Single layer Multimodal OAM Reflectarray

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***Abstract*—In this work, the procedure for the design of innovative reflectarray (RA) antennas able to radiate multiple Orbital Angular Momentum (OAM) modes is introduced. Extending the concepts at the base of multifocal lenses, the RA is designed in such a way that, depending on the direction of arrival of the incident field, it radiates a broadside beam carrying an OAM with different index. As a proof of concept, a circular RA with diameter $D = 20\lambda$ at the the frequency $f_0 = 30\,\text{GHz}$, able to radiate OAMs with $\ell = 2$ and $\ell = 4$ has been designed. The results obtained through its full-wave simulation, confirm the effectiveness of the proposed solution.**

***Index Terms*—Antennas, Reflectarrays, OAM.**

I. Introduction

The next generation of wireless communication networks will require larger channel capabilities than those provided by the present systems. They could be obtained moving the carrier frequency up to millimeter or (sub)THz bands and enhancing the efficiency of the frequency spectrum through the use of a suitable multiplexing technique. Besides the most conventional approaches as the frequency division multiplexing (FDM), recently the use of antennas able to generate Orbital Angular Momentum (OAM) - carrying beams has been investigated as an efficient spatial multiplexing method. This because modes with different index ℓ are orthogonal each other, and therefore they could be used to carry on different channels. For this reason, in the last years the interest on the possibility to design antennas able to radiate OAM modes has been rapidly grown. Among the different solutions proposed, it is worth to mention spiral plates antennas [2], [3] and traveling-wave antennas [4], [5], as well transmitarrays [6] - [7], metasurfaces [8] - [11] and reflectarrays (RAs). For what concerns these last ones, several solutions have been suggested. Following [12], where the feasibility of designing OAM reflectarrays is proved by preliminary numerical results on a perforated dielectric RA radiating OAM mode with $\ell = +1$, several papers on the design of single OAM mode RAs have been published [13] - [15].

To take advantages of the orthogonality among OAM modes it is however necessary to study antenna configurations that could radiate more than one OAM mode. In [16], the design of a reflectarray radiating 4 OAMs ($\ell = \pm 1$ and $\ell = \pm 2$) is considered: the RA is divided in 4 parts, and each of them is used for the generation of a single mode. The solution proposed in [17] is a composite structure including a transmitarray, a polarization rotated RA and a dual linear polarization horn, and it is able to radiate the OAM with index 4 and a pencil beam. The configuration in [18] is a single-layer wide band RA providing 2 OAMs in two different directions.

Here, a different antenna is proposed: properly modifying and extending the idea at the base of multifocal lenses, the RA is designed in such a way that, depending on the direction of arrival of the incident field, it radiates a broadside beam carrying an OAM with different index. The advantages of this innovative configuration with respect to those presented in literature are several: it just consists in a single layer RA, where the same aperture is used for the generation of the different modes, it does not require active components and finally the beams are all pointing in the same broadside direction. As a proof of concept, a circular RA with diameter $D = 20\lambda$ at the the frequency $f_0 = 30\,\text{GHz}$, able to radiate OAMs with $\ell = 2$ and $\ell = 4$ has been designed. The results, obtained through its full-wave simulation, confirm the effectiveness of the proposed solution.

II. RA Design

In the past years the design of multifocal (in most of the cases bifocal) reflectarrays has been largely investigated for the realization of passive scanning beam configurations [19] - [22]: the exploited idea was that of designing the RA in such a way that it was able to compensate a phase that was the superposition of two or more phases, each one evaluated considering the field impinging on the RA with a different angle of incidence and assuming a different direction of maximum radiation for the entire antenna; in this way, changing the position of the feed was possible to steer the beam.

Here, this concept is suitably modified and extended to be applied for the design of a multi OAM reflectarray: it is designed in such a way that, changing the position of the feed, it radiates, always in the broadside direction, a beam carrying a different OAM mode. For sake of simplicity and to verify that the proposed technique works properly, a configuration

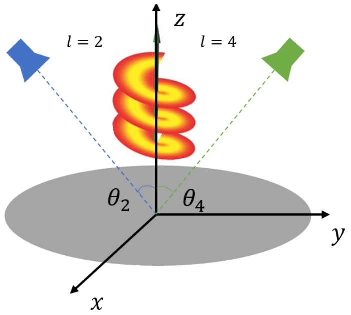

Fig. 1. Sketch of the two OAM reflectarrays: two different feed positions are used, and in correspondence of each of them a different OAM mode is generated in the broadside direction.

like that sketched in Fig. 1 is considered. The antenna is designed to radiate two modes, characterized by indices $\ell = 2$ and $\ell = 4$, respectively: the first one is generated when the incident field impinges on the RA with angle θ_2, while the OAM with $\ell = 4$ is obtained when the incident angle is θ_4.

The phase required is therefore computed separately for the two modes, considering the feed placed in one of the two positions shown in Fig. 1; an example of the resulting phase maps is plotted in Fig.2: that on the top is the phase (ϕ_2) necessary to generate the broadside beam carrying on the $\ell = 2$ mode, while ϕ_4 (on the bottom of Fig.2) is the phase required for the OAM with index $\ell = 4$.

