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DOI

[10.1109/IRMMW-THz.2019.8874477](https://doi.org/10.1109/IRMMW-THz.2019.8874477)

Publication date

2019

Document Version

Accepted author manuscript

Published in

IRMMW-THz 2019 - 44th International Conference on Infrared, Millimeter, and Terahertz Waves

Citation (APA)

Bosma, S., Alonso-Delpino, M., Jung-Kubiak, C., Blanco, D., & Llombart, N. (2019). Scanning lens phased array for submillimeter wavelengths. In *IRMMW-THz 2019 - 44th International Conference on Infrared, Millimeter, and Terahertz Waves* (Vol. 2019-September). [8874477] IEEE. <https://doi.org/10.1109/IRMMW-THz.2019.8874477>

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Scanning Lens Phased Array for Submillimeter Wavelengths

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Abstract— In this contribution, we propose a hybrid electro-mechanical scanning antenna array architecture suitable for highly directive phased arrays at submillimeter wavelengths with field-of-views (FoV) of ± 30 degrees. The concept relies on combining electrical phase shifting of a sparse array with a mechanical translation of an array of lenses. The use of a sparse phased array significantly simplifies the RF front-end, while the translation of a lens array steers the element patterns to angles off-broadside, reducing the impact of grating lobes over a wide FoV. The mechanical movement of the lens array can be done using a low-weight, low-power piezo-actuator. In order to achieve wide bandwidth and steering angles, a novel leaky wave feed concept is also introduced. A 540 GHz prototype is currently under fabrication.

I. INTRODUCTION

NEXT planetary missions to Mars or Venus require the development of submillimeter-wave heterodyne instruments to enable limb-sounding measurements to characterize the temperature and composition of gases of their atmosphere. To observe the required large field-of-view at these frequencies, bulky mechanical quasi-optical systems are the main solution in use. However, the total volume, mass and power required for these mechanical scanning systems is impractical for most of these planetary missions.

In this contribution, we present a sparse phased lens array antenna capable of wide angle beam scanning using a piezo-electric motor. The array of silicon lenses is linearly translated from its central position of the antenna and, simultaneously, each element is progressively phased, creating the steering of the main beam. The required displacement of the lens array with this approach is significantly reduced compared to free standing lenses; for submillimeter-wave applications, the maximum translation can be in the order of a few millimeters, which can be covered by a piezo electric motor.

This architecture combines a low mechanical complexity and a greatly reduced number of active elements compared to a fully sampled array. The grating lobes due to the sparse array are attenuated by using a very directive element pattern (lens antenna), an approach similar to limited-scan arrays [1]. However, contrary to limited-scan arrays, the proposed architecture can reach large steering angles thanks to the steering of the element pattern.

In this work, the leaky wave lens feed originally presented in [2] and its integration with a piezo-electric motor at 550 GHz in [3] is extended to an array of lenses. Furthermore, the leaky wave feed was improved by adding a dielectric layer between the lens and the air cavity to improve the aperture efficiency and the bandwidth compared to [2]. Additionally, this dielectric layer allows the omission of the double-slot iris required in [2] for impedance matching, significantly

simplifying the fabrication process. Simulated results of a 7-element hexagonal array prototype that is currently being developed (see Fig. 1) show aperture efficiencies $>80\%$ for a bandwidth of 20%. Scanning angles of ± 20 degrees are achieved with a scan loss lower than 1.5 dB.

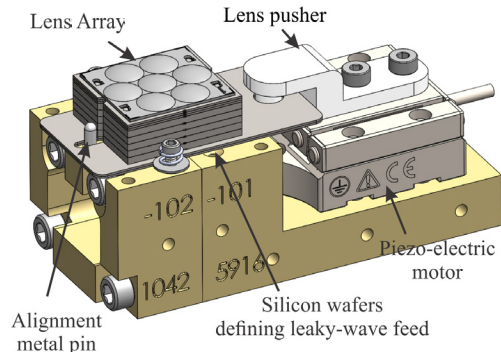


Fig. 1. Sketch of lens phased array prototype at 540 GHz with integrated piezo electric motor. The aperture diameter of each element is 5.13mm.

II. IMPROVEMENT OF THE LEAKY-WAVE FEED

The patterns of the leaky-wave lens feed, first presented in [2] and shown in blue in Fig. 2, couple well to a Gaussian beam. However, the proposed lens phased array requires high aperture efficiency illumination of the lens elements. This will reduce the impact of the grating lobes caused by the array's sparsity.

To increase the aperture efficiency of the leaky-wave feed, a quarter-wavelength dielectric layer with permittivity ϵ_m is placed between the half-wavelength air cavity and the silicon lens. This dielectric slab acts as an impedance transformer and changes the leaky-wave propagation constants inside the cavity such that the radiation points towards larger angles.

