OBJECTIVE OF THE PROJECT

This project aims at developing efficient methods of automatic synthesis of optimal compact cells to be subsequently used as building blocks of miniaturized microwave circuits. Moreover, automatic tools for the comparison, assessment, classification, and selection of compact cells will be realized. These specified procedures will embody the concept of surrogate-based optimization and involve electromagnetic models of variable fidelity, fast space-mapping-corrected equivalent circuits, as well as data-driven models, apart from local and global optimization methods, and specification adjustment techniques. The scope of the project also covers an extensive optimization-based study of various configurations of reference circuits, which aims at identifying the available families of numerical design solutions pertaining to each class of microwave circuits under consideration and opens an avenue for finding novel compact structures that outclass conventional-solution-based designs. In addition, a procedure for rapid fine-tuning of reduced-size microwave circuit composed of previously selected optimal compact cells will be proposed.

BASIC RESEARCH DESCRIPTION

The project aims at the development of efficient procedures for EM-simulation-driven design of compact microwave/RF components and structures of high complexity. It will be realized in the following stages:

- Development of methodologies for creating fast surrogate models. The emphasis will be on physics-based models that embed knowledge about the structures of interest (e.g., models involving coarse-discretization simulations or simplified physics description). Combination of low-fidelity simulation models and structure decomposition (possible due to the modular architecture of majority of compact structures) with response-surface approximations (particularly local ones) is another promising direction towards reducing the cost of surrogate model setup and evaluation cost.
- Development of fast, robust and reliable simulation-driven optimization algorithms. Our approach will be based on surrogate-based optimization (SBO), where the computational burden is shifted into an inexpensive replacement model and the high-fidelity EM-simulation is only launched occasionally. The specific techniques to be developed include: (i) two-level surrogate-based optimization (involving both equivalent circuit and response surface approximation cell modeling), (ii) concurrent cell design with subsequent fast tuning based on local approximation models, (iii) SBO with constrained extraction of model parameters (for improved convergence), as well as (iv) utilization of co-calibrated port technology for fast structure tuning.
- Software implementation and numerical validation of modeling and optimization techniques.
- Design of compact microwave/RF structures for selected applications, which is mandatory for verification of practical usefulness of the tools (both modeling and optimization) developed under the project.

JUSTIFICATION FOR CHOOSING THE RESEARCH TOPIC

The review of the current state of knowledge on microwave circuit miniaturization revealed several pending issues to be resolved. The core problems are highlighted below:

1. The general approach to microwave circuit size reduction involves decomposition of a uniform-transmission-lines-based reference structure, followed by replacement of its building blocks with compact cells whose parameterized topologies are proposed by the designer in a completely arbitrary manner [6]–[12]. Electrical parameters exhibited by arbitrary chosen cells and their relationship with physical dimensions cannot be established prior to design closure. This means—in practice—that the entire design process is an extremely laborious trial-and-error routine that requires repeated remodeling of compact cell topology in case of design failure. It also fails to yield optimum circuit realizations.
2. The selection of a reference circuit (as outlined above) strictly determines electrical parameters (in particular, characteristic impedance and electrical length) for a compact cell to exhibit. Using an analytically-derived design solution in that regard significantly limits the number of cell realizations that are capable of satisfying such performance specifications. Addressing this issue, for example by finding alternative design specifications for compact cells, may lead to obtaining microwave circuits that are smaller or out-perform conventional-solution-based designs [5].
3. The straightforward modeling techniques available today are either too inaccurate (as in case of equivalent circuits [22]) or computationally too expensive (as for data-driven models [23]) to be directly applied to the multi-dimensional design problem of compact cells with wide-ranged geometric parameters. A possible solution to these shortcomings, as detailed in Sections 3 and 4 of this proposal, is the use of principal component analysis method for dimensionality reduction, in combination with design space confinement based on sparse simulation data of coarse electromagnetic models or space-mapping-corrected equivalent circuits.
4. The use of high-fidelity electromagnetic models is essential for accurate evaluation of miniaturized microwave circuits as well as compact cells they are composed of. However, accurate electromagnetic simulations are extremely expensive, which significantly limits their involvement in optimization procedures, extensive parameter sweeps, comparative analyses, etc. Thus, it is of primary importance to develop accurate, but also computationally efficient design methods [16], [17].