Causality Verification for Data-Driven Macromodeling

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S. Grivet-Talocia[1] and M. Bandinu[2]

[1]Dept. Electronics and Telecommunications, Politecnico di Torino, Italy
[2]IdemWorks s.r.l., Torino, Italy

The automated design and verification of electronic systems relies on accurate and robust models of components, interconnects, and subsystems. In particular, Signal and Power Integrity verification requires low-complexity models for the numerical prediction of performance degradation effects due to parasitic couplings, near-field electromagnetic interaction, and non-ideal behavior of components and materials. These models, which are often derived from tabulated frequency responses obtained by direct measurements or commercial electromagnetic solvers, should be cast in state-space form or as equivalent circuit netlists, for enabling system-level verification based on standard circuit or ODE solvers.

This contribution considers the standard problem of identifying a reduced-order model with transfer function $H(s) = C(sE - A)^{-1}B + D$, where $\{E, A, B, C, D\}$ is a suitable (generalized) state-space realization, starting from a finite number of samples of the frequency response $\hat{H}_k$ available at frequencies $s_k = j\omega_k$, with $k = 1, \ldots, K$. Several reliable methods exist for this task, including Vector Fitting [2] or Loewner approaches [3]. When dealing with passive structures, such algorithms should be complemented by passivity verification and enforcement to ensure inconditional stability in subsequent transient simulation. An overview of passive macromodeling techniques is available in [1].

There are some situations where all these methods will fail. We discuss the possible reasons for such failures, and we review the various algorithms that can be used to predict them. A frequent scenario is encountered when the available frequency samples are affected by some hidden non-causal components, which may result from measurement errors or noise, as well as from inappropriate setup or usage of electromagnetic solvers. Causality, intended as compliance with a suitable set of dispersion relations [5, 4], is a fundamental prerequisite for successful extraction of a stable and passive model. Causality verification is in fact very challenging when a finite number of frequency samples is available, due to truncation and discretization errors that inevitably affect the numerical verification of dispersion relations. In addition, more subtle checks are required to verify that the sampling density of the raw data is sufficient for the extraction of a physically meaningful model. This contribution will show how robust and reliable data consistency checks can be performed, by comparing alternative approaches based on direct dispersion relation verification and stable/unstable rational approximation.

References

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