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Radiation and scattering from a point source on an inhomogeneous substrate

Seyed Ehsan Hosseininejad, Ali Abdolali, Nader Komjani

Department of Electrical Engineering, Iran University of Science and Technology, Tehran 1684613114, Iran
E-mail: ehsan_hosseininejad@elec.iust.ac.ir

Abstract: This study presents a powerful analytical approach to investigate wave propagation and radiation in the problem involving a point source on an inhomogeneous substrate. The proposed method is based on using Taylor's series expansion for electromagnetic parameters and Fourier transformed electromagnetic fields of the inhomogeneous medium with continuous spatial variation. The fields in the Fourier domain are obtained by solving a system of linear coupled equations. The validity of the presented method is shown via some special examples. The results of the approach, simulation software and the available exact solutions are in very good agreement.

1 Introduction

The study of inhomogeneous media in the problems of electromagnetic wave propagation, scattering and radiation has been the subject of numerous researches in recent years. These studies have led to the introduction of wide applications in different microwave devices such as shields and filters [1, 2], absorbers [3, 4], antennas [5], radomes [6], polariser [7] and waveguide [8].

Interaction analysis of plane waves with inhomogeneous media have been presented in the literature by several approaches such as Richmond [9], Riccati [10], full-wave analysis [11], finite-difference [12], Taylor's series expansion [13], Fourier series expansion [14, 15], a semi-analytic method [16] and notation of propagators [17, 18]. In the real world, waves are non-planar as they are generated by sources such as antennas and scatterers. Fortunately, these waves can be expressed as a superposition of plane waves by virtue of the Fourier transform [19]. The radiation from different sources can be obtained by knowing the radiation from a point source (infinitesimal dipole) analytically [20]. Therefore it is important that we examine the radiation from such a basic source. The expressions of the Green's functions (point source response solutions) are well known in homogeneous, anisotropic, biisotropic and bianisotropic substrates [21–23]. On the contrary, when the substrate exhibits a continuous inhomogeneity, there are no general analytical expressions for the Green's functions. Of course, some analytical expressions have been found for particular permittivity profiles [24]. Furthermore, a formulation in the problem of an infinitesimal dipole near layered media (not inhomogeneous media with continuous spatial variation) has been presented [25].

In this work, following a previous effort made on the scattering analysis of a linear antenna near an inhomogeneous layer [26], we present an analytical approach to analyse wave propagation and electromagnetic scattering from an inhomogeneous planar medium with continuous spatial variation in proximity of a point source. The proposed method is based on combination of Fourier transform and Taylor's series expansion. In this method, Taylor's series expansion is used for all electromagnetic parameters and Fourier transformed electric and magnetic fields of the inhomogeneous medium. Afterward, the fields in the Fourier domain (spectral Green's function) are obtained by solving a system of linear coupled equations constituted by Maxwell's equations and boundary conditions. In Section 2, the theory of the problem is discussed with details. Section 3 verifies accuracy of the method by comparing its results, simulation software and the available exact solutions for some special examples. In the end, this paper finishes by a conclusion section.

2 Theory

2.1 Fields in the spectral domain

The geometry of the problem is shown in Fig. 1, where a point source is located on the surface of grounded inhomogeneous substrate with the thickness of h. We can express the current of electric dipole situated in the origin of coordinates as

$$\bar{J} = J_x\hat{x} + J_y\hat{y} = (I_x\hat{x} + I_y\hat{y})\delta(x)\delta(y) \tag{1}$$

The general wave function can be constructed by integrating any path in the eigenvalue domains as follows

$$\psi(x, y, z) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(k_x, k_y, z)\mathrm{e}^{jk_x x}\mathrm{e}^{jk_y y}\,\mathrm{d}k_x\,\mathrm{d}k_y \tag{2}$$