UNRESTRICTED ARBITRARY SHAPE OPTIMIZATION BASED ON 3D ELECTROMAGNETIC SIMULATION

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ABSTRACT

An efficient computer system, for automatic synthesis of passive microwave structures of novel geometrical shapes, based on 3D FD-TD electromagnetic simulation was developed. The first robust multilevel hybrid optimization which allows unrestricted evolution of an arbitrary circuit shape is presented. Two designs of unique microwave structures illustrate our technique.

INTRODUCTION

The optimization systems based on efficient electromagnetic simulation, which consider various effects such as: multimodal propagation, coupling, radiation, surface wave modes and packaging, are becoming indispensable tools for novel microwave passive element first-pass success design.

The majority of approaches to the optimization problems utilizing EM-simulators are based on the parametrization of the selected circuit dimensions [1,2,3,4,5]. Using such an approach we stay within the class of standard topologies obtained from the classical methods of circuit analysis and synthesis. We can only change some parameters to optimize the structure in order to match user-defined requirements. The EM simulators are usually used only to obtain better accuracy of modelling and not to eliminate the shape restriction of classical design. To ease these restrictions, another direction has been already taken by some researchers who introduced representation of a circuit as a polygon which could be deformed by displacing its vertices [6,7]. Although the free movement of vertices seems to be the first choice, the possible generation of structures with looped boundary pushed authors to the concepts of the user controlled vertices movement. The group of vertices can be driven by the operator of translation, rotation, expansion [6] or their movement is mapped by the function [7]. The important fact for those approaches is that movable parts operate on the separate areas and the movement is restricted to designer intuition constraints, which in general are difficult to define or predict.

The approach presented in this paper is different. We developed an efficient and robust method which allows free evolution of the vertices avoiding the boundary loops but at the same time leaving to each of the vertices the freedom to move in the whole box limiting the circuit. Moreover, on the algorithm demand the boundary shape flexibility can be automatically improved by insertion of new movable vertices, without loosing currently achieved results.

The power of EM-optimization systems which explore the unconventional structures of circuits leads to synthesis of novel microwave structures which can be designed without any human support or control. The engineer intuition can sometimes limit the available solution space.

Our method has been applied to variety of examples and experimentally verified. Two examples are presented in this paper.

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UNRESTRICTED ARBITRARY SHAPE OPTIMIZATION (UASO)

The idea of optimization of arbitrary shape structures comes from the utilization of gradient estimation of an objective function for boundary points of synthesised circuit, as it is illustrated in Fig.1.

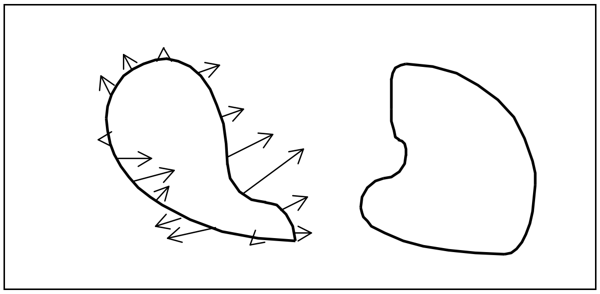

Figure 1: Circuit evolution based on boundary gradient

To provide estimation of development, the circuit is treated as the set of polygons defined by the sequence of its vertices, with assumption that each pair of vertices determines an edge (with the last vertex connected to first one). The gradient is calculated in the vertices of those structure parts which are supposed to be optimized. The direction and the value of gradient determines the position of the movable vertices in the next iteration.

The problems related with UASO are connected with discretization, analysis, existence of local minima, possibility of boundary loops and insufficient boundary approximation.

The discretization is done automatically by the robust, integrated in the whole system, parametric editor which can transform unpredictable shapes of the structures, generated by the optimization module, into specific input data for EM-solver. The local integral approximation, allowing various shapes of cells, is used to model oblique parts of the circuit [8].

The local minima of objective function are overcome by the random distortion of the coordinates values of movable vertices. If the improvement is achieved the search algorithm is reset to the gradient mode.

To avoid generation of boundary loops the optimization module automatically checks the correctness of the circuit structure. If an unwanted solution appears the gradient walk is stopped and new gradient evaluation or random search is done.

If the local minima can not be overcome by random mode of the algorithm, then the boundary is automatically stretched by introducing the new movable vertices. They are placed in the middle of the edges what secures not loosing current achieved state of the search. The whole algorithm was presented in Fig. 2.

