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Dual-Band Leaky-Wave Lens Antenna for Submillimeter-Wave Heterodyne Instruments

Sjoerd Bosma[1], Maria Alonso-delPino[2], Darwin Blanco[1], Cecile Jung-Kubiak[2], Nuria Llombart[1]
[1]Terahertz Sensing Group, Delft University of Technology, Delft, The Netherlands, s.bosma@tudelft.nl
[2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

***Abstract*— In this contribution, we propose an antenna for a dual-band focal plane array (FPA) heterodyne receiver at 210-240 GHz and 500-580 GHz to perform cometary observations. The proposed antenna is composed of a fused silica lens fed by a leaky wave waveguide feed. The dual-band leaky wave feed is based on a single-layer Frequency Selective Surface (FSS) with a transformer layer which allows to have a quasi-optical system that achieves a footprint of the field of view with overlapped beams and equal beamwidths for both frequency bands. A single pixel antenna prototype is currently being developed.**

I. INTRODUCTION

SUBMILLIMETER-WAVE instruments are well-suited to remotely observe comets due to the presence of rotational lines of major volatiles in the 210-240 GHz and 500-580 GHz bands. For example, the Microwave Instrument on the Rosetta Orbiter (MIRO) [1] has successfully surveyed comet 67P/Churyumov-Gerasimenko in 2014-2016. To improve on the spatial and temporal sampling of comae for future submillimeter instruments, a multi-pixel system is required. Furthermore, an architecture in which both beams are aligned in the field of view with the same beamwidth to spatially cover the same area on the comae (see Fig. 1a) would significantly simplify the data analysis tasks. And last, a lower power, more compact and more integrated instrument would facilitate infusion in future space missions.

To fulfill the stated requirements, we will develop a dual-band integrated FPA that achieves a footprint of the field of view with overlapped beams and identical beamwidths at f_L=210-240 GHz and f_H=500-580 GHz. In particular, we propose using a fused silica elliptical lens that is fed by two individual waveguide feeds offset from the center of the lens as the FPA single element. The two waveguides act as a frequency duplexer integrated directly in the antenna. In order to achieve high Gaussicity and overlapped patterns with the same beamwidth at f_L and f_H, a leaky-wave stratification based on a single-layer FSS will be used.

II. DUAL-BAND LEAKY-WAVE LENS ANTENNA

The proposed lens antenna is shown in Fig. 1b, fed by two waveguides that couple from the f_L and f_H receivers to a single leaky-wave stratification. Each waveguide is excited by its fundamental TE_{10} mode and their polarizations are parallel to facilitate integration. Each waveguide is terminated by a double-slot iris to match the waveguide impedance to the leaky-wave stratification.

The leaky wave stratification is composed of an air cavity with a thickness of $h = 0.4\lambda_0$, a fused silica layer with a thickness of $h = 0.27\lambda_d$ (λ_0 defined at 385 GHz) and an FSS followed by a fused silica lens modelled as a semi-infinite medium.

The fused silica layer acts as an impedance transformer for the FSS and the semi-infinite medium. The transformer and FSS are co-designed such that leaky waves propagate in the air cavity with the same propagation constant (normalized to frequency) [2] at f_L and f_H. This means the same directivity and phase center are achieved in both bands.

The waveguide feeds are laterally offset from the lens focus ($d_{\mathrm{LF}} = 163\mu m$, $d_{\mathrm{HF}} = 488\mu m$) and will produce a beam tilt on the field radiated outside the lens, the secondary fields, of 1.8° and −3.8° for f_L and f_H, respectively. This tilt has been minimized by using a low permittivity lens of fused silica ($\varepsilon_r = 3.8$).

