Ultra-high gain transmitarray antenna for wireless backhauling at 280 GHz

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Ultra-high Gain Transmitarray Antenna for Wireless Backhauling at 280 GHz

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***Abstract* — An ultra-high gain transmitarray antenna for point-to-point backhaul links at 280 GHz is presented here. The proposed array exhibits a 3-bit phase resolution, comprising only three metal layers and no metallized vias. Thanks to a dedicated synthesis procedure, the unit-cells achieve very low losses, full phase coverage and are compatible with a standard printed circuit board process. A 140×140-element transmitarray is numerically optimized and experimentally characterized, using a 10 dBi horn as a feed. A peak gain of 44.5 dBi with 52.3% aperture efficiency and 0.9° half-power beamwidth are reported at the center frequency.**

I. Introduction

THE use of the unregulated sub-THz spectrum around 300 GHz can be a key enabler for future high-speed wireless communications, enabling unprecedented data-rate capability. In this beyond-5G network vision, one of the most important blocks is the point-to-point backhaul, which should support fixed links for stationary outdoor connections over range up to a hundred of meters. These systems require naturally ultra-directive antennas with high radiation efficiency, to compensate for the extremely high propagation losses.

The key to achieving ultra-high gain with good performance is the selection of a low-loss beamforming architecture. Classical dielectric lenses [1], quasi-optical systems [2] and waveguide-based corporate-feed slot arrays [3] have been recently proposed for sub-THz applications. However, dielectric lens antennas are bulky and with limited beam-steering capability. Moreover, at these frequencies, they become sensitive to manufacturing and achieve reduced radiation efficiency due to the dielectric losses. In the case of the quasi-optical networks and the corporate-feed arrays, their implementation requires expensive micromachining techniques to attain low-loss and broadband performance. These costly fabrication processes are not suitable for the expected massive antenna deployment in densified networks.

Transmitarrays (TAs) are an attractive alternative solution to the aforementioned antenna systems. Thanks to the spatial feed mechanism, they do not require lossy feed networks, they are generally thin and compatible with standard printed circuit board (PCB) technology. However, most TAs demonstrated at sub-THz frequencies are limited in gain (< 25 dBi) and aperture efficiency (< 25%) [4]. Alternatively, they include multiple through-vias and metal layers [5] and leverage on costly fabrication techniques, such as low temperature co-fired ceramic (LTCC) process, to reach high gain.

An ultra-high gain TA antenna, fabricated using standard PCB technology at 280 GHz, is presented here. The array comprises only three metal layers and no vias, easing the fabrication process. The unit-cell (UC) theoretically provides nearly perfect transmission and complete phase coverage [6].

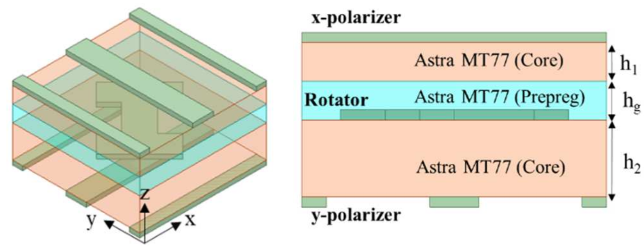

Fig. 1. 3D view (left) and stack-up (right) of the proposed PCB-based unit-cell.

By optimizing only the inner metal layer, a 3-bit TA design has been realized. To the best of authors' knowledge, this is the first antenna fabricated in PCB technology that exhibits a gain greater than 40 dBi operating at such high frequencies.

II. Unit-Cell Design

The proposed stacked UC comprises two linear polarizers arranged orthogonally on the outer surfaces and a polarization rotator placed in the middle layer, as shown in Fig. 1. The extended study and the design procedure of this topology were reported in [7]. This structure can achieve nearly perfect transmission in a relatively large bandwidth, rotating the polarization of an incoming linearly-polarized wave by 90°. The thicknesses of the substrates and the bonding film are set to $h_1 = h_g = 64$ µm and $h_2 = 127$ µm, in order to space apart the layers by a distance close to a quarter of the wavelength in the dielectric. The length of the edge of the square UC is set to 500 µm ($\lambda_0/2$ at 300 GHz) to avoid grating lobes in the operating band (260-300 GHz).

In order to make the element suitable for standard PCB manufacturing and achieve high phase-resolution, different rotator designs were employed. Four shapes with a dipole-like geometry were found. By mirroring the rotators with respect to the *x*-axis, four additional UCs were realized, resulting in a 3-bit TA design. The common 1-dB transmission bandwidth of the eight unit-cells is about 85 GHz, or 30% at the center frequency of 280 GHz. Therefore, the insertion loss is less than 1 dB in the operating band. Thanks to the mirroring approach, the relative phase errors are minimized, presenting maximum absolute variations of 10°. Despite the different rotator shapes, the relative phase shifts among adjacent phase states are very close to 45°, as shown in Fig. 2.

