Wide Field of View Dual-Lens Antenna at Sub-Millimeter Wave Frequencies

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***Abstract*— A wide field of view dual-lens system is presented in this contribution. The antenna is designed to work from 250 to 500 GHz. An outline of the design considerations is discussed. The lens system is designed for near-field focusing at a range of 2.1 m from the primary aperture. It can be refocused by displacing one single lens in a range from 1.8 to 2.5 m. The simulated results show that over the required field of view of ±25.4° (±1 m at the nominal range) the directivity variation is approximately 1 dB. The dual lens system was fabricated and measured. The experimental results confirm the predicted performance for all the discussed ranges and over the entire 50.8° field of view.**

Keywords*— *Focusing systems, lens antennas, terahertz.

I. Introduction

The main challenge in the design of imagers for concealed objet detection at sub-millimeter wavelengths [1] is to achieve a large field of view (FOV) to cover a full person with satisfactory spatial resolution and fast image acquisition. A viable path towards solving such challenge is the use of a highly populated focal plane arrays (FPA) coupled to a wide-FOV focusing systems. The object of this contribution is the design and experimental demonstration of the quasi-optical system of a passive imager working in the 250 to 500 GHz frequency band. The quasi-optical system will be used in combination with a large FPA composed by approximately 10000 kinetic inductance detector (KID) absorbers [2]. This large number of receivers allows for quasi-video rate image acquisition of a large FOV while reducing significantly the need for top performance mechanical scanners.

The designed dual-lens system is shown in Fig. 1. Its FOV is located at 2.1 m from the aperture of the top lens. The half power beamwidth (HPBW) at 250 and 500 GHz is 0.55° and 0.27° cm, respectively, corresponding to a directivity of 50 to 56 dB. The FOV is circular with a diameter of approximately 2 m, corresponding to an angular FOV of 50.9° (±25.4°) and the edge pixel corresponds to a scan of 50 and 100 HPBW at the lower and higher frequencies, respectively. Since the imager will require near-field focusing optics, a mechanical based mechanism for changing the focusing distance will also be required.

II. Dual-lens design

A dual-lens configuration (Fig. 1) was selected for the design because it is not affected by blockage for large scanning

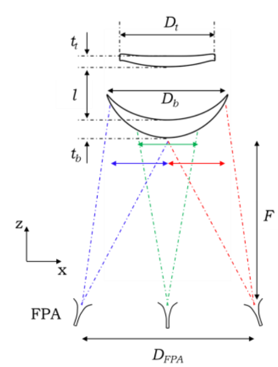


Fig. 1. Dual lens architecture.

(as it is the case of offset reflector systems). The diameter of the top lens, D_t, and imaging range, R_f, define the resolution at the center of the FOV. The bottom lens (diameter: D_b) was oversized so that the field corresponding to different receivers in the FPA illuminates only part of this lens (see ray-tracing in Fig. 1). This configuration allows the shape of the bottom lens to be varied so that different parts of the lens compensate for the phase aberrations associated to different scanning points. This was done by defining the surfaces of the lenses as conic shapes plus higher order polynomials. The surfaces were optimized to reduce the phase aberration loss over a large scanning range using the ray-tracing commercial tool ZEMAX [3]. The material and thickness of the lenses were chosen to reduce the dielectric (reflection and absorption) losses. The selected material is TOPAS COC resin [4] (ε_r = 2.34). The associated reflection loss is approximately 1 dB considering the reflection at the four air-dielectric interfaces of the system. The thicknesses of the lenses are t_b = 2.5 cm and t_t = 1.5 mm, corresponding to an estimated absorption loss of 0.7 and 2 dB at 250 and 500 GHz, respectively.

The optimized dual-lens system was simulated by using GRASP [5] when illuminated by a feed in the FPA. The directivity at 500 GHz as a function of the observation point in the FOV is shown in Fig. 2 and compared to a standard single refractive lens of thickness 4 cm (i.e. the sum of the thicknesses of the two designed lenses) that provides a perfect focus in the center of the FOV (x_{FOV} = 0 cm). A small directivity reduction at broadside is allowed for the dual-lens system to achieve an almost flat behavior over a FOV of 100 HPBW.

