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Exploiting Composite Vortices in the Design of Reconfigurable Intelligent Surfaces

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Abstract

Recently, great efforts have been made in the research of new enabling technologies for beyond 5G communication systems. In this framework, Reconfigurable Intelligent Surfaces (RISs) are considered as one of the most promising solutions and, thus, they have been the subject of several investigations by both the electromagnetic and the communication communities. In this contribution, we further discuss, from an electromagnetic point of view, about the synthesis of a RIS. In particular, by exploiting the topological properties of vortex modes, we present a possible solution to simplify the synthesis and the reconfigurability of a RIS composed of concentric annular rings.

1. Introduction

Reconfigurable Intelligent Surfaces (RISs) are planar structures made by metallic and/or dielectric scattering elements, whose response can be independently controlled [1]. Their properties have been proposed as a possible solution to manipulate the electromagnetic environment and, thus, to control the main characteristics of a radio channel [2]-[5]. In particular, in the simplest operative scenario, a RIS can be exploited for avoiding blockage or diffraction effects by obstacles, by passively redirecting the impinging wave toward a specific direction(s). For this purpose, the typical design strategy is to tailor the response of each constituting element of the RIS itself. However, for large objects and complex operative scenarios, this requires complicated design procedures and reconfigurable strategies.

In this contribution, we propose a new strategy for the synthesis of a RIS, which is based on the topological properties of composite vortices [6]. Vortex modes are, in fact, peculiar electromagnetic waves exhibiting many interesting properties, such as the robustness of their amplitude and phase spatial distribution [7]. By properly engineering the RIS for reflecting different vortex modes, we show that the reflected beam can be redirected toward a specific direction without the need of controlling independently each constituting element.

2. Design Fundamentals and Preliminary Results

Composite vortices, i.e. the collinear superposition between different vortex modes, have been recently investigated at microwave frequencies as a possible tool for shaping the radiation pattern of patch antennas [8]-[12]. In particular, as discussed in [11], by superimposing two vortex modes, the number and the location of the phase singularities in the overall beam can be controlled by tailoring the relative amplitude and phase between the two constituting beams. Moreover, as any phase singularity is inherently related to an amplitude null, the amplitude of the overall radiated field can be tailored as well.

The aim of this contribution is to exploit the degrees of freedom provided by the composite vortices for the synthesis of a RIS consisting of reflective metasurfaces. For this purpose, as shown in Fig. 1, we have designed a single metal-backed metasurface structure consisting of two different regions. The external annular region has been designed to impart the required helical phase profile to an orthogonal impinging plane wave and, thus, to reflect a pure vortex mode with a central amplitude null [13]-[14]. In the inner region, instead, the metallic rings controlling the response of the metasurface have been removed, allowing to reflect with a constant phase shift the impinging plane wave.

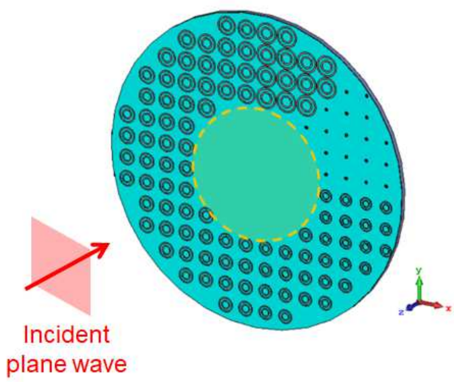

Figure 1. Perspective view of the reflective metasurface designed for superimposing a vortex and a vortex-free component when excited by an incident plane wave.

In this way, similarly to the results reported in [10] for concentrically placed patch antennas, we expect that the position of the amplitude null in the overall reflected beam can be controlled almost at will, by properly choosing the radius of the central region or by rotating the external one on the azimuthal angle. These expectations are confirmed by Fig. 2, where some results for the Scattering Cross Section (SCS) of the RIS have been reported. In particular, the scattering pattern exhibits the expected directive behavior, and its main beam direction can be controlled by acting on the radius R of the central region.

We remark here that by engineering the response of the central region by using metallic rings with a constant radius, as well as, adding tunability to their constituting elements, we may further tailor the overall scattering pattern. Moreover, since the overall response can be controlled by just acting on the central portion of the RIS, we can reduce the number of control elements compared to the standard approach where all the metasurface elements should be independently controlled. A more comprehensive study on the possibilities offered by this approach will be presented at the conference, as well as, more details on the design procedure.

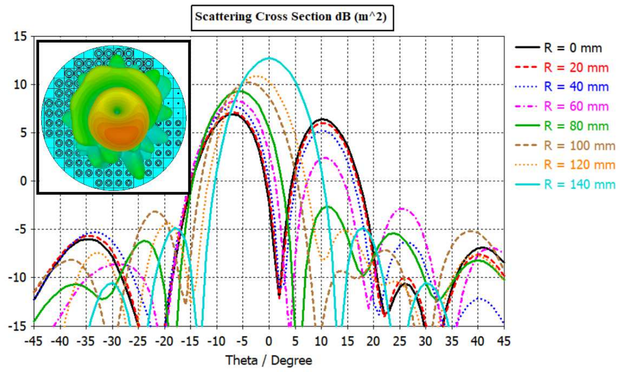

Figure 2. SCS on the yz-plane for different radius R of the center constant-phase region. In the inset, 3D SCS of the proposed metasurface exhibiting an off-centered scattering null for R = 60 mm at 5.5 GHz.

4. Acknowledgements

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