Guest Editorial

A. About This Special Issue

MICROWAVE engineers involved in computer-aided design (CAD) have exploited optimization techniques for device, component, and circuit modeling for decades. Automatic optimization in modeling, simulation, and design is taken for granted. However, the continued enhancement of computing capabilities, the development of more efficient techniques of analysis, and the challenge to produce new components with increased performance and reduced cost in a modest time, pose new challenges on the efficient use of optimization techniques.

This Special Issue marks the first comprehensive treatment of the subject in this TRANSACTIONS since the "Special Issue on Automated Circuit Design Using Electromagnetic Simulators" [1]. It evolved from a series of recent workshops [2]–[6]. These workshops discussed the effective use of optimization techniques in the design of microwave components with state-of-the-art analysis tools. They blended methodological aspects of wide applicability, such as the space-mapping (SM) technique and neural-network approaches, new developments in electromagnetic (EM) simulation, design procedures currently applied in research and development centers, and the use of well-known and widely available full-wave tools for design purposes.

Papers that were submitted to this Special Issue demonstrate significant activity in the field of microwave CAD and its rapid evolution. It is now well ascertained that EM simulators can be effectively used for the arduous task of designing practical microwave components of high complexity, hence, requiring considerable effort both in computer capabilities, EM modeling, and the appropriate use of optimization techniques. In addition, developments in modeling techniques have made available a variety of models for representing specific structures. These models vary in generality, efficiency, accuracy, ease of application, reliability, etc.

We have brought together the foremost practitioners in these fields including designers, software developers, and microwave component academic innovators. We focus on the state of the art and address designers' needs for effective methodologies for optimal designs, including yield optimization, exploiting accurate physically based device and component models. We address the challenge of real life optimization, i.e., to produce in a relatively short amount of time and with limited resources a design both competitive and innovative.

The papers included here may be grouped into a few categories. While this grouping is somewhat arbitrary, it allows us to extract some interesting features. Naturally, some papers might fit into alternative categories. Three principal categories, from our perspective, emerge from the submitted papers:

- investigations to improve EM modeling and optimization efficiency: through new hybrid methods, by extending well-established techniques, by closely relating the optimization method with the full-wave analysis technique;
- techniques that link different models of components or devices, coarse, fine, etc., in a systematic and consistent way, by means of the SM approach;
- papers that exploit circuit-theoretic or network methods in microwave problems, either artificial neural networks (ANNs) or adjoint network techniques, or techniques new to the microwave field, e.g., fuzzy logic.

In Section I-B, we illustrate to the reader the organization of this Special Issue.

B. Special-Issue Content

Here we review the contents of this Special Issue. Since our classification is arbitrary, and since the presentation of each paper is subjective, we hope our authors will not feel that their papers have been inappropriately categorized.

1) EM Modeling: The ability to model a microwave component in an accurate and efficient manner is the foundation for further development in microwaves CAD. Not surprisingly, this subject receives considerable continual attention from researchers. Relevant papers in this Special Issue reveal that, although the subject is not strictly new, it is nevertheless under steady and rapid evolution. Comparisons of microwave simulators of ten years ago with current simulators might be embarrassing: evolution has been present not only in computation capabilities, but also in simulator features.

The invited paper by De Zutter *et al.* provides an overview of recent trends for the general EM circuit co-optimization approach based on an EM database. This paper addresses the development of an efficient planar EM simulator and its seamless integration into a circuit design environment.

Rautio describes a method for joining small subsections so that the large subsections so formed can follow the arbitrarily curving edges of a complicated circuit while including the high edge current. Using such conformal subsections, non-Manhattan geometries, such as circular spiral inductors, can be effectively analyzed.

Mattes and Mosig present a new adaptive sampling to accelerate frequency-domain calculations using genetic algorithms and rational functions to approximate the frequency response. The sampling algorithm is derivative free and adapted to devices with rapidly varying frequency responses such as microwave filters.

With the introduction of methods that significantly speed up numerical computation of large realistic EM structures, EM-based design and optimization is increasingly attractive. Siah *et al.* propose a new hybrid method that exploits Kriging

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metamodeling in conjunction with the divided rectangles (DIRECT) global optimization technique.

Reiche and Uhlmann apply an optimization technique to the design of cascaded waveguide structures. In their case, the traditional high-dimensional optimization problem is decomposed into several one- or two-dimensional problems in the time domain.

The invited paper by Arndt *et al.* surveys hybrid mode-matching, finite-element, method-of-moment, and finite-difference techniques developed at the University of Bremen, Bremen, Germany. Applications include a rigorous fast CAD and optimization of waveguide components, combline filters, coupled horns, and slot arrays. The hybrid methods offer efficiency and versatility.

Webb presents an efficient method for computing the derivatives of responses with respect to geometric variables using an appropriate finite-element method for the analysis. He applies it to predicting parametric tolerance effects.

Peverini *et al.* describe a novel reduced-order model for the mode-matching technique that is derived from the application of the Krylov subspace concept and singular value decomposition.

