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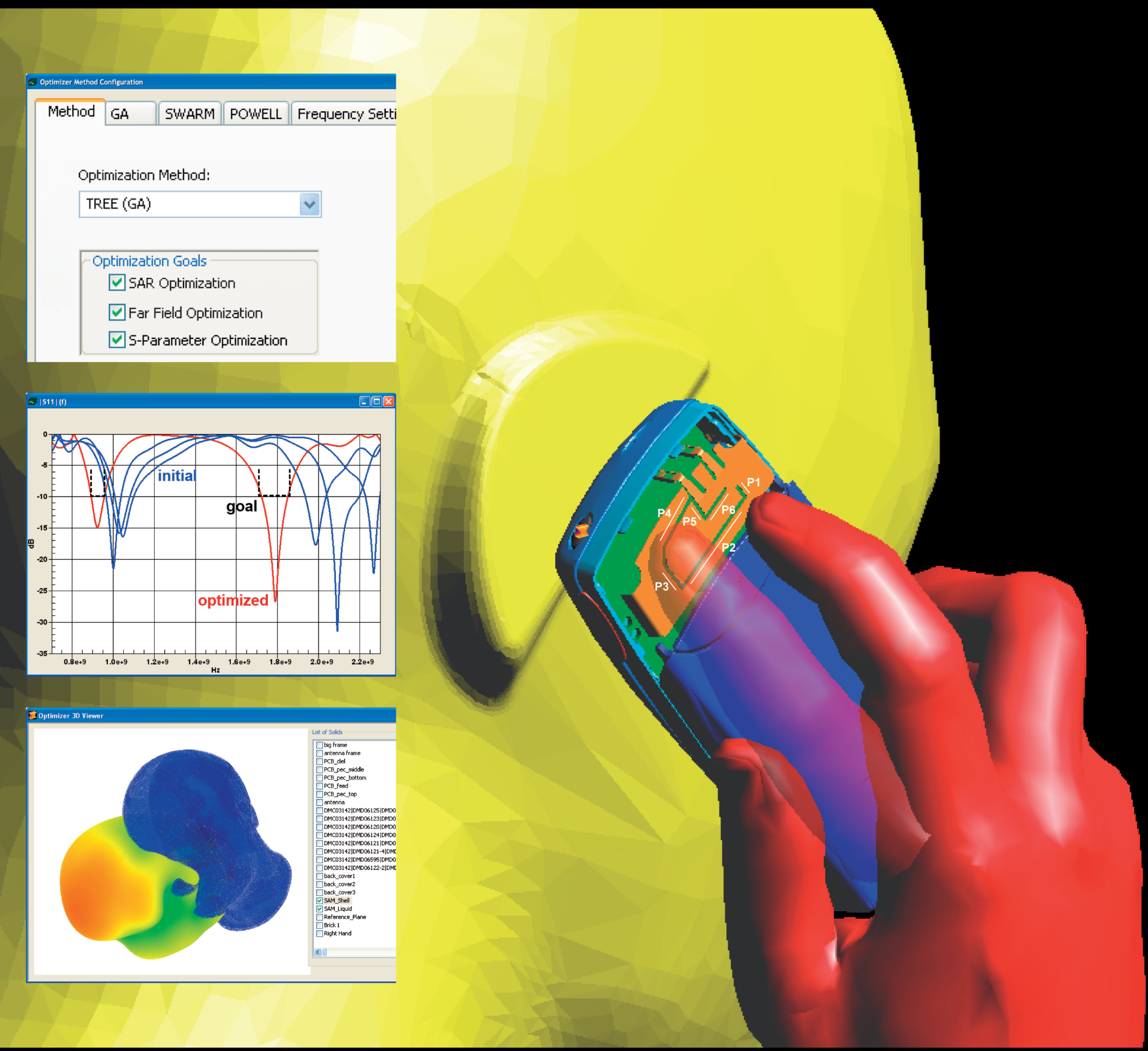

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Multi-goal (S11, OTA, SAR) optimization of mobile phones using effective novel genetic algorithms

