivers,” J. Appl. Phys. 100 (4), 043116 (2006).

[4] I. Cámara Mayorga, et al., "First in-field application of a full photonic local oscillator to terahertz astronomy", *IEEE Trans. THz Sci. Technol.*, vol. 2, no. 4, pp. 393-399, Jul. 2012.

[5] R. Güsten, et al., “The Atacama pathfinder experiment (APEX), a new submillimeter facility for southern skies” A&A, 454(2): L13–L16, 2006.

[6] P. Day, et al., “A broadband superconducting detector suitable for use in large arrays,” *Nature*, vol. 425, no. 6960, pp. 817–821, Oct. 23, 2003.

[7] R. M. J. Janssen *et al.*, “High optical efficiency and photon noise limited sensitivity of microwave kinetic inductance detectors using phase readout,” *Appl. Phys. Lett.*, vol. 103, no. 20, 2013

[8] L. Esteras, “The optical system and the astronomical potential of A-MKID, a new camera using microwave kinetic inductance detector technology” Ph.D. dissertation. University of Bonn, 2014

NOTES: