Ultra-Wideband Dielectric Reflectarray Antenna with OAM beams for mm-Wave Applications

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Abstract—The proposed structure is presented to improve the inherited limited bandwidth and reduce the production of grating lobes in reflectarray antennas (RAs). A dielectric RA with 200 mm × 200 mm is designed and simulated to produce an orbital angular momentum beam (OAM) of the second mode with averaged realized gain of around 20 dBi in the band of 25-40 GHz, which covers most of 5G mm-wave bands (n257, n258, n260, and n261). To achieve the mentioned specifications, an inter-element spacing of 0.25λ is adopted.

I. INTRODUCTION

Recently, mm-wave antennas have gained increased attention due to the capability to produce reduced size antennas and broader bandwidth. Different 5G mm-wave bands are assigned to be utilized in various applications based on the geographical location as n257 (26.5 to 29.5 GHz), n258 (24.25 to 27.5 GHz), n261 (27.5 to 28.35 GHz), and n260 (39 GHz). Since path loss levels increase at mm-wave bands, it will be necessary to employ high-gain antennas to avoid attenuation from the ambient environment. Although conventional high-gain parabolic and array antennas succeeded in satellite and pre-fifth generation (5G) applications, they suffered from the high cost and bulky structure [1]. The advancement in printing technologies led to the presence of printed antennas such as ultra-wideband monopole antennas [2] and reflectarray antennas (RAs). RAs are low cost, low profile, and high gain structures, which makes them suitable for several applications, including radars, satellite communications, and 5G applications [3]. Besides that, RAs can reflect the incident beam and impart its phase, so they merge the properties of the bulky conventional parabolic reflectors and phased array antennas. A reflectarray antenna is a grounded planar structure with printed patches on the other face and is illuminated by a horn antenna. It is considered a quasi-periodic structure since patches do not preserve the same size over the whole surface. The variation in the elements’ sizes returns to the fact each patch needs to compensate for the path difference from the feeder to the element position. Accordingly, the electric field (E-field), received on the surface, is reflected with a shaped wavefront based on the phase distribution. Thus, RAs exhibit the possibility of beam-shaping to reflect different wavefronts including pencil and helical beams [4].

Beams with a helical wave-front and orbital angular momentum (OAM) have drawn attention due to the possible capability to enhance the spectral efficiency through the additional degree of freedom (DoF) achieved by the inherited orthogonality among the modes [5]. Hence, data can be exchanged for the same bandwidth by different modes. That means designing OAM based RAs can exploit the limited bandwidth of RAs. These waves can be generated by spiral phase plates, specially designed waveguides, and uniform circular arrays (UCAs) [6]. No matter what the generation method is, an intensity null at the centre and a helical phase distribution should be observed in the E-field of the generated wave.

This paper presents an ultra-wideband RA that carries OAM beams based on a hexagonal lattice with an element dimension of 0.25λ to solve the bandwidth limitation of conventional RAs and alleviate grating lobes at the 5G mm-wave bands.

II. ANTENNA CONFIGURATION AND DESIGN

The shape, inter-distance, and dimensions of the chosen element play a key role in defining the radiation bandwidth of the designed RA. Usually, squared, rectangular, and circular shapes are used for elements to produce a satisfactory phase curve. Here, a sub-wavelength hexagonal shape is selected to broaden the bandwidth of the RA, which will be discussed as follows:

A. Unit Cell

The volumetric element, shown in Fig. 1, is made of Taconic CER-10 dielectric with a thickness in the range of h = 0.8-
2.7 mm and a bottom cladding equal to t. The parameter p stands for the length of each edge, so the dimension of the unit cell is $2 \times p$. The acquired phase range is approximately $305^\circ$ from 25 to 40 GHz, as illustrated in Fig. 1, which is adequate to generate the desired beam since it is above $300^\circ$. Results were obtained by CST Studio Suite with the periodic boundary condition and Floquet excitation.

B. Simulation Results

The reflection phase curve, illustrated in Fig. 1, characterizes the response of the element with regard to the substrate’s thickness. The needed phase distribution over the surface to produce OAM mode with $l = 2$ is demonstrated in Fig. 2 (a), which results the reflector displayed in Fig. 2 (b). The desired phase for $m \text{th}$ element of a RA with a mode number equals $l$ can be given by [7]:

$$\psi_{mn} = k \left( R_{mn} - r_{mn} \hat{u}_b \right) + l \times \arctan \left( \frac{y_n}{x_m} \right) + \psi_0 \quad (1)$$

where $k$ is the phase constant, $R_{mn}$ is the distance between the position of the element and the feeding horn. Whereas $\hat{u}_b$ stands for the beam direction and the point $(y_n, x_m)$ is the element’s position and $r_{mn}$ is its vector. $\psi_0$ is a constant phase.

Fig. 2 (c) exhibits the simulated normalized radiation patterns for the proposed RA at $f=25 \text{ GHz}$, $f=30 \text{ GHz}$, $f=35 \text{ GHz}$, and $f=40 \text{ GHz}$. These patterns clearly show the intensity null along with the low grating lobes. Whereas Fig. 3 depicts the simulated results of the cross-sectional e-field with the phase distribution and the hollow area in the intensity pattern for the second OAM mode. The phase distribution completes a $360^\circ$ as shown in Fig. 3 (a). The magnitude distribution displayed in Fig. 3 (b) follows a doughnut shape, which confirms the generation of the OAM beam by the introduced RA.

III. Conclusion

This work introduced a hexagonal lattice of a small inter-element spacing with an OAM beam to solve the narrow bandwidth of RAs. To the best of the authors’ knowledge, this is the first time an OAM based RA achieves a fractional bandwidth of around 47% between 25 and 40 GHz. This RA can be a potential candidate for 5G-and-beyond applications.

REFERENCES