

ANN-Incorporated Absorbing Boundary Conditions for the Wave-Equation-Based FDTD method

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The finite-difference time-domain (FDTD) method(A. Z. Elsherbeni and V. Demir, The finite-difference time-domain method for electromagnetics with MATLAB simulations. Raleigh, NC: SciTech Pub., 2009.) requires truncating the computational domain to a finite space using absorbing boundary conditions (ABCs) that emulate the unbounded exterior region by absorbing outgoing electromagnetic waves. Among various ABCs, the perfectly matched layer (PML) is widely recognized for its robustness, though it typically requires multiple layers, consuming large computational resources. Recent advancements have integrated artificial neural networks (ANNs) with PML, reducing its thickness to a single layer or boundary line, thereby saving memory and computation time.

However, the performance of ANN-based PMLs(H. M. Yao and L. Jiang, “Machine-Learning-Based PML for the FDTD Method,” IEEE Antennas Wirel. Propag. Lett., vol. 18, no. 1, pp. 192–196, 2019) heavily depends on the quality of training data, which is often derived from multilayer PMLs, such as layers complex-frequency-shifted (CFS)-PML. This introduces inherent errors stemming from the numerical methods used in the training process. Furthermore, existing ANN-based PMLs have not been explored for the wave-equation-based FDTD method.

To address these limitations, we propose an ANN-incorporated absorbing boundary condition tailored for the wave-equation-based FDTD method(J.-F. Wang, G. Li, and Z. Chen, “Convolutional Implementation and Analysis of the CFS-PML ABC for the FDTD Method Based on Wave Equation,” IEEE Microw. Wirel. Compon. Lett., vol. 32, no. 7, pp. 811–814, 2022). Our approach collects training data from a large, reflection-error-free computational domain, eliminating errors introduced by multilayer PMLs. The resulting accuracy depends solely on the chosen neural network model. Unlike conventional FDTD methods, which solve Maxwell’s equations involving both electric and magnetic fields, the proposed method focuses exclusively on the wave equation for the electric field, simplifying computations. As a result, our proposed absorbing condition enhances both computational efficiency and accuracy, outperforming traditional ABCs and existing ANN-based boundary conditions.