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Quasi-Optical System for the ASTE Telescope with 1:3 Bandwidth at Sub-mm Wave

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***Abstract*—DESHIMA is a spectrometer for astronomical applications targeting sources at sub-mm wavelengths from 240GHz to 720GHz that will operate in the ASTE telescope in Atacama Desert, Chile. In this work, a quasi-optical system based on a hyper-hemispherical leaky lens antenna and a series of Dragonian reflectors is presented as the coupling chain for the EM radiation captured by the telescope into the detector. The design procedure is based on a field matching technique in reception. The achieved average illumination efficiency over the band is approximately 70%. The directivity patterns in the sky are also estimated. The side lobe, and cross-polarization levels, over the whole frequency band, are below -16dB, and -18dB, respectively. The measurement of the system is on-going, and will be presented at the conference.**

I. Introduction

Spectroscopy for astronomical applications requires a large operation bandwidth due to the lack of prior knowledge from the source. DESHIMA [1] is an on-chip spectrometer based on direct-detection using microwave kinetic-inductance detectors (MKIDs) [2] at sub-mm wavelengths. The system is being developed as a collaboration between the Delft University of Technology and the Netherlands Institute for Space Research (SRON). DESHIMA aims at analyzing astronomical sources from 240GHz to 720GHz (relative bandwidth of 1:3) and will be deployed at ASTE in Chile. In this work, a single lens antenna element coupled quasi-optical system has been proposed to receive the incoming electromagnetic radiations at the corresponding 1:3 frequency band. Specifically, the design procedure for a wideband hyper-hemispherical lens [3] with a leaky antenna feed, similar to the one in [4], coupled quasi-optical system is presented. The performance of this design in terms of the aperture efficiency is presented and validated using GRASP.

II. Proposed Design and Achieved Performance

The entire quasi-optical chain of DESHIMA, Fig. 1(a), is modeled via a single parabolic reflector, with a diameter related to the first truncating aperture to optimize the aperture efficiency of the instrument. This geometry is then analyzed in reception. Let us assume that a plane wave illuminates the parabolic reflector from broadside direction as shown in Fig. 1(b). By resorting to a Physical Optics (PO) code, the EM field at the lens surface scattered by the reflector, can be calculated. Furthermore, by using a Geometrical Optics (GO) code, the incident fields at the lens surface are propagated into the lens up to the surface of a sphere centered at the antenna's position. This sphere is referred to as the GO sphere. The field evaluated at its surface, $\vec{E}_l^{GO}$, is referred to as the GO field. By knowing this GO field and resorting to antenna in reception formulations [5], the coupling mechanism between the quasi-optical system and an antenna can be evaluated. In particular, the power delivered to the load of the antenna is directly related to the field matching between this incoming GO field and the antenna far field. Where this far field is also evaluated at the GO sphere.

The performance of the hyper-hemispherical leaky lens antenna coupled parabolic reflector can be optimized using the following lens parameters: the displacement from focus of the reflector, F_v, diameter, D_l, and extension length, L_e. By optimizing the design over these parameters, one can maximize the average aperture efficiency over the 1:3 bandwidth.