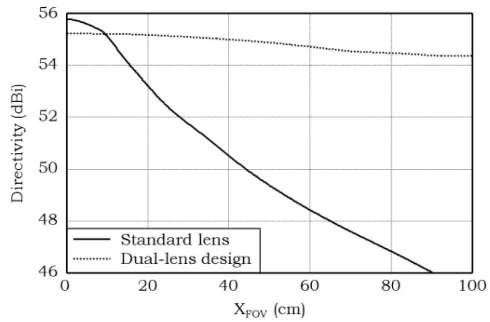


Fig. 2. Normalized gain as a function of the observation point at 500 GHz at R_f = 2.1 m.

The quasi-optical system includes refocusing capabilities. In particular, its range can be changed from R_f = 1.8 to 2.3 m by displacing the bottom lens in the z-direction (see Fig. 1). The closest range is achieved by moving the lens closer to the top one by 5 mm, instead, a displacement of 4.5 mm towards the FPA allows to change the range to 2.5 m.

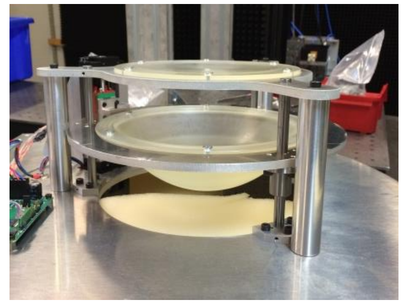
III. Experimental validation

The prototype of the described dual-lens system is shown in Fig. 3(a). The lens is illuminated by an open ended waveguide (OEWG) with size 0.56 × 0.28 mm^2, and the antenna patterns were measured using a near-field xy-scanner system. A OEWG with the same size of the transmitting one was used as receiving probe. The measurements to evaluate the design were performed at the highest operation frequency, 500 GHz and the patterns were measured at the center of the FOV for three different ranges, R_f = 1.8, 2.1 and 2.3 m, whereas the scanning performance was evaluated only at the closest range. The profiles of the fabricated lenses were measured and they showed an rms error of 37 µm.

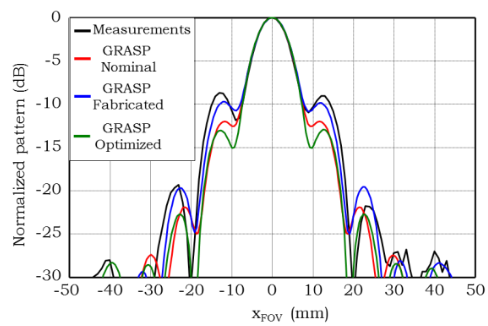
The measured patterns at the center of the FOV are shown in Fig. 3(b) and compared to the corresponding GRASP simulations. The simulations were performed both considering the nominal and the fabricated surfaces of the lenses. As it can be noticed, the inaccuracy of the fabrication results in an increase of the side lobe level (SLL). The measured and simulated patterns are in excellent agreement when the fabricated surfaces are considered. The high side lobe can be reduced by properly optimizing the position of the bottom lens. Additional simulations considering the fabricated surfaces showed that an SLL reduction to -13 dB can be achieved (green curve in Fig. 3(b)). The results corresponding to the other ranges and to the scanning performance are also in good agreement with the simulations but are not reported here for brevity.

IV. Conclusion

In this contribution, a dual-lens antenna system at sub-millimeter wave frequencies was presented. The quasi-optical system was designed to focus in the near-field and a simple mechanical refocusing mechanism was implemented. The required field of view is 2 m at approximately 2 m distance from the primary aperture, corresponding to a 50.8° angular field of view. The dual-lens system was designed to work in the frequency band from 250 to 500 GHz. The design trade-offs to achieve a wide field of view with low scan loss and dielectric loss were outlined. The surfaces of the lenses were optimized using higher order polynomials and allowed to achieve a directivity reduction of 1 dB for 100 HPBW scan. The predicted performance was successfully verified experimentally.



(a)



(b)

Fig. 3. Experimental configuration: (a) dual lens prototype, (b) Measured patterns at 500 GHz at R_f = 1.8 m at the center of the FOV.

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