A TRUST REGION AGGRESSIVE SPACE MAPPING TECHNIQUE FOR EM OPTIMIZATION

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SOS-98-15-V

June 1998

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presented at

1998 IEEE MTT-S Int. Microwave Symposium, Baltimore, MD, June 1998

Basic Concepts

it is assumed that the circuit under consideration can be simulated using two models: a fine model and a coarse model

the fine model is accurate but is computationally intensive

$\boldsymbol{x}_{em}$ is the vector of fine model parameters

the coarse model is a fast model but it is less accurate than the fine model

$\boldsymbol{x}_{os}$ is the vector of coarse model parameters

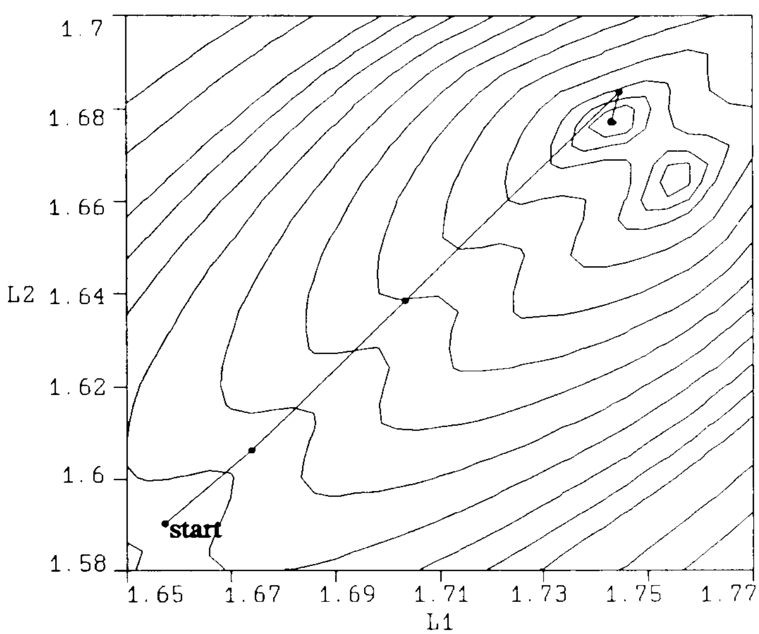
Space Mapping (SM) aims at avoiding the computationally intensive direct optimization of the fine model

Comments on the Parameter Extraction Step

the parameter extraction step aims at finding a point $\boldsymbol{x}_{os}$ whose coarse model responses match corresponding fine model responses

the extracted coarse model parameters may be nonunique

nonuniqueness of the parameter extraction step hinders the convergence of the Aggressive Space Mapping technique



contours of the parameter extraction objective function (*Bandler et al., 1996*)

The Multi-Point Parameter Extraction

to overcome problems caused by nonuniqueness of the parameter extraction step a multi-point parameter extraction step was suggested (*Bandler et al., 1996*)

the step aims at matching not only the response but also the first-order derivative of the two models

the extracted coarse model point $\boldsymbol{x}_{os}$ is obtained by solving

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

simultaneously for a set of perturbations *D**x***

this step is more likely to improve the uniqueness of the parameter extraction step

Questions Regarding the Original Multi-Point Extraction

the original multi-point parameter extraction (*Bandler et al., 1996*) suffers from two main drawbacks

the first drawback is that the fine model points were arbitrarily selected

the second drawback is the assumption that a perturbation of $\Delta\boldsymbol{x}$ in the fine model space corresponds to an equal perturbation in the coarse model space

in the *i*th iteration, the most recent information about the mapping between the two spaces is given by the matrix $\boldsymbol{B}^{(i)}$, which should be integrated with the multi-point parameter extraction step