III. Antenna Design

To facilitate the study of electrically large TAs, a numerical simulation tool, presented in [8], was employed to synthesize the TA and evaluate its performance. To achieve a gain close to 45 dBi, a 140×140 TA ($70\times70\lambda_0^2$ at 300 GHz) is optimized when illuminated by a standard gain horn (model 32240-10 by Flann Microwave) with a nominal gain of 10 dBi. The horn is

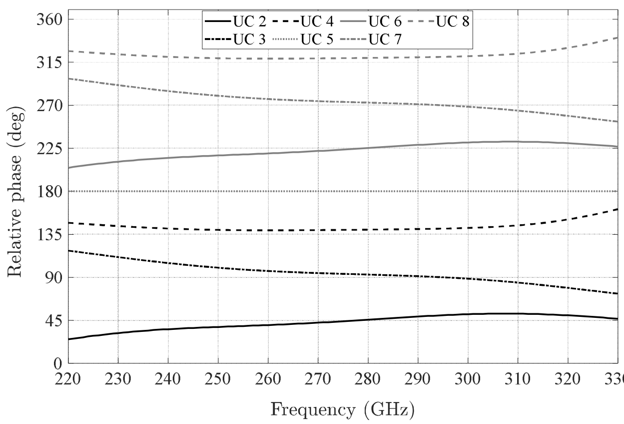

Fig. 2. Simulated relative phase of the transmission coefficient of the eight unit-cells, with UC 1 used as a reference. The UCs 5 – 8 comprise the mirrored design of the rotators in UCs 1 – 4, respectively, exhibiting exactly 180° phase difference. This can be seen clearly in the relative phase of UC 5, with respect to that of UC 1.

mounted on a WR3 waveguide. The optimal phase distribution is derived numerically, employing the simulated radiation pattern and scattering parameters of the focal source and the unit-cells, respectively. For a central frequency of 280 GHz, the focal distance for maximum aperture efficiency was set at F = 42 mm, resulting in a focal-to-diameter ratio F/D = 0.6.

The simulated gain and aperture efficiency are plotted versus frequency in Fig. 3. The peak gain is 44.5 dBi at 280 GHz and the corresponding aperture efficiency is 52.3%. The 3-dB gain relative bandwidth is about 6%, from 272 to 289 GHz. The half-power beamwidth (HPBW) is only 0.9°, as shown in Fig 4. The corresponding first sidelobe level is lower than -16.7 dB. The prototype has been characterized at CEA-Leti in a far-field antenna measurement facility. The measurement distance in the anechoic chamber is around 11 meters. A quick estimation of the antenna's far-field gives 19.6 m at 300 GHz, using the diagonal size of the TA as the largest dimension. Although the effective aperture is smaller, due to the non-uniform illumination of the array, the estimated value remains less than half of the measurement distance. Therefore, a gain error in the order of 0.1 dB as well as an increased sidelobe level should be expected. Nevertheless, a good agreement between simulated and measured radiation pattern is observed, validating the performance and the design approach.

IV. Conclusion

An ultra-high gain transmitarray antenna, fabricated in standard printed circuit board technology was presented and experimentally validated. The low-cost prototype achieves very high aperture efficiency (52.3%) that is comparable to very expensive antenna technologies, paving the way for the integration of the proposed design in future long-range wireless communications at sub-THz frequencies.

Acknowledgment

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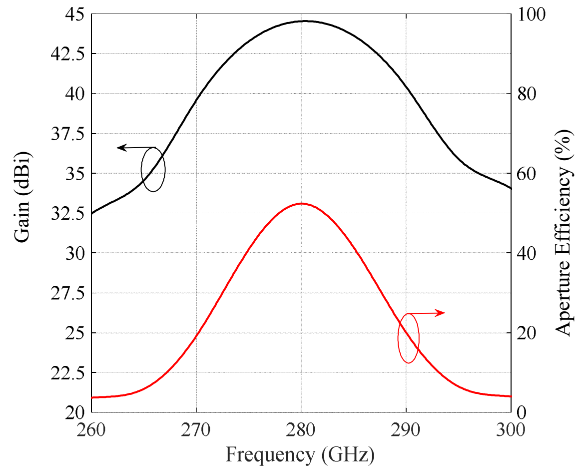

Fig. 3. Simulated gain and aperture efficiency of the proposed TA antenna.

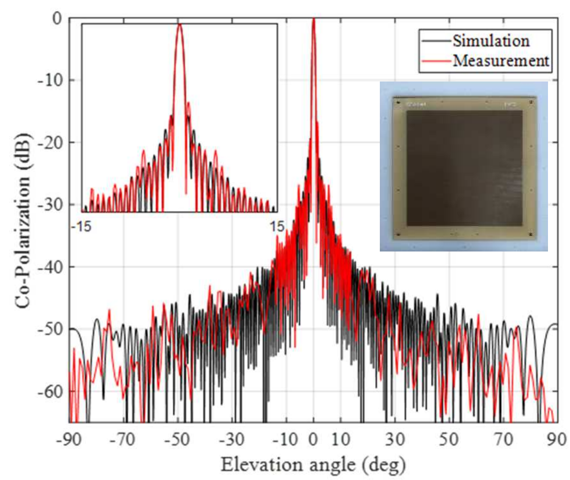

Fig. 4. Simulated and measured co-polarized radiation pattern in the E-plane at 280 GHz. A photograph of the TA prototype is shown in the right side.

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