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Demonstration of a Broadband Quasi-Optical Power Distribution and Beam-Steering with Transmit Lens Arrays at 550 GHz

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***Abstract*— A novel transmit lens array is proposed to provide broadband quasi-optical power distribution and beam-steering capabilities for array architectures in future submillimeter-wave heterodyne instruments. The transmit array is composed of a double array layer of lens antenna elements with high aperture efficiency. To enable broadband and low loss quasi-optical (QO) power distribution, the transmit lens array is coupled with a high aperture efficiency single lens antenna. The high aperture efficiency is achieved by using a recently introduced multi-mode leaky wave feed. The top lens array can be used to achieve beam-steering capabilities when fed coherently and mechanically translated using a piezo-motor. In this contribution, we present the development of a prototype based on a transmit lens array of 7 elements at 450-650 GHz with measurements showing a good agreement with simulations. This prototype demonstrates a quasi-optical power coupling efficiency of nearly 60%. Moreover it also shows beam-steering of a 36dBi directivity beam to few discrete angles up to +/- 25 degrees with less than 2dB scan loss.**

I. Introduction

Technology development for arrays is essential to enable a broad spectrum of applications at submillimeter wavelengths for space, communications, radar and spectroscopy [1].

The power distribution to these arrays still constitutes a bottleneck for heterodyne instruments at these high frequencies. The Local Oscillator (LO) power distribution to different array elements on Schottky, HEB, or SIS technology is done using waveguide-based distribution or phase gratings. Using waveguide power splitters can be efficient for arrays with small number of elements physically close together. However, for higher frequency and more elements, this solution becomes increasingly complex, lossy, and costly [2]. Another approach has been the generation of multiple beams from a single source by using phase gratings [3]. These gratings are based on a $> \lambda_0/2$ periodic reflectarray that transforms the incident wave into a series of diffraction orders with different angles. This solution is narrowband and challenging to scale up in the number of diffraction orders.

On the other hand, many of these applications require a highly directive beam to be scanned over a certain field of view with wide bandwidth. Currently, this is achieved by using a reflector-based quasi-optical (QO) system in combination with mechanical scanning. Overall, this solution is limited for its high volume, mass and power for the quasi-optics and its mechanical scanners, which hinders future applications that require smaller platforms such as SmallSats and Cubesats.

To tackle these limitations, we recently proposed a novel QO power distribution based on a double layer lens transmit array [4, 5] as shown in Fig.1. In between the two lens arrays, a layer with active elements coupled via waveguide could be placed. We showed that it is possible to achieve a power coupling efficiency of 60% over a wide bandwidth, thanks to the multi-mode leaky wave feed presented in [6]. This efficiency is mostly defined by the lens array filling factor and the aperture of the lens antennas. Therefore it will not change significantly if the number of the array scales up. Moreover, the bandwidth is defined by the multi-mode leaky wave feed [6], and hence will not decrease as the number of array elements increases.

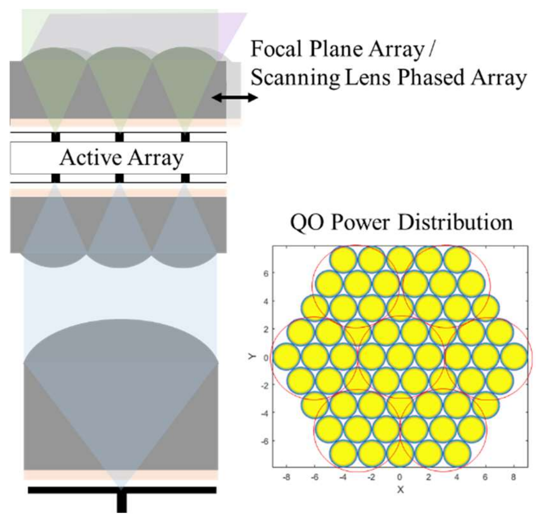


Fig. 1. Proposed transmit lens antenna array architecture. It is composed of a lens antenna that provides the QO power distribution to a lens array. The lens array feeds an active array that is coupled to a top array based on a FPA or a scanning lens phased array.

This architecture is modular and scalable to adapt to the different number of array elements. The proposed QO power distribution can be used to feed arrays in coherent mode, i.e. scanning lens phased arrays [6]as well as in non-coherent mode, i.e. focal plane arrays. Moreover, the proposed lens antenna architecture and technologies can be scaled up to a least 2 THz due to the tolerances and surface roughness of the fabrication processes.

In this contribution we present a demonstration of a 7-element transmit array in the 450-650 GHz band, which is fed coherently and has scanning capabilities. We present the modeling, design, fabrication and measurements of the prototype.

