A TRUST REGION AGGRESSIVE SPACE MAPPING ALGORITHM FOR EM OPTIMIZATION

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ABSTRACT

A robust new algorithm for EM optimization of microwave circuits is presented. The algorithm integrates a trust region methodology with aggressive space mapping (ASM). A new automated multi-point parameter extraction process is implemented. EM optimization of a double-folded stub filter and of an HTS filter illustrate our new results.

INTRODUCTION

A novel algorithm for aggressive space mapping (ASM) EM optimization [1] is introduced. Space mapping aims at aligning two different simulation models: a "coarse" model, typically an empirical circuit simulation and a "fine" model, typically a full wave EM simulation. The technique combines the accuracy of the fine model with the speed of the coarse model. Parameter extraction is a crucial part of the technique. In this step the parameters of the coarse model whose response matches the fine model response are obtained. The extracted parameters may not be unique, causing the technique to fail to converge to the optimal design.

Recently, a multi-point parameter extraction concept was proposed [2] to enhance the uniqueness of the extraction step at the expense of an increased number of fine model simulations. The selection of points was arbitrary, not automated and no information about the mapping between the two spaces was taken into account.

Our proposed ASM algorithm automates the selection of fine model points used for the multi-point parameter extraction step. An iterative approach utilizes all the fine model points simulated since the last successful iteration in the multi-point parameter extraction. Also, the current approximation to the mapping between the two spaces is integrated into the parameter extraction step. The space mapping step at each iteration is constrained by a suitable trust region [3].

THE NEW ALGORITHM

At the ith iteration, the error vector $\boldsymbol{f}^{(i)} = \boldsymbol{P}(\boldsymbol{x}_{em}^{(i)}) - \boldsymbol{x}_{os}^{*}$ defines the difference between the vector of extracted coarse model parameters $\boldsymbol{x}_{os}^{(i)} = \boldsymbol{P}(\boldsymbol{x}_{em}^{(i)})$ and the optimal coarse model design $\boldsymbol{x}_{os}^{*}$ in the "*os*" space. Subscript "*em*" identifies the fine model space and $\boldsymbol{P}$ denotes the mapping function. The mapping between the two models is established if this error vector is driven to zero. Thus, the value $\|\boldsymbol{f}^{(i)}\|$ can serve as a measure of the misalignment between the two spaces in the ith iteration. The step taken in the ith iteration is given by

$$(\boldsymbol{B}^{(i)T}\boldsymbol{B}^{(i)} + \lambda \boldsymbol{I})\boldsymbol{h}^{(i)} = -\boldsymbol{B}^{(i)T}\boldsymbol{f}^{(i)} \qquad (1)$$

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where $\boldsymbol{B}^{(i)}$ is an approximation to the Jacobian of the coarse model parameters with respect to the fine model parameters at the *i*th iteration. The parameter λ is selected such that the step obtained satisfies $\|\boldsymbol{h}^{(i)}\| \le \delta$, where δ is the size of the trust region. This is done utilizing the iterative algorithm suggested in [3]. The candidate point for the next iteration is $\boldsymbol{x}_{em}^{(i+1)} = \boldsymbol{x}_{em}^{(i)} + \boldsymbol{h}^{(i)}$. Single point parameter extraction is then applied at the point $\boldsymbol{x}_{em}^{(i+1)}$ to get $\boldsymbol{f}^{(i+1)} = \boldsymbol{P}(\boldsymbol{x}_{em}^{(i+1)}) - \boldsymbol{x}_{os}^{*}$. The point $\boldsymbol{x}_{em}^{(i+1)}$ is accepted if it satisfies a success criterion related to a reduction in the ℓ_2 norm of the vector $\boldsymbol{f}$. Then the matrix $\boldsymbol{B}^{(i)}$ is updated using Broyden's formula [4]. Otherwise, the validity of the extraction process leading to $\boldsymbol{f}^{(i+1)}$ at the suggested point $\boldsymbol{x}_{em}^{(i+1)}$ is suspect. The residual error $\boldsymbol{f}^{(i+1)}$ is then used to construct a candidate step from the point $\boldsymbol{x}_{em}^{(i+1)}$ by using (1). The new point is then added to the set of points employed for simultaneous parameter extraction: a new value for $\boldsymbol{f}^{(i+1)}$ is obtained by solving

