

**WFA (IMS) Friday 08:00 – 17:00 BCEC Room 151B**

**EM-Based Microwave Optimization Technology: State of the Art and Applications**

**Full-day workshop reviewed by MTT-1, MTT-8, MTT-15**

**Organizer(s):**

John W. Bandler, Bandler Corporation, Canada; MTT-1, IMS TPC.

Slawomir Koziel, Reykjavik University, Iceland.

This workshop addresses the state of the art of EM-oriented CAD technology for effective modeling and optimization of microwave and related circuits. Going beyond conventional approaches, recent advances exploit available adjoint sensitivity information, sophisticated modeling algorithms, multilevel co-simulation, space mapping, and more. Our objective is to assist the microwave engineer in accelerating convergent design solutions while avoiding needless expensive simulations, all without sacrificing EM accuracy. Yet, where possible we take the EM simulator out of the classical optimization loop. We cover the fundamentals, some methodologies, practical applications, and expected trends in research and development. We illustrate the material through RF and microwave designs, antenna designs, photonic device design, and inverse problems for industrial and biomedical applications. We consider exciting new points of view suggested by work on design closure, port tuning, and perfectly calibrated ports. We review the state of artificial neural network modeling and space-mapping-based modeling and optimization, both interacting concurrently with full-wave EM tools. We address macromodeling, mixed linear/nonlinear simulation, and multilevel EM field/circuit co-simulation. We review approaches to image reconstruction through microwave tomography and demonstrate the power of adjoint sensitivity analysis in detecting electrically small scatterers (tumors) as well as in full image reconstruction. We review the latest developments in accelerating EM-based design through adjoint response sensitivities and gradient-based optimization. We discuss adjoint techniques capable of accurately predicting the complete time-domain EM response of perturbed structures, and estimating the sensitivity of the time-domain response with respect to all parameters. A substantial part of the workshop will be tutorial, devoted to introducing the state of the art and explaining to the microwave engineer how existing CAD tools can be taken advantage of, and what to expect in the years ahead. We will present progress in the development of advanced algorithms and user-friendly software. The workshop will also allow state-of-the-art microwave practitioners to review their achievements.

**Speakers:**

1. Ming Yu, Com Dev, Canada

“Electromagnetic Simulators for The Design of Large Microwave Circuits”

Microwave/RF passive devices are mission critical components for a variety of electronics systems. Using 3D electromagnetic (EM) field simulators to design such devices is considered a must for most microwave/RF engineers today. In many cases, virtual prototyping can take place inside EM simulators rather than in a real lab bench. As microwave industries continue to invest heavily in electromagnetic simulators, it is very important to understand their capabilities in order to use them effectively. In this paper,

resonators, filters, ortho-mode transducers (OMT), and switches are selected as examples of passive components to be solved and designed in a story telling fashion using EM simulators and state of the art CAD techniques.

2. Q.J. Zhang, Carleton University, Canada

“Neural Network Inverse Modeling and Applications to Microwave Filter Design”

We develop neural network (NN) based methods for modeling EM behavior of microwave components. We present a recently developed inverse modeling technique based on NN. The direct formula for the inverse solution is difficult to find. We develop a NN approach where input neurons represent electrical parameters and output neurons represent geometrical parameters. The NNs are trained from EM data. Techniques addressing non-uniqueness of the inverse modeling problem are developed. The techniques are applied to microwave filter design, achieving quality design results in a fraction of time used by iterative EM optimization. A new EM-field based formulation of NN is also presented and incorporated into the finite element method (FEM) environment. The NN can learn the EM behavior across the interface of an EM substructure, and the trained neural model can be incorporated into EM-field simulation. This method provides fast simulation result compared to existing FEM.

3. José E. Rayas-Sánchez, ITESO, Mexico

“Neural Space Mapping Approaches to EM-based Statistical Analysis”

Computationally efficient neural space mapping methods for highly accurate electromagnetics-based statistical analysis and yield estimation are described and contrasted in this presentation. The statistical analysis of RF and microwave circuits is realized around space-mapped nominal solutions. A comparison is described between different strategies for developing neural networks that implement suitable (input and output) mappings. These strategies allow the transformation of conventional equivalent circuit models into accurate vehicles for EM-based statistical analysis and design. The corresponding neural space mappings are “trained” using reduced sets of EM data. The design and statistical analysis of synthetic problems and microstrip circuits, using commercially available CAD tools, illustrate the techniques.

