

A Simple ADS Schematic for Space Mapping

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Abstract—In this paper we present a simplified space mapping implementation in Agilent ADS. All the space mapping steps are integrated into one ADS schematic. We also describe a generic sequential optimization implementation method using the Application Extension Language functions to activate and deactivate certain design blocks or components to achieve the necessary automatic iteration and looping. The methodology is demonstrated through two microwave design examples.

Index Terms—space mapping, electromagnetics-based CAD, circuit design, microwave modeling.

I. INTRODUCTION

Space Mapping (SM) technology [1] addresses the issue of reducing the time-consuming full-wave electromagnetic (EM) simulations of microwave structures with the help of a fast physics-based model or surrogate for device modeling and optimization. Many engineers have adopted SM [2][3]. Because SM requires more than one model, implementation is not straightforward. The first implementation was in OSA90¹. A comprehensive Matlab-based framework, the SMF system, was introduced in 2005 [4].

The purpose of this paper is to introduce a strategy to semi- or fully-automate the SM process in a simpler way than in [5]. We illustrate our strategy solely in Agilent ADS², a widely-used Electronic Design Automation (EDA) system for high-frequency and microwave modeling and design applications. The strategy allows for easy application expansion and application-dependent algorithm adjustments.

II. AUTOMATIC SPACE MAPPING ADS IMPLEMENTATION

In [5] an automated four-schematic implementation of the space mapping technique is described. The steps for input,

implicit or output SM are implemented as four separate schematics: coarse model optimization, fine model simulation, parameter extraction, and re-optimization of the surrogate.

In our new methodology, we combine the four schematics into one schematic. The schematic is partitioned into different functional blocks (Fig. 1). This way, the optimization results are saved explicitly in the schematic and no temporary files are required to transfer data between iterations, except for the external fine model simulation. The new schematic design is capable of calling either ADS Momentum or Sonnet *em*³ as a fine model.

The new implementation also facilitates manual operation if preferred. Simply disabling and enabling appropriate blocks in each step will do the trick.

Depending on the application, extra steps to make the optimization robust can easily be added into the schematics.

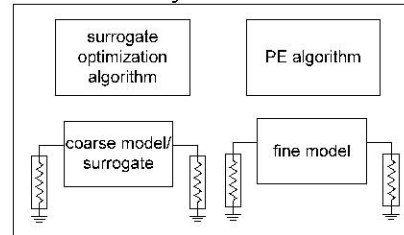


Fig 1. An ADS schematic including 4 functional blocks.

III. ROBUST PARAMETER EXTRACTION AND COARSE MODEL OPTIMIZATION

We take a few measures to improve the robustness of the parameter extraction and surrogate model optimization. The parameter extraction (PE) process matches the surrogate to the fine model. In some cases, the traditional gradient-based PE fails. Therefore, depending on the application, we implement various two-state PE strategies. Normally, we use the ADS random search followed by the Quasi-Newton optimization. If the random search leads to a poor match, we restart our SM algorithm with a two-stage gradient and/or Quasi-Newton optimization.

Surrogate optimizations are frequently performed by the ADS Minimax optimization routine. Occasionally the routine may get trapped in a local minimum, especially after a parameter extraction process that brings the surrogate to a

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¹ OSA90/hopeTM version 4.0, User's Manual, August 1997, Optimization Systems Associates Inc. (now Agilent Technologies), P.O. Box 8083, Dundas, Ontario, L9H 5E7, Canada.

² Agilent ADS 2005A, Agilent Technologies, 1400 Fountaingrove Parkway, Santa Rosa, CA 95403-1799, USA.

³ *em*TM Version 11.52, Sonnet Software, Inc., 100 Elwood Davis Road, North Syracuse, NY 13212, USA.

frequency-shifted design. We use a specification tracking technique to guide the path of surrogate optimization.

Step 1 Connect the specifications to form a piecewise-linear specification function.