The leaky-wave lens feed patterns obtained with a dielectric layer of $\epsilon_m = 2.5$ are shown in red in Fig. 2. The high degree of uniformity over the lens area (high taper efficiency) and the rapid attenuation of the field outside the lens area (high spill-over efficiency) result in an aperture efficiency of $>80\%$ for a bandwidth of 20%. Additionally, the double-slot iris that was required in [2] for impedance matching is no longer necessary due to the inclusion of the dielectric layer. The -10 dB impedance match bandwidth is larger than 50%, meaning the bandwidth of the array is limited to 20% due to the pattern quality.

III. PROTOTYPE DEVELOPMENT

We are currently developing the prototype in Fig. 1 to show the feasibility of the phased array at 540 GHz.

The scanning lens phased array is fabricated from a silicon wafer using laser micromachining. Each of the seven lenses forming the hexagonal array is 5.13 mm in diameter ($\approx 9\lambda$).

The array is coated with a Parylene anti-reflection coating. Further silicon wafers are stacked to create the required thickness of the array using the DRIE process developed in [4]. The dielectric transformer layer ($\epsilon_m = 2.5$) is synthesized from a silicon wafer by periodic cylindrical perforations a quarter wavelength deep.

The silicon wafer stack is sustained on a metal block fixture that integrates the piezo-electric actuator and can integrate the receiver front-end. The piezo-electric actuator is a commercial miniature translation stage based on piezoelectric inertia that is able to achieve a travel range of 12 mm with a 1 nm resolution at 10 mm/s.

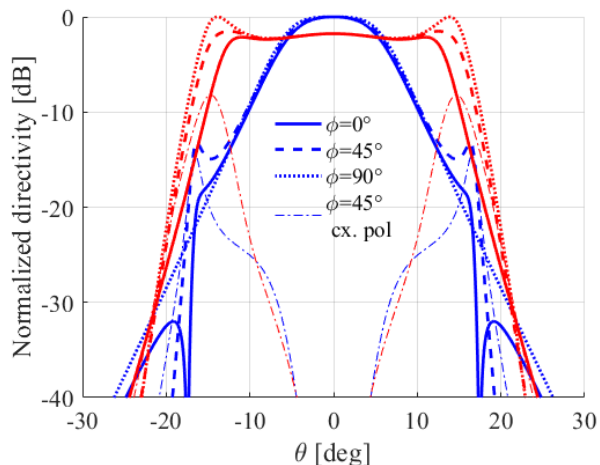


Fig. 2. Far-field radiation patterns into an infinite silicon medium of stratification with resonant air cavity (blue) [1] and the stratification with resonant air cavity and quarter-wavelength dielectric layer $\epsilon_m = 2.5$ (red).

The simulated directivity and gain of the array prototype are shown in Fig. 3. High directivity (>37 dBi) is achieved with only 7 elements due to the large element diameter. The scan loss is below 1.5 dB for scan angles up to 20 degrees.

The details of the design, fabrication and integration of the proposed lens antenna array will be presented in the conference along with the measured performance.

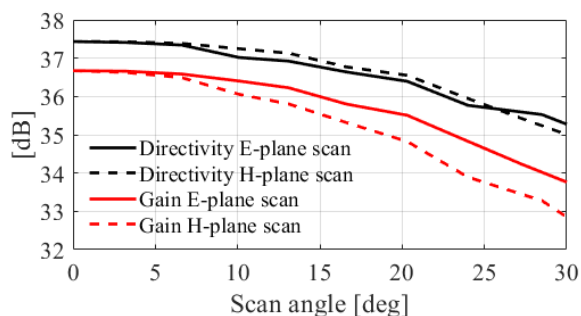


Fig. 3. Directivity and gain of the proposed array in Fig. 1 vs scan angle.

IV. CONCLUSION

In this contribution, we proposed a scanning lens phased array concept suitable for highly directive phased arrays at submillimeter wavelengths with field-of-views (FoV) of ± 30 degrees. The concept relies on combining electrical phase shifting of a sparse array with a mechanical translation of an

array of lenses. An improved leaky-wave stratification was developed to feed the lens elements. This stratification achieves $>80\%$ aperture efficiency over a 20% bandwidth. The double-slot iris required for impedance matching in previous leaky-wave stratifications is no longer necessary, simplifying fabrication. A 7-element hexagonal array prototype is being developed to show the feasibility of the concept. The prototype has a simulated directivity of >37 dBi and scan loss below 1.5 dB for scan angles up to 20 degrees.

V. ACKNOWLEDGMENTS

This work is supported by the European Union through the ERC Starting Grant LAA-THz-CC (639749). A part of the work was carried out at the Jet Propulsion Laboratory (JPL), California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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