SPACE MAPPING OPTIMIZATION OF MICROWAVE CIRCUITS USING EM SIMULATORS

J.W. Bandler

SOS-98-14-V

June 30, 1998

SPACE MAPPING OPTIMIZATION OF MICROWAVE CIRCUITS USING EM SIMULATORS

John W. Bandler

Simulation Optimization Systems Research Laboratory
and Department of Electrical and Computer Engineering
McMaster University, Hamilton, Canada L8S 4L7

bandler@mcmaster.ca
soya.sos.mcmaster.ca

presented at

Workshop on Microwave Filters and Multiplexers: Theory, Practice and CAD
28th European Microwave Conference, Amsterdam, The Netherlands, October 5, 1998

Trust Region Aggressive Space Mapping Algorithm

(Bakr, Bandler, Biernacki, Chen and Madsen, 1998)

using $\boldsymbol{f}^{(i)} = \boldsymbol{P}(\boldsymbol{x}_{em}^{(i)}) - \boldsymbol{x}_{os}^{*}$

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

this corresponds to minimizing $\left\| \boldsymbol{f}^{(i)} + \boldsymbol{B}^{(i)}\boldsymbol{h}^{(i)} \right\|_2^2$ subject to $\left\| \boldsymbol{h}^{(i)} \right\|_2 \leq \delta$ where δ is the size of the trust region

λ, which correlates to δ, can be determined (*Moré et al., 1983)*

single point parameter extraction is performed at the new point $\boldsymbol{x}_{em}^{(i+1)} = \boldsymbol{x}_{em}^{(i)} + \boldsymbol{h}^{(i)}$ to get $\boldsymbol{f}^{(i+1)}$

if $\boldsymbol{f}^{(i+1)}$ satisfies a certain success criterion for the reduction in the l_2 norm of the vector $\boldsymbol{f}$, the point $\boldsymbol{x}_{em}^{(i+1)}$ is accepted and the matrix $\boldsymbol{B}^{(i)}$ is updated using Broyden's update

otherwise a temporary point is generated using $\boldsymbol{x}_{em}^{(i+1)}$ and $\boldsymbol{f}^{(i+1)}$ and is added to the set of points to be used for multi-point parameter extraction

a new $\boldsymbol{f}^{(i+1)}$ is obtained through multi-point parameter extraction

Trust Region Aggressive Space Mapping Algorithm

the last three steps are repeated until a success criterion is satisfied or the step is declared a failure

step failure has two forms

(1) $\boldsymbol{f}$ may approach a limiting value without satisfying the success criterion or
(2) the number of fine model points simulated since the last successful step reaches n+1

Case (1): the parameter extraction is trusted but the linearization used is suspect; the size of the trust region is decreased and a new point $\boldsymbol{x}_{em}^{(i+1)}$ is obtained

