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FINITE-DIFFERENCE MODELING OF DIELECTRIC INTERFACES IN ELECTROMAGNETICS AND PHOTONICS

MODELOVANJE RAZDVOJNIH DIELEKTRIČNIH POVRŠI U ELEKTROMAGNETICI I FOTONICI METODOM KONAČNIH RAZLIKA

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Sadržaj – *Metoda konačnih razlika (FDM) omogućava brzu i efikasnu analizu i simulacije elektromagnetskih polja, što je posebno pogodno za CAD programiranje i dizajn. Mana metode konačnih razlika u frekvencijskom domenu (FDM-FD) je nedovoljno tačna diskretizacija razdvojnih površi dielektrika različitih permitivnosti, a uzrok je neizbežna takozvana stepeničasta aproksimacija. U ovom radu je dat pregled i međusobno poređenje nekih veoma atraktivnih numeričkih koncepata koji omogućavaju efikasan tretman razdvojnih dielektričnih površi. Takozvane poboljšane FD šeme omogućavaju izvođenje FD formula u okolini razdvojnih površi, uz drugi red tačnosti. Metode transformacije koordinata, kao što je strukturno vezana metoda konačnih razlika, omogućavaju da postupak FD diskretizacije prati lokalnu geometriju analizirane strukture. Jedan drugi pristup, koji je predložio autor rada, dovodi do FD formula veće tačnosti od često korišćenih poboljšanih FD formula.*

Abstract – *The finite difference method (FDM) enables electromagnetic field calculations and simulations at reduced time, what is particularly suitable for CAD software implementations. Frequency domain based FDM (FDM-FD) discretization of structures with the permittivity step at the interface between two dielectric regions suffers from reduced accuracy due to the inevitable staircase approximation. In this paper a few very attractive numerical concepts that allow accurate FD treatment of dielectric interfaces are reviewed and compared. So-called improved FD-schemes enable the derivation of FD formulas providing true accuracy of the second order. In co-ordinate transformation methods, such as the structure related FDM, the discretization procedure exactly matches the local geometry of the structure under analysis. Another approach, proposed by the author, results in the derivation of FD formulas with better accuracy then often-used improved FD formulas.*

Keywords – *Numerical modeling, Finite difference method, Electromagnetics, Photonics.*

1. INTRODUCTION

The finite-difference method (FDM) is widely used numerical method in electromagnetics, [1,2]. FDM has been extensively used in photonics and optoelectronic design in mode solvers, in beam propagation methods (BPMs), [3-5], as a standard method of choice in simulation programs or computer-aided design (CAD) tools where shortened simulation time is mandatory. BPM techniques available include both frequency and time domain approaches for analyzing optical waveguides and waveguide-based optoelectronic devices. CAD applications based on the frequency domain FDM (FD-BPM) have become particularly an attractive approach because of the simplicity of FDM implementation and the sparsity of FDM resultant matrix.

Most conventional implementations of FD-BPM for structures with constant cross-section in a rectangular co-ordinate system are characterized by low-order truncation errors. Difference equations obtained by standard centered differencing in two dimensions in homogeneous regions are second-order accurate, $n = 2$, or $O(h^2)$, where h is the FD mesh size. Near the step-index dielectric interfaces, accuracy usually drops to $n-1$, and near dielectric corner points difference equations are $(n-2)$th-order accurate, resulting with $(n-1)$th-order of accuracy of the modal index and modal electromagnetic field. This deficiency of FDM, known as the inevitable staircase approximation of the dielectric boundaries, has pushed most of the researches to concentrate either on the development of the new numerical approaches, or the solution techniques employed to solve the large matrix equation sets that usually result during the FD discretization procedure.

Over the last two decades, certain research efforts have been spent on increasing understanding of the effects of truncation error near the step-index dielectric interfaces and increasing the accuracy of the employed FD discretization procedure, both in semi-vectorial and full-vectorial FD-BPM formulations. The starting point was Stern's work [6] where the concept of a semi-vectorial mode, which neglects minor field components (quasi-TE and quasi-TM cases), has been