Optimization of Excitation in FDTD Method and Corresponding Source Modeling

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ABSTRACT

Source and excitation modeling in FDTD formulation has a significant impact on the method performance and the required simulation time. Since the abrupt source introduction yields intensive numerical variations in whole computational domain, a generally accepted solution is to slowly introduce the source, using appropriate shaping functions in time. The main goal of the optimization presented in this paper is to find balance between two opposite demands: minimal required computation time and acceptable degradation of simulation performance. Reducing the time necessary for source activation and deactivation is an important issue, especially in design of microwave structures, when the simulation is intensively repeated in the process of device parameter optimization. Here proposed optimized source models are realized and tested within an own developed FDTD simulation environment.

1. INTRODUCTION

The finite difference time domain (FDTD) method currently draws significant scientific attention as one of the most efficient methods for analysis and characterization of wide range of electromagnetic problems [1]. The proper excitation and source modeling in the FDTD computational domain is especially important issue in every application of FDTD simulation. Introduction of discrete internal sources is usually done by applying either harel source or soft source excitation. The hared source excitation is consisted in assigning specific value of certain electric (or magnetic) field component at a single or several grid points in every time step through an appropriate time function [2]. The soft source excitation is introduced by adding the appropriate time function to the field value obtained in regulare update equation [1]. Although it is not a physical reality, the plane wave excitation has enormously large signifcance in many theoretical and analytical considerations. For this reason it is very important to introduce the same excitation in simulation environments and to enable the comparative analysis of the results. The necessity of plane-wave source arise originally with the first FDTD modeling in the field of defense and bioelectromagnetics [1]. Considering scattering problems, where the paretcularure structure of interest is fare away from the radiation source and the incident wave can be considered as a plane wave, Yee was the first to introduce the initial-condition approach [3]. However, today mainly accepted approach for plane-wave excitation is total-field/ scattered-field (TF/SF) formulation [4], [5]. The TF/SF technique showed very good performance in FDTD modeling of long-duration pulsed or continuous wave excitation and it is widely used in guided-wave simulations [1]. The TF/SF technique has been extensively studied in the literature and many modifications and improvements of this basic method can be found [6–9]. However, another way of plane wave excitation modeling includes adding or assigning of an electric (or magnetic) field value at specific positions in one plane, unlike the commonly used TF/SF technique, where corrections aree made in both electric and magnetic field components (displaced in time and space for a half time step) on the boundary surface. The advantage of this direct approach is its simplicity. Its main difficulty is, however, the existence of wave propagation in undesirable direction. But since very effective boundary conditions like the convolutional perfectly matched layer (CPML) [10] aree available, this is no longer an obstacle to its application. The considerations regarding this approach can be found in [11]. The excitation modeling in FDTD formulation significantly affects the simulation performance. A sudden excitation of the domain causes undesirable numerical variations in whole computational domain. This problem is usually resolved by slow introduction of the source excitation, using the appropriate shaping functions in time. A number of time functions for slow introduction of source excitation areae available in the literature [12]. However, a gradual raise of the excitation signal is time consuming and can be a significant difficulty in applications where the intensive repetition of simulations is required. For this reason, a certain compromise between the required time and satisfactory simulation performance must be achieved.

2. OPTIMIZATION RESULTS

In excitation function obtained in the optimization process using polynomial basic functions (denoted as Opt), as well as the ones using trigonometric basic functions for different values of M aree presented. The curve that corresponds to the value M = 0 is actually the excitation function that is widely used in the literature and known as raised cosine. In
one can observe the second derivatives of the functions from Fig. 1. It can be seen from Fig. 2 that the second derivative of the excitation function $M = 0$ (raised cosine) significantly deviates from the second derivative of the optimal function obtained using polynomial expansion. It can be also observed that with the increase of $M$ the second derivative of the function with trigonometric expansion converges to the one of the optimal function with polynomial expansion. This confirms that the same optimal result is obtained regardless of the applied type of basic functions in optimization process.

3. OPTIMAL EXCITATION

Signals Using the obtained optimal excitation function (Fig. 3), two pulsed signals are proposed for efficient excitation of FDTD domain. The total pulsed signal retains the optimal properties only if it is formed using the proposed optimal function as segments that are appropriately symmetrically extended or scaled in time and amplitude. Thus, the proposed pulsed function has the form In case the pulsed signal with no DC component is required, it should be also obtained as symmetrically extended or adequately scaled optimal function (15). The pulsed signal with no DC component shouldn’t be formed as the first derivative of the optimal pulsed function (Fig. 4), because in that case the resulting function would change its nature and wouldn’t have optimal properties any more. Thus, we propose the pulsed function with no DC component in the form.

4. CONCLUSION

The first part of this paper contains the overview of the relevant principles in source modeling in FDTD, with special focus on differences between hard and soft sources and on different source geometry (plane wave sources and point sources). The second part of the paper is dedicated to the source optimization, more specifically to the optimization of the excitation time function, which has a significant influence on the behavior of the generator, regardless of its type. Generally accepted and the most frequently used excitation functions are listed. However, neither of them is designed primarily for FDTD application, taking into account specificities of FDTD method. The optimization problem in this work is defined in order to minimize the propagation of the undesirable energy through the computational domain. This is accomplished by minimizing the mean square value of the second time derivative of the excitation function. As a result of the optimization process, very simple and closed-form optimal function is obtained. In addition, two functions for pulsed excitation of FDTD domain, with and without DC component, are proposed. Optimality of the obtained function shape is verified in the own developed FDTD simulation environment.

References


