Parameterized Model Order Reduction of Nonlinear Circuits and MEMS

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The presence of several nonlinear analog circuits and micro-electro-mechanical (MEM) components in modern mixed-signal system-on-chips (SoC) makes the fully automatic synthesis and optimization of such systems an extremely challenging task. Our research is the development of techniques for generating parameterized reduced-order models (PROM) of nonlinear dynamical systems. These reduced-order models could serve as a first step towards the automatic and accurate characterization of geometrically complex components and subcircuits, eventually enabling their synthesis and optimization. Our approach combines elements of an existing non-parameterized trajectory piecewise linear method [1] for nonlinear systems with an existing moment matching parameterized technique [2] for linear systems. By building on these two existing methods, we have created four different algorithms for generating PROMs for nonlinear systems. The algorithms were tested on three different systems: a MEM switch, shown in Figure 1, and two nonlinear analog circuits. All of the examples contain distributed strong nonlinearities and possess some dependence on several geometric parameters.

The reduced-order models can be constructed to possess strong local or global accuracy in the parameter-space, depending on which algorithm is used. Figure 2 shows the output of one PROM created for the example in Figure 1 and compared to the field solver output of the full nonlinear system. In this example the system was parameterized in the width of the device and simulated at a parameter value different from the values at which the model was created. We found that in general the best algorithm is application-specific, but the PROMs are very accurate over a practical range of parameter values. For further details on parameter-space accuracy and cost of the algorithms, see [3].

REFERENCES


Development of Specialized Basis Functions and Efficient Substrate Integration Techniques for Electromagnetic Analysis of Interconnect and RF Inductors

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The performance of several mixed-signal and RF-analog platforms depends on substrate effects that need to be represented in the library model with critical field solver accuracy. For instance, substrate-induced currents in RF inductors can severely affect quality and hence RF filter selectivity. We have developed an efficient approach to full-wave impedance extraction that accounts for substrate effects through the use of two-layer media Green’s functions in a mixed-potential-integral-equation (MPIE) solver. In particular, we have developed accelerated techniques for both volume and surface integrations in the solver.

In this work, we have also introduced a technique for the numerical generation of basis functions that are capable of parameterizing the frequency-variant nature of cross-sectional conductor current distributions. Hence skin and proximity effects can be captured utilizing many fewer basis functions in comparison to the prevalently-used piecewise-constant basis functions. One important characteristic of these basis functions is that they only need to be precomputed once for a frequency range of interest per unique conductor cross-sectional geometry, and they can be stored off-line with a minimal associated cost. In addition, the robustness of these frequency-independent basis functions is enforced using an optimization routine.

We have shown in [2] that the cost of solving a complex interconnect system using our new basis functions can be reduced by a factor of 170 when compared to the use of piecewise-constant basis functions over a wide range of operating frequencies. Furthermore our volume and surface integration routines result in additional efficient improvement by a factor of 9.8 as shown in [1]. Our solver accuracy is validated against measurements taken on fabricated devices.

Figure 1: Measured and simulated Q-factors for a square RF inductor with an area of 15 mm x 15 mm and surrounded by a ground ring.

Figure 2: Our basis functions avoid the expensive cross-sectional discretization shown in figure necessary to account for trapezoidal cross-sections or skin and proximity effects.

REFERENCES


A Quasi-convex Optimization Approach to Parameterized Model-order Reduction

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This work proposes an optimization-based model-order-reduction (MOR) framework. The method involves setting up a quasi-convex program that explicitly minimizes a relaxation of the optimal H-infinity norm MOR problem. The method generates guaranteed stable and passive reduced models and it is very flexible in imposing additional constraints. The proposed optimization approach is also extended to the parameterized model reduction problem (PMOR). The proposed method is compared to existing moment-matching and optimization-based MOR methods in several examples. For example, a 32nd order parameterized reduced model has been constructed for a 7-turn RF inductor with substrate (infinite order) and the error-of-quality factor matching was less than 5% for all design parameter values of interest.

Figure 1: A 7-turn RF inductor for which a parameterized (with respect to wire width and wire separation) reduced model has been constructed.

Figure 2: Matching of quality factor of 7-turn RF inductor when wire width = 16.5 µm, wire separation = 1, 5, 18, and 20 µm. Blue dash line: Full model. Red solid line: ROM.

REFERENCES