

Asymmetric PML for the Absorption of Waves. Application to Mesh Refinement in Electromagnetic Particle-In-Cell Plasma Simulations.

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We present an extension of the original Bérenger's formulation of the Perfectly Matched Layer with additional terms and tunable coefficients. We show that under certain constraints on the additional parameters, the newly introduced "medium" does not generate any reflection at any angle or any frequency and is thus a Perfectly Matched Layer (PML). Unlike the original PML, however, the new formulation introduces some asymmetry in the absorption rate and is therefore labeled APML for Asymmetric Perfectly Matched Layer.

We present the numerical considerations that have led us to introduce such a medium as well as its theory. Several finite-difference numerical implementations are derived (in one, two and three dimensions) and the performance of the APML is contrasted with that of the PML in one and two dimensions. Using plane wave analysis, we show that our APML implementations lead to higher absorption rates than the considered PML implementations. Although we consider the finite-difference discretization of Maxwell-like equations only, the APML system of equations may be used with other discretization schemes, such as finite-elements, and may be applied to other equations, for applications beyond electromagnetics.

Taking advantage of the high rates of absorption of the APML, we have devised a new strategy for introducing the technique of Mesh Refinement into electromagnetic Particle-In-Cell plasma simulations. Previous attempts have relied on algorithms of various complexity to connect calculations of EM fields at the border of regular grids at different resolutions. Most were unstable at low wavelengths while the stable ones suffered from inherent limitations on their ability to avoid spurious wave reflection at interfaces and were complicated to implement.

Instead, we propose a technique by substitution using the following procedure: (1) a usual EM-PIC calculation is performed on a grid G at resolution R_1 , (2) in an area A where one is interested in a higher resolution R_2 , we perform EM-PIC calculations on a patch P_1 at R_1 and a patch P_2 at R_2 , both covering A and being terminated by an APML. The EM force F acting on a macroparticle is $F(G)$ outside A and is $F(G)-F(P_1)+F(P_2)$ inside. We will present the details of the algorithm as well as 2-D examples of application to laser-plasma interaction in the context of fast-ignition.