Book Review

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Simulation-Driven Design Optimisation and Modelling for Microwave Engineering
by: Slawomir Koziel, Xin-She Yang and Qi-Jun Zhang
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Electromagnetic (EM) simulation is undoubtedly one of the most important tools for contemporary microwave designs. High-fidelity EM analysis allows for realistic performance evaluation of microwave components and structures. It is also utilised directly in the design process, where geometry and/or material parameters of the structure of interest are adjusted in order to meet given performance requirements. The typical workflow would be to perform multiple EM analyses sweeping through adjustable parameters with the aim to find a better design. The entire process, i.e., selection and ordering of particular parameters and corresponding ranges, is normally guided by expert knowledge and engineering experience of designers and decision-makers. The initial design is usually obtained from simplified theoretical models or from existing design options. This hands-on simulation-driven procedure is tedious and time consuming, and it does not guarantee optimum results.

Design automation using numerical optimisation techniques is therefore highly desirable but, at the same time, quite challenging. The major bottleneck is the high computational cost of accurate, full-wave EM analysis: even for individual components, such as filters or antennas, the simulation time may typically be as high as a few hours when using fine discretisations. Conventional optimisation methods – both gradient-based and derivative-free methods – require a large number of such analyses to converge to an optimum design, thus leading to very high computational costs and often becomes impractical. Numerical noise that is usually present in EM-simulated responses (one of the reason being adaptive meshing techniques that results in sometimes substantial change of the mesh topology under relatively small changes of the device's geometry) poses additional challenges, particularly for gradient-based methods. It should be stressed that the rapid development and availability of massive computational resources can only partially alleviate these difficulties because of the tendency to increase the accuracy of the numerical models and the necessity to simulate larger and more complex structures, including not only the components under design but also their environment that might affect the performance. A typical example here could be an antenna housing, connectors and installation fixtures.

The book *Simulation-Driven Design Optimisation and Modelling for Microwave Engineering* by S. Koziel, X.S. Yang, and Q.J. Zhang (Eds.) published by Imperial College Press in 2013 addresses the aforementioned issues from both modelling and optimisation perspectives. The main topic of the book is feasible EM-simulation-driven microwave design and design optimisation. It focuses on the recent techniques and paradigms that have been developed to alleviate the difficulties related to the high-computational cost of EM analysis and allow the engineers to use EM solvers in a computationally efficient manner.

The book contains 16 chapters. The first three chapters provide a compact and self-contained introduction to optimisation methods. Chapter 1 gives a formulation of an optimisation problem and an overview of gradient-based optimisation algorithms, both those utilising line search and trust-region framework. Derivative-free methods (such as pattern search or the well-known Nelder-Mead's algorithm) as well as meta-heuristics (including 'traditional' ones such as genetic algorithms and the most recent, such as firefly algorithm) are covered in Chapter 2. Chapter 3 provides an introduction to surrogate-based optimisation (SBO), which is the main topic of the book. In this chapter, the authors describe the key SBO concepts, SBO techniques, as well as surrogate modelling methods, both approximation-based and physics-based.

Chapter 4 is an introduction to space mapping, which is – historically – the first and the most recognised SBO method used in microwave engineering. Tuning space mapping (TSM), which is one of the recent variations of SM, particularly for the design of filters and other planar microwave devices, is described in detail in Chapter 5. An overview and applications of knowledge-based response correction techniques is given in Chapter 6. The approaches addressed in these chapters aim at the maximum utilisation of the knowledge embedded in the underlying low-fidelity model of the structure/system at hand and, consequently, reducing the computational cost of the design process.

The remaining part of the volume describes both theory and applications of various simulation-driven design methods. Chapter 7 is devoted to the simulation-driven design of broadband antennas using variable-fidelity EM simulations. There are several chapters on artificial neural network (ANN) modelling (Chapters 8, 9, 11, and 12), which is probably the most popular type of surrogate modelling technique in microwave engineering with numerous applications for modelling and design of both passive and active microwave components and structures. Chapter 10 deals with parameterised macromodels of microwave components and applications for microwave filter designs. Chapter 13 discusses the simulation-driven design of microwave filters for space applications, where the main optimisation engine is an aggressive space mapping technique. Chapter 14 discusses adjoint sensitivity approach, which allows to obtain derivative information of the EM-simulated response with little or no extra computational effort. Adjoint sensitivity is, apart from surrogate-based methods, one of the most promising paradigms for realising feasible EM-simulation-driven designs, particularly in the context of gradient-based optimisation methods. Chapters 15 and 16 have more theoretical background and describe finite-element modelling of microwave devices (both two- and three-dimensional cases).

It should be emphasised that surrogate-based modelling and optimisation techniques as well as adjoint sensitivity approaches described in the book are the state-of-the-art methodologies; many of them have been developed over the last few years only. At the same time, the attention and interest in these techniques have been constantly growing, partly because of their ability to dramatically reduce the simulation-driven design time or even solve optimisation-related problems that are not solvable using conventional methods. On the other hand, it can be expected that commercial availability of adjoint sensitivity (e.g., in *CST Microwave Studio or Ansoft HFSS*) may revive the interest in gradient-based algorithms.

So far, information about these methods has been scattered in the literature, mostly available through recent proceedings of international conferences such as *International Microwave Symposium*, *European Microwave Conference or Antenna and Propagation Symposium*, as well as major microwave- and antenna-related journals, such as *IEEE Transactions on Microwave Theory and Techniques*, *IEEE Microwave Magazine*, *IEEE Transactions on Antennas and Propagation*, *International Journal on RF and Microwave CAA*, or *IET Microwaves*, *Antennas and Propagation*. This work is the first book where all these methods have been gathered in one volume. The editors managed to put together contributions from a number of world-leading researchers in the field of simulation-driven microwave design, particularly those working on surrogate- and knowledge-based methods and adjoint sensitivity techniques.

An important advantage of this volume is that it is self-contained. The introductory chapters, particularly Chapters 1 to 3 giving an overview of modern engineering optimisation methods with special emphasis on surrogate-based approaches, make it interesting for the readers who are interested in microwave design optimisation, even if they have no previous experience in numerical modelling and optimisation. On the other hand, the work is a valuable reference for experienced engineers and researchers who are looking for more efficient ways of utilising commercial EM solvers in the design process.

It is worth mentioning that although the book presents the state-of-the-art in efficient simulation-driven microwave design, many of the presented techniques are in the initial stage of their developments. As a consequence, there are a number of practical issues and open problems that are yet to be addressed in the future research. Some of these issues (common to both novel and more matured techniques such as space mapping) include potential convergence problems, the lack of full automation of the design procedures, as well as the necessity of careful selection of the underlying low-fidelity models (for methods exploiting physics-based surrogates). These problems are identified and discussed in the relevant chapters of the volume. Moreover, in many cases, the presented material includes recommendations regarding the selection of modelling/optimisation methods for solving specific types of design problems, as well as both qualitative and quantitative comparisons of SBO and conventional methods.

All of the aforementioned features make the book *Simulation-Driven Design Optimisation and Modelling for Microwave Engineering* a unique endeavour. The volume is highly recommended for both researchers and industry engineers interested in using numerical modelling and optimisation methods in their design work. It will also be a useful reference for graduate courses in microwave engineering, engineering optimisation and computational sciences.