Study of Electromagnetic Diffraction Phenomena Immersed in Arbitrary Linear Media in Spectral Domain

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The analysis of electromagnetic diffraction phenomena in arbitrarily linear media is a challenging problem in computational electromagnetics either with numerical, analytical, semi-analytical and asymptotic techniques.
In the framework of semi-analytical techniques, we recall attempts in physical domain for particular media using separation of variables method combined with transformations in the physical domain (L.B. Felsen, "Propagation and diffraction in uniaxially anisotropic regions. Part 1. Theory," *Proc. Inst. Electr. Eng.,* vol. 111, issue 3, pp. 445–453, 1964). The methodology is restricted to uniaxial method and does not present the powerful features of spectral methods such as asymptotic evaluation of fields and physical interpretation of field components in relation to structural and source spectral singularities. Other works have investigated the behavior of the field near the edge of a wedge immersed in a complex medium (F. Olyslager, "The behavior of electromagnetic fields at edges in bi-isotropic and bi-anisotropic materials," *IEEE Trans. Antennas Propag.,* vol. 42, issue 10, pp. 1392–1397, 1994), as well as the diffraction effects produced by a wedge placed in a special isotropic chiral medium with the Sommerfeld-Malyuzhinets(SM) method (S. Vashtalov, V. Fisanov, "Diffraction of a plane wave from a wedge in a chiral medium," *Russ. Phys. J.*, vol. 36, issue 10, pp. 982–989, 1993). While powerful traditional spectral methods such as Sommerfeld-Malyuzhinets(SM) method, the Kontorovich-Lebedev(KL) transform method, and the Wiener-Hopf(WH) method are fundamental and complementary in studying diffraction problems in presence of sharp discontinuities immersed in isotropic region, the analysis in arbitrarily linear media has not been developed. This limitation is due to the fact that in such complex media the spectral problem shows intrinsically multiple propagation constants. This physical property connected to mathematical properties does not allow the definition of a unique complex plane for the formulation of the problem, thus the main advantage of the aforementioned techniques (SM, KL, WH) becomes a limitation (spectral complex angular plane derived from the Sommerfeld integral theory).
To the best of our knowledge, no spectral method has been developed to address the diffraction problems by wedges in arbitrary linear media (i.e., bianisotropic media) characterized by multiple propagation constants to date.
In this work we present a novel and general spectral method that exploits a generalization of Bresler-Marcuvitz transverse equations for angular regions, the generalization of the Wiener-Hopf technique to non-rectangular shapes immersed or made by arbitrary linear media, and the Fredholm factorization method, all generalizations originally introduced by the authors of this work (V.G. Daniele, G. Lombardi, "Spectral Analysis of Electromagnetic Diffraction Phenomena in Angular Regions Filled by Arbitrary Linear Media," *Applied Sciences*, vol. 14, issue 19, 8685, pp. 1-37, 2024.). In particular the present work extends the capability of Wiener-Hopf technique presented in (V.G. Daniele, G. Lombardi, G. Scattering and Diffraction by Wedges 1: The Wiener-Hopf Solution—Theory; *John Wiley & Sons*: Hoboken,NJ, USA, pp.220, 2020). This novel approach provides accurate semi-analytical solutions to new and intricate scattering problems, preserving the robust features of analytical solutions found in spectral methods, including the asymptotic estimation of fields and the physical interpretation of field components through spectral singularities. The work introduces a comprehensive self-consistent theory along with a complete mathematical package that allows the analysis of diffraction problems constituted by impenetrable/penetrable wedges immersed in or made of arbitrary linear media. The research activity proposes for the first time in literature a spectral method that analyzes problems in presence of angular regions/layers filled by complex media with multiple propagation constants starting from the analysis of half-plane diffraction. This work was supported by Next-Generation EU-PNRR M4C2-Inv 1.4–National Centre for HPC, Big Data, and Quantum Computing (HPC)—Multiscale Modeling and Engineering App.