Reducing Complexity of Intelligent Surfaces by Controlling the Beam-width of the Illuminating Field

Mirko Barbuto* (1), Mohsen Karamirad (2), Michela Longhi (1), Alessio Monti (2), Davide Ramaccia (2), Luca Stefanini (2), Stefano Vellucci (1), Andrea Alù (3), Filiberto Bilotti (2), and Alessandro Toscano (2)
(1) Department of Engineering, "Niccolò Cusano" University, Rome, Italy (mirko.barbuto@unicusano.it)
(2) Department of Industrial, Electronic and Mechanical Engineering, "Roma Tre" University, Rome, Italy
(3) Photonics Initiative, Advanced Science Research Center, City University of New York, New York, USA

Abstract

In the development of smart electromagnetic environments, Reconfigurable Intelligent Surfaces (RIS) emerge as pivotal elements. However, some challenges persist toward their deployment in a real-world scenario, mainly due to the complexity and costs associated with reconfiguring a large RIS with good efficiency. In this context, this contribution explores a novel solution to simplify the inherent complexity of RIS. By exploiting the characteristics of composite vortices and shifting reconfigurability to the illuminating field, we propose a method to deploy static surfaces whose characteristics are properly engineered for reflecting a vortex mode. This paradigm allows for the manipulation of scattering patterns through the control of the beam-width of the impinging field.

1. Introduction

Reflective Intelligent Surfaces (RISs) are viewed as a crucial technology for creating smart electromagnetic environments, offering a promising solution for next-generation wireless systems [1]. Their potential lies in precise control over electromagnetic wave interactions by covering objects with RISs, allowing tailored and electronically adjusted reflection characteristics [2]-[3]. Despite their advantages, widespread implementation faces challenges such as cost, complexity, and regulatory issues. Moreover, real-world deployment, especially in dense urban areas or complex indoor environments, requires consideration of RIS installation and illumination, with challenges like beam size exceeding RIS dimensions and reflections from surrounding walls [4].

In this context, we propose here a possible solution that involves exploiting the surrounding walls to shift reconfigurability complexity to the illuminating beam. In particular, by exploiting the uniform wall response and designing a metasurface to reflect a specific vortex field, the study demonstrates that the overall reflected field can be tailored according to the composite vortex theory.

2. Considered Scenario and Preliminary Results

Composite vortex fields, resulting from the interaction of multiple vortex and/or vortex-free components, offer notable field manipulation capabilities, which have been used in various electromagnetic devices [5]-[10]. In particular, some previous studies demonstrated the manipulation of radiation or scattering patterns of antennas and RISs, enabled by the precise control over the relative amplitude and phase of the constituent vortex modes. In the case of RISs, concentric regions with different helical phase responses were employed for enabling reconfigurability [10]. However, these structures were analyzed in free space, neglecting real-world deployment considerations. This contribution aims to address this gap by considering the surrounding environment of the RIS, offering both a more realistic deployment scenario and possible additional degrees of freedom.

For this purpose, we examine the scenario depicted in Fig. 1, involving a circular RIS with a radius R_1 designed to convert an illuminating field into a first-order vortex mode. When the impinging field only illuminates the RIS, a conical scattering pattern is expected due to the presence of a centered phase singularity point and corresponding amplitude null. However, in a practical setting, the RIS is mounted on a building wall with an almost uniform amplitude and phase response [4]. Therefore, expanding the illuminated area including a portion of the uniform wall will result in an additional vortex-free component to the overall reflected field, enabling manipulation of the whole scattering pattern based on the composite vortex theory [6].

To preliminarily validate these insights, in Fig. 2 we have reported the normalized scattering pattern of the structure shown in Fig. 1, evaluated by using the analytical approach already used in [10] (not reported here for sake of brevity). From this picture we can observe that introducing a vortex-free component by illuminating more of the surrounding wall allows shifting the centered amplitude null away from the beam center, enabling beam-steering capabilities. It's essential to note that, unlike the original structure in [10], the RIS here is entirely passive, and reconfigurability is achieved by controlling only the beam-width of the transmitting antenna.

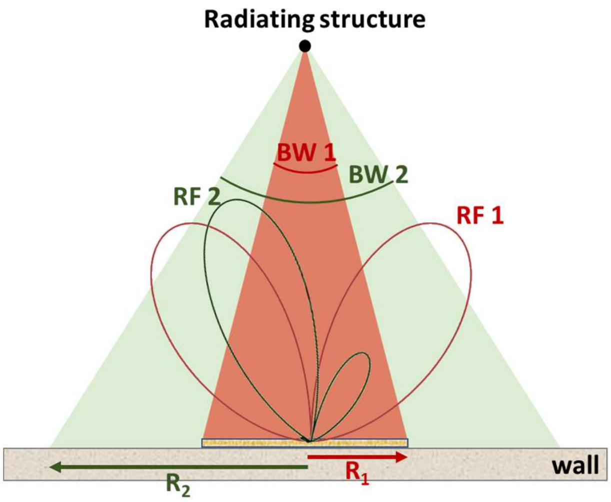

Figure 1. Geometrical sketch of the considered scenario: a circular reflective metasurface of radius R_1 is designed to convert an impinging field in a vortex mode with a conical scattering pattern; by enlarging the beam-width of the impinging field, also a portion of the surrounding uniform wall will contribute to the reflected field, allowing the manipulation of the overall scattering pattern.

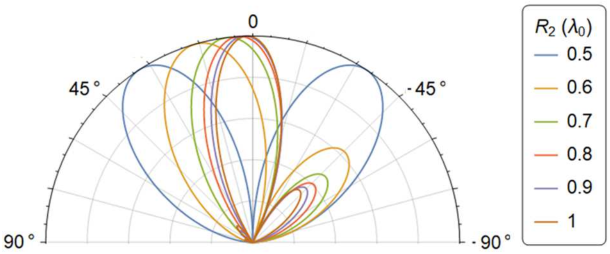

Figure 2. Normalized scattering pattern of the structure shown in Fig. 1 for different radius R_2 of the illuminated area. Here the reflective metasurface has a radius $R_1 = \lambda_0/2$.

3. Conclusions

In this contribution, we have exploited the adaptability of composite vortices to simplify the implementation of RISs. Specifically, through the design of the RIS to exhibit a vortex mode and exploiting the uniformly reflected field from a surrounding wall, we introduce a novel technique for incorporating reconfigurability. This approach involves the control of the size of the illuminated area, i.e. adjusting the beam-width of the transmitter.

Please note that a more detailed and comprehensive exploration of the presented methodology will be provided at the conference.

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