Trust Region Aggressive Space Mapping Algorithm

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

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

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

l, which correlates to d, 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

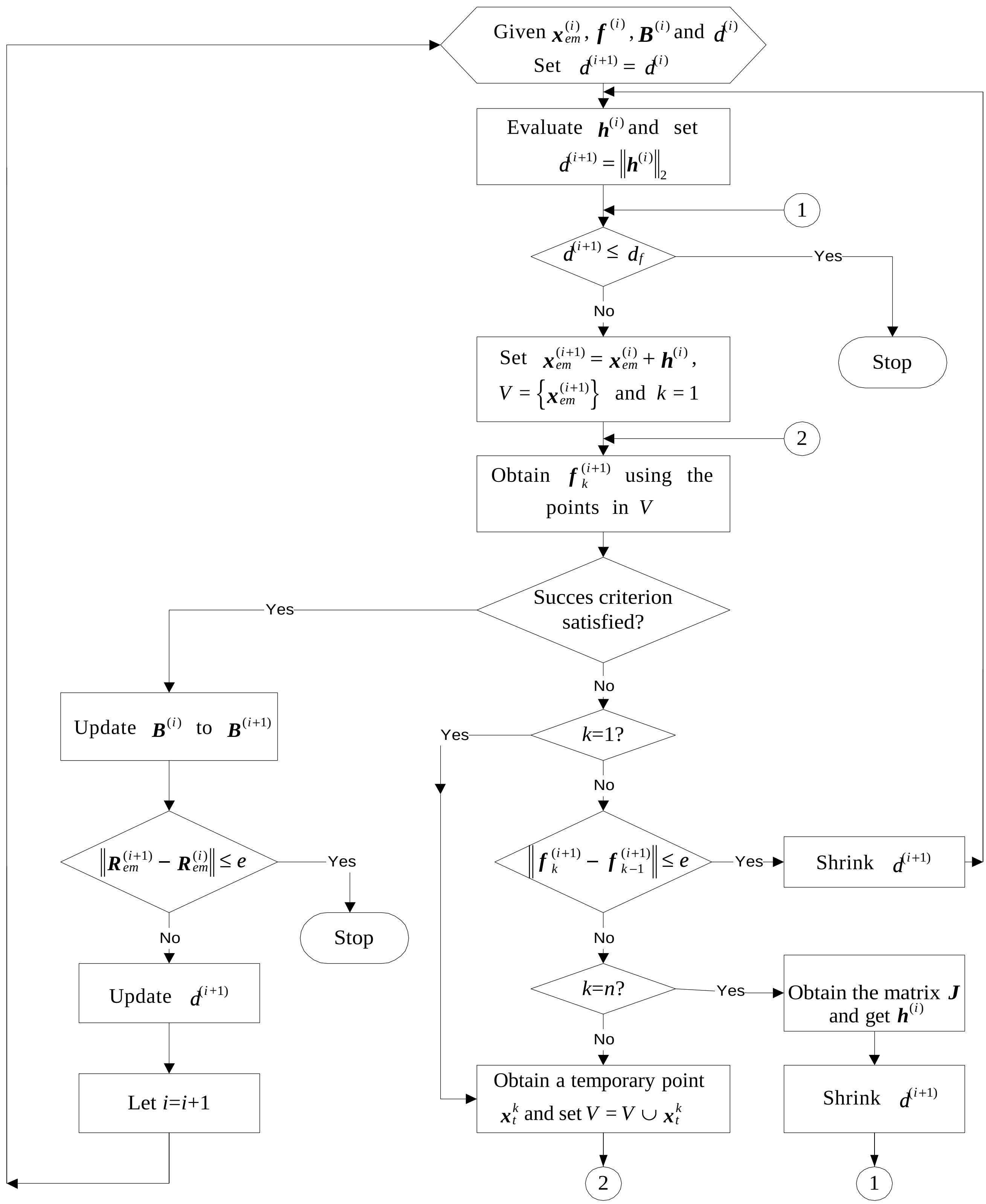
Case (2): sufficient information is available for an approximation to the Jacobian of the fine model responses w.r.t. the fine model parameters used to predict the new point $\boldsymbol{x}_{em}^{(i+1)}$