4. Natalia K. Nikolova, McMaster University, Canada

“Adjoint Sensitivities in Microwave Imaging and Design Tuning”

The optimization tasks faced by microwave engineers are often overwhelming in their complexity and required resources. Simulation-based optimization is a major vehicle of technology solutions but the right tools implementing its principles are yet to be built. The weakest link is the interface between the electromagnetic analysis engine and the optimization algorithms. The information provided by a full-wave solution is much richer than a set of S-parameters and the power of this information is not fully harnessed in optimization. On the other hand, electromagnetic solutions are also prone to errors whose

impact on optimization is yet to be fully understood. We present the latest developments in simulation-based microwave optimization with an emphasis on system sensitivity analysis and its applications. The importance of these developments is illustrated through examples of microwave imaging and design tuning.

5. Mohamed Bakr, McMaster University, Canada

“Efficient Surrogate Model Optimization of High Frequency Structures Exploiting Adjoint Sensitivities and Cauchy Methods”

We discuss some recent approaches to surrogate model optimization of time intensive simulations. A surrogate model is a fast model with reasonable accuracy that can be utilized in the optimization process instead of the time intensive electromagnetic (EM) simulator. The concept of adjoint sensitivities is utilized in constructing linearized surrogate models of the EM responses. They are used in the solution of inverse problems such as those arising in microwave imaging. They are also applied to the design of different microwave and photonic components. The construction of surrogate models using Cauchy rational function approximations is also addressed. We show that the rational model parameters can be extracted through solving a fast linear program. This model can then be utilized in optimization, tolerance, and yield analyses. We illustrate this approach through the efficient design of structures with rapidly varying responses such as microwave filters and antennas.

6. Peter Thoma, CST, Germany

“Complete Technology for Optimizing EM Designs”

This presentation focuses on the application of the “complete technology” approach for optimizing EM designs. The term “complete technology” stands for a seamless combination of various EM simulation methods allowing easy selection of the most efficient technique for a particular simulation task. A combination of various techniques can then be applied to efficiently support the different stages during an optimization process. The presentation starts with some general concepts of the “complete technology” approach including some recent advances in the simulation methods. Afterwards some application examples are shown in order to illustrate the potential of this approach for EM based optimization.

7. John Bandler, Bandler Corporation, Canada

“Surrogate Modeling and Space Mapping: The State of The Art”

EM-validated design optimization threatens hundreds of costly simulations, and perhaps days or weeks of CPU time. Using an appropriate underlying surrogate model and the space mapping methodology, we can take the EM simulator out of the classical optimization loop. Suitable surrogates arise, for example, through fast-to-compute, physically-based “coarse” models that describe the expensive “fine” model behavior relatively well. A space mapping algorithm then provides excellent designs after only a

handful of EM simulations. Here, we review new developments, including “implicit” space mapping, in which preassigned parameters not used in the optimization process can change in the coarse model; “output” space mapping, where we transform the response of the coarse model; surrogates that interpolate; frequency mappings; and the new “tuning” space mapping. Through examples, we report on successes in the RF and microwave arena, including the design of LTCC circuits.

8. Slawomir Koziel, Reykjavik University, Iceland

“Coarse Models and the Robustness of the Space Mapping Optimization Process”

It is well known that the performance of the space mapping optimization algorithm depends on the quality of the underlying coarse model, which should be as good a representation of the fine model as possible but also significantly less expensive than the fine model. The space mapping algorithm can then reach a satisfactory solution after a few fine model evaluations without significant overhead related to operations on the coarse/surrogate model. This presentation discusses techniques for creating computationally cheap and reliable coarse models, including interpolated models, multi-coarse-model techniques and the use of built-in capabilities of the coarse model simulator. Examples involving microwave design optimization problems are provided.

9. James Rautio, Sonnet Software, USA

“Examples of Microwave Filter Optimization Using Perfectly Calibrated Ports”

The “tuning” methodology is illustrated using filter design examples. In the tuning methodology, additional perfectly calibrated ports (“tuning ports”) are inserted in and between filter resonators prior to EM analysis of the layout. Thus, instead of analyzing a 2-port filter repeatedly while trying to adjust the layout for desired performance, a 20 or 30 or 40+ port layout is EM analyzed once. Then tuning elements are connected into the filter by circuit theory (i.e., nodal analysis) connection to the tuning ports. The net result is that the filter is tuned at circuit theory speed with full EM accuracy. This technique can be immediately applied using any microwave design framework (e.g., Agilent, AWR, Cadence) that allows interoperability with an appropriate EM analysis tool. Design closure typically decreases from about 2 weeks to 1 day in practice.