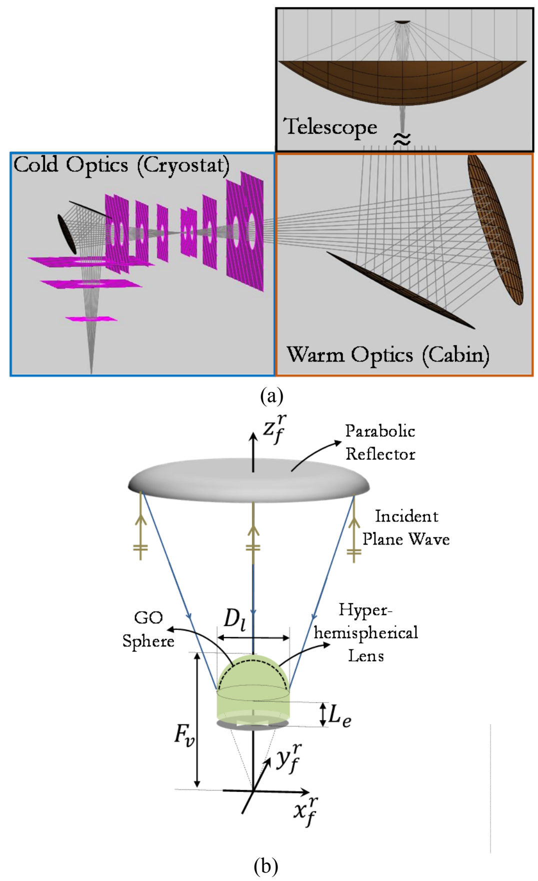
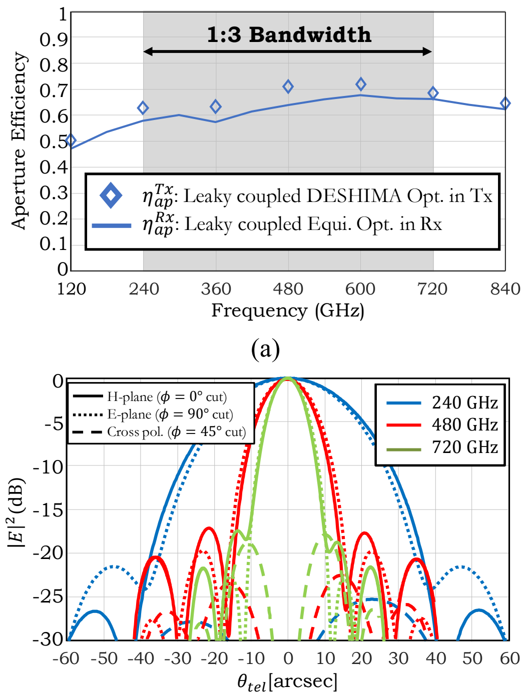


Fig. 1. (a) The GRASP model of the DESHIMA optical system. (b). The equivalent optics used for optimization in reception.

In Fig. 2(a), the aperture efficiency of the optimized design obtained in reception is compared against a PO based analysis performed in transmission when considering the complete DESHIMA quasi-optical system (Fig. 1(a)). As shown, the agreement between the obtained results assuming a single reflector analyzed in reception and the full optics chain modelled in GRASP is good. However, the former method takes only a few minutes while the latter is quite time consuming. The illumination efficiency of the design is over 70% in the whole 1:3 relative bandwidth. Including the feed losses, an averaged aperture efficiency of 65% is achieved. Moreover, in Fig. 2(b), the pattern of system after the ASTE telescope (Beam in the sky) is shown for three frequency points over the full band. The side lobe, and the cross-polarization levels of these pattern are below -16dB, and -18dB, respectively.



(b)

Fig. 2. (a) The performance of the leaky lens antenna coupled DESHIMA optics in terms of the aperture efficiency. (b) The pattern of the system after the telescope dish.

III. Conclusion

In this work, a wideband quasi-optical system for the ASTE telescope based on a hyper-hemispherical leaky lens antenna is presented. The lens antenna is optimized to maximize its coupling to a parabolic reflector. The design procedure is based on a field matching technique in reception. The quasi-optical system has an illumination efficiency over 70% in the whole 1:3 relative bandwidth. Including the feed losses, an averaged aperture efficiency of 65% is obtained. The pattern in the sky of the system is also simulated in GRASP. The side lobe, and the cross-polarization level of this pattern, over the bandwidth, is below -16 dB, and -18dB, respectively. The measurement of the performance of system is on-going and will be presented at the conference.

Acknowledgment

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References

[1]. A. Endo, et. al. “Development of DESHIMA: a redshift machine based on a superconducting on-chip filterbank”, *Proc. of SPIE*, vol. 8452, pp. 1–15, Sep. 2012.

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

[3]. G. M. Rebeiz, “Millimeter-wave and terahertz integrated circuit antennas,” *Proc. of IEEE*, vol. 80, no. 11, pp. 1748-1770, Nov. 1992.

[4]. O. Yurduseven, et. al, “A Dual-Polarized Leaky Lens Antenna for Wideband Focal Plane Arrays”, *IEEE TAP.*, vol. 64, no. 8, pp. 3330–3337, 2016.

[5]. V. Rumsey, “On the design and performance of feeds for correcting spherical aberration,” *IEEE TAP.*, vol.18, no.3, pp.343–351, 1970.