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 $\boldsymbol{x}$

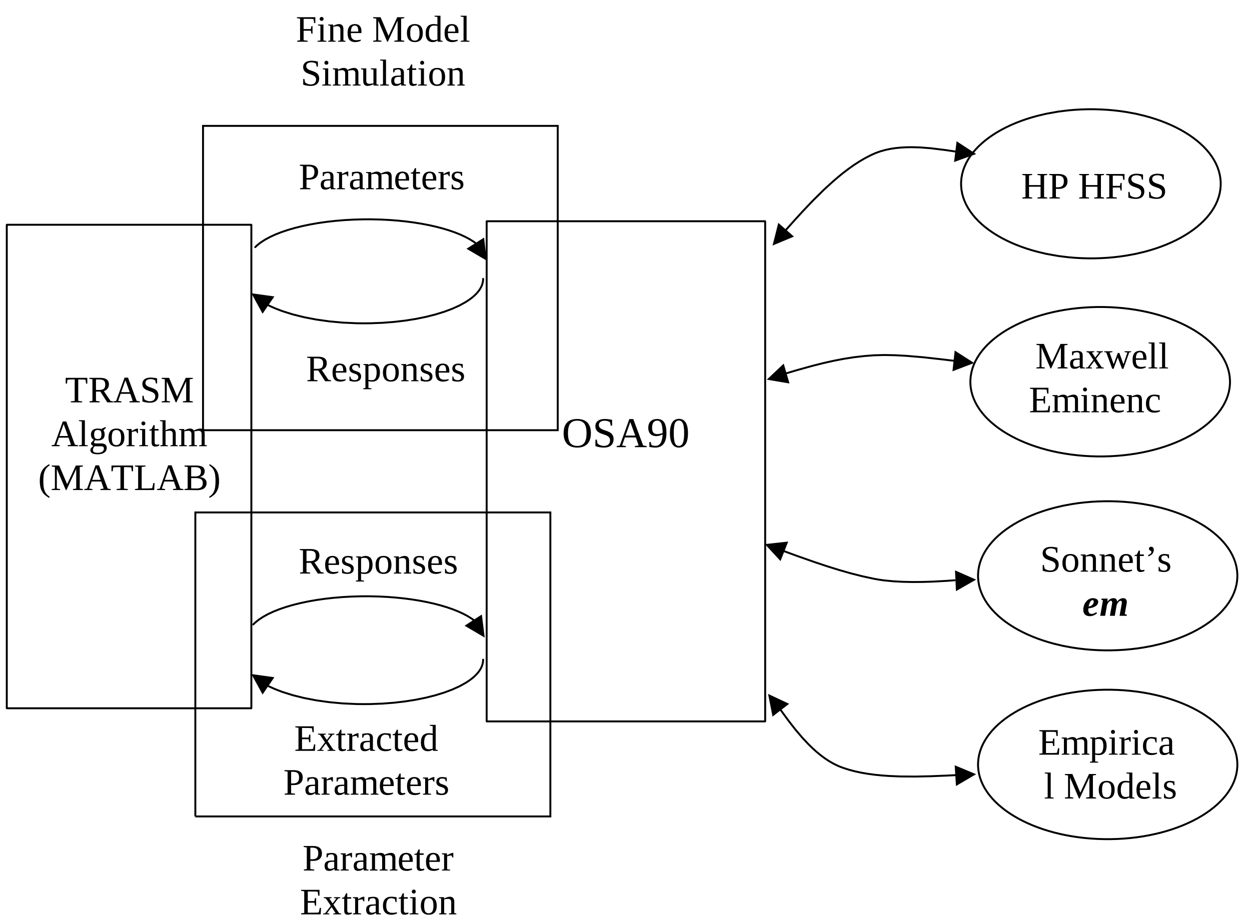
Flow Chart


Given $x_{em}^{(i)}$, $f^{(i)}$, $B^{(i)}$ and $d^{(i)}$
Set $d^{(i+1)} = d^{(i)}$
Evaluate $h^{(i)}$ and set $d^{(i+1)} = \|h^{(i)}\|_2$
1
$d^{(i+1)} \le d_f$
Yes
No
Stop
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
$\|R_{em}^{(i+1)} - R_{em}^{(i)}\| \le e$
Yes
Stop
No
Update $d^{(i+1)}$
Let i=i+1
$\|f_k^{(i+1)} - f_{k-1}^{(i+1)}\| \le e$
Yes
Shrink $d^{(i+1)}$
No
k=n?
Yes
Obtain the matrix J and get $h^{(i)}$
No
Obtain a temporary point x_t^k and set $V = V \cup x_t^k$
Shrink $d^{(i+1)}$
2
1

The Current Implementation

The algorithm is currently implemented in MATLAB

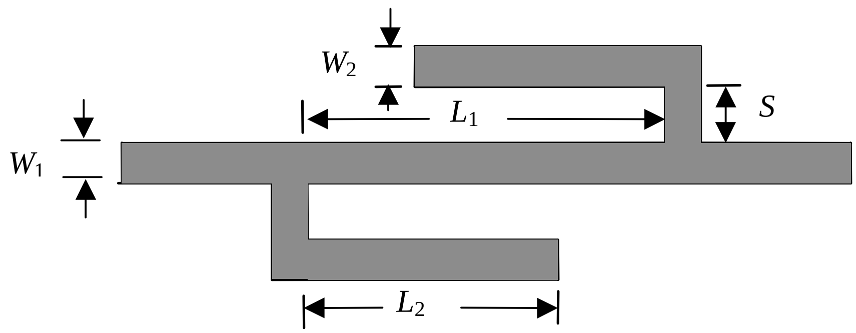
OSA90 is used as a platform for the multi-point parameter extraction and for the fine model simulations