$$\underset{\boldsymbol{x}_{os}}{\text{minimize}} \left\| \boldsymbol{R}_{os}(\boldsymbol{x}_{os} + \boldsymbol{B}^{(i)}(\boldsymbol{x}_{em} - \boldsymbol{x}_{em}^{(i+1)})) - \boldsymbol{R}_{em}(\boldsymbol{x}_{em}) \right\| \quad (2)$$

simultaneously for all $\boldsymbol{x}_{em} \in V$, where V is the set of fine model points used for multi-point parameter extraction.

The new extracted coarse model parameters either satisfy the success criterion or they are used to predict another candidate point which is then added to the set of points used for parameter extraction and the whole process is repeated. Using this recursive multi-point parameter extraction process improves the accuracy. This may lead to the satisfaction of the success criterion or the step is declared a failure. The step failure is declared in one of two cases: either the vector of extracted parameters approaches a limiting value with the success criterion not satisfied, or the number of fine model simulations since the last successful iteration has reached $n+1$. In the first case, the extracted coarse model parameters are trusted and the accuracy of the linearization used to predict $\boldsymbol{h}^{(i)}$ is suspected. Thus, to ensure a successful step from the current point $\boldsymbol{x}_{em}^{(i)}$, the trust region size is shrunk and a new suggested point $\boldsymbol{x}_{em}^{(i+1)}$ is obtained. In the latter case, sufficient information is available to obtain an estimate for the Jacobian $\boldsymbol{J}$ of the fine model responses with respect to the fine model parameters. This matrix is then used to make a step $\boldsymbol{h}^{(i)}$ in the parameter space by solving the system of equations

$$(\boldsymbol{J}^T\boldsymbol{J} + \lambda \boldsymbol{I})\boldsymbol{h}^{(i)} = -\boldsymbol{J}^T\boldsymbol{g}^{(i)}, \quad (3)$$

varying parameter λ until $\|\boldsymbol{h}^{(i)}\| \le \delta$. The vector $\boldsymbol{g}^{(i)}$ is the difference between the fine model responses in the *i*th iteration and the optimal coarse model responses. If there is no reduction in the ℓ_2 norm of the vector function $\boldsymbol{g}$, the trust region is shrunk and (3) is resolved. This is repeated until either the size of the trust region has shrunk significantly and hence the algorithm terminates or a successful step is taken. This successful step is then used instead of the step obtained by (1) and the algorithm proceeds.

EXAMPLES

Double-folded Stub Filter

We consider the double-folded stub (DFS) microstrip structure shown in Fig. 1 [5,6].

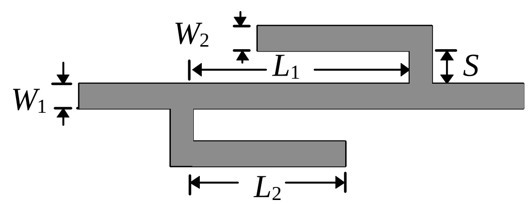

Fig. 1. The DFS filter [5,6].

The filter is characterized by five parameters: W_1, W_2, S, L_1 and L_2 (see Fig. 1). L_1, L_2 and S are chosen as optimization variables. W_1 and W_2 are fixed at 4.8 mil. The design specifications are given by $|S_{21}| \ge$ -3 dB in the passband and $|S_{21}| \le$ -30 dB in the stopband, where the passband includes frequencies below 9.5 GHz and above 16.5 GHz and the stopband lies in the range [12 GHz, 14 GHz]. The structure is simulated by Sonnet's ***em*** [7] through OSA's Empipe [8]. The coarse model is a coarse-grid ***em*** model with cell size 4.8 mil by 4.8 mil. The fine model is a fine-grid ***em*** model with cell size 1.6 mil by 1.6 mil.

