Rapid quasi-global optimization of high-frequency components using forward and inverse surrogates

One of the important prerequisites for reliable design of any engineering system is accurate evaluation of the underlying components and devices. High-frequency electronics, in particular the design of RF and microwave circuits, antenna engineering, photonics, and electromagnetic compatibility are no exceptions here. In all of these areas, although the initial (and necessarily rough) evaluation of the system characteristics can be often obtained by means of circuit simulators, the extraction of reliable data (e.g., critical electromagnetic and thermal stresses, electrical and field performance of antenna systems, etc.) requires full-wave electromagnetic (EM) analysis. EM-driven design has become a commonplace as it allows for incorporation of various effects that cannot be accounted for otherwise (e.g., using transmission line theory). Representative examples include cross-coupling effects in miniaturized RF/microwave structures, proximity effects in antennas, cross-talks and dispersion of digital interconnects, environmental and packaging effects on active devices. Unfortunately, EM analysis of realistic structures is CPU-intensive. Consequently, its design application is challenging. This is especially pertinent to the processes that require numerous and repeated simulations. Representative examples of such procedures include parametric optimization as well as uncertainty quantification (e.g., statistical analysis or tolerance-aware design). In many cases, global search is required due to the necessity of accounting for several objectives and constraints as well as topological complexity of modern structures, which leaves little room for employing engineering insight to locate even roughly a promising region of the parameter space. Unfortunately, population-based metaheuristics (evolutionary algorithms, particle swarm optimizers, differential evolution), routinely used for this purpose are associated with significant computational expenditures. Alternative methods, largely based on surrogate modeling or machine learning techniques, may alleviate these difficulties to a certain extent, yet their computational costs are still considerable.

The primary purpose of this project is the development of techniques for rapid and globalized design optimization of high-frequency structures, including RF and microwave components, antennas, and integrated photonic devices. These methods will go beyond the capabilities of the state-of-the-art approaches in terms of providing improved trade-offs between the efficacy and computational efficiency. The major tasks consist of the development of procedures for rapid design space exploration involving global search on appropriately defined reduced-dimensionality manifolds, exploitation of characteristics features of the system responses (e.g., resonances) to flatten the functional landscape to be handled, as well as low-cost identification of promising parameter space regions involving, among others, variable-fidelity simulation models. Other tasks include software implementation of the optimization frameworks, as well as comprehensive validation and benchmarking against state-of-the-art optimization methods, both local and global.

The project contains several highly innovative components, among others:

- The development of new paradigms for quasi-global EM-driven optimization of high-frequency structures incorporating response feature technology, surrogate modeling, and variable-fidelity EM simulations;
- The development of techniques for expedited knowledge-based quasi-global search procedures, incorporating pre-existing designs acquired during prior work with the structures at hand;
- The development of novel optimization frameworks that enable globalized search at the cost comparable to local algorithms;
- Implementation of software packages for reliable and automated quasi-global optimization of high-frequency structures, interfaced with commercial EM solvers such as CST Microwave Studio or Ansys HFSS.

The principal outcome of the project will be novel, reliable, automated and computationally efficient methodologies for globalized EM-driven design optimization (parameter tuning) of high-frequency structures. The expected results will go far beyond currently available simulation-driven design techniques, thus making a direct and significant impact on the state of the art of high-frequency circuit and component design. They will also contribute to the development of CAD techniques in other engineering areas involving CPU expensive simulations (mechanical, structural, aerospace, etc.).

Furthermore, the results of the project will be published in leading technical journals in the field of RF electronics and disseminated in the form of international conference papers. The developed techniques will be also presented to the leading EM simulation software manufacturers (CST, Sonnet Software Ltd.) to stimulate future collaboration.