TRASM : Trust Region Aggressive Space Mapping

Double-Folded Stub Microstrip Filter

(*Rautio, 1992*)



passband specifications: $|S_{21}| \geq$ -3 dB for $f \leq$ 9.5 GHz and 16.5 GHz $\leq f$

stopband specifications: $|S_{21}| \leq$ -30 dB for 12 GHz $\leq f \leq$14 GHz

designable parameters: L_1, L_2 and S; W_1=W_2=4.8 mil

substrate thickness is 5 mil and the relative dielectric constant is assumed to be 9.9

coarse model: a coarse grid Sonnet ***em*** model with $\Delta x = \Delta y =$ 4.8 mil

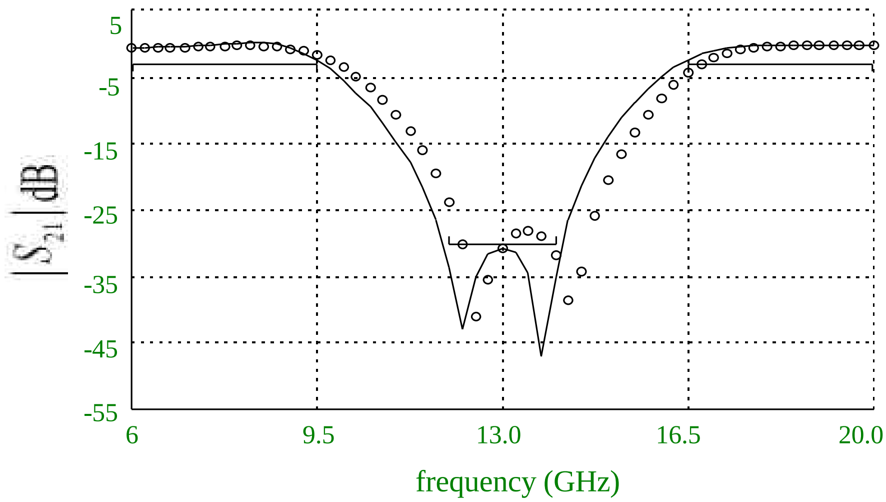
fine model: a fine grid Sonnet ***em*** model with $\Delta x = \Delta y =$ 1.6 mil

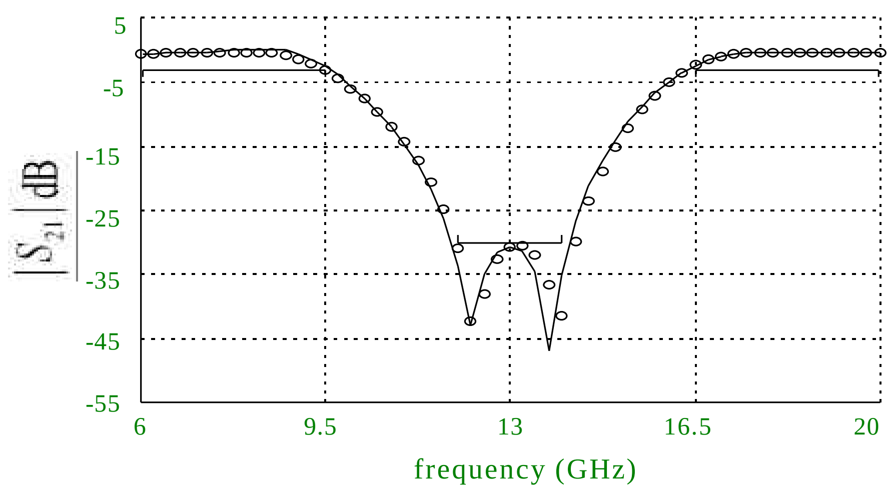
final design is obtained in 2 TRASM iterations, requiring 5 fine model points

