ScuDo
Scuola di Dottorato ~ Doctoral School
WHAT YOU ARE,TAKES YOU FAR

XXXIV Cycle

Fast Simulations of Energy Selective Surfaces via Reduced Order Models

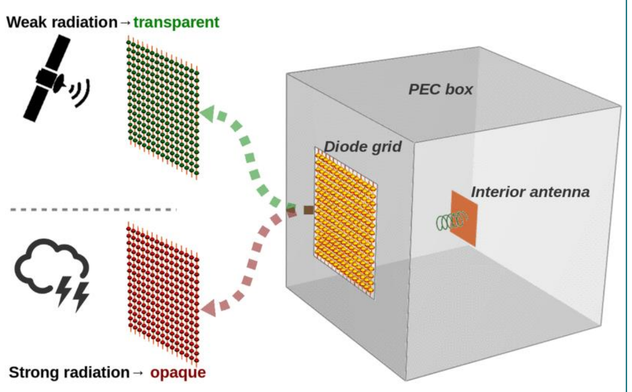
Marco De Stefano

Supervisor: Prof. S.Grivet-Talocia

Research context and motivation

- **ElectroMagnetic Interference (EMI)** is a major concern in robust electronic design.
- Different kind of **wireless applications** are likely to **coexist in the same environment: communication** must be **allowed,** but all components should be **shielded** from dangerous signals, i.e. electromagnetic pulses (**EMP**) and high-power microwaves (**HPM**).
- Conventional shielding techniques involve passive coating structures (absorbers), to dissipate part of the energy of an incident wave.
- **Metamaterials**, combined with **nonlinear circuitry** (e.g. diodes bridges), are gaining attention for improving electromagnetic shielding.
- **Nonlinear elements** allow to **decouple** the attenuation of **high power** and **low power signals.**

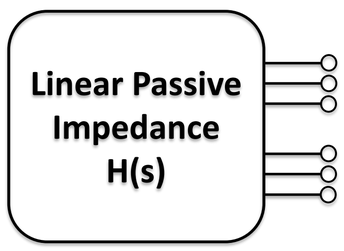
- **Numerical techniques**, to design an energy selective structure, include:
  - **co-simulation** approaches, that combine full-wave and circuit solvers;
  - **hybrid approaches**, based on
    1. decoupling linear from nonlinear structures;
    2. building dedicated behavioral models;
    3. solving with fast methods.



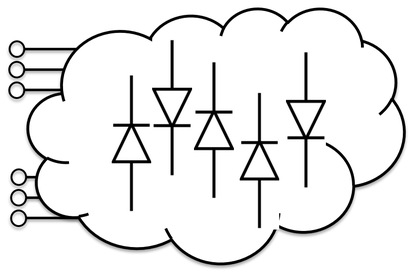
Field-intesity-dependent protection scheme from:
Yang, C., Brüns, H.D., Liu, P. and Schuster, C.. "*Impulse response optimization of band-limited frequency data for hybrid field-circuit simulation of large-scale energy-selective diode grids*", IEEE Trans. EMC, 58(4), pp.1072-1080.

Addressed research questions/problems

In **collaboration** with the **Institute of Electromagnetic Theory of the Hamburg University of Technology (TUHH)**, that provides the expertise necessary for the characterization of the electromagnetic system, we develop a fast time-domain hybrid solver, that must scale to high-complexity energy-selective surfaces with thousands (or more) NL elements.



ELECTRICALLY LARGE STRUCTURES
Macromodeling (and Passivity) Issues



SEVERAL NONLINER LOADS
Expensive Simulations

- Can we exploit the **port signal redundancy** of the linear part, and **couple** the two systems **only** in a **reduced space**? Can we extend this concept to the time-domain?
- Can we apply a **reduction** technique also to the **nonlinear** part?
- Can we take advantage of the two reductions, and work only with a very **limited amount of variables** to obtain the full time domain behavior of the system? Can we **sparsify** the transformations at play to reduce even further the complexity at each time step?

Submitted and published works

- **Journal:** E. Fevola, A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*An Adaptive Sampling Process for Automated Multivariate Macromodeling Based on Hamiltonian-Based Passivity Metrics*". IEEE TCPMT, 2019 (early access), pp. 1-14.
- **Journal**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*Enforcing passivity of parameterized LTI macromodels via Hamiltonian-driven multivariate adaptive sampling*". IEEE TCAD, 2018 (early access), pp. 1-14.
- **Conference**: T. Bradde, S. Grivet-Talocia, M. De Stefano, A. Zanco," *A Scalable Reduced-Order Modeling Algorithm for the Construction of Parameterized Interconnect Macromodels from Scattering Responses*". IEEE EMC SI-PI 2018. Long Beach, 30 July – 3 August 2018. pp. 650-655. **BEST PAPER AWARD**
- **Conference**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano, "*On stabilization of parameterized macromodeling*". In: IEEE SPI 2019, Chambery, 18-21 June 2019. pp. 1-4. **BEST STUDENT PAPER AWARD**
- **Conference**: M. De Stefano, S. Grivet-Talocia, T. Bradde, A. Zanco, "*A framework for the generation of guaranteed stable small-signal bias-dependent behavioral models*". In: IEEE EuMIC 2018, Madrid, 23-25 September 2018. pp. 142-145.
- **Conference**: T. Bradde, P. Toledo, M. De Stefano, A. Zanco, S. Grivet-Talocia, P. Crovetti, "*Enabling fast power integrity transient analysis through parameterized small-signal macromodels*", EMC Europe, Barcelona, 2-6 September 2019, pp.1-6
- **Conference**: A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano. "*Multivariate macromodeling with stability and passivity constraints*". In: IEEE SPI2018, Brest, 22-25 May 2018. pp. 1-4.
- **Conference**: E. Fevola, A. Zanco, S. Grivet-Talocia, T. Bradde, M. De Stefano," *A 3D passivity-based adaptive algorithm for automated parameterized macromodeling of electromagnetic structures"*. ICEAA 2019, Granada, 9-13 Sept. 2019, pp. 1-4.

