

Field and Dispersion Engineering in Cylindrical Metallic Waveguides Using Cascaded Metasurfaces

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Metasurfaces (MTSs), the two-dimensional counterparts of metamaterials, have gained significant attention in recent years for their ability to control and manipulate various electromagnetic (EM) functionalities. Leveraging the unique properties of metasurfaces opens extensive possibilities for dispersion engineering and wave manipulation. One notable application is their use in modifying the propagation characteristics of cylindrical waveguides enclosed by perfect electric conductors (PECs), which inherently support a discrete spectrum of modes (C. J. M. Barker, N. De Zanche, and A. K. Iyer, *IEEE Trans. Microw. Theory Tech.*, 71(8), 3392, 2023). Metasurfaces generally exhibit electric, magnetic, or magnetoelectric responses. Among these, bianisotropic surfaces represent a class of metasurfaces that offers complete control over wave propagation. The bianisotropic transition condition can be realized using cascaded patterned metallic sheets. However, maintaining the local periodicity approximation requires that these layers be positioned extremely close to one another. A rigorous method for analyzing cascaded layers involves using network parameters, such as ABCD matrices or wave matrices. By applying the ABCD matrix method, the overall response of the cascaded layers can be calculated by multiplying the matrices of individual layers (C.-W. Lin and A. Grbic, *IEEE Trans. Antennas Propag.*, 69(10), 6546, 2021). This approach accurately models wave propagation between layers, relaxing the constraints on small separation distances and enabling more flexible designs and easier fabrication.

This paper presents a comprehensive method for analyzing the dispersion characteristics and electromagnetic field distributions in cylindrical metallic waveguides lined with cascaded MTS and dielectric layers using the matrix approach. Analytical equations are derived to predict the dispersion relation and electromagnetic fields within a metallic waveguide for a given MTS liner configuration. By designing the metasurface layers, the waveguide's dispersion and field distribution properties can be tailored and controlled. To this end, a root-finding algorithm based on the Particle Swarm Optimization (PSO) method is developed to optimize the surface parameters of the layers for different electromagnetic functionalities, such as controlling the polarization, field properties, and propagation of different modes. A key application of this method is in MRI systems, which utilize metallic cylindrical waveguides. The field distribution within these waveguides significantly affects the quality of the resulting images. Achieving control over these distributions, such as creating a uniform transverse magnetic field, is therefore crucial. Design examples, validated through simulations in ANSYS HFSS, demonstrate the accuracy and practicality of the method. In conclusion, this study provides valuable insights and tools for engineering the dispersion and field distribution properties of cylindrical waveguides. These findings have potential applications in systems requiring control of electromagnetic wave behavior.