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Doctoral dissertation.

Modeling and Simulation of Nonlinearly Loaded Electromagnetic Systems via Reduced Order Models

A Case Study: Energy Selective Surfaces

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Dissertation Summary

Modern applications require sensitive electronic devices to process high-speed signals under exposure to several disturbing sources. The Electromagnetic Interference (EMI) is one of the main threats for reliable and robust electronic systems, where different external Electromagnetic (EM) sources can compromise (or even destroy) unprotected devices. An example is the High-Intensity Radiated Field (HIRF) induced either by a lightning strike or by a standard radiation transmitter (as well as an intentional EM weapon) that can induce system failure or even damage.

Recently, the Electromagnetic Compatibility (EMC) community has shown an increasing interest in energy-selective surfaces. These novel structures distinguish between high-power interference and weaker signals, enabling protection and (wireless) communication at two different energy levels. A simple energy-selective enclosure is designed by covering an aperture of a conductive shield with a grid of nonlinear devices, usually diodes. The diodes array remains transparent to weak signals, while the energy of strong fields is attenuated thanks to the nonlinear response of the diode grid.

Repeated numerical simulations are required to assess the Shielding Effectiveness (SE) of these structures, i.e. their performances, under different working conditions (in terms of shield parameters, incident field or termination type). On one hand, full-wave solvers allow computing the transient solution of the scattering problem with a relevant computational cost at every change in the system configuration. On the other hand, the unloaded enclosure is a Linear Time Invariant (LTI) system that obeys Maxwell's equations. This observation opens the investigation to hybrid simulation approaches that convert the fully coupled linear/nonlinear EM problem into an equivalent circuit formulation. The system is represented by a linear multiport loaded with lumped nonlinear terminations, and excited with the contribution of the incident field.

A data-driven macromodeling framework fits the above procedure and enables a reusable Reduced Order Model (ROM) of the (linear) shielding enclosure. Such macromodel can be extracted during a characterization phase, and then exploited to perform multiple efficient transient simulations for

performance assessment. Several challenges affect both generation of the ROM and their fast transient simulation. The objective of this work is to address such challenges, in order to establish a complete modeling and simulation framework that is robust and efficient, so that it can be used as a numerical tool during computer-aided design of energy-selective enclosures.

The first contribution of this work is a sequence of data preprocessing strategies, that combine a regularization and extrapolation procedure in a suitable asymptotic modal domain, with structured data compression approaches built on a modified Singular Value Decomposition (SVD). We show that these complementary approaches drastically improve model accuracy and robustness, while reducing model sensitivity and identification complexity. Then, we address the large-scale modeling problem by providing a structured and compressed rational fitting framework. We equip this process with an efficient passivity verification based on an adaptive-sampling strategy, since we have experienced that standard approaches are either unreliable or impractical due to high computational cost. A passivity enforcement scheme takes advantage of this algorithm and provides a final model that is suitable for guaranteed stable numerical simulations. The last contribution of this work is a robust hybrid transient solver that combines the above macromodeling framework with an efficient Waveform Relaxation (WR) based decoupling scheme. The presented result combines an inexact Newton-Krylov iteration and a time partitioning strategy to improve the well-known convergence issues of a standard WR, resulting in a fast and reliable transient solver for energy-selective shields and, in general, for nonlinearly-loaded large-scale electromagnetic structures.

Several numerical results demonstrate how the various formulations and algorithms introduced in this work effectively advance the state-of-the-art.