The time needed to simulate the structure (coarse model) using ***em*** at a single frequency is only 5 s on a Sun SPARCstation 10. This includes the automatic response interpolation carried out to accommodate off-grid geometries. The new ASM technique required only two iterations to reach the solution shown in Fig. 2, using 17 fine model simulations. Most of these simulations were needed for response interpolation. The CPU time needed is approximately 70 s per frequency point.

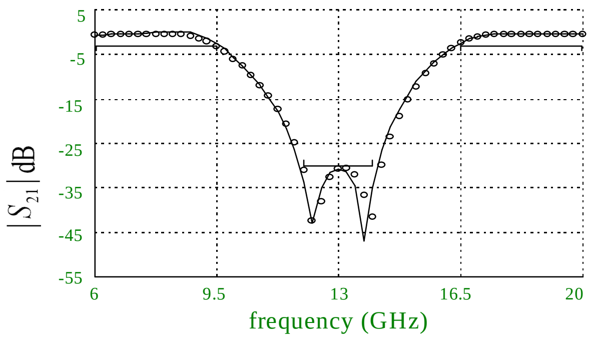

Fig. 2. The optimal coarse model response (—) and the optimal fine model response (o) for the DFS filter.

HTS Filter

We consider the high-temperature superconducting (HTS) filter [1,9] illustrated in Fig. 3.

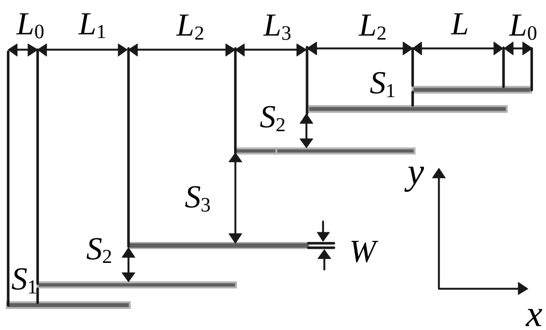

Fig. 3. The structure of the HTS filter [9].

The specifications are $|S_{21}| \geq 0.95$ in the passband and $|S_{21}| \leq 0.05$ in the stopband, where the stopband includes frequencies below 3.967 GHz and above 4.099 GHz and the passband lies in the range [4.008 GHz, 4.058 GHz]. The design variables for this problem are L_1, L_2, L_3, S_1, S_2 and S_3. We take L_0 = 50 mil and W = 7 mil. The coarse model exploits the empirical models of microstrip lines, coupled lines and open stubs available in OSA90/hope. The fine model employs a fine-grid ***em*** simulation. The coarse model is optimized using the OSA90/hope minimax optimizer. The fine mode1 response at the optimal coarse model design is shown in Fig. 4.

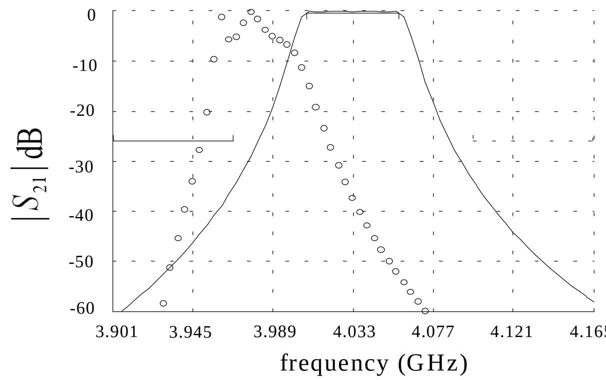

Fig. 4 The optimal coarse model response (—) and the fine model response (o) at the starting point for the HTS filter.

