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Evanescent Field Boundary Conditions for Modelling of Light Propagation

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Abstract

In this work, we introduce a straightforward and original approach for evanescent field boundary conditions (EBCs), which can be, in principle, applied in both Beam Propagation Method (BPM) and Finite Difference Time Domain Method (FDTD) numerical simulations. Importantly, suggested method may serve as an efficient alternative to typically applied ones, such as transparent boundary conditions (TBCs), absorbing boundary conditions (ABCs) or perfectly matched layer (PML) boundary conditions, giving comparable or even better results in terms of smaller reflections and of shorter computation time. Definition of proposed evanescent function, a way of its practical implementation, as well as an influence of its parameters on the light beam propagation in the free-space and in exemplary photonic structures are described in detail. In addition, results of EBCs application are compared with those achieved for Dirichlet, TBC and PML boundary conditions used in analogous arrangement of the physical systems.

Keywords: numerical simulations, boundary conditions, beam propagation method.
2010 MSC: 00-01, 99-00

1. Introduction

Modelling of electromagnetic wave propagation is a very important branch of scientific research from both theoretical and experimental point of view. The main reason for this is that new photonic materials, structures and systems, as well as the effects of light-matter interactions can be easily tested and optimized before actually being fabricated. In most cases numerical methods are applied to solve equations describing electromagnetic (EM) wave propagation and currently many suitable schemes are available, including those based on the Beam Propagation Method (BPM) [1] or the Time Domain Method (TDM) [1]. Their successive long-term development has resulted in many different algorithms, such as Finite Difference Beam Propagation Method (FD-BPM) [2], Finite Difference Time Domain Method (FDTD) [3], Finite Element Beam Propagation Method (FE-BPM) [4], Finite Element Time Domain Method (FETDM) [5] or Fast Fourier Transformation Beam Propagation Method (FFT-BPM) [6, 7]. Choice of the specific algorithm depends on the particular case under consideration. Nevertheless, no matter which method is put to practical use, there is one common issue occurring in numerical algorithms, that is directly related to a finite size of the computational window. Application of suitable boundary conditions may be considered as a possible way of dealing with mentioned restriction. In fact, Maxwell's equations, as well as their reduced forms, cannot be solved numerically without specifying the boundary conditions, while numerical computation window can not have an infinite dimension. In this sense, boundary conditions, which in principle are only numerical artefacts designed to limit a computation window in a region where physical problem has no boundary at all, play significant role in scientific computing. They can easily make a difference between a correct and an incorrect computation, or between a fast and a slow one. The simplest ones, namely Dirichlet and Neumann boundary conditions, may cause reflections from the edge of the calculation window, resulting in EM field distortions and additional numerical errors. While total elimination of such reflections is difficult or even impossible to achieve,they can be minimized by considering boundaryless beam propagation [8]. Other options are assumptions for the field close to boundaries of the calculation window to be of: (i) nearly plane wave exponential behaviour or (ii) evanescent in some area in the certain distance from the edge of the calculation window. The first of the aforementioned assumptions corresponds to well-known transparent boundary conditions (TBCs). Proposed first by Hadley [9, 10] TBCs are well-suited when applied for slowly-varying electromagnetic waves and may be successfully applied under the paraxial approximation, while failing for wide angle and for broad spectral range. They are ineffective for more complicated wave patterns as it is used for simulation of two Gaussian beams propagating simultaneously in the system. Some improvement of the TBCs scheme can be found in its generalized form

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