OSA's Empipe linear interpolation is used to simulate off-grid points

Double-Folded Stub Microstrip Filter Responses

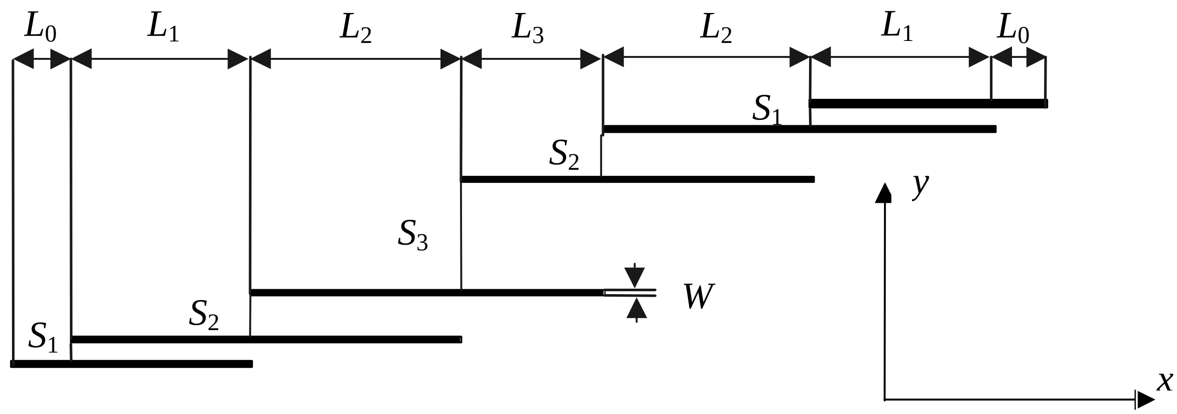
the optimal coarse model (—) response and the fine model response (o) at the initial and final designs





High-Temperature Superconducting Filter

(*Westinghouse, 1993*)



20 mil thick substrate

the dielectric constant is 23.4

passband specifications: $|S_{21}| \geq 0.95$ for $f \leq 3.967$ GHz and 4.099 GHz $\leq f$

stopband specifications: $|S_{21}| \leq 0.05$ for 4.008 GHz $\leq f \leq$4.058 GHz

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

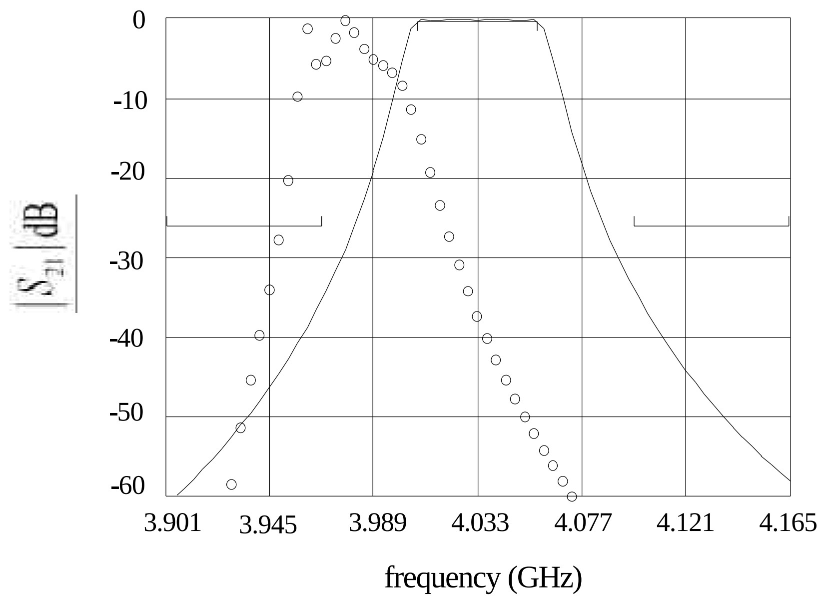
100 elapsed minutes are needed for ***em*** analysis at single frequency on a Sun SPARCstation 10

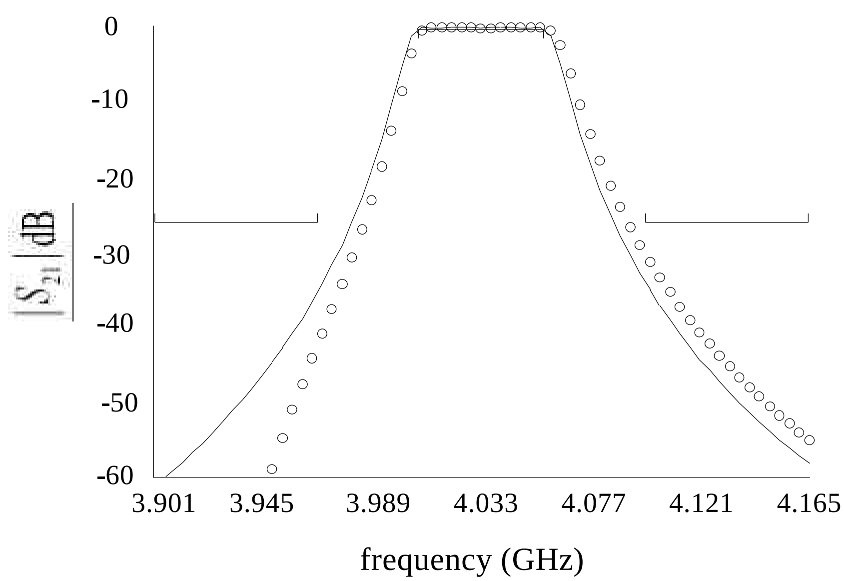
final design is obtained in 5 TRASM iterations, requiring 8 ***em*** simulations