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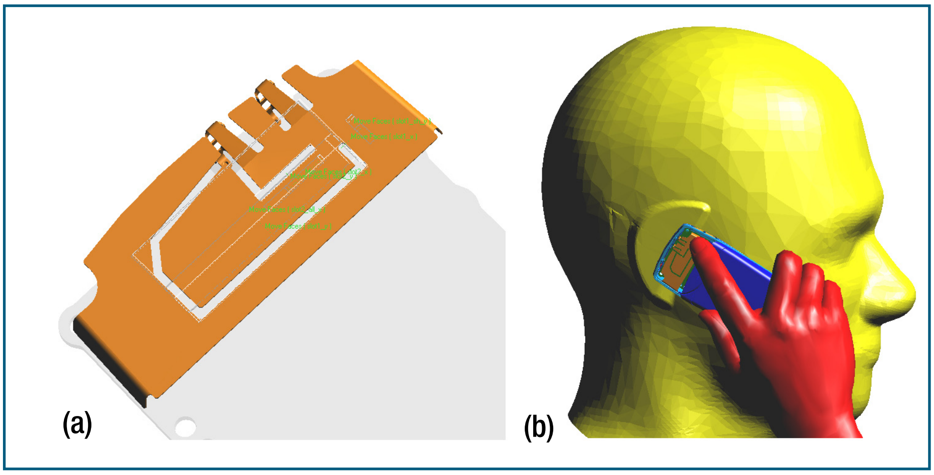
I. Introduction

Increasing consumer demand for multi-band multi-application phones and personal assistants in combination with the growing requirements of service providers for minimal performance requirements poses growing challenges on RF and product design engineers to develop small and highly efficient mobile devices. The parameters of interest are: meeting S11 for multiple communication bands; satisfying over-the-air performance (OTA) requirements for all bands independent of all practical hand and phone positions; minimizing the losses in the phone/body as well as meeting peak spatial SAR limits. A TCAD tool allowing optimization of all these multiple parameters in an effective way would be a big step forward in computational electromagnetics (CEM).

In recent years, full-wave numerical simulation has become an effective means to support RF engineers in the analysis and design of such devices. The Finite-Difference Time-Domain (FDTD) method in particular has become the preferred technique due to its general applicability. Simulations of CAD derived phones became first possible around 2003 ([1], [2]). Improved algorithms (such as ADI-FDTD, conformal/FIT techniques, novel gridding schemes, special subcells, etc.) and growing computational power reduced the simulation time from several hours to a few minutes (FPGA/GPU based hardware acceleration). Nevertheless automated optimization was restricted to simple cases in the past due to large number of required simulations for multi-goal optimization.

This paper presents a novel approach which allows one to perform - to our knowledge for the first time - the effective optimization of entire CAD derived devices, embedded in complex environments. The new optimizer combines the advantages of enhanced Genetic Algorithms with the unique and superior speed of FDTD hardware acceleration. On the basis of a commercial mobile phone, the applied methods are outlined and demonstrated whereas the devices' antenna is optimized with respect to return loss/matching, radiation performance and SAR under real usage conditions, i.e., including head and hand. In addition, our optimization technique runs a sensitivity study for each optimized parameter in parallel.

Figure 1: SEMCAD X simulation engine models of: (a) the parameterized antenna and (b) the mobile phone next to the SAM head phantom with hand.



II. Methods

A) Modeling/general:

For all implementations and assessments the simulation platform SEMCAD X [3] was applied. Its main method is based on 3-D FDTD, furthermore it consists of an ACIS® based Graphical User Interface (GUI), CAD importer, modeling interface, an own 3-D OpenGL rendering engine (handling 10'000 CAD parts or more) and automated non-homogeneous grid generation [1]. A set of different electromagnetic (EM) solvers (FDTD, FIT, ADI-FDTD, C-ADI-FDTD, hardware accelerated [4], etc.) and native 64 bit functionality for GUI and all solvers provide problem-specific simulation effectiveness. A postprocessing engine and Python scripting allows for result extraction/visualization and automation in general.

B) CAD/parameterization:

For the purpose of this project, a novel 3-D parameterization engine has been developed. It allows the full parameterization of arbitrarily complex CAD data such as, e.g., an antenna embedded in the 3-D CAD electro-mechanical dataset of an industrial mobile phone. User-defined entities of the CAD object can be selected and easily transformed into a parameterized form, processable by the optimizer. In addition, the user can add his own 3-D solid objects to enrich the model.

