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W-Band Demonstration of Dynamic, High-Gain Beam Steering with a Scanning Lens Phased Array

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***Abstract*—We report the measured results of a sparse, 4x1 scanning lens phased array prototype at W-band that is capable of beam steering a directive (>30 dBi) beam towards ±20° with sidelobe levels around -10 dB. The array elements are high-aperture-efficiency resonant leaky-wave lens antennas with a feed that suppresses the spurious TM_0 mode over a wide bandwidth by using a circular waveguide in a ground plane surrounded by annular corrugations. The scanning lens phased array relies on simultaneous electrical and mechanical phase shifting to steer the beams. We use 15 GHz IQ-mixers followed by x6 multipliers to achieve electronic amplitude and phase control at W-band and a piezo-electric motor for mechanical phase shifting, which allows us to scan this array up to 20°. Measurements at 90 GHz of the lens array are in excellent agreement with simulations. More measurement results will be presented at the conference.**

I. Introduction

We have recently proposed a scanning lens phased array concept in [1] that achieves a high-gain, steerable beam using a very sparse array of only a few electrically large lens antenna elements. The grating lobes resulting from the sparsity of the array are suppressed by the directive beams from the lens elements. To achieve this suppression, high aperture efficiency lens antennas are required as the array elements [1]. Such lens arrays are suitable for (sub)millimeter-wave wireless links that will play a major role in backhaul and point-to-point communication scenarios for 6G and beyond [2].

Beam steering from the scanning lens phased array is achieved by mechanically displacing the lens array relative to their feeds and, simultaneously, applying a relative electronic phase shift between the array elements. The mechanical displacement causes the element pattern of the lenses to be steered towards the desired angle, while the electronic phase shifts steer the array factor. This combination allows the scanning lens phased array to steer far beyond the grating lobe-free region.

In a previous paper [3], we demonstrated the scanning lens phased array concept at 28 GHz for several discrete scanning angles using corporate feeding networks. In this contribution, we demonstrate continuous, dynamic beam steering ($\pm 20°$) of a high-gain beam (>30 dBi) at W-band (75-110 GHz, with λ_0 defined at 90 GHz). The mechanical phase shifting is achieved with a piezo-electric motor as in [4] and electrical phase shifting is achieved with an ad-hoc electronics setup similar to [5].

II. Scanning Lens Phased Array Design and Prototype

We have developed a sparse, linear, scanning lens phased array composed of four lens antennas with a diameter of $6\lambda_0$ (20 mm) each, see Fig. 1(a). Each lens is fed by the wideband (2:1), high aperture efficiency (>80%) leaky-wave feed that was proposed in [6]. This feed consists of a circular waveguide in a ground plane surrounded by annular corrugations, see Fig. 1(b).

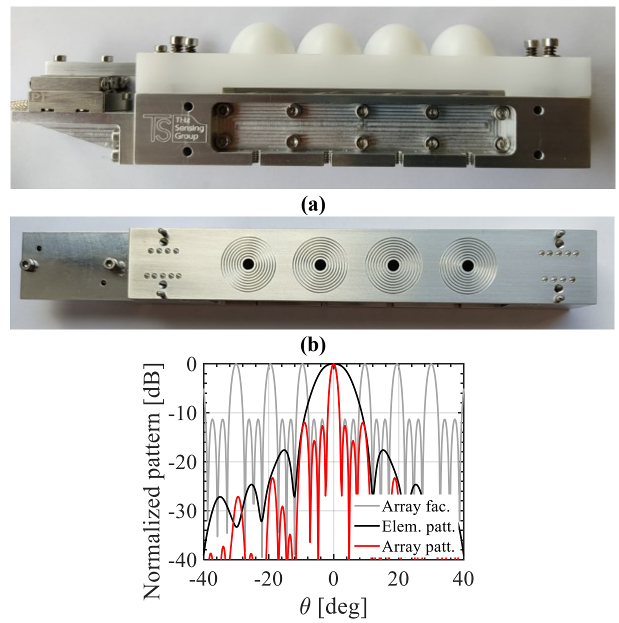

Fig. 1. (a) Photograph of the assembled W-band scanning lens phased array prototype. (b) Photograph of the circular waveguide feeding structure and the annular corrugations in the prototype. (c) Simulated array factor, single-element pattern and array pattern at 90 GHz of the prototype in (a).

A half-wavelength resonant air cavity between the ground plane and plastic (HDPE) lens supports the propagation of the main TM_1 and TE_1 leaky-wave modes that together radiate a symmetric, directive beam into the lens. The spurious TM_0 mode is suppressed over a wide bandwidth by the combination of annular corrugations and the circular waveguide.

The simulated broadside array factor of this sparse array and the simulated single-element pattern are shown in Fig. 1(c) at 90 GHz. The array pattern is simulated as the multiplication of the array factor and the single-element pattern and is also shown in Fig. 1(c). Indeed, the grating lobes resulting from the array's sparsity are suppressed to levels below -10 dB. The simulated gain of this array is 31 dBi.

The lens array has been milled from a block of HDPE using a CNC mill. The waveguide feeding structure is milled in an aluminum split-block. The waveguide block contains four WR-10 flanges in the bottom that taper to the circular waveguide in the top of the block.