Step 2 Match the piecewise-linear specification function to the initial surrogate response using a discrete search.

Step 3 Shift the specification function back towards the original specification in a few stages. In each stage, a Minimax optimization is applied to the surrogate to satisfy the intermediate specification. In other words, the piecewise-linear specification function guides the surrogate to a design that satisfies the original specification in steps (stages).

The specification tracking technique normally works better in the first space mapping iteration in which the fine model and the surrogate are usually misaligned in frequency. The algorithm disengages the specification tracking step for the follow-up iterations.

IV. SPACE MAPPING AND SEQUENTIAL OPTIMIZATION

The space mapping is implemented in 4 major steps as in [5]. Instead of four separate schematics we use only one schematic that combines all the necessary SM algorithm components. We deactivate appropriate components in the schematic in each step. The fine model is embedded using co-simulation (Momentum) and an external executable (Sonnet *em*) call from the ADS schematic.

A. The Space Mapping Algorithm Steps

Step 1 Multi-stage coarse model optimization. [Deactivate fine model, PE optimization routine, PE goals.] (Use specification tracking described in Section III, if necessary.)

Step 2 Fine model simulation. [Deactivate coarse model, coarse model optimization routine, coarse model goals, PE optimization routine, PE goals.]

Step 3 Multi-stage parameter extraction. [Deactivate coarse model optimization routine, coarse model goals.]

Step 4 Multi-stage re-optimization of the surrogate. [Deactivate fine model, PE optimization routine, PE goal.] (Use specification tracking, if necessary.)

The steps can be implemented manually. We also designed an AEL⁴ script to automate the space mapping algorithm steps.

B. General Purpose Sequential Optimization/Simulation Script

We have designed a general purpose sequential optimization/simulation program in AEL to facilitate automatically connecting several simulations or optimizations. To initialize the script, the user creates the necessary components for all the optimization/simulation steps in an ADS schematic. The user creates a list of deactivation component *rows* in our AEL script. Each iterative step corresponds to a component *row* in which the names of the components to be deactivated are saved. The rows are linked to become another list called *steps*. The user specifies the loop starting point and the number of loops. The user starts the sequential optimization/simulation AEL script below.

⁴ Application Extension Language, ADS internal C-like script language.

Step 1 The script reads a *row* in the *steps* list and deactivates corresponding components described in that *row*.

Step 2 The script runs a simulation (optimization).

Step 3 The script updates the optimization variables.

Step 4 The script saves the schematic (the resulting datasets are saved too).

Step 5 If the algorithm is not completed, the script points to the next *row* in the list and goes to *Step 1*.

The user-defined list of deactivation component *rows* are shown as follows:

```
//list of components to be deactivated in each step
step1 = list("component 1", "component 3", ...); //1st row
step2 = list("component 2", "component 4", ...); //2nd row
step3 = list("component 1", "component 2", ...); //3rd row
...
steps = list(step1, step2, step3, ...); //list of deactivation rows
decl loop = 0; //starting point of the loop; 0: step 1
decl repeat = 0; //number of times to repeat the loop
```

Users can replace the above list with any other combination of components to implement a different algorithm. The method we show here is much simpler than designing multiple schematics and including their names in the batch list file in [5]. Since all the components in each iteration are placed in the same schematic, it is easier to make changes to the model and algorithm. The parameter transfer between steps is easily maintained through the *Update Optimization Values* command after each step. Adding new iteration steps is as simple as adding a line of code.

We connected Sonnet *em* and Agilent Momentum as fine models in our space mapping implementation. To drive Sonnet *em* from within the ADS schematic, we need to save the predicted design parameters in a file on the fly, which can be done using the `write_str()` function [Agilent Knowledge Center Example ID: 299744]. The next step (simulate the structure using the saved design parameters) is easily achieved by calling the Sonnet *em* command line in a *var* component.

Agilent Momentum can be called using co-simulation in the schematic view. Design parameters and response data are easily communicated between layout and schematic design.

