Source-model technique analysis of transient electromagnetic scattering by dielectric cylinders

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Abstract: This study considers the application of the source-model technique to the solution of the problem of electromagnetic scattering by an arbitrarily shaped dielectric cylinder illuminated by a transient plane wave. The technique is utilized to study the scattering from a dielectric cylinder of circular cross-section and from a cylindrical void of the same cross-section lying in a dielectric medium. The effect of numerical parameters on accuracy and stability is studied and guidelines as to the choice of source location and their number are given. The scattering from a dielectric circular cylinder is then compared with the scattering by a cylinder of a rectangle capped by semi-circles cross-section, and the results are interpreted from a physical point of view.

1 Introduction

Time-domain integral equation (TDIE)-based solvers that harness the advantages inherent to integral equation-based techniques towards efficiently treating wide-band phenomena directly in the time domain have gained renewed interest in recent years [1–14]. The continuous recent interest in TDIE-based solvers is also due to a few recently suggested methods [15–18] that alleviate efficiency and stability problems that were originally responsible for abandoning these solvers in the past. Motivated by the renewed interest, this research work utilises a TDIE solver for the analysis of two-dimensional dielectric structures that are illuminated by a transient plane wave.

The SMT has been used extensively in frequency-domain solutions [19–24] and was found to be a viable alternative to integral equation-based techniques in which ordinary surface formulations amenable to conventional moment method solutions are used. A discussion of the advantages of the SMT can be found in [20]. Recently, a time-domain SMT (TD-SMT) solver for calculating electromagnetic transient scattering by perfectly electric conducting (PEC) cylinders has been proposed [25, 26], and later on extended to study photonic crystal structures comprising periodic dielectric inclusions [27]. However, the TD-SMT solution method of [27] was specifically aimed at treating photonic crystals and hence only incident pulses of large temporal widths, whose frequency bands matched the frequency bandgap of the photonic crystal, were assumed. In this paper, we give a compact and lucid description of the TD-SMT solution method for the general problem of electromagnetic scattering by a dielectric cylinder illuminated by a transient plane wave and study the scattering by a few types of cylindrical scatterers that are illuminated by both narrow and wide pulses. The case of a narrow incident pulse is particularly interesting as it allows a geometrical-optics interpretation of the results. Finally, in continuation to our earlier study on the choice of numerical parameters for the TD-SMT solution of scattering by PEC cylinders [25], we study here the effect of the additional numerical parameters involved in the case of dielectric cylinders have on the accuracy and stability of the solution, and give guidelines as to the choice of these parameters.

The remainder of this paper is organised as follows. In Section 2, a general formulation of the TD-SMT for a two-dimensional dielectric scatterer is given. In Section 3, results for different scatterers, pulse widths and numerical parameters are presented. The solution accuracy and stability and the temporal behaviour of the backscattered field are also discussed in Section 3. Finally, a summary is given in Section 4.

2 Formulation

A general TD-SMT formulation for the scattering problem of an incident field \((E^{\text{inc}}, H^{\text{inc}})\) by a dielectric object of permittivity \(\varepsilon_\text{I}\) and permeability \(\mu_\text{I}\), lying in a homogeneous isotropic medium of permittivity \(\varepsilon_\text{II}\) and permeability \(\mu_\text{II}\), can be obtained by replacing the scatterer with two sets of unknown fictitious surface current distributions \(J^{\text{ext}}_{\text{int}}\) and \(J^{\text{int}}_{\text{ext}}\) that reside on mathematical surfaces \(S^{\text{int}}\) and \(S^{\text{ext}}\) that are retracted some distance from the scatterer surface \(S\). The mathematical surface \(S^{\text{int}}\) is interior to the scatterer surface \(S\) and the current distribution residing on it is assumed to radiate in an unbounded space filled with homogeneous material identical to that of the exterior region in a manner that creates a simulated equivalence to the original fields in