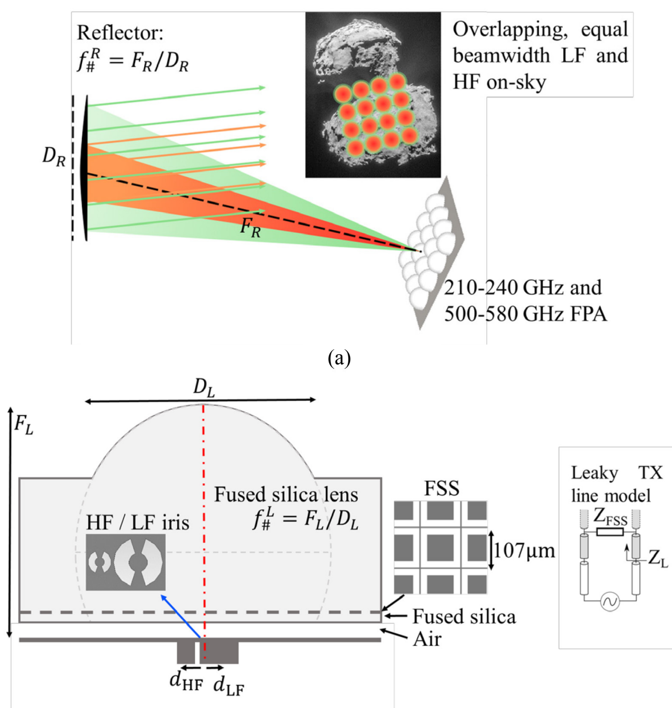

Fig. 1 (a) Quasi-optical system and (b) detail of lens antenna geometry. Comet image credit to Rosetta/NAVCAM..

The simulated performance of the leaky-wave feed is shown in Fig. 3. The radiation patterns into the fused silica lens are shown in Fig. 3a and Fig. 3b for f_L and f_H, respectively. A Gaussian beam with $\theta_0 = 23.7°$ is superimposed on these patterns and the coupling to this Gaussian is shown in Fig. 3c. The Gaussicity is higher than 91% in both bands.

The impedance match of both waveguide feeds to the stratification is well below -10 dB, shown in Fig. 3d. The

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coupling of the high frequency waveguide to the low frequency waveguide (S_{HL}) is also shown in Fig. 3d. This is well below -20 dB, leading to a negligible effect on the radiation patterns of the high frequency.

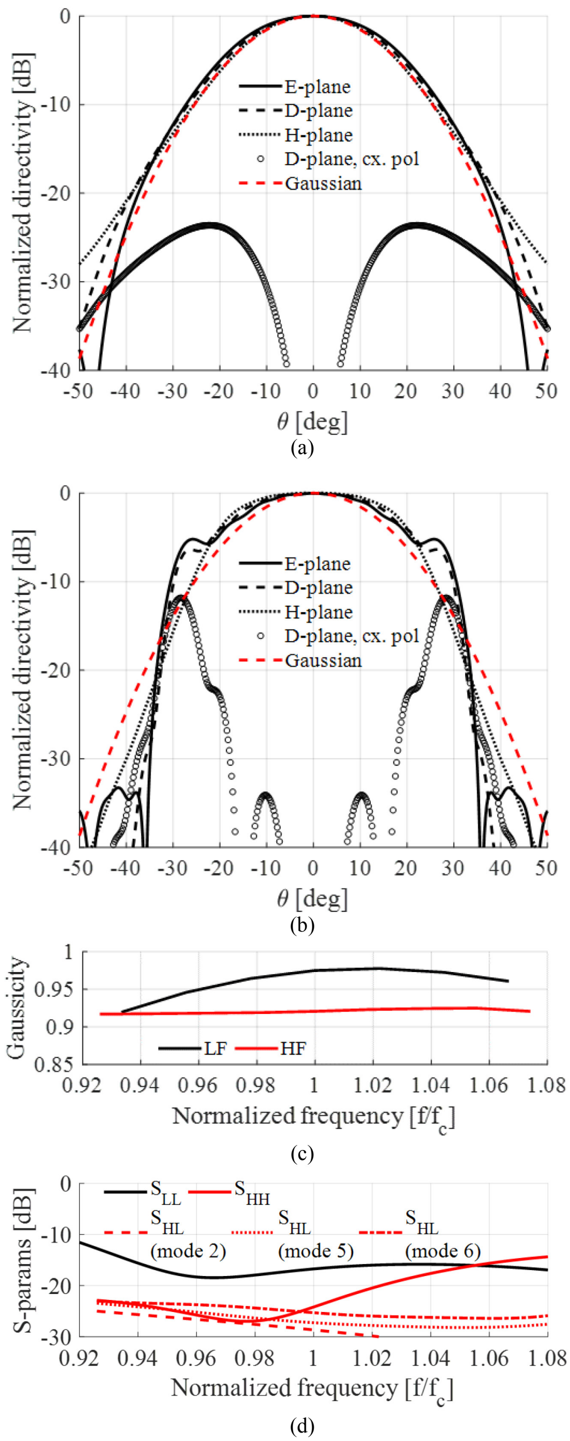

Fig. 2. Primary fields radiated into the low permittivity lens at (a) low and (b) high frequency. In red, the Gaussian beam with $\theta_0 = 23.7°$ to which it couples is shown, with (c) showing the Gaussicity. (d) Shows the reflection coefficient and mutual coupling between the two waveguides.