V. DESIGN EXAMPLES

We show two examples of how this is actually implemented. Our first example is the open-loop ring resonator bandpass filter [6] shown in Fig. 2. The design parameters are $\mathbf{x} = [L_1 \ L_2 \ L_3 \ L_4 \ S_1 \ S_2 \ g]^T$ mm. Other parameter values are: $W = 0.6$ mm, $W_1 = 0.4$ mm. The fine model is simulated in Agilent Momentum. The design specifications are $|S_{21}| \geq -3$ dB for $2.8 \text{ GHz} \leq \omega \leq 3.2 \text{ GHz}$, and $|S_{21}| \leq -20$ dB for $1.5 \text{ GHz} \leq \omega \leq 2.5 \text{ GHz}$ and $3.5 \text{ GHz} \leq \omega \leq 4.5 \text{ GHz}$. The coarse model is implemented in Agilent ADS (Fig. 3). Implicit space mapping is applied. The preassigned parameters (substrate height and dielectric constant) of the components with the same hatch pattern change simultaneously in the parameter extraction process.

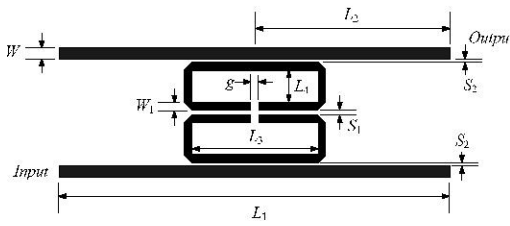


Fig 2. Open-loop ring resonator bandpass filter [6] fine model.

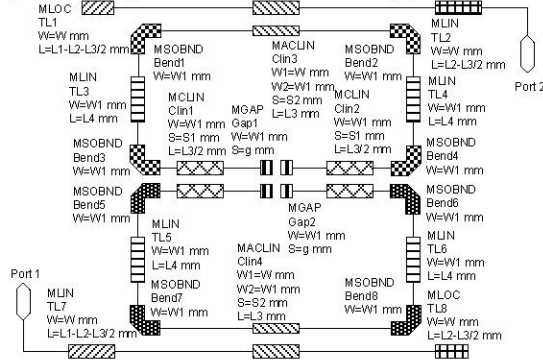


Fig. 3 Open-loop ring resonator bandpass filter ADS coarse model.

In this example we use one stage surrogate optimization and two stage parameter-extraction optimization (Random and Quasi-Newton). The schematic is composed as in Fig. 4. We list the components to be deactivated.

The first step is the surrogate (coarse model) optimization. The *PE*, *PE1* and *PEGoal1* and *PEGoal2* components in the Parameter Extraction block are deactivated. The *fine* component is also deactivated.

The second step is fine model simulation. *S_Opt* and *PE*, *PE1* are deactivated.

In the third step (the first stage of parameter extraction), *S_Opt*, *SGoal1*, *SGoal2*, *SGoal3* and *PE1* are deactivated.

In the fourth step (the second stage of parameter extraction), *S_Opt*, *SGoal1*, *SGoal2*, *SGoal3* and *PE* are deactivated.

After two iterations, we obtained the responses shown in Fig. 5. The final fine model specification error is -0.392 dB.

We consider a more complicated example, an interdigital filter design [7]. The fine model, shown in Fig. 6, is implemented in Sonnet *em*. The substrate height and dielectric constant are 15 mils and 9.8 respectively. The shielding cover height is 75 mils. The cell size is set at 1 mil \times 1 mil. The design specifications are $|S_{21}| \leq -30$ dB for 4.0 GHz $\leq \omega \leq 4.5$ GHz and for 5.45 GHz $\leq \omega \leq 6.0$ GHz and $|S_{11}| \leq -0.1$ dB for 4.9 GHz $\leq \omega \leq 5.3$ GHz.

