An Explicit Time Marching Scheme for Solving the Nyström-discretized Scalar Potential Integral Equation

Rui Chen* and Hakan Bagci
Division of Computer, Electrical, and Mathematical Science and Engineering (CEMSE),
King Abdullah University of Science and Technology (KAUST),
Thuwal 23955-6900, Saudi Arabia

The electric field (surface) integral equation (EFIE), magnetic field (surface) integral equation (MFIE), and their different combinations are often used for analyzing electromagnetic scattering from homogeneous penetrable scatterers. However, the EFIE suffers from low-frequency and dense-mesh break down problems (G. Vecchi, IEEE Trans. Antennas Propag., 47(2), 339-346, 1999). Although the MFIE is always well-conditioned (it is a second-kind integral equation), its discretization with the Rao-Wilton-Glisson (RWG) functions results in an inaccurate solution at low frequencies. Even though the effects of break-downs and the inaccuracy problems can be alleviated using preconditioning techniques and new discretization schemes (F. P. Andriulli et al., IEEE Trans. Antennas Propag., 56(8), 2398-2412, 2008; K. Cools et al., IEEE Antennas Wireless Propag. Lett., 10, 528-531, 2011), implementations of these often come at the expense of simplicity. Additionally, potential surface integral equations have been developed to overcome these bottlenecks while maintaining the simplicity of the implementation. The potential integral equations have been formulated for perfect electrically conducting as well as homogeneous penetrable objects. A de-coupled version of these formulations results in two sets of surface integral equations that can be individually solved for scalar and vector potentials (J. Li et al., IEEE Int. Symp. Antennas Propag., 2017; W. C. Chew, Progr. Electromagn. Res., 149, 69-84, 2014). These sets of integral equations are second kind and do not suffer from the aforementioned break-down issues.

In this work, a fully explicit marching-on-in-time (MOT) scheme is proposed to solve the time domain scalar potential integral equation (TD-SPIE) for analyzing transient electromagnetic scattering from penetrable scatterers. The scalar potential (induced on the surface of the scatterer) and its normal derivative are expanded using a higher-order Nyström scheme, which makes use of interpolation functions defined at a set of discrete points in space (G. Kang et al., IEEE Trans. Antennas Propag., 49(6), 908-915, 2001), and Lagrange polynomial functions in time (K. Aygun et al., IEEE Trans. Electromagn. Compat., 44(1), 152-164, 2002). These expansions are inserted in the TD-SPIE and the resulting equation is point-tested at the interpolation points, which yields a system of ordinary differential equations (ODEs). This ODE system is integrated in time using a PE(CE)^m-type multistep scheme for the unknown expansion coefficients. The resulting time marching scheme is explicit since the Gram matrix arising from the Nyström discretization is diagonal. Additionally, this explicit MOT scheme uses the same time step as its implicit counterpart without sacrificing from accuracy and stability. Overall, the explicit MOT scheme is faster than its implicit counterpart especially under low-frequency excitations.

Numerical results, which demonstrate the proposed solver's efficiency and higher-order accuracy, will be presented.