Arcioni *et al.* present an algorithm for the wide-band optimization of H- and E-plane waveguide components with irregular shapes. The algorithm, based on the boundary integral-resonant mode expansion method and used in conjunction with a variational technique, permits the determination of the objective function and of its gradient by solving a single EM problem.

Hussein and El-Ghazaly deal with global modeling of microwave devices where they consider Maxwell's equations in conjunction with the hydrodynamic model. They propose a new technique for solving these equations by using a real-coded genetic algorithm and an appropriate objective function.

2) SM Technology: As pointed out earlier, recent developments in modeling technology have resulted in a variety of models differing in generality, efficiency, accuracy, ease of application, reliability, etc. It is natural to try to relate these models. Readers accustomed to dealing with numerical methods know that each method offers certain parameters that can be tuned to deliver correct results. Such processes have been typically associated in the past with measurements, assumed as true references, in order to tune the methods. However, the concept can be generalized when dealing with different numerical methods to exploit desired characteristics, e.g., efficiency, accuracy, reliability, etc. A methodology to relate the various methods in a consistent manner is typically referred to as SM.

SM manifests itself in a variety of different formulations. It is a simple CAD methodology, which closely follows the traditional experience and intuition of microwave designers, yet can be treated rigorously. Proper management of space-mapping (surrogate) models promises effective tools for design, tuning, and alignment, including yield optimization, exploiting accurate physically based device and component models.

Bandler *et al.* provide a review of space-mapping technology in its various forms, including the space-mapping-based surrogate (modeling) concept. They discuss many recent applications in engineering design optimization. In addition to a historical perspective, they present a mathematical motivation and place SM into the context of classical optimization.

The invited paper by Rizzoli *et al.* considers nonlinear microwave circuit optimization based on EM simulation. To keep the CPU time for a typical design within acceptable limits, the number of expensive EM analyses must be tightly controlled. This may be achieved through SM, domain partitioning, and neural-network modeling of the passive subnetwork and/or of its most critical parts. While these techniques are well established for linear microwave circuit design coupled with EM analysis, their extension to the nonlinear case is not trivial.

The surprisingly simple idea of implicit SM is introduced by Bandler *et al.* They express the implicit approach in terms of surrogate modeling and show how it relates to the well-established (explicit) SM between coarse and fine device models.

A novel design methodology for filter and multiplexer design is presented by Ismail *et al.* Finite-element EM-based simulators and space-mapping optimization are combined to produce an accurate design for manifold-coupled output multiplexers with dielectric resonator loaded filters. Finite-element EM-based simulators provide a fine model of each multiplexer channel, while a coupling matrix representation is used as a coarse model.

What the authors call a dynamic coarse model is proposed by Wu *et al.* It is applied via aggressive SM to design optimization of low-temperature co-fired ceramic (LTCC) multilayer RF circuits. The coarse model combines an evolutionary equivalent circuit model and an efficient quasi-static numerical EM model–partial element equivalent circuit (PEEC) model. Two forms of coarse model are jointly used: coarse schematic and coarse EM. The coarse schematic model evolutionarily incorporates parasitic effects that can be extracted from its accompanying coarse EM model. This process facilitates the original aggressive SM by determining a "high quality" optimized coarse model.

3) Network and Fuzzy-Logic Methods: In view of the importance of network methods to microwave circuit design, we are very happy as guest editors to have two review papers: one on adjoint network methods and the other on neural-network techniques.

The adjoint-variable methods reviewed by Nikolova *et al.* for design sensitivity analysis offer computational speed and accuracy. They can be used for efficient gradient-based optimization, in tolerance and yield analysis. This paper reviews adjoint-variable methods used in high-frequency structure design with both circuit analysis techniques and full-wave EM analysis techniques. A note on adjoint-based sensitivity analysis for nonlinear dynamic systems is included.

In his invited paper, Rayas-Sánchez reviews the current state of the art in EM-based design and optimization of microwave circuits using ANNs. Among the other topics, measurement-based design of microwave circuits using ANNs is also reviewed; the use of ANNs to speed up "global modeling" for EM-based design of monolithic microwave integrated circuits (MMICs) is briefly described and future directions in ANN techniques for microwave design are suggested.

The paper by Ding *et al.* presents ANN approaches to EM-based modeling in both the frequency and the time domains and applications to nonlinear circuit optimization. Formulations are described for standard frequency-domain neural modeling, and a recent time-domain approach based on the state–space concept. A new EM-based time-domain ANN approach combining existing knowledge in the form of equivalent circuits with state-space equations and ANNs is introduced.

Miraftab and Mansour introduce an improved algorithm based on fuzzy logic for tuning microwave filters. They consider slightly detuned and highly detuned eight-pole elliptic function filters. Employing a Sugeno-type fuzzy-logic system with fuzzy subtractive clustering results in fewer fuzzy rules. Moreover, only one fuzzy-logic system is adequate to deal with both cases.

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