The initial Agilent ADS coarse model is shown in Fig. 7. The space mapping approach we adopt is input and implicit space mapping. In the interdigital filter case, the lengths of the microstrip lines (x_1, x_2, x_3, x_4, x_7 and x_8) and the gaps (x_5 and x_6) are defined as design parameters. The implicit space mapping explores the preassigned parameters in an attempt to match the details of the surrogate to the fine model. For the interdigital filter, the preassigned parameter set consists of ϵ_r (substrate dielectric constant) and capacitors C_1 to C_6 added between non-adjacent conductors (cf. Fig. 7). The parameters

for input space mapping are the shifts of the design parameters, i.e., $\delta x_i, i = 1, \dots, 8$. We combine the input and implicit space mapping in one parameter extraction step.

Open-loop Ring filter S-Parameter Simulation
Linear Frequency Sweep

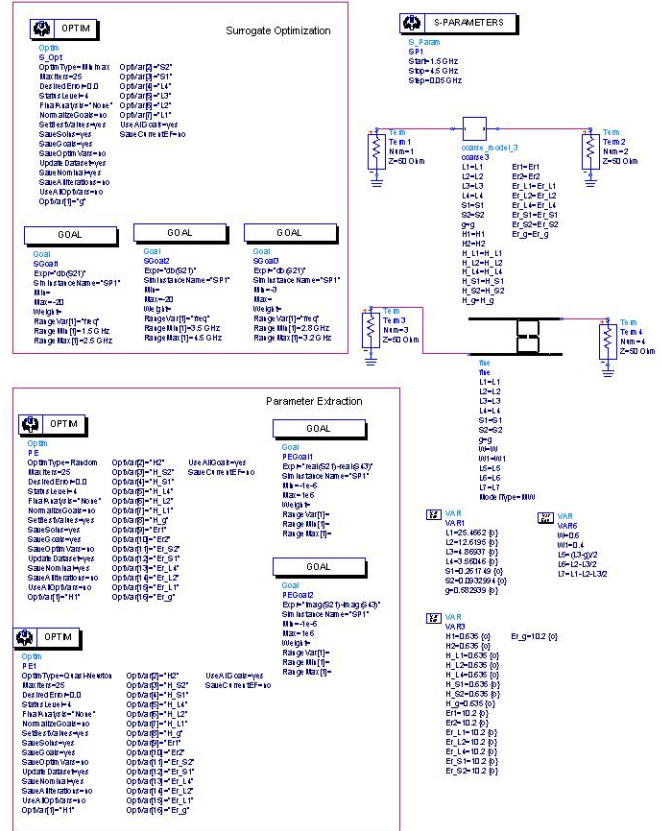


Fig. 4. ADS space mapping schematic.

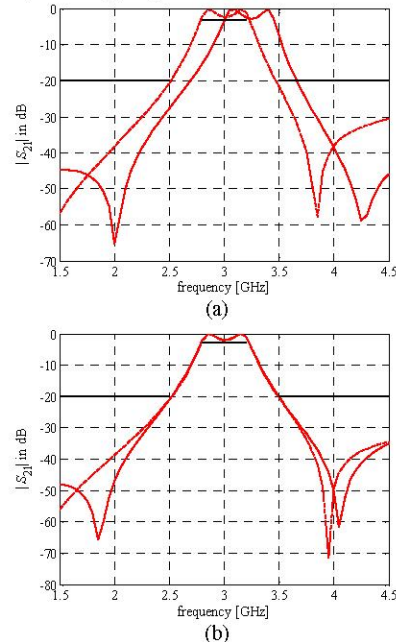


Fig. 5. Fine (—) and surrogate (---) responses: (a) after initial coarse model optimization; (b) after 3 iterations.