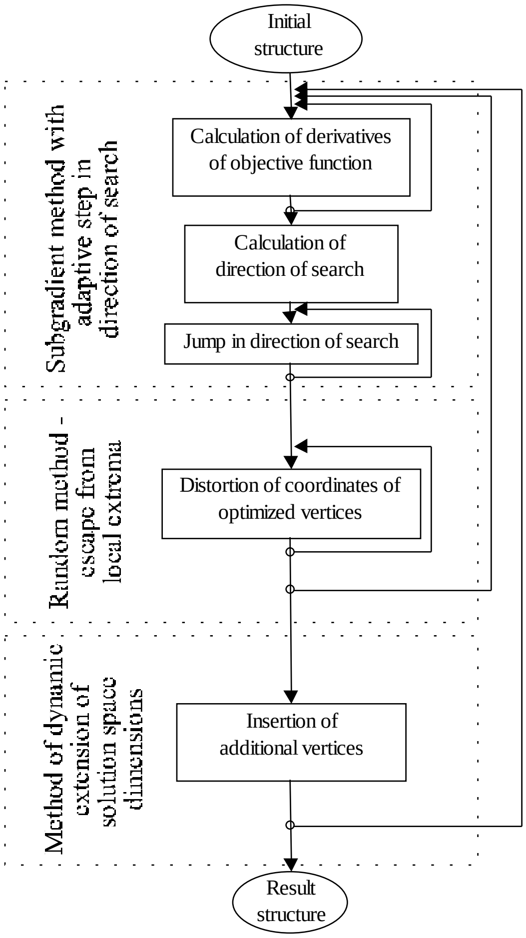

Figure 2: Multilevel hybrid optimization

EXAMPLES

As an example of a novel structure synthesised by the UASO system is microstrip 50 Ohm T-junction (Fig. 3).

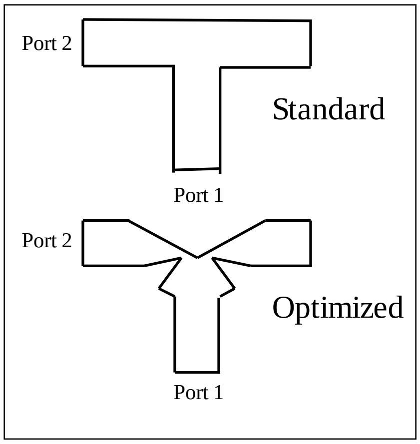

Figure 3: T-junction structures

We used here a substrate of ε_r =2.7 and 1.5 mm thick. Such parameters allows easier experimental investigation of the junction in the presence of locally generated higher modes. Metalization thickness was 35 μm. The responses of standard and optimized circuit are shown in Fig. 4.

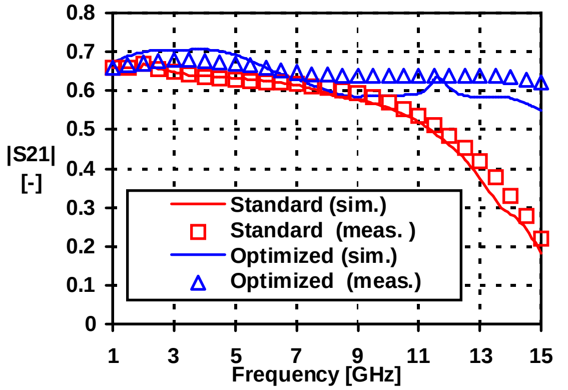

Figure 4: The simulated and measured |S21|[-] responses of T-junction structures

In a classical junction the power is divided into two branches and the transmission is somewhat smaller than -3dB (due to reflections). For higher frequencies the development of higher modes deteriorates the transmission. The situation can be improved using the structure obtained by UASO which produces a kind of unusually shaped transformer (Fig. 3).

In the second example of dielectric waveguide bend (ε_r =3.75) optimized in 18-30 GHz range it is demonstrated the effect of self expanding boundary feature of the algorithm. The optimization was started from structure with 90° corners and only two points assumed to be movable and it reached a solution presented in Fig. 5 after expanding the process to 14 movable points.

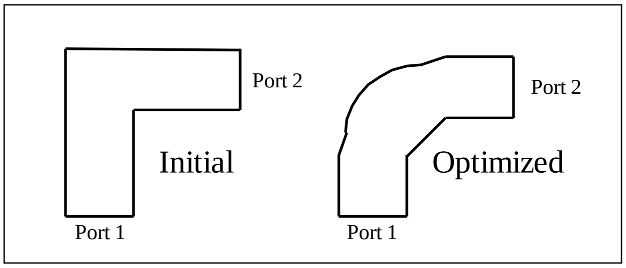

Figure 5: Dielectric waveguide

This way high losses (Fig. 6) of the initial structure, which were due to radiation effect, were significantly reduced.

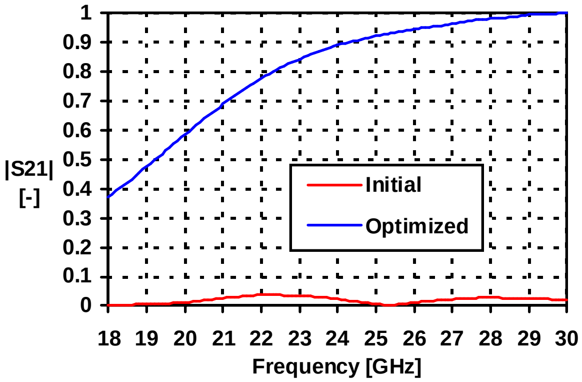

Figure 6: The simulated |S21|[-] responses of the bends

CONCLUSIONS

The Unrestricted Arbitrary Shape Optimization based on highly efficient 3D EM simulation described in this paper is a very effective and versatile tool for automatic synthesis of novel types of passive components. The optimization, which allows the free evolution of the circuit structures, explores the new area of the solution space, which were virtually unattainable for the currently available computer programs.

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