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

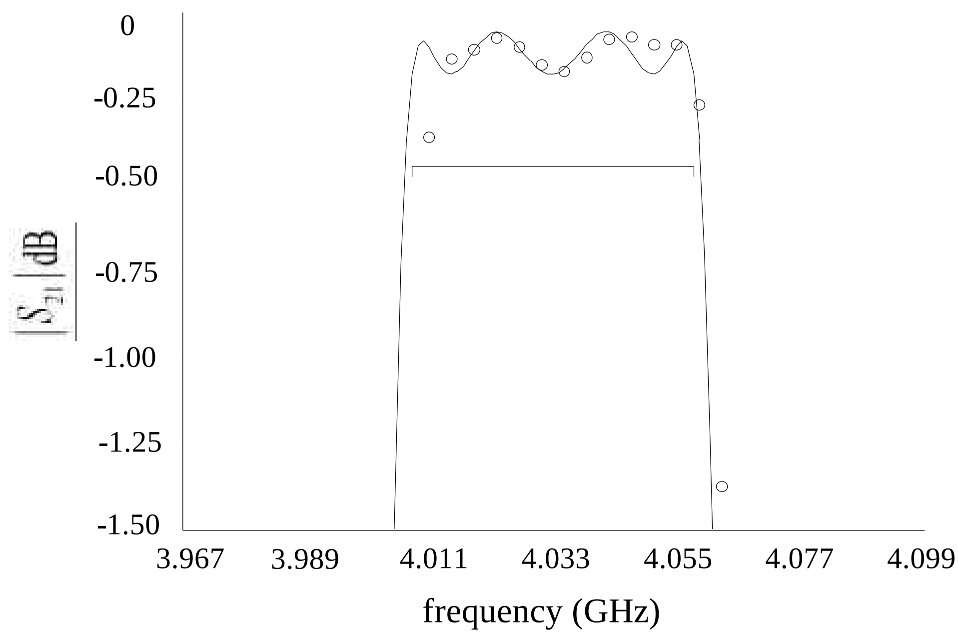
High-Temperature Superconducting Filter Responses

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

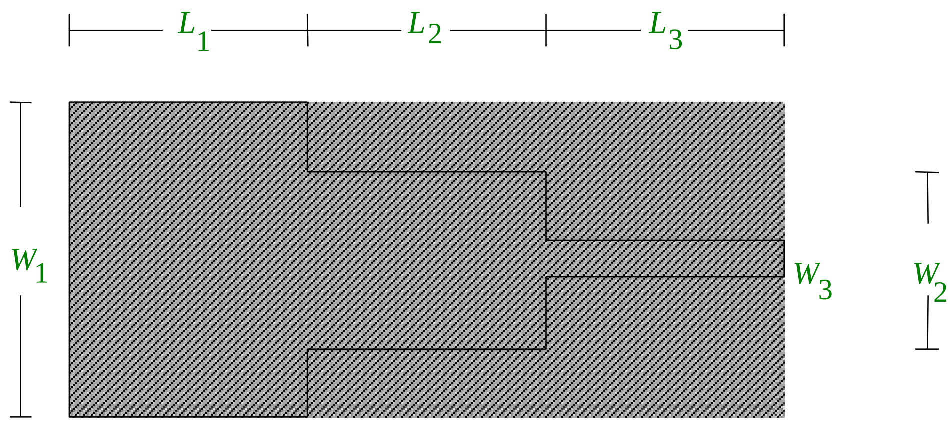




Passband Details for the High-Temperature Superconducting Filter



Three-Section 3:1 Microstrip Transformer
(*Bandler et al., 1994*)



source and load impedances 50 Ω and 150 Ω

design constraints $|S_{11}| \leq 0.11$ for the frequency range
5 GHz $\leq f$ £ 15 GHz.

