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Development of a Multi-Lens Quasi-Optical Imaging Spectrometer for Ground-Based Astronomy

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***Abstract*— Achieving a wide instantaneous bandwidth and wide scanning capabilities are essential for development of (sub)-millimeter imaging spectrometers for astronomical observations. Such an instrument can be realized using complex quasi-optical (QO) systems. In this work, we propose a QO architecture based on refractive components to reduce the overall size and volume of the instrument. This compact design is optimized using a sequential Geometrical Optics based technique. The performance of the preliminary design is reported in terms of the aperture efficiency over an octave of bandwidth and the field of view of the telescope hosting the instrument exhibiting less than 1dB of scan loss. The finalized design of the instrument, its performance, and realization approach will be discussed at the conference.**

I. INTRODUCTION

IMAGING spectrometers for observations at (sub)-millimeter wavelengths are a major topic of interest in the astronomical community [1,2]. Such an instrument is desired to map relatively large cosmic volumes and extract spectral information to characterize their chemical composition and distance. To address a wide range of related science question, Terahertz Integral Field Unit with Universal Nanotechnology (TIFUUN) instrument [3] is proposed to operate over a wide spectral bandwidth (90-370GHz) with 2:1 (an octave) instantaneous bandwidth sub-arrays. TIFUUN will operate at the ASTE telescope in Chile and cover a Field of View (FoV) of 7.4 arcmin in diameter. The background limited sensitivity for detection and the spectral information will be extracted using on-chip superconductive filter banks [4] based on Microwave Kinetic Inductance Detectors (MKIDs) [5], similar to the ones developed for a previous single pixel instrument [6].

In this work, a Quasi-optical (QO) system is developed to efficiently couple the Electromagnetic (EM) radiation from the ASTE telescope to the focal plane array of antenna based MKIDs, see Fig. 1. The antenna feeders are based on tapered leaky wave slots [7]. Such an antenna feeder exhibits more than one octave of instantaneous impedance bandwidth as well as uniform radiation patterns. The QO system is based on refractive components to reduce the size and volume of the instrument specially within the cryogenic system hosting the detectors. The multi-lens system is designed using a novel sequential Geometrical Optics (GO) technique combined with an analysis in reception mode [8]. The lens positions, surfaces and overall geometry are designed using a multi-objective optimiser to maximize the aperture efficiency over the FoV.

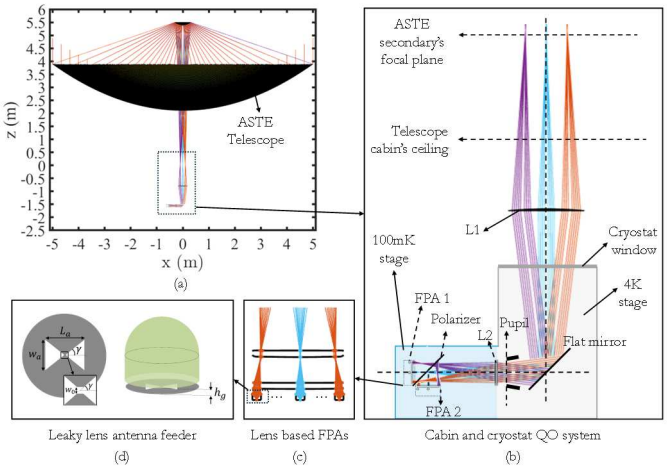


Fig. 1. A ray tracing sketch of the proposed TIFUUN QO system: (a) overview of the ASTE telescope and the cabin (warm) QO system of the instrument, (b) cabin (warm) and cryogenic (cold) QO systems, (c) Lens based FPAs, and (d) leaky lens antenna feeders.

II. MULTI-LENS QUASI-OPTICAL SYSTEM

A major portion of the QO system of TIFUUN must be shared by multiple lens based Focal Plane Arrays (FPAs) targeting separate science cases, wavelength ranges, and polarizations. As a consequence, a modular approach was considered where the multi-lens FPAs can be exchanged. The baseline for the warm (telescope cabin) optics was a near field crossed Dragonian reflector system to widen the scanning capabilities of the antenna system. However, the size constrains within the telescope cabin led to a telecentric lens design instead, as marked by L1 and L2 in Fig. 1(b). The former is located outside the cryogenic system below the opening within the telescope cabin while the latter is a cryogenically cooled lens. These components form a well-defined pupil plane within the cryostat to control the stray light radiation. The cold optics lens (L2) is coupled to two sets of multi-lens FPAs via a polarizer. Such a geometry enables the possibility for simultaneous observation at two linear polarizations and at two separate wavelength ranges.

The lenses in the proposed QO system are made of high-resistivity silicon with wide band anti-reflection coatings similar to the ones described in [9]. The lens shapes are modelled as a rotationally symmetric conic section with added symmetric higher order polynomials [8]. The geometry is optimized in reception mode by a conjugate field matching criteria [10, 11] between the incident EM fields and the ones

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that equivalently radiated by the antenna feeder in transmission mode. Both of these fields are evaluated at the same chosen surface (here a sphere centered at the focus of L2). In each iteration of the multi-objective optimizer (gamultobj from MATLAB [12]), amplitude, phase, and polarization of the two described GO fields are compared against each other.

The performance of the preliminary design in terms of aperture efficiency over an octave of bandwidth and over the FoV are reported in Table I. These values are obtained by a numerical validation of the optimize design using Physical Optics solver of TICRA tools, GRASP [13].

Aperture Eff. (GRASP)	Centre of the FoV	Edge of the FoV
185 GHz	56.1%	55.8%
277.5 GHz	61.3%	63.4%
370 GHz	64.9%	63.6%

Table I. Aperture efficiency of the proposed QO system obtained using GRASP with respect to telescope aperture over its FoV and an octave of bandwidth.

III. SUMMARY

In this contribution, a multi-lens QO system is proposed for a compact realization of an imaging spectrometer operating at (sub)-millimetre wavelengths. The QO system is optimised using a sequential GO technique combined with analysis in reception mode. The proposed design covers most of the FoV of the host telescope within an octave of instantaneous bandwidth with a maximum scan loss below 1dB. The finalized lens-based system, its performance and its realization steps will be discussed in details at the conference.

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