III. On-Sky Radiated Patterns

A parabolic reflector with a diameter of 30 centimeters and $f_{\#}^{R} = 3.2$ fed by the designed lens antenna at f_L and f_H has been simulated using GRASP. The spill-over losses in both bands are below 0.32 dB.

The on-sky radiation patterns are very similar in both bands. This is shown in Fig. 3a with the f_L patterns in blue and the f_H patterns in black. The Gaussian beam with $\theta_0 = 0.28°$ to which these patterns couple maximally is also shown in red. The Gaussicity is higher than 93% in both f_L and f_H, as shown in Fig. 3b.

A gain of 55 dB and 54.3 dB is achieved at the central frequency of both bands (see Fig. 3c). The gain includes the loss due to impedance mismatch, lens reflection, lens spillover and reflector spillover.

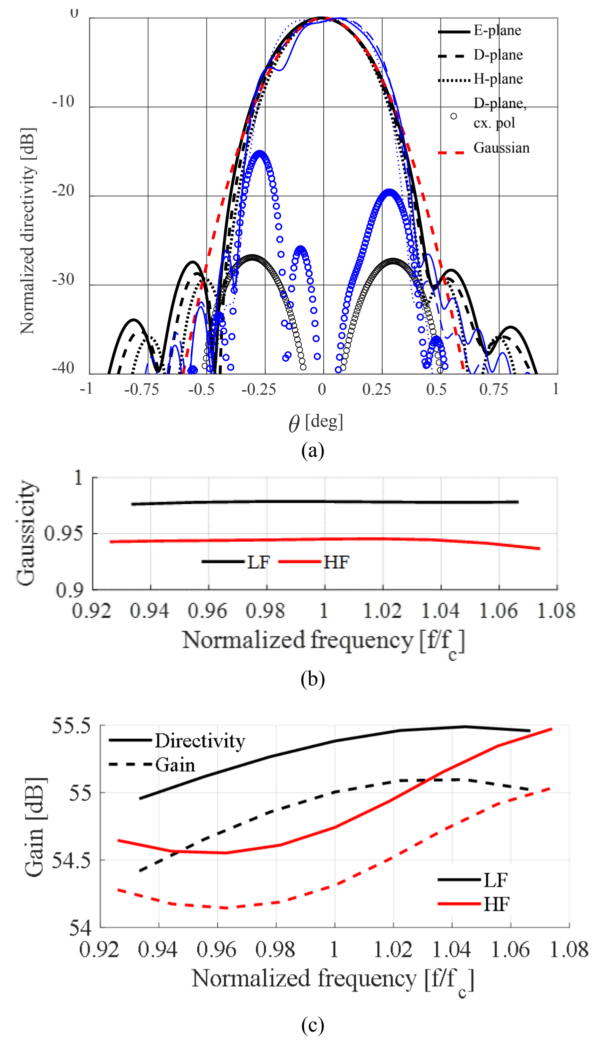

Fig. 3. (a) Tertiary fields radiated by the reflector at low (black) and high (blue) frequency with a Gaussian beam of $\theta_0 = 0.28°$ superimposed (red).

IV. Conclusion

In this contribution, we have proposed a dual-band lens antenna operating at f_L=210-240 and f_H=500-580 GHz to perform cometary observations. The antenna is composed of a fused silica lens on top of a leaky-wave stratification that is fed by two waveguide feeds. The leaky-wave stratification is based on a single-layer FSS and a transformer layer. This stratification achieves nearly identical patterns at f_L and f_H, enabling a quasi-optical system that achieves a footprint of the field of view with overlapped beams and equal beamwidths for both f_L and f_H. A gain of 55 dB and 54.3 dB, which includes the loss due to lens reflection, lens spill over and reflector spill over, are achieved at the central frequency for both bands. This new design will enable the development of submillimeter spectrometer instruments with multi-pixel capability and co-aligned beams of the same footprint.

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