designable parameters: W_1, W_2, W_3, L_1, L_2 and L_3

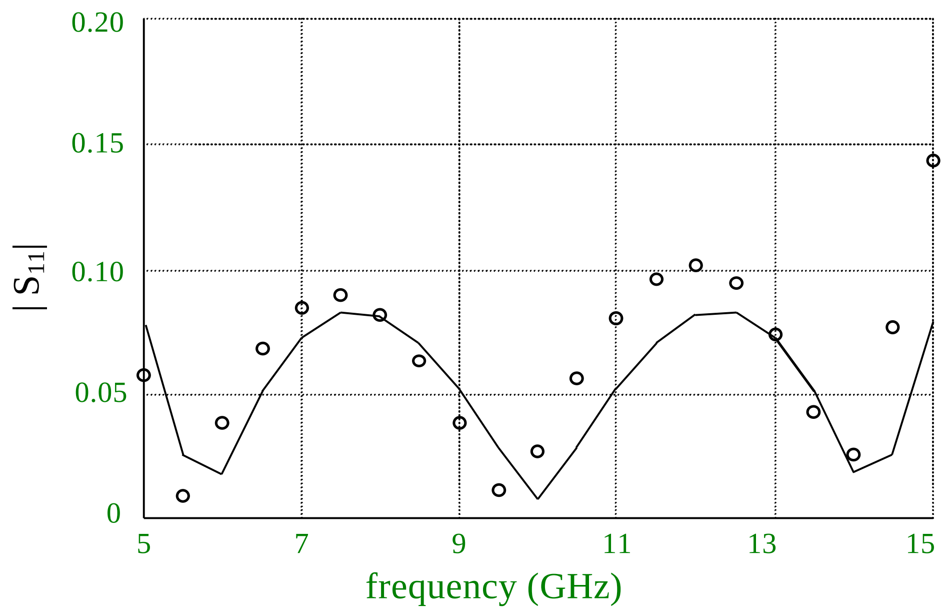
coarse model: ideal transmission-line model supplied by OSA90/hope

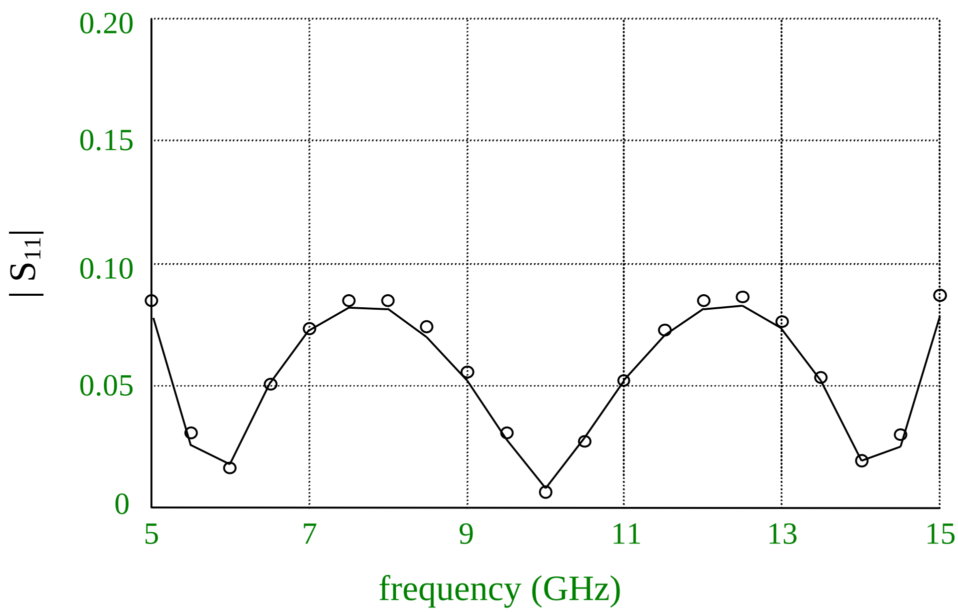
fine model exploits microstrip and microstrip step models supplied by OSA90/hope

the final solution is obtained in 2 TRASM iterations, requiring 6 fine model simulations

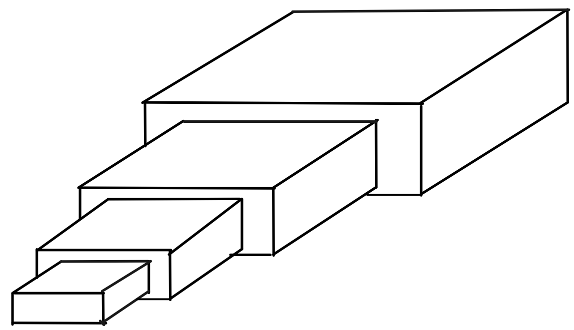
Three-Section 3:1 Microstrip Transformer Responses