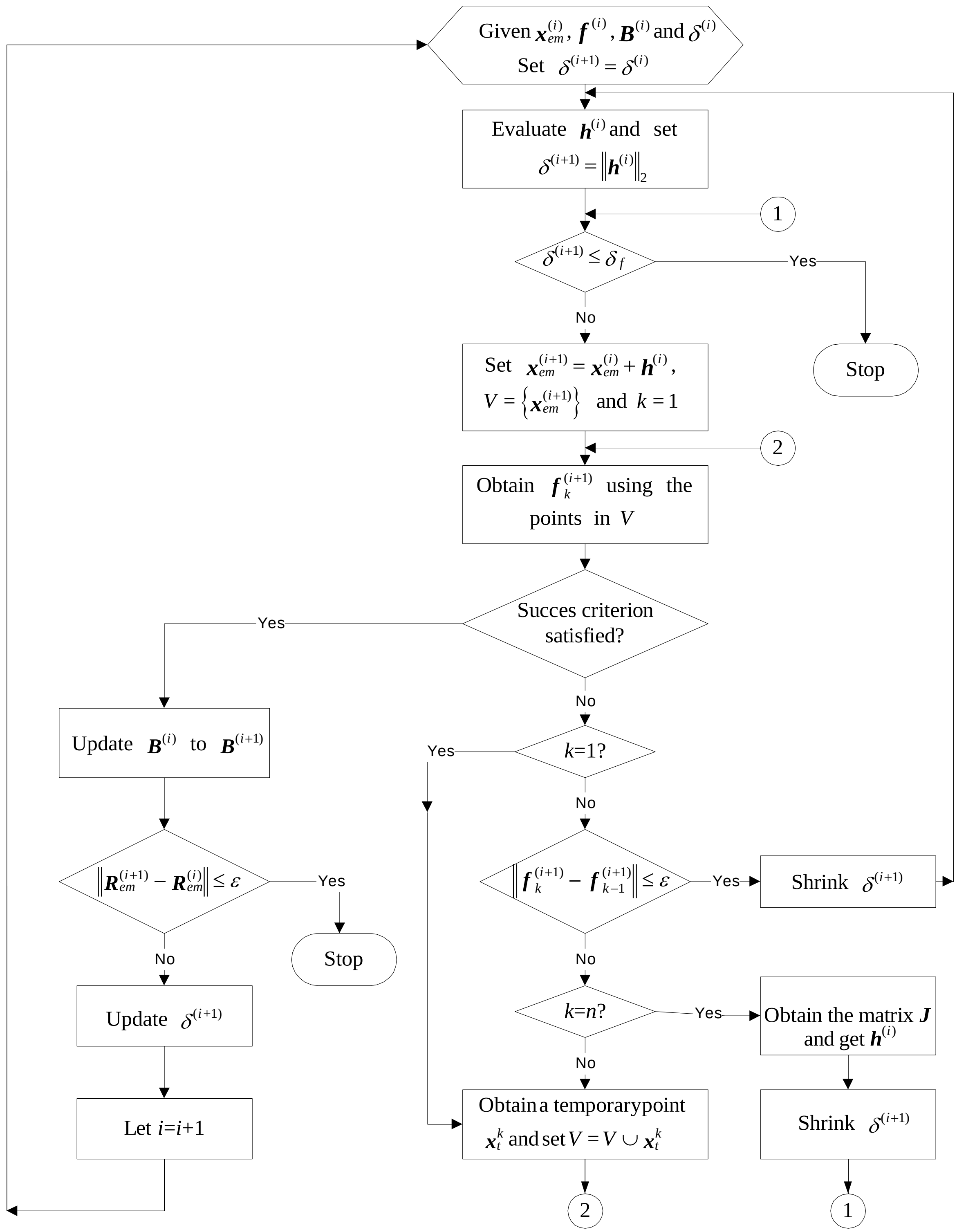
Case (2): sufficient information is available for an approximation to the Jacobian of the fine model responses w.r.t. the fine model parameters used to predict the new point $\boldsymbol{x}_{em}^{(i+1)}$

the mapping between the two spaces is exploited in the parameter extraction step by solving

