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Time domain electromagnetic scattering using finite elements and perfectly matched layers

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Abstract

We consider a model for the interrogation of a planar Debye medium by a non-harmonic microwave pulse from an antenna source in free space, and we compute the reflected solution using finite elements in the spatial variables and finite differences in the time variable. Perfectly matched layers (PMLs) and an absorbing boundary condition are used to damp waves interacting with artificial boundaries imposed to allow finite computational domains. We present simulation results showing that numerical reflections from interfaces at PML boundaries can be controlled.

Keywords: Scattering; Debye; Perfectly matched layers; Absorbing boundary condition

1. Introduction

The purpose of this paper is to demonstrate computationally that one can implement a two-dimensional version of the electromagnetic interrogation problems introduced in [3]. Here we use perfectly matched layers (PMLs) as absorbing layers at artificial boundaries used to define finite computational domains. We carry out calculations to verify that artificial reflections do not contaminate reflections from dielectric layer interfaces used to determine dielectric parameters as well as physical geometry in inverse problem formulations. Our results provide evidence that the one-dimensional normally incident plane wave ideas in [3] can be extended to treat higher dimensional problems in which obliquely incident waves play a nontrivial role.

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In [3] the authors develop a theoretical and computational framework to use pulsed electromagnetic interrogating signals to determine dielectric and geometric properties of materials. This framework involves time domain computations of electromagnetic signals from an antenna through vacuum to the target and return. Even in the one-dimensional case treated in [3] (where one uses an infinite antenna sheet and polarized plane waves to achieve a one-dimensional finite spatial domain), the problems are computationally intensive. Moreover, there are several difficulties in extending this methodology to two and three dimensions in addition to the usual increased computational complexities involved in moving to higher spatial dimensions. First, interrogating signals from a finite antenna will produce oblique incident waves to the target and these must be treated in the reflections. The uniformity assumptions made in [3] to yield one-dimensional finite spatial domains will not be applicable and an infinite spatial domain must be approximated by a finite computational domain with artificial boundaries. Since perfectly absorbing boundary conditions are not available in higher dimensions, some type of boundary damping must be formulated so that artificial reflections will not interfere with reflections from the target.

In the treatment here, we model the propagation of a non-harmonic pulse from a finite antenna source in free space across a planar interface into a dielectric. The dielectric is a Debye medium with Ohmic conductivity. We use finite elements in the spatial variables and finite differences in the time variable to compute the components of the electric field in the case where the signal and dielectric parameters are independent of the y variable (the only uniformity assumption made here). Fig. 1 depicts the antenna and dielectric slab geometry we use in our problem formulation with the infinite dielectric slab perpendicular to the z-axis and uniform in the region $z_1 \leqslant z \leqslant z_2$. The uniform strip antenna is located in the xy-plane, is infinite in the y-direction and finite in the x-direction lying in the region $-\infty \leqslant y \leqslant \infty,\ -\bar{x} \leqslant x \leqslant \bar{x}$. An alternating current along the x-direction then produces an electric field that is uniform in y with nontrivial components E_x and E_z depending on (t, x, z) which, when propagated in the xz-plane, results in oblique incident waves on the dielectric surface in the xy-plane at $z = z_1$.

We also assume that the dielectric is backed by a supraconductive material with an infinite conductivity, so one side of the computational domain will have a perfectly reflecting boundary condition. Artificial boundaries on the other three sides are assumed, producing an approximating finite computational domain. Energy will also reflect off the boundaries on these other three sides of the computational domain, and there is a critical need to prevent or delay this energy's return to the domain of interest. We use perfectly matched

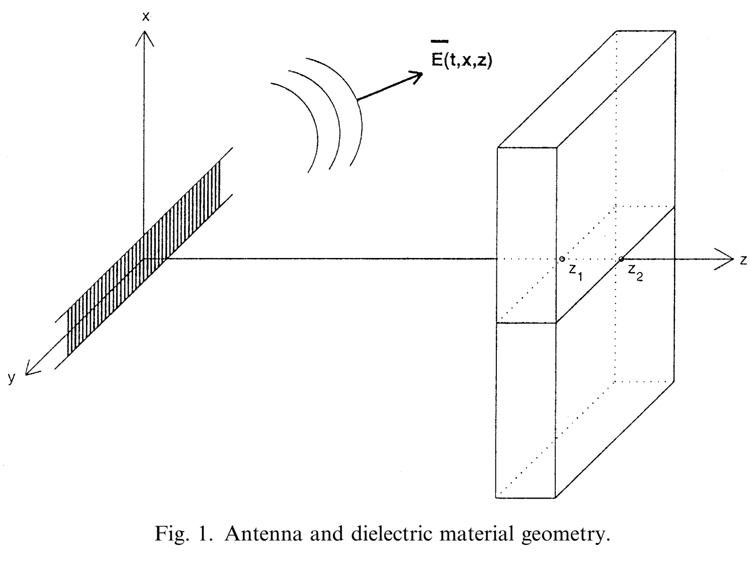

Fig. 1. Antenna and dielectric material geometry.