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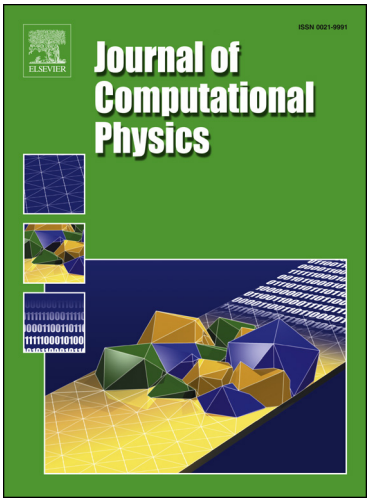

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An Optimized Hybrid Convolutional Perfectly Matched Layer for Efficient Absorption of Electromagnetic Waves

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***Abstract*— A hybrid technique is studied in order to improve the performance of Convolutional Perfectly Matched Layer (CPML) in the Finite Difference Time Domain (FDTD) medium. This technique combines the first order of Higdon's annihilation equation as Absorbing Boundary Condition (ABC) with CPML to vanish the Perfect Electric Conductor (PEC) effects at the end of the CPML region. An optimization algorithm is required to find optimum parameters of the proposed absorber. In this investigation, the Particle Swarm Optimization (PSO) is utilized with two separate objective functions in order to minimize the average and peak value of relative error. Using a standard test, the overall performance of the proposed absorber is compared to the original CPML. The results clearly illustrate this method provides approximately 10 dB enhancements in CPML absorption error. The performance, memory and time requirement of the novel absorber, hybrid CPML (H-CPML), was analyzed during 2D and 3D tests and compared to most reported PMLs. The H-CPML requirement of computer resources is similar to CPML and can simply be implemented to truncate FDTD domains. Furthermore, an optimized set of parameters are provided to generalize the hybrid method.**

***Index Terms*— Absorbing Boundary Condition, Numerical Analysis, Finite Difference Method, Perfectly Matched Layer, Optimization methods.**

I. Introduction

The finite difference time domain (FDTD) method, introduced by Yee [1], is a differential equation solver. It is extensively used in numerical simulation of electromagnetic waves. One of the most significant challenges in the implementation of this solver is finding a technique to terminate its computational domain. Many techniques are introduced to this end, but the efforts can be divided into two distinct areas.

The first research area includes analytical Absorbing Boundary Condition (ABC). One of the initial ABCs for acoustic waves, proposed by Engquist and Majda, reveals the acceptable absorption of outgoing waves [2]. Mur implemented the first and second order of Engquist and Majda's ABC in electromagnetics [3]. By focusing on annihilation operators, Higdon enhanced Engquist and Majda's ABC for absorption of outgoing waves in specific directions within complex layered media [4, 5]. Ramahi presented the complementary operators method (COM) in order to cancel the boundary reflections [6]. These methods use the tangential fields near boundaries to calculate the equivalent current at the boundaries using Green theorem. The process usually requires storing the time-history tangential fields on the boundary. In addition, most ABCs only operate for particular wave directions. Otherwise stated, they usually trigger an unwanted reflection in other incident directions, especially in near grazing incidences. These drawbacks have made them inefficient for a broad range of electromagnetic problems.

High-order ABCs can be more effective. However, the formulation of Higdon's ABC is not used for higher orders because the original formulations of these ABCs usually involve high-order derivatives. In [7] a new high-order sequence of Non-Reflecting Boundary Condition (NRBC) has been proposed based on the reformulation of Higdon's wave-product conditions for time-dependent waves. This scheme introduces special auxiliary variables that facilitates the use of an NRBC of any arbitrarily high-order. Furthermore, it involves no high derivatives beyond second order. In [8], however, another new auxiliary variable formulation of high-order RBC has been developed. Besides the previous works, there are some other studies about high-order ABCs that can be found in [9-11]. It should be mentioned that despite the acceptable performance of high-order ABCs, these methods often involve complex implementations.

The second structure to truncate FDTD lattice (the second area) is a physical layer around the domain of the problem. By specifying the material of the layer, it can physically absorb the waves and behave like the walls of anechoic chambers. Perfectly

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