C) Optimization:

Traditional Genetic Algorithm (GA) operators like crossover become inefficient in large optimization problems because during crossover operations, good schemata can be destroyed by the mating process, enlarging convergence and computation time. Nevertheless in small problems or in case of independency between variables, traditional GA with some diversity features can be enough for our purposes.

The SEMCAD X Optimizer provides four optimization algorithms, which are based on the traditional GA (Dual), modified GA (Tree), Swarm algorithm and Powell algorithm. The Tree algorithm implemented into SEMCAD X, codifies the vector parameters to be optimized into a binary string (chromosome), and generation after generation tries to approximate the best chromosome bit distribution, based on the algorithms presented in [5] and later in [6]. It neglects progressively those chromosomes that have not given good fitness results. The convergence is reached when this estimated bit distribution responds to a delta.

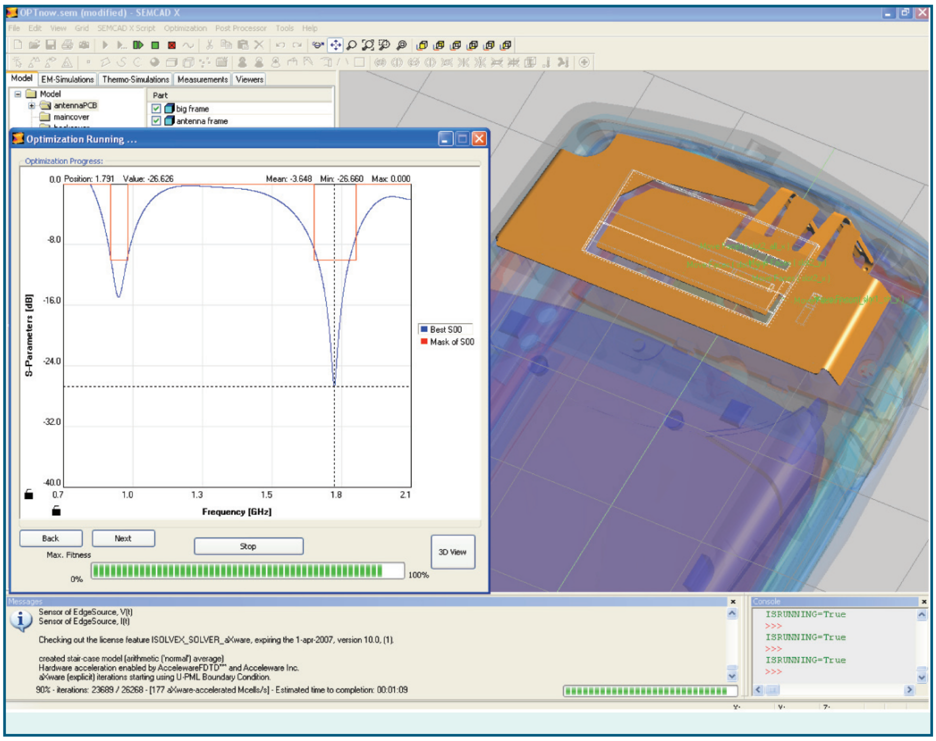
The optimization engine subsequently allows one to handle multi-goal (weighted) complexity (e.g., return loss, farfield, SAR) based on 20 parameters or more. The considered method also tracks the probability of each bit to be equal to 1, which is used to build a vector of the bit probability associated to each parameter binary codification. Generation after generation this vector of bit probabilities converges to probabilities of 0 or 1, defining a clear solution result. The optimization follows up the convergence of this vector and builds a sensitivity analysis for the parameter by computing the convergence speed of this vector.

III. Modeling and parameterization

In the study, a commercial mobile phone was used. Its CAD dataset (IGES) consisted of more than 200 distinguished parts. The integrated antenna was subsequently converted into a parameterized form leading to a total of 6 parameters, allowing one to simulate and optimize the targeted multi-band performance in different operational situations (Figure 1a).

The optimization is performed in two steps: In the first step, a suitable and robust antenna design was developed for free-space by using the optimizer. In the second step, this antenna design was the initial solution to optimize S11, OTA performance and peak spatial SAR when the phone was operated next to the SAM head (touch position) including homogeneous hand phantoms (Figure 1b). The resulting grid for free space phone optimization contained about 5 million FDTD cells, while the grid for the phone, head and hand simulations contained about 11 million cells. The optimization goal for the first optimization step is to obtain a dual-band antenna which covers the bands from 890 MHz to 960 MHz and from 1710 MHz to 1880 MHz with a return loss better than -10dB. SAR and far-field optimization were performed at 1747 MHz, looking for the minimization of the SAR and back radiation of the antenna towards the user's head. The previous optimized structure was used as a starting point (forcing it to be a member of the first population).

Figure 2: Typical optimization run with simulation, optimization and modeling windows.



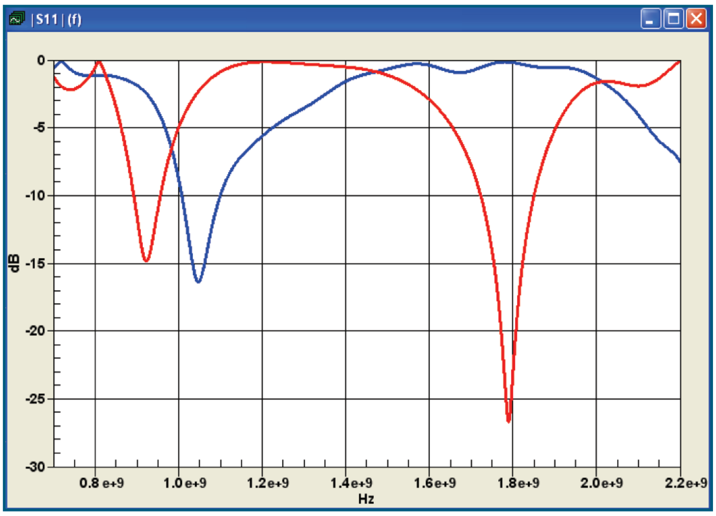


Figure 3: Return loss performance of the mobile phone in free space before (blue line) and after (red line) the optimization of antenna CAD element.

IV. Results

The optimizations were run using SEMCAD X and hardware-accelerated workstations [4]. Using this configuration we were able to achieve simulation speeds of more than 450 million cells/s; enabling the resolution of 20 million cells problems in less than 10 minutes. The maximum number of iterations/evaluations was 280 (10 generations), achieving convergence of the problem in less than 2 days.

Figure 2 shows the typical optimization run with simulation, optimization and modeling windows. The optimization process ends if either the maximum number of iterations is reached or the optimization goal is achieved. The return loss of the patch antenna before and after optimization is shown in Figure 3. The achieved antenna matching for this configuration is better than –8dB in the two specified bands.

The optimized antenna geometry is initially simulated with head and hand phantoms and the return loss shown in Figure 4 clearly demonstrates the detuning effects. The last step of the optimization procedure enabled us to reduce the initially obtained SAR and farfield back radiation values as well as to obtain better return loss in the multi-goal optimization (Figure 5). SAR optimization was performed at 1747 MHz which finally allowed one – while maintaining the optimum return loss – to reduce the initially obtained SAR by more than 10%. The far-field back radiation reached a level better than -9dB respect to the maximum. Further improvement in SAR and far-field performance can be obtained by including other parts of the mobile phone

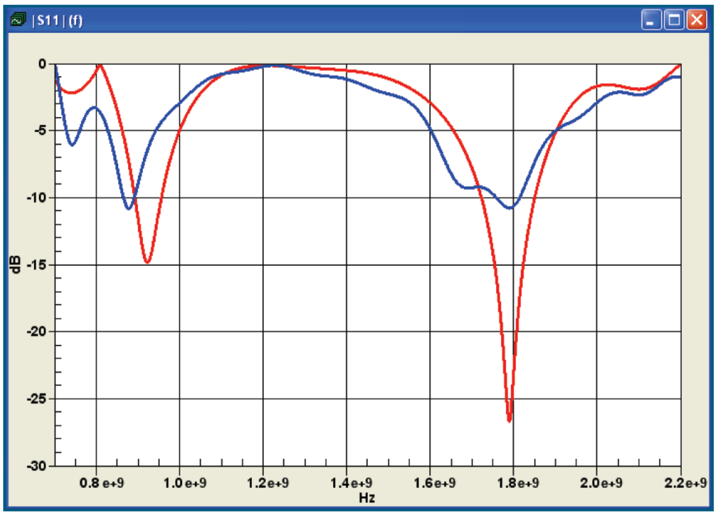


Figure 4: Return loss performance of the optimized antenna in free space (red line) and with head and hand phantoms (blue line).