Fig. 5 shows how two of the extracted coarse model parameters changed with the number of points used for parameter extraction. The first point (1) is obtained using normal parameter extraction. These extracted values would have caused the original ASM technique to diverge. The new technique automatically generates a candidate point which is used together with the original point to carry out a multipoint parameter extraction and the second point (2) is obtained.

To confirm that this point is the required one a third candidate point is automatically generated and the extraction is repeated using the three points to obtain the third extracted point (3).

For the remaining iterations, single point parameter extraction worked well. The optimal fine model design was obtained in 5 iterations which required 8 fine model simulations. The optimal fine model response is shown in Fig. 6. The passband ripples are shown in Fig. 7.

CONCLUSIONS

A powerful new algorithm implementing the aggressive space mapping technique is introduced. It aims at automatically improving the uniqueness of the parameter extraction step, the most critical step in the space mapping process, and exploiting all available fine model simulations. Through examples which have proved difficult in the past we show that the new ASM algorithm automatically overcomes the nonuniqueness of the parameter extraction step in a logical way.

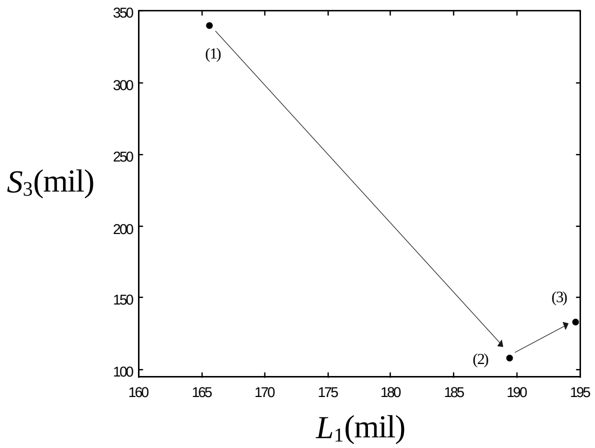

Fig. 5. The variation of two of the extracted coarse model parameters in the first iteration with the number of points used for parameter extraction .

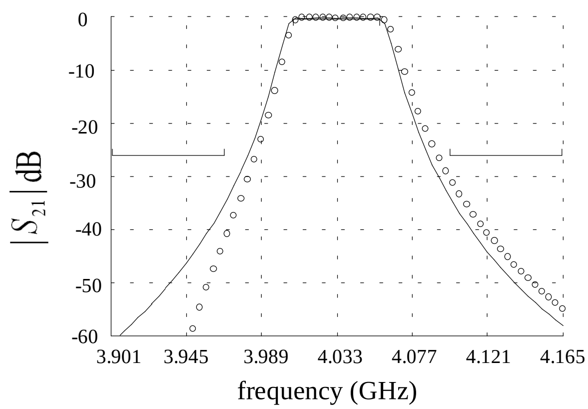

Fig. 6. The optimal coarse model response (—) and the optimal fine model response (o) for the HTS filter.

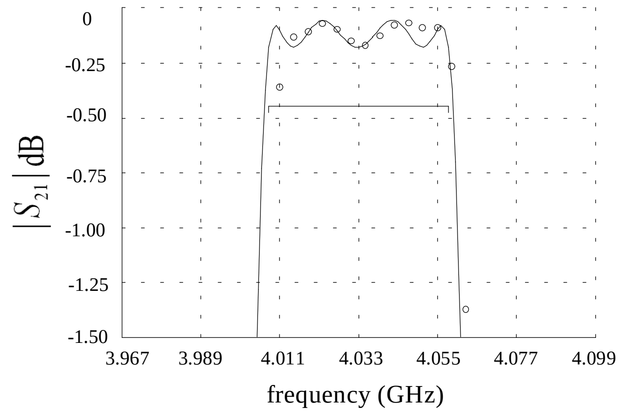

Fig. 7. The optimal coarse model response (—) and the optimal fine model response (o) for the HTS filter in the passband.

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