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

simultaneously for a set of points $\boldsymbol{x}$

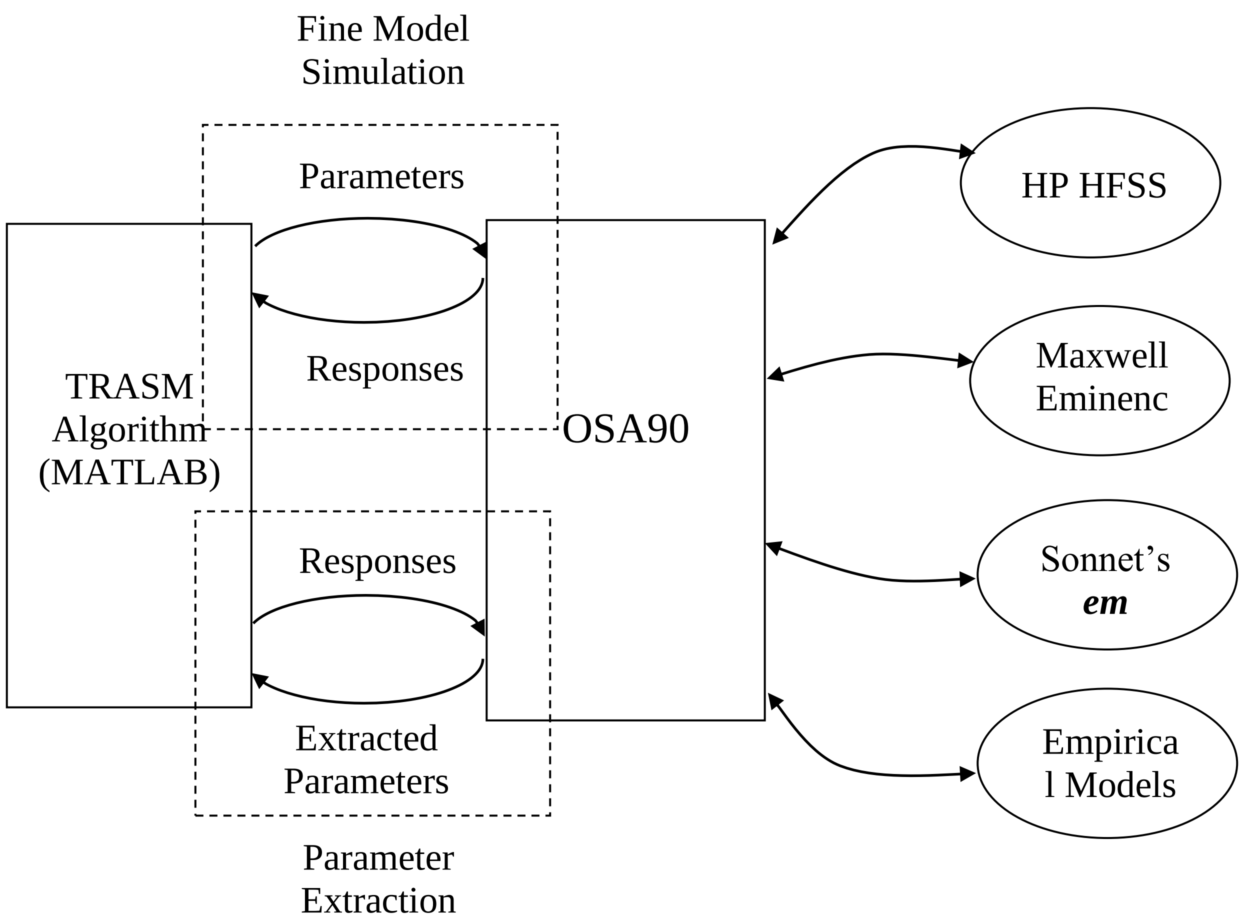
Flow Chart


Given $x_{em}^{(i)}$, $f^{(i)}$, $B^{(i)}$ and $\delta^{(i)}$
Set $\delta^{(i+1)} = \delta^{(i)}$
Evaluate $h^{(i)}$ and set
$\delta^{(i+1)} = \|h^{(i)}\|_2$
1
$\delta^{(i+1)} \le \delta_f$
Yes
Stop
No
Set $x_{em}^{(i+1)} = x_{em}^{(i)} + h^{(i)}$,
$V = \{x_{em}^{(i+1)}\}$ and $k = 1$
2
Obtain $f_k^{(i+1)}$ using the
points in V
Succes criterion
satisfied?
Yes
No
Update $B^{(i)}$ to $B^{(i+1)}$
k=1?
Yes
No
$\|R_{em}^{(i+1)} - R_{em}^{(i)}\| \le \varepsilon$
Yes
Stop
No
$\|f_k^{(i+1)} - f_{k-1}^{(i+1)}\| \le \varepsilon$
Yes
Shrink $\delta^{(i+1)}$
No
Update $\delta^{(i+1)}$
k=n?
Yes
Obtain the matrix J
and get $h^{(i)}$
No
Let i=i+1
Obtain a temporary point
x_t^k and set $V = V \cup x_t^k$
Shrink $\delta^{(i+1)}$
2
1

