Multilayered Discrete Green's Functions Based on Mixed-Potential Finite-Difference Formulation

S. Mirhadi, M. Soleimani, and A. Abdolali

***Abstract*— An approach to calculating discrete Green's functions (DGFs) in multilayered media is proposed based on the finite-difference scheme of time-domain mixed-potential equations. The calculated DGFs have very high accuracy in comparison to the direct FDTD solution. Furthermore, the steady-state values of the DGFs are properly estimated in terms of the scalar potential, ensuring stability out of the truncating window. These DGFs are applicable to the analysis of antennas with multilayered planar structures. In such analysis, the proposed method has the advantage of the method of moments in that the computations are performed only on the antenna, regardless of the white space around it. Moreover, the broadband frequency characteristic of the antenna is achieved with a single simulation run, such as in the FDTD method. The theoretical results have been verified by the experimental results on a wideband coplanar waveguide (CPW)-fed monopole antenna.**

***Index Terms*— Discrete Green's function, finite-difference time-domain equations, mixed-potential equations, printed antennas.**

I. Introduction

Promising features of discrete Green's functions (DGFs) were originally identified by Vazquez and Parini [1, 2]. As opposed to the discretized version of continuous Green's functions, DGFs have attributes consistent with the finite-difference time-domain (FDTD) method, such as dispersion and stability. Thus far, various closed-forms of DGFs in infinite free space have been derived by several authors [1, 3-5]. The applications of DGFs have also been investigated in terms of their implementation as absorbing boundary conditions [6-8], in FDTD simulations on disjoint domains [9], in the truncation of the FDTD computational grid in the presence of reflecting external media [10], and in terms of savings in runtime and memory usage in radiation and scattering problems [3, 11-14].

The analytical closed-form of DGFs includes binomial coefficients, in which the accurate generation of these functions, especially for high upper indices, requires significant processor time due to the necessity of handling multiple precision arithmetic libraries [15, 16]. Nevertheless, closed-form-DGFs return exact values of the FDTD computations in the infinite Yee's mesh with multiple precision arithmetic and do not reflect the numerical error stemming from the finite numerical precision of the FDTD computations in standard arithmetic [16, 17]. However, the extracted analytical DGFs are only for homogenous media, which restricts their application in antenna modeling.

In this paper, a new procedure for extracting the time-domain DGFs in multilayered media is introduced. The proposed method is based on the finite-difference scheme for time-domain mixed-potential equations. This method does not suffer from the drawbacks of analytical closed-form implementation. In [18], the time-domain layered-medium Green's functions for mixed-potential integral equations (MPIE) were established through the fast Hankel transform and fast Fourier transform (FFT) of Green's functions in the complex frequency domain. However, the salient feature of the proposed method is that the solution space is inherently discrete and the equations are in the time-domain. Therefore, the formulation of the problem is much more straightforward than in the method presented in [18]. The calculated DGFs show very high accuracy in comparison to the direct FDTD solution. We have also shown that, in the derivation of multilayered DGFs, the direct implementation of the FDTD has some limitations with regard to the estimation of the steady-state values of DGFs. These steady-state values are required for the truncating window in the convolution calculation.

The proposed method has potential applications in printed antenna modeling. Numerous papers have presented MPIE based on spectral domain Green's functions toward solving printed antennas, [19-21]. On the contrary, we have developed mixed-potential finite-difference equations based on time-domain discrete Green's functions. Our proposed method has the advantages of MPIE in that a three-dimensional problem is reduced to a two-dimensional one.

The whole formulation, implementation, and evaluation of the extracted DGFs through the finite-difference scheme of mixed-potential equations are presented in Section II. In Section III, two types of printed antennas are analyzed in the time-domain with the discrete Green's function method, and the computer resources required for the analysis of these antennas are discussed.

Manuscript received October 15, 2013. The authors are with the Electrical Engineering Department, Iran University of Science and Technology (IUST), Tehran 16846-13114, Iran (e-mail: s_mirhadi@iust.ac.ir, soleimani@iust.ac.ir, and abdolali@iust.ac.ir).