EM-Based Optimization Exploiting Adjoint Sensitivities

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Outline

ASM for microwave circuit design

Gradient Parameter Extraction (GPE)

mapping update

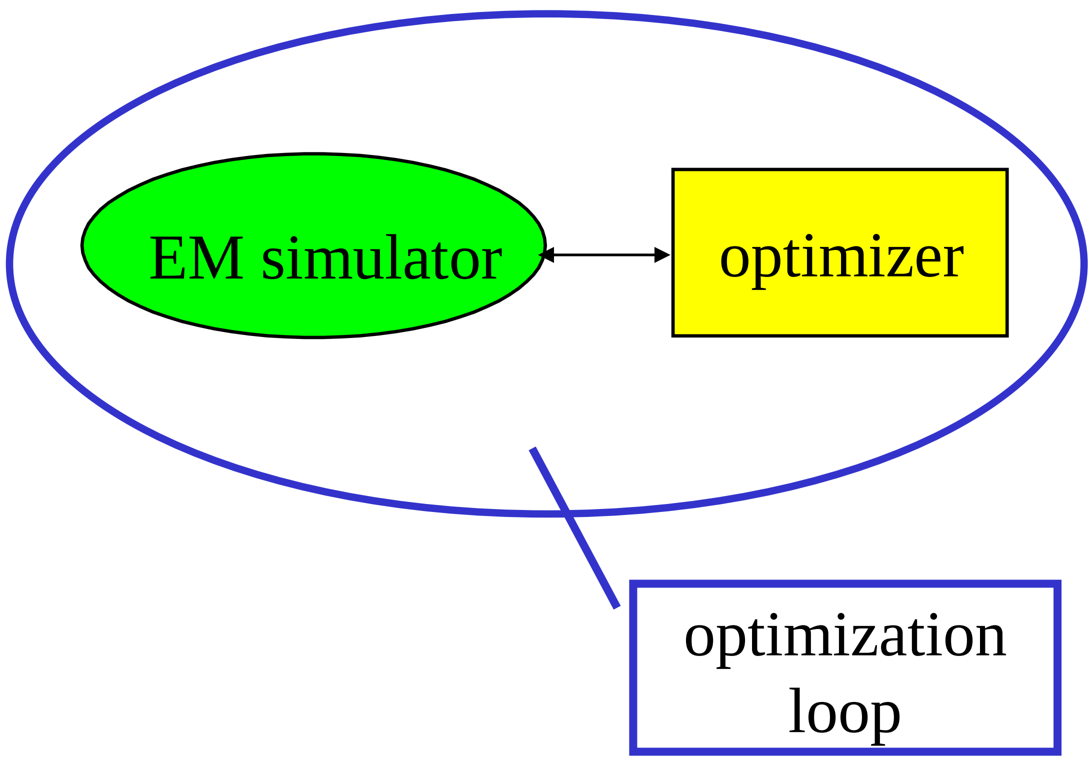
proposed algorithm

examples

conclusions

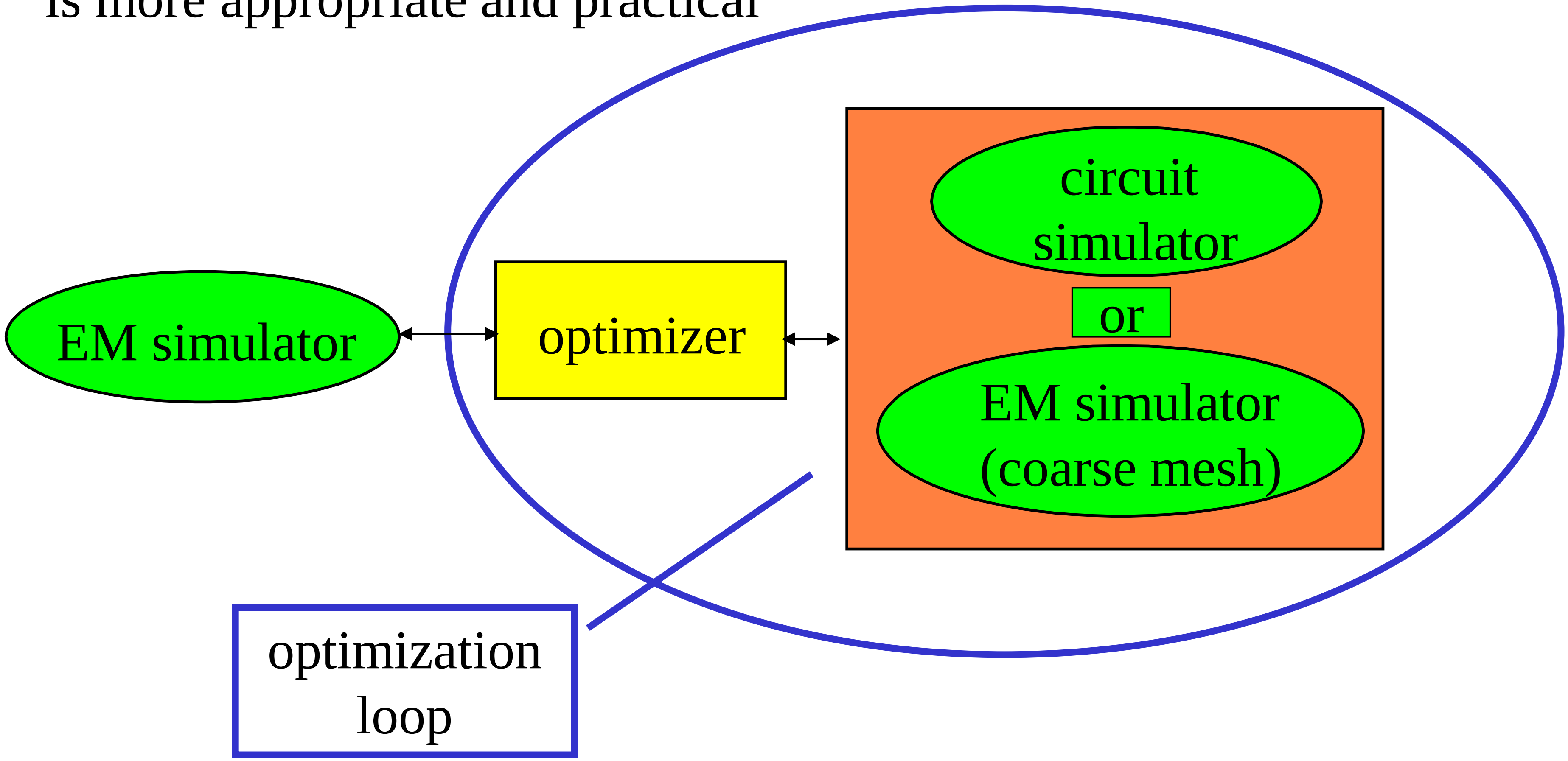
Introduction

using full wave EM simulator (fine model) inside the optimization loop is prohibitive



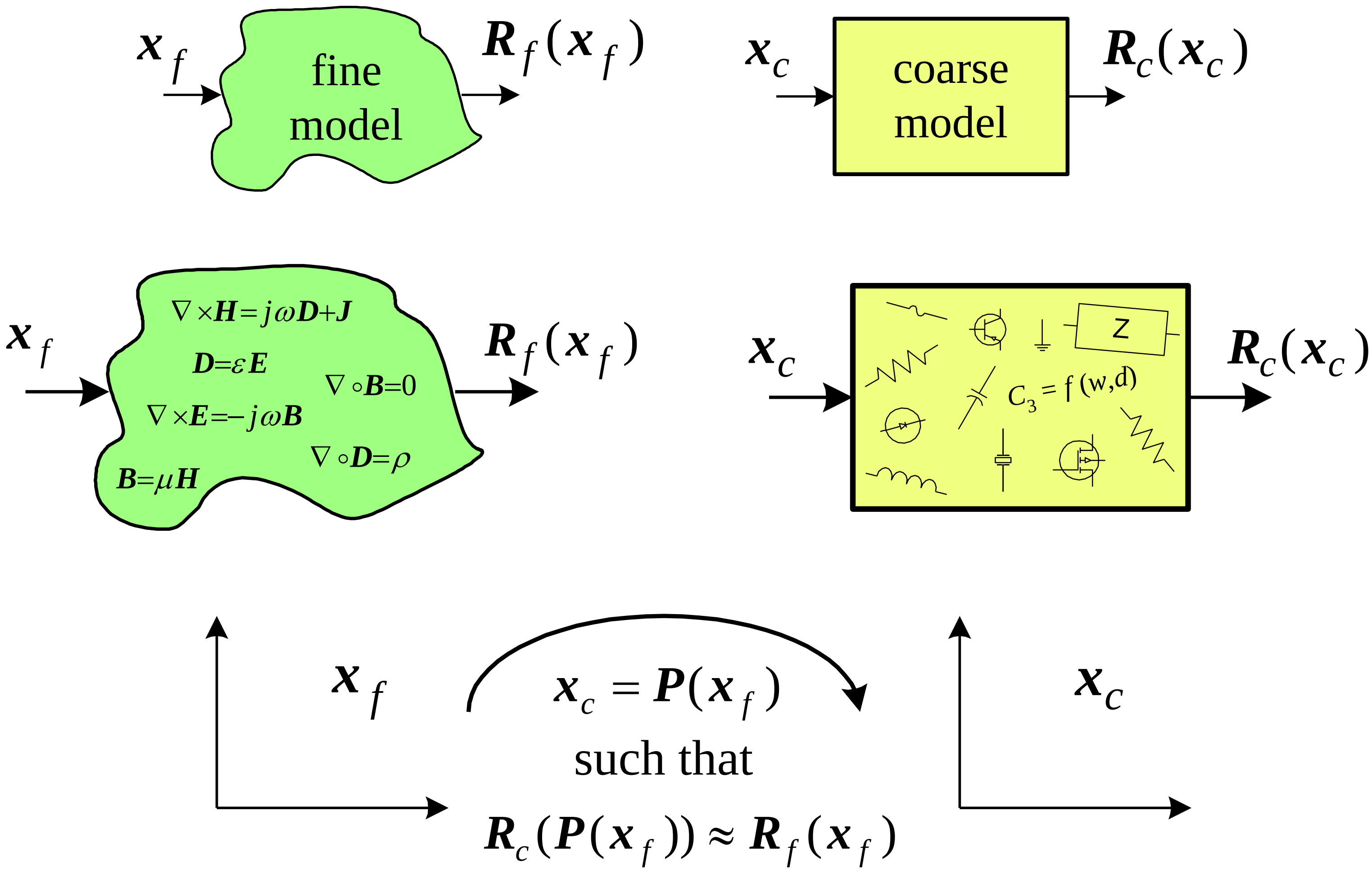
Introduction

using simpler (less accurate) model inside the optimization loop is more appropriate and practical



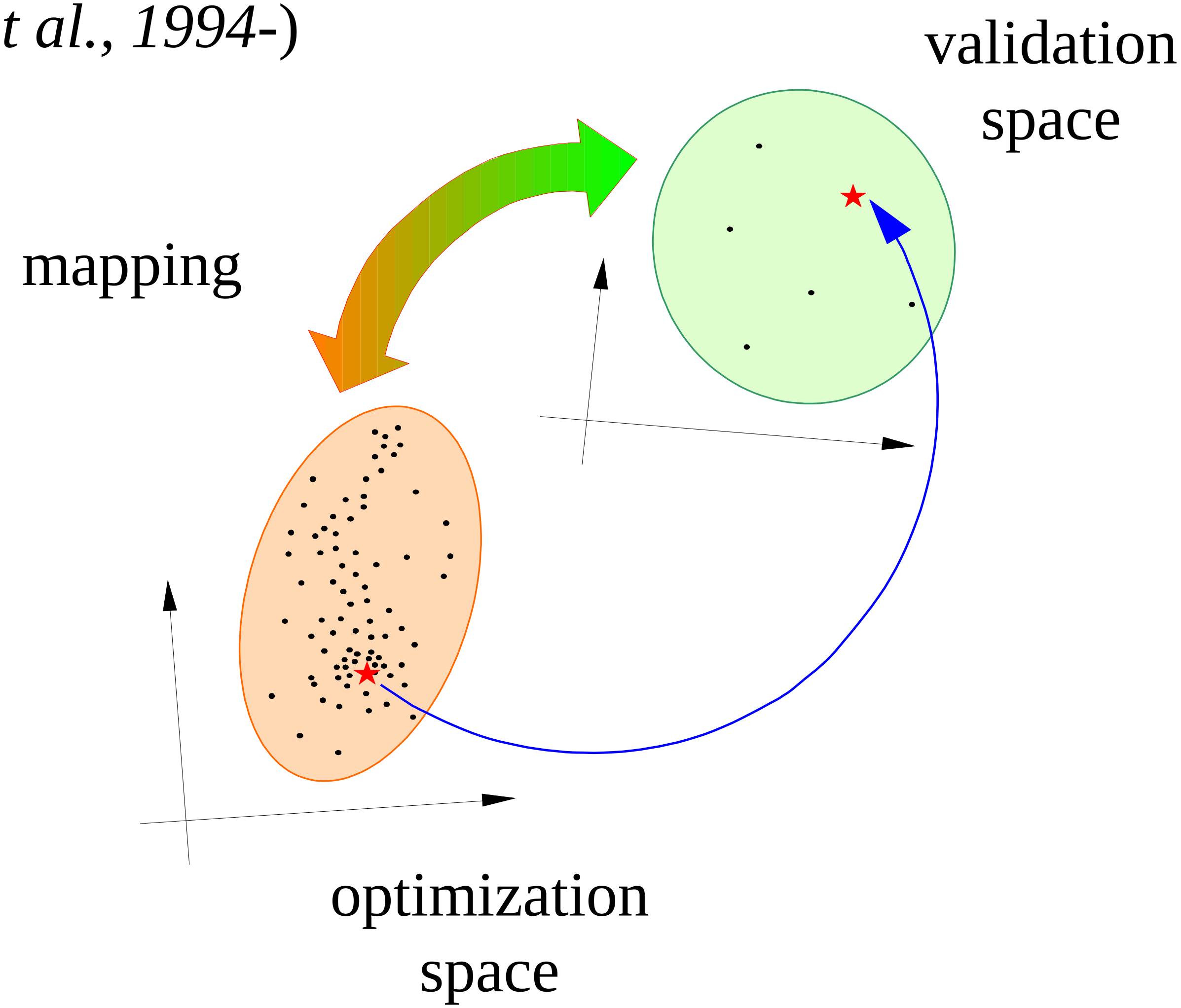
The Space Mapping Concept

(*Bandler et al.*, 1994-)



The Space Mapping Concept

(*Bandler et al., 1994-*)



Jacobian-Space Mapping Relationship

(*Bakr et al., 1999*)

through PE we match the responses

$$\boldsymbol{R}_f(\boldsymbol{x}_f) \approx \boldsymbol{R}_c(\boldsymbol{P}(\boldsymbol{x}_f))$$

by differentiation

$$\left(\frac{\partial \boldsymbol{R}_f^T}{\partial \boldsymbol{x}_f}\right)^T \approx \left(\frac{\partial \boldsymbol{R}_c^T}{\partial \boldsymbol{x}_c}\right)^T \cdot \left(\frac{\partial \boldsymbol{x}_c^T}{\partial \boldsymbol{x}_f}\right)^T$$

Jacobian-Space Mapping Relationship

(*Bakr et al., 1999*)

given coarse model Jacobian $\boldsymbol{J}_c$ and space mapping matrix $\boldsymbol{B}$ we estimate

$$\boldsymbol{J}_f(\boldsymbol{x}_f) \approx \boldsymbol{J}_c(\boldsymbol{x}_c)\boldsymbol{B}$$

given $\boldsymbol{J}_c$ and $\boldsymbol{J}_f$ we estimate (least squares)

$$\boldsymbol{B} \approx (\boldsymbol{J}_c^T \boldsymbol{J}_c)^{-1} \boldsymbol{J}_c^T \boldsymbol{J}_f$$

Gradient Parameter Extraction (GPE)

at the *j*th iteration

$$\boldsymbol{x}_c^{(j)} = \arg\min_{\boldsymbol{x}_c} \left\| [\boldsymbol{e}_0^T \quad \lambda\boldsymbol{e}_1^T \quad \cdots \quad \lambda\boldsymbol{e}_n^T]^T \right\|, \ \lambda \geq 0$$

where λ is a weighting factor and $\boldsymbol{E} = [\boldsymbol{e}_1 \ \boldsymbol{e}_2 \ \ldots \ \boldsymbol{e}_n]$

$$\boldsymbol{e}_0 = \boldsymbol{R}_f(\boldsymbol{x}_f^{(j)}) - \boldsymbol{R}_c(\boldsymbol{x}_c)$$

$$\boldsymbol{E} = \boldsymbol{J}_f(\boldsymbol{x}_f^{(j)}) - \boldsymbol{J}_c(\boldsymbol{x}_c)\boldsymbol{B}$$

Mapping Update

Using Exact Derivatives

$$\boldsymbol{B}^{(j)} = (\boldsymbol{J}_c^{(j)T} \boldsymbol{J}_c^{(j)})^{-1} \boldsymbol{J}_c^{(j)T} \boldsymbol{J}_f^{(j)}$$

Using Hybrid Approach

exact derivatives not available: use finite differences

$$\boldsymbol{B}^{(0)} = (\boldsymbol{J}_c^{(0)T} \boldsymbol{J}_c^{(0)})^{-1} \boldsymbol{J}_c^{(0)T} \boldsymbol{J}_f^{(0)}$$

then update using Brodyen formula

Constraining *B*

(*Bakr et al., 2000*)

constrain the mapping matrix to be close to ***I***

Proposed Algorithm

Step 1 set $j = 1$, $\boldsymbol{B} = \boldsymbol{I}$ for the PE process

Step 2 obtain the optimal coarse model design $\boldsymbol{x}_c^*$

Step 3 set $\boldsymbol{x}_f^{(1)} = \boldsymbol{x}_c^*$

Step 4 if derivatives exist execute GPE
otherwise, execute the traditional PE with $\lambda = 0$

Step 5 initialize the mapping matrix $\boldsymbol{B}$

Step 6 stop if

$$\left\| \boldsymbol{f}^{(j)} \right\| < \varepsilon_1 \text{ or } \left\| \boldsymbol{R}_f^{(j)} - \boldsymbol{R}_c^* \right\| < \varepsilon_2$$

Proposed Algorithm (continued)

Step 7 evaluate $\boldsymbol{h}^{(j)}$ using

$$\boldsymbol{B}^{(j)}\boldsymbol{h}^{(j)} = -\boldsymbol{f}^{(j)}$$

Step 8 find the next $\boldsymbol{x}_f^{(j+1)}$

Step 9 perform GPE or PE as in Step 4

Step 10 if derivatives exist obtain $\boldsymbol{B}^{(j)}$ using

$$\boldsymbol{B}^{(j)} = (\boldsymbol{J}_c^{(j)T}\boldsymbol{J}_c^{(j)})^{-1}\boldsymbol{J}_c^{(j)T}\boldsymbol{J}_f^{(j)}$$

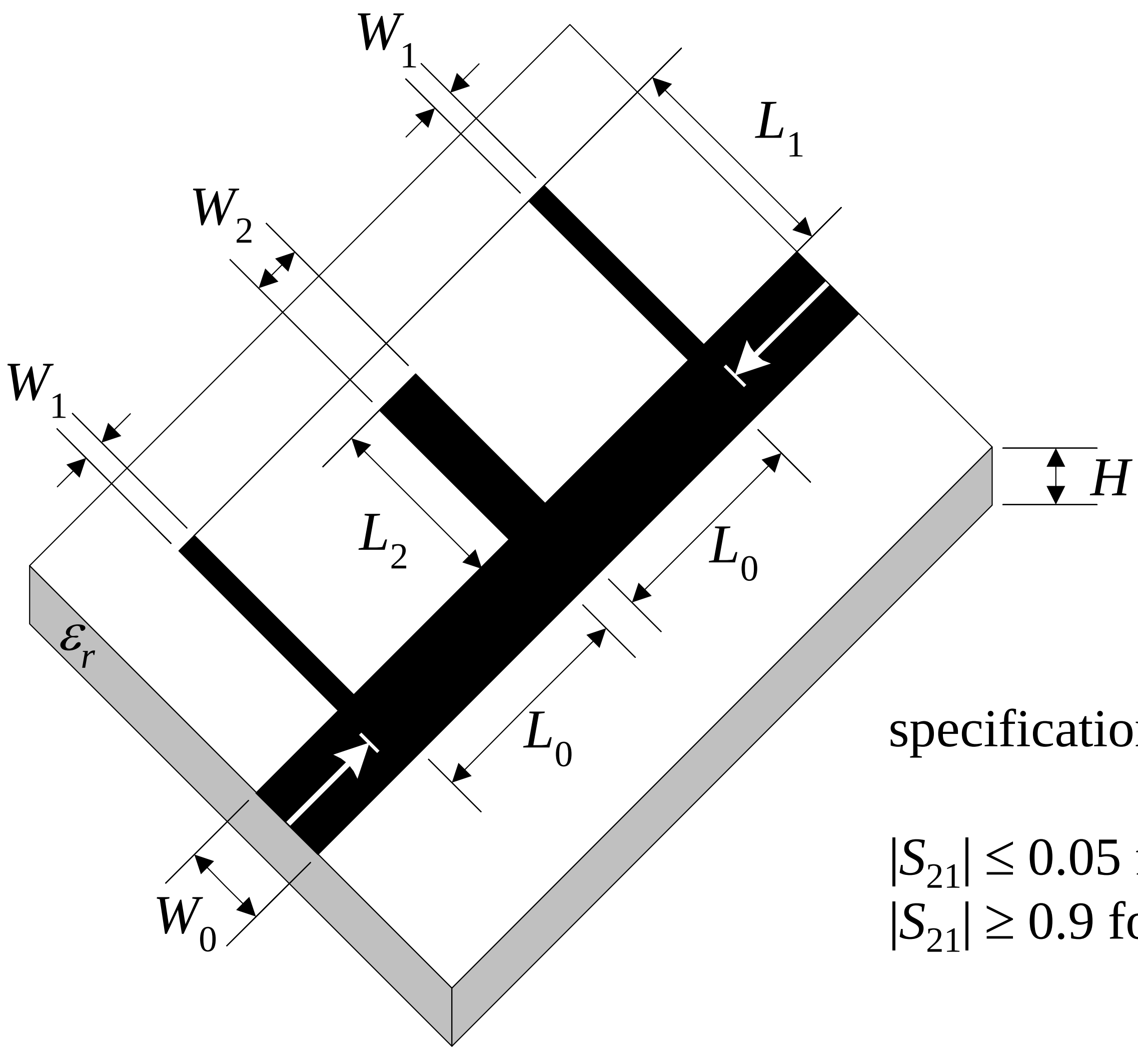
otherwise update $\boldsymbol{B}^{(j)}$ using a Broyden formula

Proposed Algorithm (continued)

Step 11 set $j = j+1$ and go to *Step* 6

the result is the solution $\bar{\boldsymbol{x}}_f$ and mapping matrix $\boldsymbol{B}$

Bandstop Microstrip Filter with Quarter-Wave Open Stubs



H = 25 mil, W_0 = 25 mil,
ε_r = 9.4 (alumina)

the design parameters are
$\boldsymbol{x}_f = [W_1\ W_2\ L_0\ L_1\ L_2]^T$

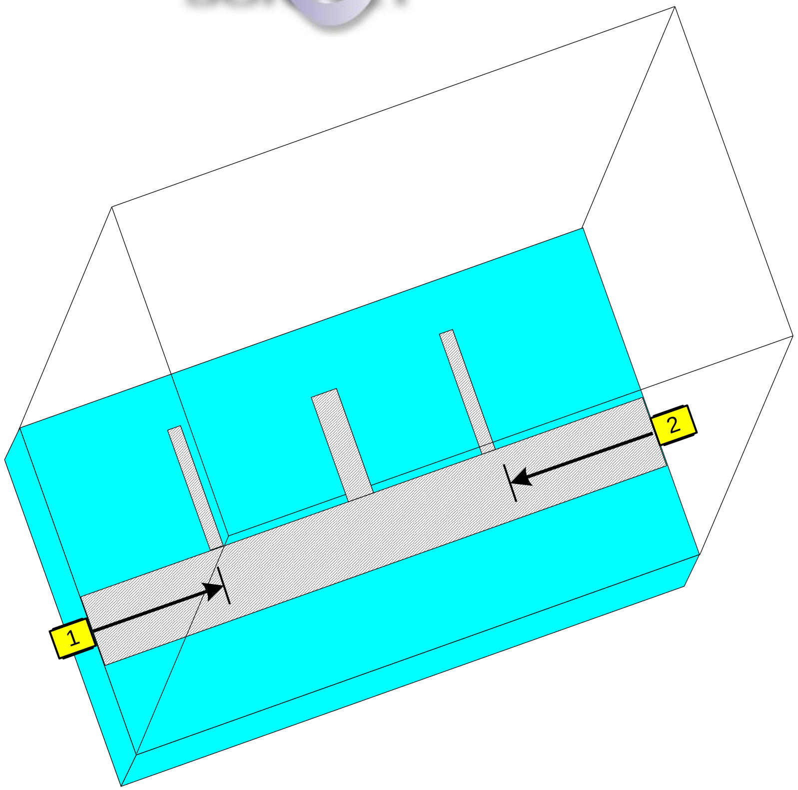
specifications

$|S_{21}| \leq 0.05$ for 9.3 GHz $\leq \omega \leq$ 10.7 GHz
$|S_{21}| \geq 0.9$ for $\omega \leq 8$ GHz and $\omega \geq 12$ GHz

Bandstop Microstrip Filter: Fine and Coarse Models

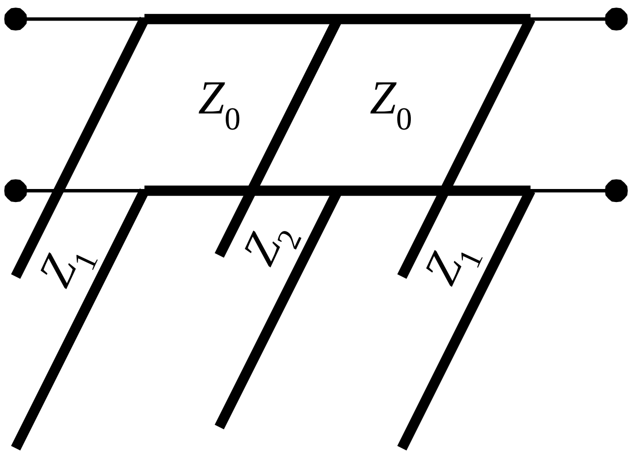
fine model:

Sonnet's ***em***™ with high resolution grid



coarse model:

OSA90/hope™ ideal transmission line sections and empirical formulas



Optimization of the Bandstop Filter

finite differences estimate the fine and coarse Jacobians

use hybrid approach to update mapping

the final mapping is

$$\boldsymbol{B} = \begin{bmatrix} 0.532 & -0.037 & 0.026 & 0.017 & -0.006 \\ -0.051 & 0.543 & 0.022 & -0.032 & 0.026 \\ 0.415 & 0.251 & 1.024 & 0.073 & 0.011 \\ 0.169 & -0.001 & -0.022 & 0.963 & 0.008 \\ -0.213 & -0.003 & -0.045 & -0.052 & 0.958 \end{bmatrix}$$

Optimization of the Bandstop Filter (continued)

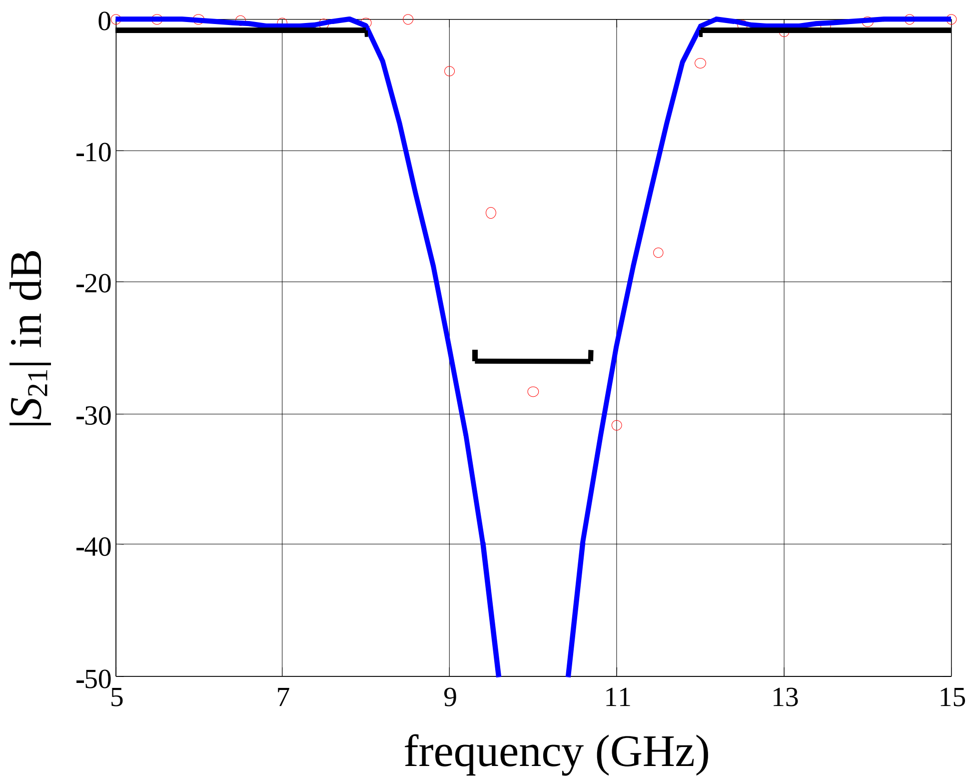
initial and final designs

Parameter	$x_f^{(0)}$	$x_f^{(5)}$
W_1	4.560	8.7464
W_2	9.351	19.623
L_0	107.80	97.206
L_1	111.03	116.13
L_2	108.75	113.99

All values are in mils

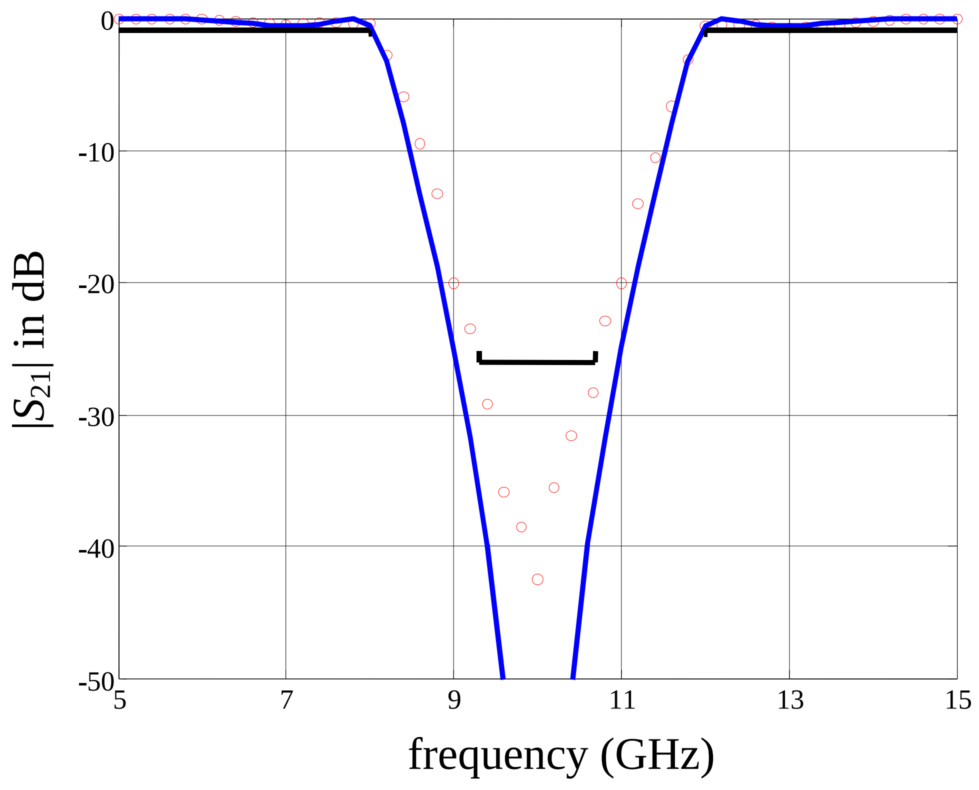
Optimization of the Bandstop Filter (continued)

