p-Refined Large-Domain 3-D Curvilinear FEM Solutions of Arbitrarily Loaded and Shaped Waveguide Sections and Bends in the Time Domain

Nada J. Šekeljić*[1], Milan M. Ilić[1],[2], and Branislav M. Notaroš[1]
(1) Electrical & Computer Engineering Department, Colorado State University, Fort Collins, CO
(2) School of Electrical Engineering, University of Belgrade, Serbia
inadasek@engr.colostate.edu, milanilic@etf.rs, notaros@colostate.edu

The finite-element method (FEM) has been well established as a method of choice for applications involving full-wave three-dimensional (3-D) solutions to closed-region (e.g., waveguide and cavity) problems based on discretizing partial differential equations (PDEs) in electromagnetics, especially for structures containing inhomogeneous and complex electromagnetic materials, as well as geometrical irregularities. In terms of the numerical discretization of PDEs in spatial coordinates, conventional 3-D FEM tools are low-order, small-domain techniques, using low-order basis functions for the approximation of electric and/or magnetic fields on small elements and *h*-refinement (mesh refinement). In addition, while most of the available FEM techniques perform the analysis in the frequency domain, FEM analysis of closed-region structures in the time domain (TD) is also of great theoretical and practical importance.

This paper focuses on accurate and efficient FEM modeling and analysis of arbitrarily loaded and shaped 3-D waveguide sections and bends in the time domain. The spatial discretization of PDEs is performed using high-order basis functions on large elements and *p*-refinement, where the field-approximation orders over elements (where needed) are increased to improve the accuracy of the solution without subdividing the elements. The waveguide port boundary condition is used for mesh truncation. The suitability of the technique for *p*-refinement is substantially enhanced by the use of generalized curved hexahedral finite elements of arbitrary geometrical-mapping orders for geometrical modeling and by the hierarchical nature of field bases, as well as by high-order modeling of materials in elements, which can be filled with inhomogeneous anisotropic media with continuous spatial variations of material parameters. The temporal discretization of PDEs is carried out using implicit unconditionally stable finite difference scheme constituting the Newmark-beta method (N. J., Sekeljic, M. M. Ilic, and B. M. Notaros, "Higher Order Time-Domain Finite Element Method for Microwave Device Modeling with Generalized Hexahedral Elements," IEEE Transactions on Microwave Theory and Techniques, Vol. 61, No. 4, April 2013, pp. 1425-1434). Combined with the time-stepping solution in the FEM-TD method, the higher order spatial basis functions are able to accurately and efficiently capture the transient field response across large finite elements.

Numerical examples include transient analysis of a variety of 3-D waveguide structures, such as single and cascaded U- and S-shaped *E*- and *H*-plane waveguide bends and waveguide sections with various metallic and homogeneous and continuously inhomogeneous dielectric loads. The results show excellent agreements with indirect numerical solutions obtained from the higher order FEM in the frequency domain and alternative full-wave numerical solutions of different types, as well as measurements. The emphasis is on the *p*-refinement and convergence properties of the solutions, along with conformal geometrical modeling. The examples demonstrate very effective higher order hexahedral meshes constructed from a very small number of large curved conformal finite elements (large domains) and *p*-refined high-order field expansions, which results in solutions with minimal total numbers of unknowns.