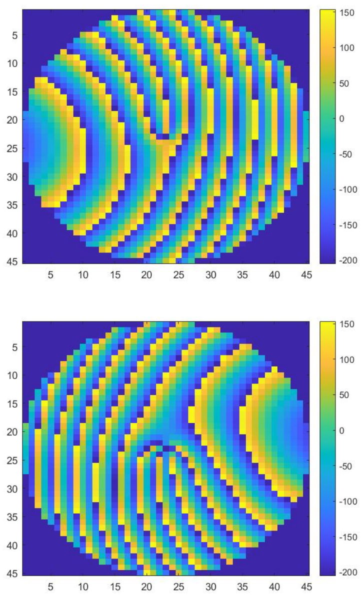

Fig. 2. Phase map necessary to generate the OAM mode with index $\ell = 2$ (top) or index $\ell = 4$ (bottom).

Once the two phase maps are computed, the average between the twos is evaluated, and this constitutes the actual phase distribution that the single aperture RA must provide.

III. Numerical results

In order to validate the proposed approach, it has been applied to the design of a circular RA, with 1596 re-radiating elements. They are square patches, printed on a single layer Diclad 527 ($\epsilon_r = 2.55$, $\tan_\delta = 0.0022$) substrate with a thickness $h = 0.8$ mm. Each unit cell has a size slightly smaller than $\lambda/2$ at the design frequency $f_0 = 30\,\text{GHz}$. The feed [23] has been located at a distance from the planar surface corresponding to $f/D = 1$, being D the diameter of the circular aperture, equal to 20.8λ at f_0. The incident angles are $\theta_2 = 30°$ and $\theta_4 = -30°$. The resulting antenna is sketched in Fig. 3: from the layout on the planar reflector it clearly emerges that it has not been designed to radiate a single OAM mode, but that it is the superposition of two of them.

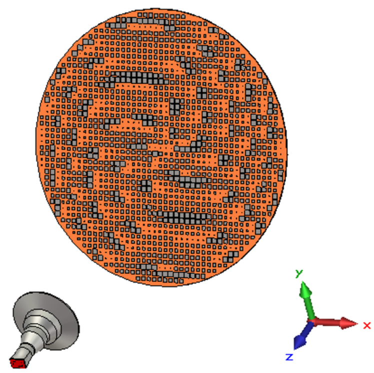

Fig. 3. Sketch of the designed dual OAM mode reflectarray.

The antenna has been simulated with the full-wave approach of the commercial software CST Microwave Studio, considering both the positions of the feed. The simulations have been carried out in the frequency band 29-31 GHz.

In Figs. 4-5 the radiation patterns and the field intensity obtained at 30 GHz for the two positions of the feed are reported. The results in Fig. 4 refer to the case in which the field radiated by the feed impinges on the RA with the angle θ_2: as expected, the field re-radiated by the planar reflector is broadside and shows the typical doughnut-shaped intensity with the hole in the center where it is possible to detect the presence of the two singularities, characteristic of an OAM with index $\ell = 2$; vice versa, when the position of the feed is changed and the angle of incidence is θ_4, the resulting radiation pattern (shown in Figs. 5) still presents the central hole, where there are four zeros, and therefore it is the field associate to the OAM mode with index $\ell = 4$.

IV. Conclusion

In conclusion, it is possible to state that an innovative configuration for multimodal OAM RAs

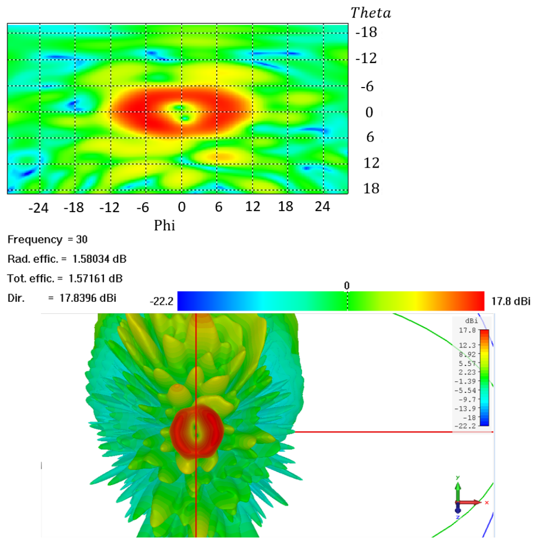

Fig. 4. Simulated field intensity (top) and 3-D radiation pattern (bottom) for the mode $\ell = 2$.

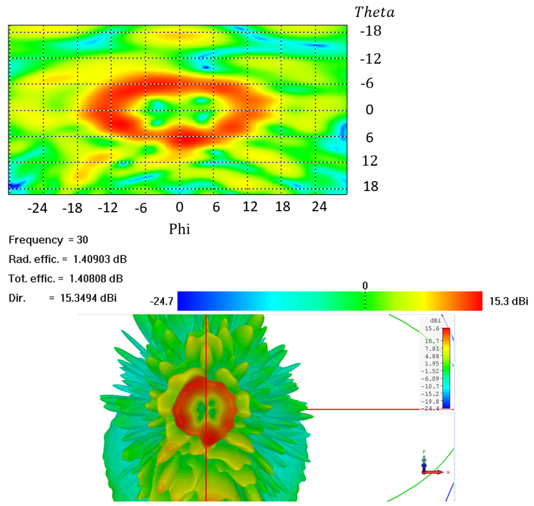

Fig. 5. Simulated field intensity (top) and 3-D radiation pattern (bottom) for the mode $\ell = 4$.

has been presented: with a single layer surface is possible to generate more modes, just considering different directions of arrival from the incident field. The numerical results relative to a configuration able to radiate OAM modes with indices $\ell = 2$ and $\ell = 4$ confirm the antenna feasibility. At the conference time, the effectiveness of the proposed solution will be further proved comparing its performance with that of 2 RAs, designed to radiate the singles OAMs with index $\ell = 2$ or $\ell = 4$, and through the experimental characterization of a prototype.

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