Fly's Eye Lens Phased Array for Submillimeter Wavelengths

N. Llombart, S. Bosma, D. Blanco
Terahertz Sensing Group
Delft University of Technology
Delft, the Netherlands
n.llombartjuan@tudelft.nl

M. Alonso-delPino, C. Jung-Kubiak
SWAT Group
Jet Propulsion Laboratory
Pasadena
Maria.Alonso@jpl.nasa.gov

***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 a fly's eye array of lenses. The use of a sparse phased array significantly simplifies the RF front-end, while the translation of a fly's eye 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 fly's eye lens array can be done using a low-weight, low-power piezo-actuators. 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.**

Keywords*— *fly's eye lens array, phased array, beam scanning, submillimeter-wave

I. Introduction

Coherent array technology is currently being developed in the THz domain in order to cover a broad spectrum of applications ranging from spectroscopic space observations to communications and radar. Most of these applications require highly directive beams that should be scanned over a certain field of view. Until now, the only realistic approach that yields a large field of view at submillimeter wavelengths has been the use of quasi-optical systems combined with bulky mechanical scanners [1-2]. In order to achieve more compact systems, it is necessary to develop technology that will allow for more integrated beam steering mechanisms. The challenge in developing such systems is the need for large steering angles ($\pm 30^o$) with large apertures (i.e. directivities larger than 40 dBi) and reasonable frequency bandwidths (larger than 10%).

In this contribution, we propose to combine two techniques to achieve a practical architecture for future directive phased arrays at submillimeter wavelengths with large scan angles: sparse phased arrays with mechanically translatable fly's eye lens arrays, see Fig 1. This approach combines low mechanical complexity with a greatly reduced number of RF phase shifters. The grating lobes resulting from the array's sparsity are attenuated by the directive element patterns of the lenses, similar to limited-scan arrays [3]. However, in the proposed architecture, large steering angles can be reached because both the element pattern and the array factor can be steered. The mechanical movement of the fly's eye lens array can be achieved with low-weight, low-power piezo-actuators [5].

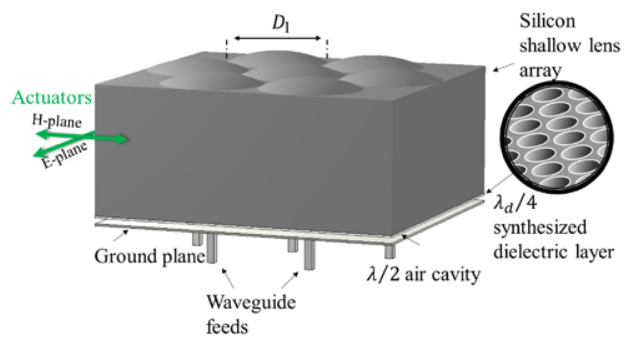

Fig. 1. Fly's eye phased array for submillimeter wavelengths. It is composed of shallow silicon lenses, each fed by a waveguide. The feed stratification consists of a half-wavelength air cavity and a quarter-wavelength synthesized dielectric layer via perforations in a silicon slab.

In this work, we have studied the scanning properties of the leaky wave feed (originally presented in [4]) and its integration with a piezo-electric motor at 550 GHz in [5]. Furthermore, we have improved the leaky wave feed by removing the iris and adding a dielectric layer in-between the lens and the air cavity to improve the aperture efficiency and the bandwidth compared to [4]. Simulated results show lens aperture efficiencies greater than 80% for a bandwidth of 35%. Array beam scanning angles of +/-20 degrees can be achieved with a directivity loss lower than 1.5dB.

We are currently developing the prototype in Figure 1 to attest the phased array feasibility at 550 GHz. The fly's eye lens array is being fabricated using laser micromachining and coated with Parylene to minimize the internal reflections of the silicon lenses. The rest of silicon wafers that define the leaky-wave feed and support the lens are being processed using the DRIE process developed in [6].

II. Beam Shaping Using a Leaky-Wave Feed

In [4], a feed based on leaky waves radiating in silicon was proposed to enable arrays of very shallow silicon lenses. The leaky wave feed used was made with a resonant air cavity that generates a couple of leaky TE and TM modes. The resulting radiation pattern is very directive and couples well to a lens of $f_{\#} = 2.7$ (see Fig. 2). Unfortunately, when displacing the lens

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to steer the element pattern, one may reach high spill over losses if the displacement reaches $D_l/4$. In order to maintain a feed displacement lower than $D_l/4$ while scanning $30°$, the lens should have $f_\# \leq 1.6$. To avoid the spill over losses while shaping the pattern to improve aperture efficiency (key to reduce the level of the grating lobes in a sparse array configuration), we propose the use of a quarter-wavelength dielectric layer between the air cavity and silicon lens. The permittivity ε_m of this layer should be lower than silicon and can be synthesized by perforating silicon using etching techniques [6]. Fig. 2 shows the far-field patterns radiated in the silicon medium at the central frequency for the feed in [4] (in blue), on which the patterns of a leaky-wave feed that contains a dielectric slab of $\varepsilon_m = 2.5$ are superimposed (in red). Simulated results of that an elliptical lens illuminated by this new feed has an aperture efficiencies greater than 80% for a bandwidth of 35%. Moreover, when $\varepsilon_m = 2.5$, the antenna can be matched over a bandwidth larger than 35% without using the double-slot iris as in [4].