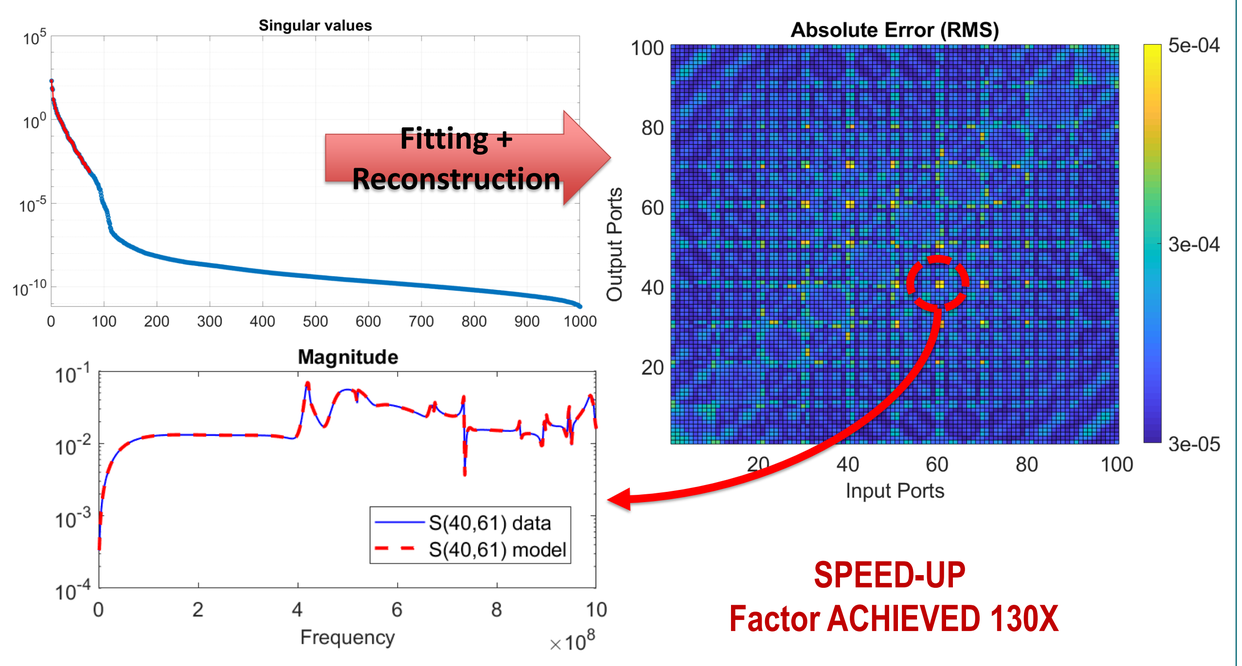
Novel contributions

- **Consolidation** of a **reliable passive compressed macromodeling** procedure, improving the passivity characterization in the projected (reduced) space (now unavailable).
- Realization of an **hybrid simulation environment** that takes advantage of the **compressed** model representation enabling fast **time-domain numerical simulations** of the entire interconnect system.
- Further **reduction** of the computational complexity by exploiting redundancies of the **nonlinear part,** and integration of the obtained small model in a **time-domain set-up**.

Time Domain Simulation Environment

Adopted methodologies

- Surrogate modeling via rational function approximation, such as **Vector Fitting (VF)**;
- **Compressed macromodeling** techniques that exploit spatial correlation between port signals, based on Singular Value Decomposition (**SVD**);



SPEED-UP
Factor ACHIEVED 130X

- **Discrete Empirical Interpolation Methods (DEIM)**, for the dimensional reduction of the nonlinear loads;
- **Waveform relaxation**, as a time domain simulation technique;
- **Compressed sensing techniques**, for the sparsification of constant transformations;
- **Compressed tensor approximations**, most likely to exploit smart representations leading to faster and more efficient modeling algorithms.

Future work

- Address scalability of the entire modeling procedure, through the realization of a **flexible yet general formulation** of linear model structure **in a compressed space**.
- **Time-domain formulation** and application to the **coupled compressed systems.**
- **Enhancement of the passivity characterization and enforcement** for the linear system behavioral model in a compact representation.
- Application of **reduction techniques for multiport nonlinear circuit blocks**, and integration within the overall time-domain simulation environment.

List of attended classes

- 01QRQRV – Compressed sensing: theory and applications (28/08/2019, 4 CFU)
- 01QTEIU – Data mining concepts and algorithms (14/12/2018, 4 CFU)
- 01SFURV – Programmazione scientifica avanzata in Matlab (27/3/2019, 4 CFU)
- 01TCORV – Surrogate and compact modeling: theory for the user (12/07/2019, 4 CFU)
- Ext. Activity – Sparsity for Physics, Signal and Learning, INRIA, Paris (June 2019, 22h)
- 01RISRV – Public Speaking (4/3/2019, 1 CFU)
- 01SYBRV – Research Integrity (10/12/2019, 1 CFU)
- 01QORRV - Writing Scientific Papers in English (18/4/2019, 3 CFU)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering