Krylov Model Order Reduction of Finite-Element Approximations of Dispersive Electromagnetic Boundary Value Problems

Hong Wu and Andreas C. Cangellaris
Center for Computational Electromagnetics & Electromagnetics Laboratory
ECE Department, University of Illinois at Urbana-Champaign,
Urbana, IL 61801, U.S.A.
Phone: 217.333.6037; Fax: 217.333.5962; E-mail: {hongwu, cangella}@uiuc.edu

Abstract

In the context of state-space representations of linear systems of high dimension the objective of model order reduction (MOR) is the development of a new model of the linear system of much smaller dimension than the original one, yet capable of describing the behavior of the original model with acceptable accuracy over a broad frequency bandwidth. It is this attribute of MOR that has prompted its application for expediting solution efficiency and reducing modeling complexity of the large linear circuits associated with high-speed interconnect modeling in state-of-the art integrated electronic systems. The discretization of the spatial derivatives in Maxwell's time-dependent equations using finite methods results in state-space semi-discrete approximations of the electromagnetic system. Hence, the same techniques that have been used successfully for model order reduction of large linear circuits can be adopted with only slight modifications for the reduced-order modeling of electromagnetic systems. Among them, Krylov subspace methods have become the most popular, thanks to their numerical robustness, especially when broadband reduced-order macromodels of multi-port electromagnetic structures are to be generated.

When the electromagnetic properties of the materials are frequency dependent, characterized by Krylov subspace methods are not as readily applicable and alternative model order reduction techniques are sought. In addition to media that naturally exhibit frequency dependent electromagnetic properties, there are numerous application of practical interest where the ability to incorporate in a convenient manner in the electromagnetic model frequency-dependent relationships between the fields and associated flux quantities provides for enhanced modeling versatility and increased computational efficiency. Most typical examples are: a) the utilization of frequency-dependent surface impedance boundary conditions to account for skin effect loss in metallic volumes; b) the utilization of frequency-dependent multi-port, matrix transfer functions for the macromodeling of subdomains of arbitrary (passive) material composition; c) the macroscopic description of the electromagnetic attributes of artificially constructed materials (metamaterials).

In this paper a systematic methodology is proposed for extending the application of Krylov subspace techniques to the model order reduction of passive electromagnetic structures with material and or boundary conditions exhibiting general frequency dependence. The proposed methodology is based on the extension of the technique introduced in (Z. Bai and Y. Su, SIAM J. Sci. Comput., vol. 26, no. 5, 2005) for the reduction of second-order dynamical systems. The proposed methodology is validated through its application to the analysis of a bandpass microstrip filter with skin effect loss taken into account and the extraction of the propagation characteristics of a microstrip line on a dispersive dielectric substrate.