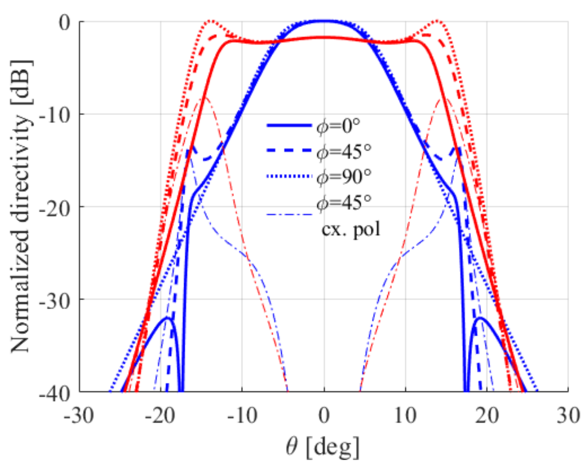

Fig. 2. Far-field radiation patterns into an infinite silicon medium of stratification with resonant air cavity (blue) and stratification with resonant air cavity and quarter-wavelength dielectric layer $\varepsilon_r = 2.5$ (red).

III. Phased Array Steering Performances

The performance of a seven-element fly's eye lens phased array in a hexagonal configuration (see Fig. 1) has been studied at the central frequency (540 GHz) using the leaky-wave lenses described above as elements coupled to elliptical silicon lenses of diameter 5mm.

Fig. 3 shows the radiation patterns of the leaky wave lens antenna elements and the array factor in the two main planes for broadside scanning and to $\theta_{scan} = 20°$ in the H-plane. For such a scanning the fly's eye array should be displaced only by -0.9 mm displacement along $\hat{x}$ (the H-plane). The directivity of the hexagonal array has been computed from the array patterns that result from the multiplication of the leaky-wave lens antenna element pattern (with displaced feed) and the array factor of the hexagonal array (with phase shifting). The gain is calculated by subtracting the reflections losses from the directivity. The directivity and gain of the array as a function of the scan angle are shown in Fig. 4 for E-plane and H-plane scanning. The scan loss is below 1.5 dB for wide scan angles up to 25°.

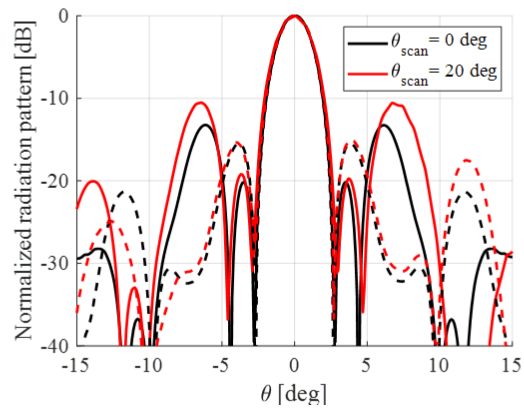

Fig. 3. Main (solid lines) and orthogonal plane (dashed lines) array patterns corresponding to $\theta_{scan} = 0°$ and $\theta_{scan} = 20°$. In (c). All patterns are plotted such that $\theta = 0°$ corresponds to the direction of the main beam.The main and orthogonal planes correspond to $\phi = 30°$ and $\phi = 120°$, respectively, when looking into the direction of the main beam.

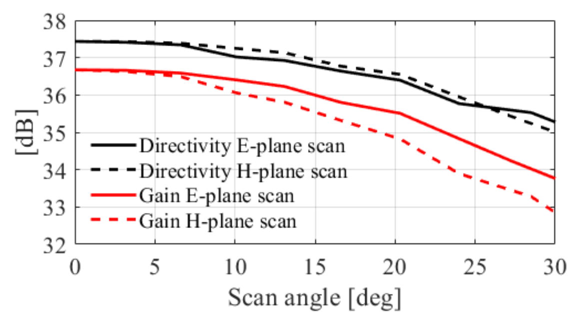

Fig. 4. Directivity and gain for the proposed array in Fig.1 vs scan angle.

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