initial coarse model response OSA90™ (–)
initial fine model response ***em***™ (o)



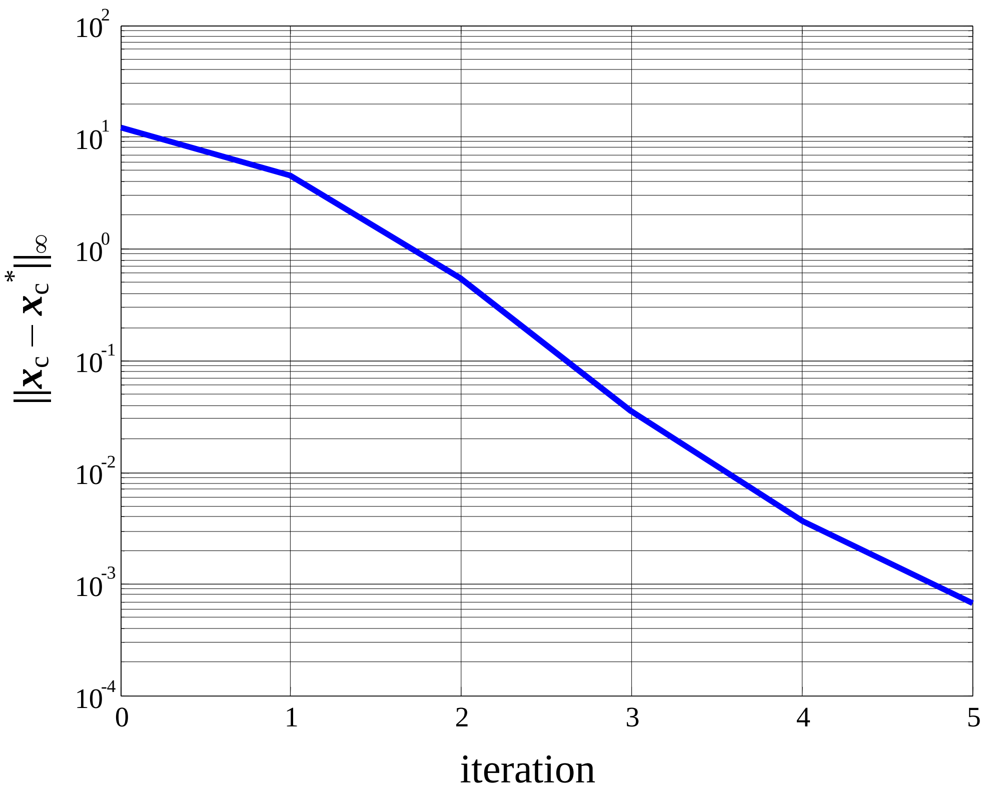
Optimization of the Bandstop Filter (continued)

initial coarse model response OSA90™ (–)
final fine model response ***em***™ (o) (fine sweep)



Optimization of the Bandstop Filter (continued)

$\|\boldsymbol{x}_c - \boldsymbol{x}_c^*\|_\infty$ versus iteration for the bandstop microstrip filter



Conclusions

Gradient Parameter Extraction (GPE) exploiting available Jacobian (exact or approximate)

consideration of mapping updates

available Jacobians can be used to build the mapping

Reference

J.W. Bandler, A.S. Mohamed, M.H. Bakr, K. Madsen and J. Søndergaard, "EM-based optimization exploiting partial space mapping and exact sensitivities," *IEEE MTT-S Int. Microwave Symp. Digest* (Seattle, WA), June 2002.