Efficient Analysis of Two-Dimensional Reconfigurable Intelligent Surfaces by Characteristic Basis Functions

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Abstract

Reconfigurable intelligent surfaces (RISs) are widely investigated as promising candidates to control and process the environment in modern high-frequency telecommunication applications. In many cases RISs are built as metasurfaces that contain concentrated parameter elements, helping with one can change the geometry of the metasurface to modify the electromagnetic (EM) wave environment according to the requirements. In this paper we present the analysis of a simple two-dimensional RIS that is able to reflect the incident EM wave in wide range of reflection angles. The analysis method used here is recently developed by the authors for the fast calculation of the EM field of metasurfaces. The applied procedure can be used for the fast evaluation of the many possible states of investigated RISs.

1 Introduction

Reconfigurable intelligent surfaces (RISs) are one of the key elements of future smart radio environments designed to meet the requirements of the modern wireless communications networks [1]. One possible realization of RISs are made of metasurfaces (MTSs) that actual geometry is controlled by concentrated parameter elements (usually various switches changing the layout of the MTSs) in real-time. If an MTS based RIS is to be analysed, one need to calculate the electromagnetic (EM) field of its many MTS realizations. Consequently, the solutions of a very large number of analysis problems give sufficient information on the characteristics of a RIS. This characterization, in the same time, is crucial for the design of the control of the RIS. One can see that the key problem is to find an effective and accurate analysis method for the calculation of the EM field of MTSs.

Authors of this paper recently developed a fast calculation method based on integral equations for the analysis of MTSs [2, 3]. Two main points of the calculations are the use of the spatial Fourier transform method for the evaluation of the kernel of the integral equation [3] and the application of characteristic basis functions (CBFs) as expansion functions for the solution of the integral equation [2]. The previous results an analytical expression for the spatial Fourier transform of kernel, the latter reduces significantly the number of unknowns required by the method of moments (MoM) solution of the integral equation.

In this paper we present the analysis of a two-dimensional RIS that is able to reflect the incident EM wave in wide range of reflection angles.

2 The considered RIS

The planar structure of the analysed RIS is parallel with the xy plane. It consist of a ground plate at the $z = -d$ plane represented by a perfect electric conductor (PEC) surface. Above this, a dielectric slab is placed that thickness and relative permittivity are d and ε_r, respectively. At the top of the dielectric slab

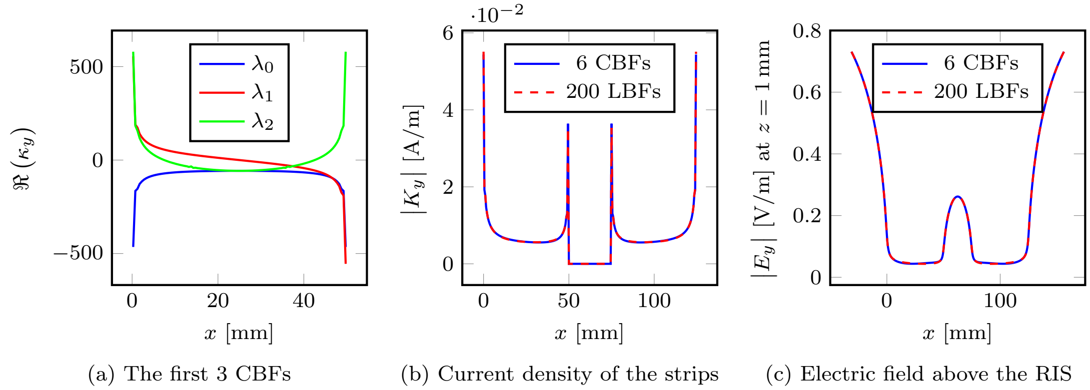

Figure 1: Analysis of an MTS made of two parallel strips

several metallic strips are arranged in a way that all these strips are parallel with the y co-ordinate direction. So, we obtained a two-dimensional (2D) arrangement invariant in the y direction. Such structures can be easily manufacture from, e.g., a two-layer printed circuit board.

Assume that the pattern of the strips are periodic in he x direction with the spatial periodicity, L_x. In this case, knowing from the Floquet-Block theorem, beyond the specular reflection other reflections may occur for any integer number $m = \ldots - 2, -1, 0, 1, 2, \ldots$ that satisfy the following inequality,

$$\left(2\pi f\sqrt{\varepsilon_0\mu_0}\right)^2 > \left(2\pi f\sqrt{\varepsilon_0\mu_0}\sin\vartheta) - \frac{2\pi m}{L_x}\right)^2, \tag{1}$$

where ε_0 and μ_0 are the permittivity and permeability of the vacuum, f is the frequency of the incident wave hitting the RIS with the incident angle ϑ.

Every possible m value is associated to a reflected plane wave propagating in different directions. The actual pattern of the strips within one period will determine that how the energy of the incident wave is distributed among the possible directions. The role of the RIS is to actively change its pattern to direct the wave to the required directions. In the full paper we will demonstrate this performance based on the analysis method outlined before.

In Fig. 1 the comparison of the results of the EM field obtained by CBFs and with conventional MoM using local basis functions (LBFs) are shown for an MTS where two strips are running close to each other.

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References

[1] M.D. Renzo, F.H. Danufane, and S. Tretyakov, Communication Models for Reconfigurable Intelligent Surfaces: From Surface Electromagnetics to Wireless Networks Optimization, *Proceedings of the IEEE*, **110.9** (2022) 1164–1209.

[2] B.T. Csahtó, Z. Badics, J. Pávó, and B.P. Horváth, Fast Numerical Analysis of Metasurfaces by Characteristic Basis Functions in EFIE Framework, *submitted to IEEE Trans. Magnetics*

[3] B.T. Csahtó, J. Pávó, Z. Badics, and B.P. Horváth, Metasurface Modeling in Plane-stratified Media via Plane Wave Decomposition, *accepted for PIERS 2023*