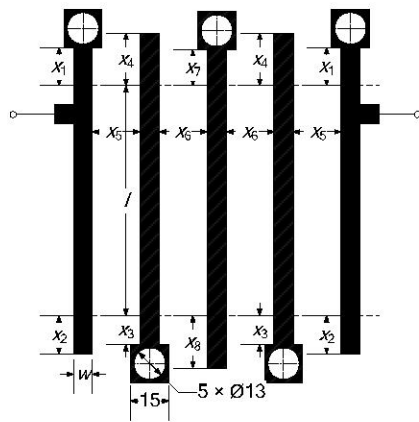


Fig. 6. Interdigital filter: fine model structure and dimensions [7]; the dimensions are in mils.

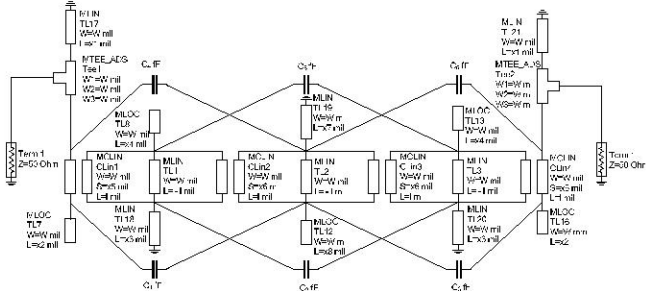


Fig. 7. Interdigital filter: coarse model in ADS.

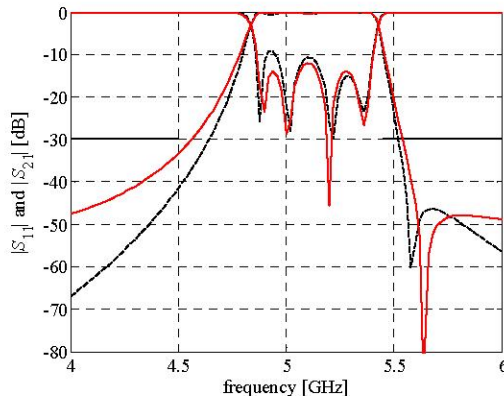


Fig. 8. Interdigital filter initial design using parameters from [7]: the $|S_{11}|$ and $|S_{21}|$ responses of the fine model simulation (—) versus the coarse model after the first parameter extraction (---).

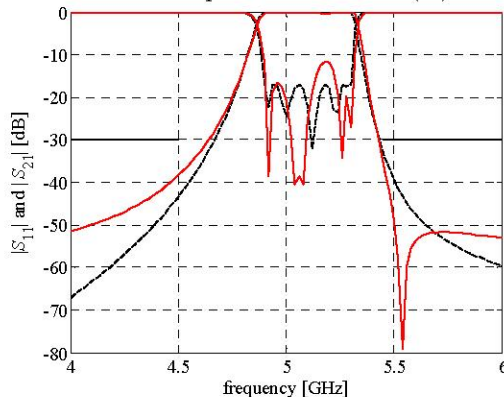


Fig. 9. The interdigital filter $|S_{11}|$ and $|S_{21}|$ responses of the fine model final simulation (—) versus the surrogate model (---).

We start our design using the optimal design from [7]. A two-stage (Gradient followed by Quasi-Newton) parameter extraction process is carried out. We can see that the specification is not satisfied after the first iteration, but the parameter extraction using input and implicit SM yields a good match between the coarse and fine models (Fig. 8). The surrogate (coarse model) is then optimized to predict a new fine model design. The specification tracking technique is deployed in the first iteration of surrogate optimization. In just three SM iterations, a good fine model solution (specification error -0.08dB) is obtained (Fig. 9). Our technique connects the steps or iterations, and repeats the loop automatically. The step-by-step results are saved after each step.

VI. CONCLUSIONS

We present a simple ADS schematic implementation of the space mapping technique. All the space mapping iteration steps are implemented in one schematic and can be automated using the AEL script. This makes the space mapping technology more accessible to microwave engineers. Model switching and data exchanges between the steps are facilitated by the new methodology. A generic sequential ADS program that facilitates connecting and looping for simulation and optimization is described. The space mapping algorithm is verified in this sequential ADS optimization schematic. We demonstrate our scheme using two examples.

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