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Fast Numerical Techniques in Computational Electromagnetics for Planar-Stratified Media

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Fast numerical algorithms for the scattering of electromagnetic waves (radar) from scatterers embedded in a planar stratified medium are presented. Applications include the modeling of ultra-wideband (UWB) ground penetrating radars (GPR) for the detection of anti-personnel (AP) or anti-tank (AT) mines, as well as large unexploded ordnance (UXO). The work also presents examples for the radar scattering from electrically large targets in the presence of a half space (e.g., vehicles above ground).

For UWB applications and/or electrically large targets, it is essential to implement numerical techniques that are as efficient as possible. Popular techniques, like the finite-element (FEM) or finite-difference time-domain (FDTD) methods, are powerful and applicable to a wide range of problems. However, for large three-dimensional (3D) problems, the memory requirements and computational complexity generally become prohibitive. Hence, although somewhat restricted in the range of applications, this work only considers fast surface-integral-equation solvers for penetrable and PEC objects situated in a planar-layered environment.

For a method-of-moments (MoM) based fast solution of the associated integral equations, a fast computation of the layered-medium Green’s function is essential. To avoid the expensive numerical integration of Sommerfeld integrals, the discrete complex-image technique (DCIT) is applied. To make the analysis of scattering from AT/AP mines tractable for ultra-wideband, short-pulse GPR systems, a MoM for body-of-revolution (BOR) geometries is presented first. Exploitation of the rotational symmetry (valid for a wide class of mines) results in significant savings in computational resources. While the MoM BOR algorithm has been utilized for some time, it is only through application of the DCIT for the efficient Green’s function evaluation that UWB analyses are tractable. Several examples of relevance to practical mine-detection systems are presented, for both conducting and plastic mines.

The BOR MoM is valuable for a specific class of scattering problems. However, in many cases the BOR assumption is not appropriate. Thus, a fully 3D MoM solution for PEC targets situated within a general layered-medium background is described next. While 3D MoM techniques have been a subject of interest for several years, most such research was restricted to scatterers in free space. But there are many radar applications (e.g., subsurface sensing) for which the free-space assumption is not acceptable. A set of examples demonstrates some of the potential applications for the efficient 3D layered-medium MoM developed in this work.

However, even though the number of unknowns is relatively small in case of surface integral equations, computational complexity of the 3D MoM becomes prohibitive for large scatterers (relative to wavelength). Consequently, there has been significant interest recently in fast integral-equation solvers, like the adaptive integral method (AIM), the fast multipole method (FMM), and the multi-level fast multipole algorithm (MLFMA). The original research has shown a remarkable reduction in computational complexity, while leaving the accuracy basically unchanged. However, these techniques have not been applied previously to general 3D targets embedded in a general layered medium. Hence, FMM and MLFMA have been extended to the case of 3D PEC targets situated within a lossy half space. Possible applications of half-space FMM and MLFMA include scattering from electrically large targets, such as vehicles or large UXO, above or buried in a soil half space. These problems have not been tractable in the past, with either differential-equation (e.g., FEM, FDTD) or integral-equation based (e.g., MoM, free-space FMM, free-space MLFMA) solvers.