II. 7 Element Transmit Lens Array Prototype

A 7-element transmit array prototype has been developed to demonstrate the potential of the proposed architecture. It is composed of one large lens antenna fed by a top-hat pattern generated by the multi-mode leaky feed from [6]. This lens antenna forms a collimated beam for coupling to a lens array (see Fig. 1). The lens antennas constituting the array are also designed to maximize their coupling to a collimated beam using the same feed. If the lens antenna had an ideal 100% aperture efficiency, the only coupling loss in this architecture would be related to how well a circular aperture of the large lens is sampled by the array of small lenses. For this architecture, where lenses of equal diameter are considered, a lens array with an hexagonal lattice has been designed since it is the one that provides the higher coverage of a circular area. The fill factor efficiency for this 7-element hexagonal array is $\eta_{fill\ factor} = 78\%$. Note that this efficiency increases with the number of pixels, reaching up to 90.7% when using an infinite hexagonal packing.

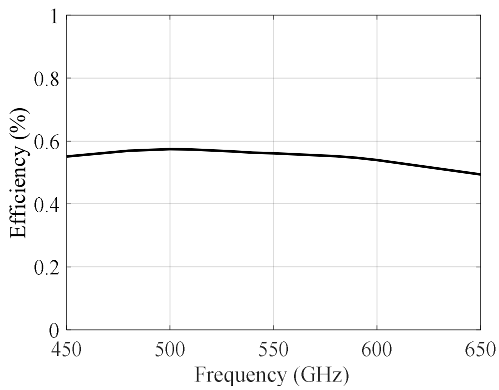


Fig. 2. Coupling efficiency of the proposed lens array coupling architecture as a function of the frequency.

To optimize the proposed transmit array geometry, the power coupling efficiency to an array of waveguides has been estimated using a semi-analytical lens-to-lens near-field analysis similar to [7]. The resulting coupling efficiency as a function of frequency is shown in Fig. 2. The overall coupling efficiency is nearly 60%, and it includes the coupling to a square waveguide array via the lens antennas. Note that the truncation angle of the pattern of the QO power distribution lens antenna has been optimized to maximize the power coupling to the array.

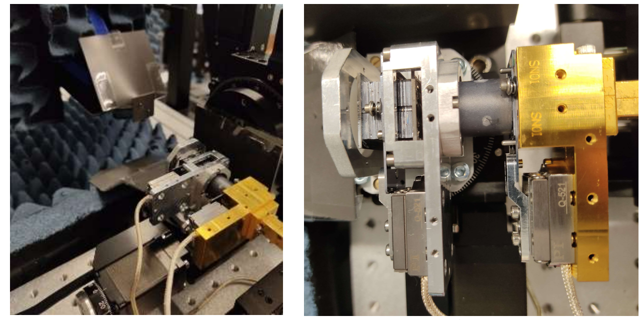
On top of the quasi-optical power distribution architecture, the prototype has a scanning lens phased array with beam-steering capabilities fed, as shown in Fig. 1. The lens array has a periodicity of 10λ. In-between the two lens arrays, the prototype contains a straight vertical waveguide where future active elements could be integrated such as mixers, amplifiers or/and phase shifters.

III. Measurements

A photograph of the measurement setup is shown in Fig 3. The waveguide flange of the frequency extender is placed at the focus of the hyperbolical lens (at 10 cm), and it is used to measure the radiation patterns in a spot.

The measured radiation patterns of the transmit array are shown in Fig. 4. obtaining an excellent agreement with the simulations. The grating lobe level of the combined array pattern is below -11dB. The simulated patterns are obtained by multiplying the simulated element pattern by the array factor.

The directivity of the 2-D patterns at the broadside position of the transmit array has been measured across the frequency band of 450-500GHz giving a nearly frequency independent value of 36dBi with excellent agreement with the simulated one. The coupling efficiency of the prototype has been extracted from a far field link applying the Friis equation showing excellent agreement with the simulations. More results on the measurement campaign will be shown at the conference.



(a) (b)

Fig. 3. Measurement setup of the transmit lens array and a photograph of the assembled transmit array and QO power distribution lens antenna.

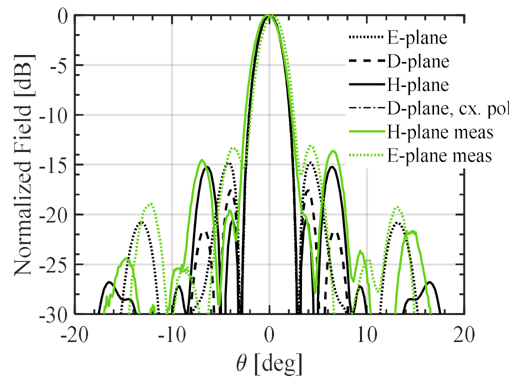


Fig. 4. Measured and Simulated radiation patterns of the transmit lens array at 475 GHz.

The proposed prototype shows great potential for future submillimeter heterodyne space instruments based on Focal Plane Arrays and scanning lens phased arrays.

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