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8-beam local oscillators multiplexer for GUSTO at 4.7 THz

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***Abstract*—We will report a full demonstration of the Fourier phase grating used as 4.7 THz local oscillator (LO) multiplexer for Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO). The design, modeling, tolerance analysis, and experimental characterization of the angular and intensity distributions among 2 × 4 output beams and the power efficiency will be presented. This is the first detailed study of a THz beam multiplexer, which will be actually integrated in an observatory.**

I. Introduction

GUSTO is a NASA balloon borne observatory, which will detect the fine structure lines of nitrogen [NII], carbon[CII] and oxygen [OI] at frequencies of 1.4, 1.9 and 4.7 THz (bands 1, 2 and 3), respectively. High spectral resolution heterodyne spectroscopy will be used in GUSTO, in which the THz celestial signal is down-converted to GHz range using a superconducting mixer and a locally generated THz signal (LO). Each band has an array of 8 (2 × 4) mixers for increasing the mapping speed and the observing efficiency. Bands 1 and 2 employ frequency multiplier-chain sources as LOs, while band 3 uses a quantum cascade laser (QCL) at 4.7 THz, which is the only LO applicable source. Here a phase grating takes the beam of such QCL at its input and generates 8 similar beams distributed in the same pattern as the array of mixers (2 x 4). This method is the most efficient way of optically pumping a THz mixer array.

We designed, modelled, and realized a 4.7 THz grating with an asymmetric surface profile to accommodate challenging design constraints caused by the limited allocated space to the optical elements. We experimentally characterized the grating using a THz QCL. With high accuracy measurements of the output beams angular distribution, the efficiency and the power uniformity, we verified that this grating meets the requirement of the band 3 for GUSTO mission [1].

Our group pioneers in research and development of the THz beam multiplexers in the high end of THz frequencies[1-3], which can be key for future large heterodyne arrays.

II. Design Parameters and Manufacturing

The designed grating consists of a unit cell with dimensions of 2.057 x 2.048 mm^2 repeated periodically 12 times in each orthogonal direction. The design was aimed for multiplexing an input beam with 2.95 mm radius and 15 ° incident angle to 2 x 4 similar beams with 1.83° angular distances. Such combination of requirement could only be fulfilled with an asymmetric grating profile leading to an output beam distance deviation of less than 0.04 °.

The grating profile was machined on aluminum by CNC micro milling in Arizona State University (ASU) with an error less than 1 μm in height, giving a negligible consequence on the array sensitivity.

III. Results

We used a 4.7 THz QCL made by MIT to characterize the grating, where we first spatially filter its radiation to get a pattern close to the required input beam. We use a pyroelectric detector mounted on a translational stage for scanning, where we could measure the output beam angles with an accuracy better than 0.3 °. Fig. 1 shows the input and output beam patterns indicating similar beams in the right configuration.

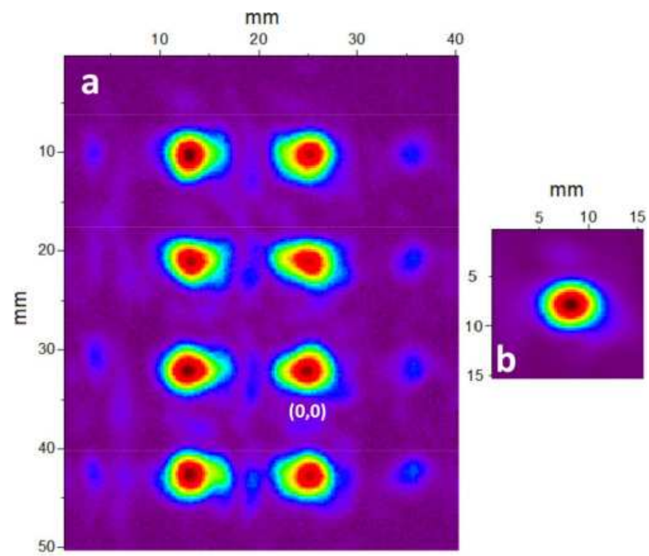

Fig. 1. Measured output beams of the grating in (a) and input beam in (b).

We found the beam directions and angular distances agreeing with our modelling with deviations smaller than the error bar of our measurements, with the best accuracy we could achieve. We measured a power efficiency of 69 % and a non-uniformity of 13 % among the output beams as we expected from simulations. The latter causes a limited variation in LO power among the 8 beams, and a negligible effect on the array averaged sensitivity.

Having achieved all important measurement results to be in good agreement with those from the design, our phase grating meets the requirements and now is integrated in the band 3 array receiver of GUSTO, which is scheduled to launch in December 2023 from Antarctica.

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