Krylov Model Order Reduction of Finite Element Models of Packaging Structures with Embedded Frequency-dependent Multiports

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In an effort to tackle the complexity of the electromagnetic analysis of the signal and power distribution networks (referred to, in the following, as SDN and PDN, respectively) in state-of-the-art integrated electronic systems, their decomposition into several parts and the development of hierarchical models for some of the resulting portions is often utilized. The term "hierarchical" is used here to define a model development process where the electromagnetic properties of different portions of the structure under modeling are described in terms of models of different degrees of complexity and, hence, accuracy, the choice of which is dictated by the specific attributes of the structure and the modeling objectives. A most representative example of a structure for which such hierarchical analysis can be applied is the electromagnetic quantification through modeling of noise generation and coupling in multi-layered substrate with multiple power and ground planes and multiple signal layers sandwiched between the planes. Assuming that multi-conductor transmission line (MTL) models can be used for the coupled interconnects in the nets, the complexity of the finite element mesh for the multi-layered substrate is simplified significantly. An integrated model for the combined SDN and PDN system, which is needed for the accurate quantification of switching noise generation and coupling is then obtained by embedding the MTL models in the finite element model, through the proper interfacing of the two models at the signal vias. Considering the fact that different types of models can be used for the coupled interconnects (ranging from lumped RLCG models for short sections, to more accurate transmission line theory-based models, or even comprehensive electromagnetic models extracted either through a full-wave solver), the hierarchical nature of the resulting model is evident.

This paper presents a methodology for the direct generation of reduced-order macromodels of the hybrid models obtained from the application of the aforementioned hierarchical modeling process. More specifically, we are concerned with finite element-based models that include frequency- dependent macromodels for portions of the SDN and/or PDN, described in terms of a multiport transfer function matrix with its elements cast in terms of rational functions of the complex frequency $s = j\omega$. The proposed methodology utilizes Krylov subspace-based methods for the direct generation of compact (low-order) macromodels of the overall structure. Like in the application of Krylov subspace methods for the direct model order reduction of finite element models of packaging structures including lumped elements [1], the resulting methodology allows for the construction of the overall multiport macromodel over a broad frequency interval, at essentially the cost of a single frequency point solution of the finite element system.

The proposed methodology will be presented and its validity and efficiency will be demonstrated through its application to typical SDN and PDN structures. The paper will conclude with a discussion of some issues pertinent to the passivity of the generated reduced-order macromodel.

REFERENCES

1. Wu, H. and A. C. Cangellaris, *IEEE Trans. Microwave Theory Tech.*, Vol. 52, 2305, 2004.