

Analysis of 2-D Transient Electromagnetic Shielding Using the Method of Auxiliary Sources

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Abstract—This article presents a time-domain (TD) formulation for modeling transient electromagnetic (EM) shielding by thin, arbitrarily shaped 2-D conductive shells using the method of auxiliary sources (MAS). The conductive shield is modeled via an impedance matrix boundary condition (IMBC), originally derived in the frequency domain and then transformed into a causal, convolution-based TD form. The proposed formulation accommodates both TM_z and TE_z polarizations and supports general excitations, including transient plane waves and cylindrical waves radiated by current filaments. Numerical results are presented for various geometries—circular, elliptical, rounded triangular, inverted elliptical, supercircular with relatively sharp edges, and multilayered shields—demonstrating the method's accuracy and stability. Simulations cover a wide range of conductivities (from 10^3 to 10^7 S/m) and submillimeter-scale thicknesses, validating the robustness and versatility of the proposed approach. Comparisons with a frequency-domain MAS solver confirm the accuracy of the TD results, establishing the developed method as an efficient and flexible tool for transient shielding analysis of electrically thin materials.

Index Terms—Composite materials, electrically thin materials, graphene, impedance matrix boundary condition (IMBC), indium tin oxide (ITO), method of auxiliary sources (MAS), scattering, thin conductive shells, transient electromagnetic (EM) shielding.

I. INTRODUCTION

TIME-DOMAIN (TD) electromagnetic (EM) analysis has gained increasing prominence due to its broad applicability in areas such as radar systems [1], [2], [3], [4], geophysical exploration [5], [6], [7], nondestructive testing [8], [9], biomedical imaging [10], [11], and—particularly relevant to the focus of our work—EM shielding [12], [13], [14]. Shielding effectiveness (SE) must be increasingly evaluated under transient and broadband excitations, especially as modern electronic systems operate at higher speeds and are exposed to fast-changing EM environments. TD techniques are particularly well-suited for this task, as they utilize short EM pulses that simultaneously excite a wide range of frequencies, capturing the system's broadband response in a single simulation or measurement. The pulse duration governs the frequency range, with shorter pulses yielding wider spectral coverage. This capability is critical for assessing the performance of

shielding enclosures subjected to real-world EM disturbances, such as electrostatic discharges, lightning-induced transients, or intentional EM interference.

A variety of numerical methods have been developed to address TD EM problems [15], including those involving shielding structures subjected to transient excitations. The finite-domain TD (FDTD) method remains one of the most widely adopted techniques, due to its conceptual simplicity and versatility in modeling complex environments [16], [17], [18]. The TD finite-element method (TD-FEM) is another powerful approach, available in commercial platforms such as COMSOL Multiphysics [19], [20]. In addition, Galerkin-based TD methods have been studied extensively [21], [22], along with surface- and volume-integral-equation formulations [23], [24], [25]. Most of these techniques require meshing of either the computational volume or the surfaces of the analyzed objects. In contrast, the method of auxiliary sources (MAS) [26]—also referred to as the method of fundamental solutions (MFS) [27], [28] or the source model technique (SMT) [29], [30]—offers a meshless alternative that has shown promising results in TD modeling of 2-D EM structures [31], [32], [33], [34]. Recently, a TD-MAS implementation of the standard impedance boundary condition (SIBC) was presented in [35].

EM shielding structures often consist of conductive shells that are thin compared to the wavelength of the impinging signal. However, the direct modeling of thin conductive layers poses challenges. In mesh-based methods, like the FEM, the fine resolution required to accurately capture the field behavior within the thin layer significantly increases the computational cost. In surface integral equation methods (SIEM), such as the boundary element method (BEM), the method of moments (MoM), or SIEM variants, like the MAS, the main challenge in modeling thin, highly conductive layers lies in the difficulty of accurately capturing field interactions across the small layer thickness. This arises due to the close proximity of opposing surfaces, which leads to ill-conditioned matrices, numerical instability, and increased computational cost, even though the methods operate on surface formulations. To overcome these difficulties, the conductive shell is often replaced by an equivalent surface formulation, such as a transition boundary condition (BC) [36], also referred to as an 1-D [37] (for flat surfaces) or 2-D [38] impedance matrix BC (IMBC), which take into account the curvature of the conductive layer. This approach enables accurate modeling of the EM response without requiring resolution of the internal fields of the layer, thus improving numerical stability and efficiency.

The 1-D IMBC technique has already been successfully extended to the TD, most notably within the FDTD frame-

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