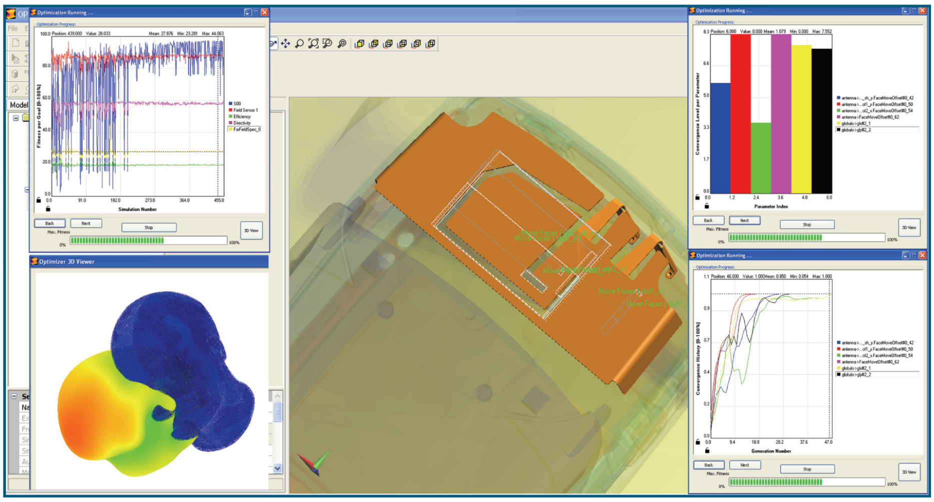


Figure 5: SEMCAD X Multi-goal optimization running: Return loss, farfield back radiation and SAR.

such as PCB, shields, pins, etc. as additional optimization variables.

The parameter sensitivity is performed in parallel during the optimization process, resulting in outlining the relevance of each parameter with respect to the others.

V. Conclusions

Within this study, Genetic Algorithms based on statistical approximation techniques were applied to optimize the performance of a CAD derived model of a commercial mobile phone, embedded into an enhanced FDTD based simulation platform. The applied methods lead to excellent results in convergence time as well as in the quality of the solution, whereas performance parameters of interest included return loss, radiation pattern/performance and SAR. The efficiency of this optimization method combined with enhanced parameterization, automated procedures (modeling, gridding) and hardware accelerated FDTD enabled the optimization of the entire mobile phone, including effects of batteries, PCB, LCD, shields, pins, connections, etc. The quality of results achieved as well as the straight-forward application of the presented novel approach demonstrated its robust integration into industrial R&D processes – ranging from device optimization to virtual prototyping and failure mode analysis – on a regular basis. We are currently working with design centers of leading manufacturers to further optimize the applicability of the tool for wireless applications ranging from mobile communication devices to medical implants. The next steps will be the extension for EMI/EMC applications.

VI. References

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About the author

Nicolas Chavannes was born in Bern, Switzerland in April 1972. He received the M.S. and Ph.D. degrees in Electrical Engineering from the Swiss Federal Institute of Technology (ETH), Zurich in 1998 and 2002, respectively.

In 1996, he joined the Bioelectromagnetics/EMC Group (BIOEM/EMC) at ETH Zurich where he was involved in computational electrodynamics and related dosimetric applications. From 1998 to 2002, he was with the Laboratory for Electromagnetic Fields and Microwave Electronics (IFH) as well as the Laboratory for Integrated Systems (IIS), both located at ETH Zurich. There, his research activities were focused on the development of FDTD local refinement techniques and their application to numerical near-field analysis.

In late 1999, he joined the Foundation for Research on Information Technologies in Society (IT'IS), Switzerland, where he is currently in charge of the development and extension of a simulation platform targeted for antenna modeling and MTE design in complex environments, dosimetry and optics applications.

In early 2002, he joined Schmid & Partner Engineering AG (SPEAG), Zurich, Switzerland, as director of the software R&D team. His primary research interests include the development, implementation and application of computational modeling and simulation techniques to electromagnetics in general, and antennas as well as bioelectromagnetic interaction mechanisms in particular.

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