The Current Implementation

The algorithm is currently implemented in MATLAB

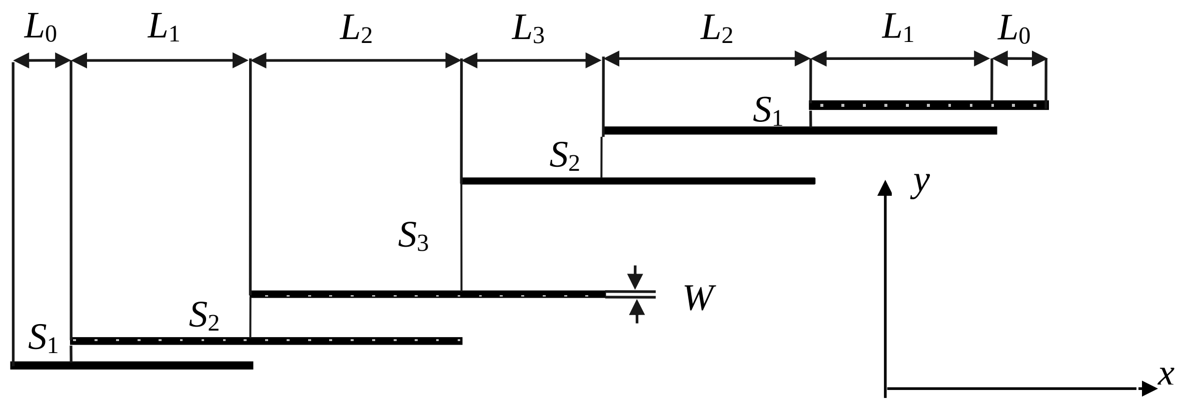
OSA90 is used as a platform for the multi-point parameter extraction and for the fine model simulations



TRASM : Trust Region Aggressive Space Mapping

High-Temperature Superconducting Filter

(*Westinghouse, 1993*)



20 mil thick substrate

the dielectric constant is 23.4

passband specifications: $|S_{21}| \geq 0.95$ for 4.008 GHz $\leq f \leq$4.058 GHz

stopband specifications: $|S_{21}| \leq 0.05$ for $f \leq$ 3.967 GHz and 4.099 GHz $\leq f$

designable parameters L_1, L_2, L_3, S_1, S_2 and S_3; L_0 and W are kept fixed

coarse model exploits the empirical models of microstrip lines, coupled lines and open stubs available in OSA90/hope

High-Temperature Superconducting Filter Fine Model

the fine model employs a fine-grid Sonnet ***em*** simulation

the *x* and *y* grid sizes for ***em*** are 1.0 and 1.75 mil

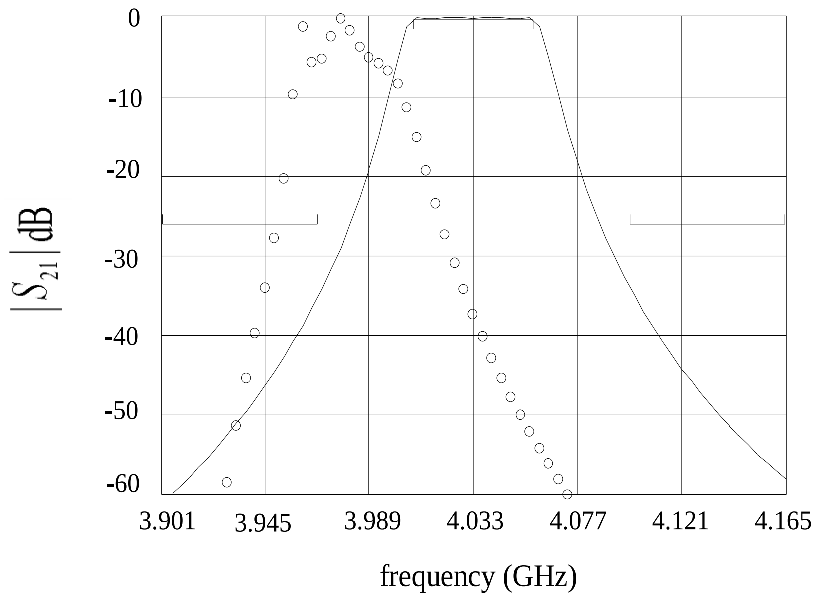
100 elapsed minutes are needed for ***em*** analysis at single frequency on a Sun SPARCstation 10

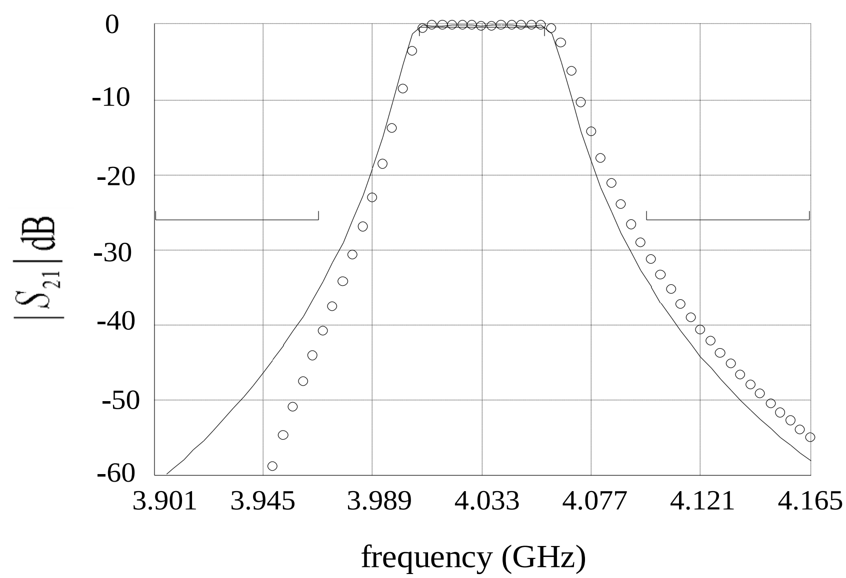
final design is obtained in 5 TRASM iterations, requiring 8 ***em*** simulations

15 frequency points are used per ***em*** simulation

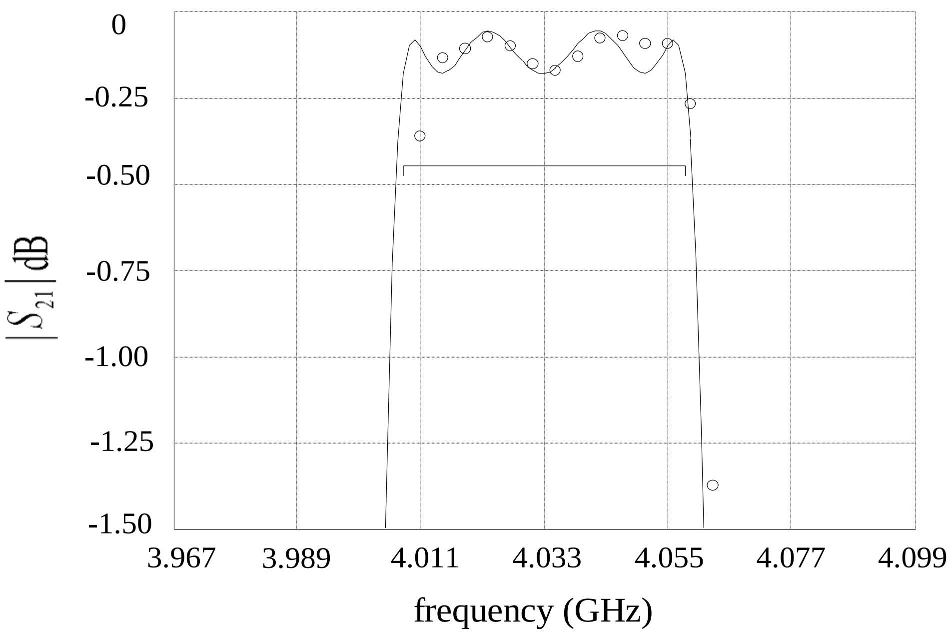
High-Temperature Superconducting Filter Responses

the optimal coarse model (—) response and the fine model response (o) at the initial and final designs





Passband Details for the High-Temperature Superconducting Filter



Discussion

Space Mapping is very broadly defined in terms of "coarse" and "fine" models

recent variants of "space mapping" techniques include:

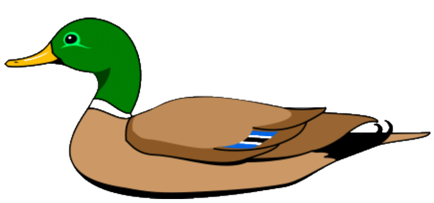
A.M. Pavio, "The electromagnetic analysis and optimization of a broad class of problems using companion models," *Workshop on Automated Circuit Design using Electromagnetic Simulators, IEEE MTT-S Int. Microwave Symp.* (Orlando, FL, 1995).

M.-Q. Lee and S. Nam, "Efficient coupling patterns design of miniaturized dielectric filter using EM simulator and EPO technique," *IEEE MTT-S Int. Microwave Symp. Dig.* (San Francisco, CA, 1996), pp. 737-739.

S. Ye and R.R. Mansour, "An innovative CAD technique for microstrip filter design," *IEEE Trans. Microwave Theory Tech.*, vol. 45, 1997, pp. 780-786.

S. Moreau, S. Gendraud, R. Comte, D. Chaimbault, S. Bila, D. Baillargeat, S. Verdeyme, M. Aubourg and P. Guillon, "Analysis and optimization of microwave filters by the finite element method," *Workshop on State-of-the-art Filter Design using EM and Circuit Simulation Techniques, IEEE MTT-S Int. Microwave Symp.* (Denver, CO, 1997).

S. Bila, D. Baillargeat, S. Verdeyme and P. Guillon, "Automated design of microwave devices using full EM optimization method," *IEEE MTT-S Int. Microwave Symp. Dig.* (Baltimore, MD, 1998), pp. 1771-1774.



Conclusions

SM promises the accuracy of EM and physical simulation and the speed of circuit-level optimization

accurate but computationally intensive fine model calibrates computationally efficient coarse models

our approach has broad applicability and can profoundly change the way the EM simulators are perceived and used as a CAD tool

a coherent framework combines the power of aggressive SM with decomposition

decomposition further accelerates the coarse model simulation

we present a novel Trust Region Aggressive Space Mapping algorithm for the optimization of microwave circuits

TRASM integrates a trust region methodology with the Aggressive Space Mapping technique

a recursive multi-point parameter extraction step is exploited to improve the uniqueness of the parameter extraction step

multi-point parameter extraction exploits the available information about the mapping between the two spaces to improve the uniqueness of the step

References

J.W. Bandler, R.M. Biernacki, S.H. Chen, P.A. Grobelny and R.H. Hemmers, "Space mapping technique for electromagnetic optimization," *IEEE Trans. Microwave Theory Tech*., vol. 42, 1994, pp. 2536-2544.

J.W. Bandler, R.M. Biernacki, S.H. Chen, R.H. Hemmers and K. Madsen, "Electromagnetic optimization exploiting aggressive space mapping," *IEEE Trans. Microwave Theory Tech.*, vol. 43, 1995, pp. 2874-2882.

J.W. Bandler, R.M. Biernacki and S.H. Chen, "Fully automated space mapping optimization of 3D structures," *IEEE MTT-S Int. Microwave Symp. Dig.* (San Francisco, CA, 1996), pp. 753-756.

J.W. Bandler, R.M. Biernacki, S.H. Chen and Y.F. Huang, "Design optimization of interdigital filters using aggressive space mapping and decomposition," *IEEE Trans. Microwave Theory Tech.*, vol. 45, 1997, pp. 761-769.

J.W. Bandler, R.M. Biernacki, S.H. Chen and P.A. Grobelny, "Optimization technology for nonlinear microwave circuits integrating electromagnetic simulations," *Int. J. Microwave and mm-Wave CAE*, vol. 7, 1997, pp. 6-28.

J.W. Bandler, R.M. Biernacki, S.H. Chen and D. Omeragic, "Space mapping optimization of waveguide filters using finite element and mode-matching electromagnetic simulators," *IEEE MTT-S Int. Microwave Symp. Dig.* (Denver, CO, 1997), pp. 635-638.

M.H. Bakr, J.W. Bandler, R.M. Biernacki, S.H. Chen and K. Madsen, "A trust region aggressive space mapping algorithm for EM optimization," *IEEE MTT-S Int. Microwave Symp. Dig.* (Baltimore, MD, 1998), pp 1759-1762.