III. Quasi-Optical Calibration and Measurement

To control the amplitude and phase of the four array elements simultaneously in the W-band, we use an ad-hoc electronics setup similar to the one described in [5]. A 12-18 GHz signal is generated and distributed to four IQ-mixers that allow amplitude and phase control using DC voltages V_I and V_Q. The output of these IQ-mixers is fed into x6 multipliers to end up

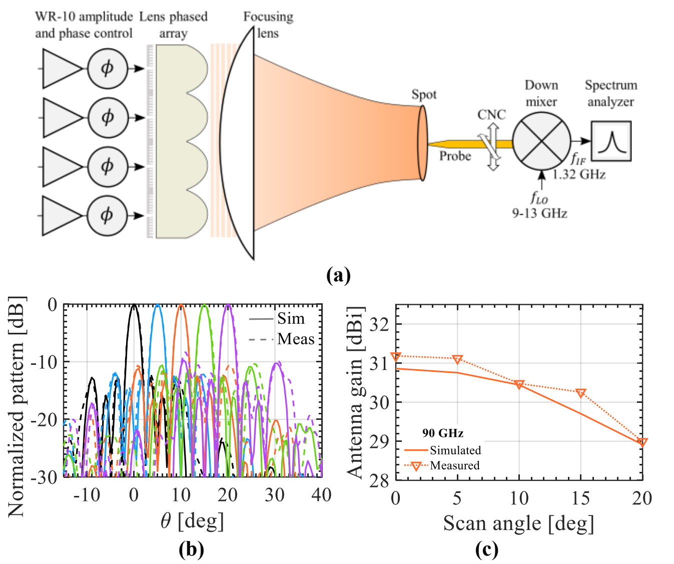

Fig. 2. (a) Schematic of the quasi-optical calibration and measurement setup. (b) Simulated and measured 90 GHz E-plane radiation patterns at broadside and scanning up to 20°. (c) Simulated and measured gain of the array at 90 GHz.

with four independent amplitude- and phase-controlled channels in the W-band waveguides, which are fed in to the array.

We measure the radiation patterns from the array using a receiver consisting of a down-converting mixer and spectrum analyzer and we measure the gain using a standard-gain horn and a WR-10 power meter. However, the far-field distance of this array, around 4 meters, is too large to accommodate in our laboratory facilities. Furthermore, our receiver implementation can only measure amplitude, making planar near-field measurements impractical. Therefore, we use a lens with a focal length of 20 cm to focus the radiation much closer than the far-field distance. It was demonstrated in [7] that such a quasi-optical system can be used to measure the gain and far-field radiation patterns by moving the receiver around the spot, which we achieve using a CNC machine. A schematic representation of the quasi-optical measurement setup is shown in Fig. 2(a).

To calibrate the array, we turn on only the first array element at a fixed power level. Next, we turn on the next array element with the same output power but unknown phase. We then measure the received power in the spot by varying the phase of the second channel using the voltages V_I, V_Q. These voltages are then fixed at the point of maximum constructive interference. We repeat this process for the third and fourth element. In total, the measured power in the spot is 12 dB higher than the power received for a single active element, which is expected due to the increased radiated power and array gain. This calibration routine was performed at broadside and for scan angles up to 20°. For broadside, the lens array was positioned exactly above the feeds using the piezo-electric motor. For scanned patterns, a mechanical displacement of the lens array of 0.24 mm per degree of beam steering is required. Note that the position of the receiving antenna must also be varied since the spot moves geometrically for a scanned beam.

IV. Measured Results

After this calibration procedure, the radiation patterns and gain have been measured using the approach outlined above. The simulated and measured E-plane radiation patterns at 90 GHz are compared in Fig. 2(b) for scan angles from broadside to 20°. The measured radiation patterns are in excellent agreement with the simulated radiation patterns. The measured sidelobe level is around -13 dB at broadside and it increases to -10 dB for maximum scanning. The measured gain is 31.2 dBi for broadside and 29 dBi when scanning to 20°, which is in excellent agreement with simulations as shown in Fig. 2(c).

V. Conclusions

We have designed and fabricated a very sparse ($6\lambda_0$ diameter elements), W-band, 4x1 scanning lens phased array consisting of lens antennas fed with a high-aperture efficiency leaky-wave feed. Simulations of this array shown good suppression of the grating lobes that arise from the sparsity of the array. Beam steering with the array is achieved using a combination of mechanical displacement and electronic phase shifting, which are implemented using a piezo-electric motor and an ad-hoc electronics setup consisting of IQ-mixers around 15 GHz and x6 multipliers. We have implemented an accurate quasi-optical setup to calibrate the array elements relative to each other. We used the same system to measure the radiation patterns and gain of the scanning lens phased array at 90 GHz. Measured radiation patterns are in excellent agreement with simulations, with sidelobe levels at -10 dB when scanning towards 20°. The measured gain of this array is 31.2 dBi at broadside and 29 dBi at 20°. More details on the array, calibration and measurement procedure and setup and results will be presented at the conference.

Acknowledgments

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