SIMULATION OF A GROUND PENETRATING RADAR USING AN ADI-FDTD/MoMTD HYBRID METHOD

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Abstract: A hybrid method that combines two numerical techniques, the ADI formulation of the Finite Difference Time Domain (ADI-FDTD) and the Method of Moments in the Time Domain (MoMTD), is employed to simulate a short-pulse ground penetrating radar (GPR). The method is applied to the detection of cracks in a marble block.

INTRODUCTION
In this communication a hybrid ADI-FDTD/MoMTD method [1-2] is applied to model a ground penetrating radar system consisting of a V thin-wire antenna located near an inhomogeneous media. The V antenna is optimized for pulse radiation using genetic algorithms (GA) [3] in order to reduce unwanted reflections at the ends of the antenna while retaining high fidelity and efficiency. As application example, the possibilities of the system to detect cracks in a marble block are investigated.

The ADI-FDTD/MoMTD method combines the ability of the FDTD to deal with arbitrary material properties and that of the MoMTD to analyze thin-wire structures. The ADI-FDTD formulation has been included so that the time step is only constrained by the maximum significant spectral component of the transient excitation and not by the Courant condition, with the consequent saving in computational resources when a fine mesh is needed to model part of the computational domain but a high temporal resolution is not needed. Moreover, the new hybrid method does not exhibit the late time instabilities observed in some cases in the hybrid explicit-FDTD/MoMTD method and therefore its use may be preferable even for problems where the computational burden is comparable for the two hybrid techniques.

The hybrid method is briefly described below and an application example is given.

DESCRIPTION OF THE HYBRID METHOD ADI-FDTD/MoMTD

The hybridization technique is based upon the use of the Huygens' principle; a detailed description of the method can be found in [1-2]. Its application basically requires the following five steps.

1) The original problem of a thin wire antenna located in the surrounding area of a heterogeneous dielectric body like the one shown in Fig. 1 is divided into two subproblems: i) The thin-wire antenna in free space and ii) the rest of the computational domain without the thin-wire antenna present.

2) The currents on the antenna at a specific time step $t_n$ are computed by solving the TD-EFIE by the MoMTD in terms of the known feed voltage at this time step, the currents at previous time steps on the
antenna and the fields scattered by the inhomogeneous body that have been previously calculated by the ADI-FDTD.

3) Equivalent sources, \( \vec{J} \) and \( \vec{M} \), are calculated on \( S \) from the fields radiated by the currents on the antenna.

4) Next, the two sub-steps [4-5], globally leading from \( n \) to \( n+1 \), of the ADI-FDTD algorithm are applied in the entire computational domain, with the antenna still removed, yielding the usual implicit (tridiagonal) updating scheme for the electric field and an explicit updating scheme for the magnetic field at each sub-step. As was explained in [1] the equivalent sources \( \vec{J} \) and \( \vec{M} \) must be evaluated at \( n + 1/2 \) instead of at the usual \( n + 1/4 \) \( n + 3/4 \) to have an accurate implementation of the sources in the hybrid scheme.

5) The application of the ADI-FDTD in the whole computational domain gives, inside \( S \), the extra incident field on the thin wire antenna necessary for solving the TD-EFIE again. If the center of the segments in the wire, where the extra incident field is needed, does not coincide with points on the FDTD grid where that field is calculated, linear interpolation in space is applied. Unlike what happens in the explicit-FDTD/MoMTD, now the ADI-FDTD time step can be synchronized with the time step utilized in the MoMTD (typically much larger than the corresponding one in the standard FDTD step) avoiding, in some cases, interpolations in time to connect the FDTD and the MoMTD solutions.

RESULTS

Fig. 2 shows a V-antenna located in front of a marble half space with a relative permittivity equal to 6 and conductivity \( \sigma = 0.001 \, S/m \) at a distance \( d_1 = 0.3 \, m \). The length of each arm of the antenna is 0.32 m, its radius is 1.6 mm and its interior angle \( \alpha = 47^\circ \). There is an empty hole of dimensions 5cmx5cmx5cm located below the antenna 1m from the air-marble interface. The antenna is excited at its center with the derivative of a Gaussian pulse of unit amplitude and a duration (full-width half-maximum) of 3.3 ns. The arms of the antenna are discretized into 16 segments and a resistive lumped element is located along them in order to improve the antenna broadband characteristics. The values of the resistive loads along the V-antenna, obtained by using GA [3], were \( (97.02, 156.04, 156.04, 77.48, 70.40, 45.45, 51.54, 0, 55.24, 0, 45.45, 0, 0, 0, 0, 0) \, \Omega \) and they were located at the segments ordered from the end of the wire to the voltage source. The loads for the other arm were symmetric. The reader is referred to [3] for more details on the specific GA adopted.

The antenna is moved along survey lines parallel to the marble surface. A short pulse is emitted at regular intervals and each time the scattered field is measured at an observation point located 30 cm directly below the vertex of the antenna. The received signals are calibrated by subtracting the signal produced when the hole is not present. As an example of the radargrams obtained, Figure 3 shows the magnitude of the electric field versus time measured along the survey line plotted with a dashed line in Figure 1. The position and depth of the hole are clearly observed from the hyperbolic response in Figure 3.
To obtain a 3D image of the hole we follow the procedure described in [6]. First, the received signals are calibrated by subtracting the signal produced when the hole is not present. Next, the calibrated signals are variably time-shifted for every point inside the marble half space and they are added to obtain a time-domain function from which an intensity function is defined. Figure 4 plots this intensity function at the different positions inside the marble, showing how a peak value occurs at the hole positions, which is where the maximum backscattered signal comes from.

![Fig3.- Radargram corresponding to the survey line shown in Figure 2](image1)

![Fig4.- Function of the position obtained from the sum of the time-shifted received signals as explained in [6](image2)

REFERENCES


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