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





Two-Section Waveguide Transformer
(*Bandler et al., 1996*)



design specifications: $VSWR \leq 1.01$ for 5.8 GHz $\leq f \leq$ 6.6 GHz

optimizable parameters: length and height of each waveguide section

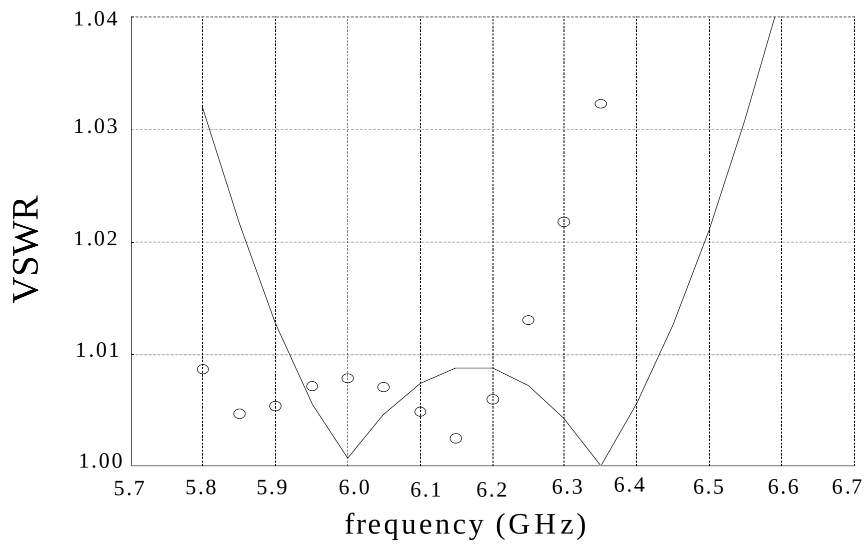
coarse model: an analytical model that neglects junction discontinuity

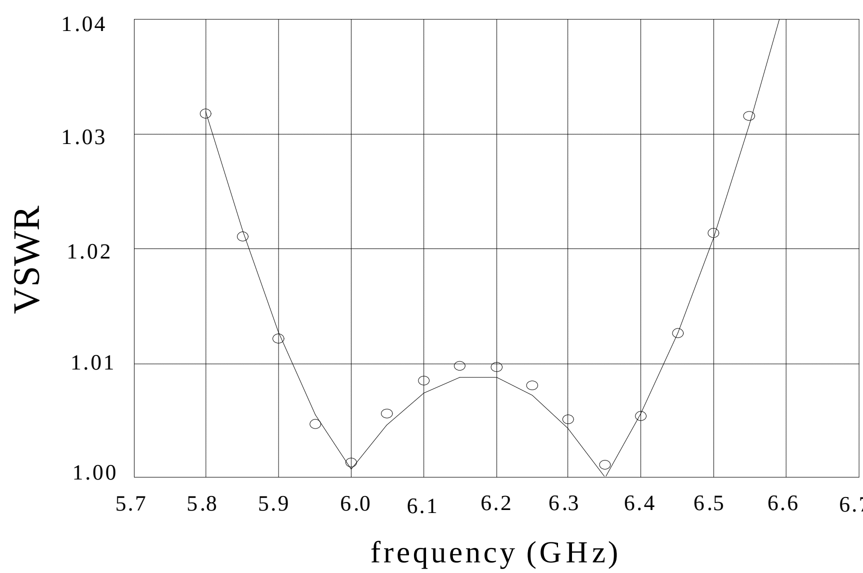
fine model exploits the 3D solver Maxwell Eminence

the optimal design is obtained in 3 TRASM iterations requiring 5 Maxwell Eminence simulations

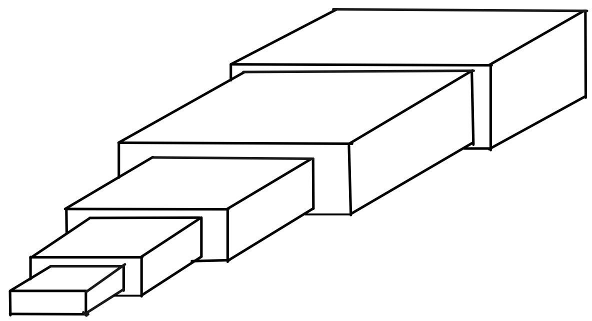
Two-Section Waveguide Transformer Responses

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





Three-Section Waveguide Transformer
(*Bandler et al., 1996*)



design specifications: $VSWR \le 1.04$ for 5.7 GHz $\le f \le$ 7.2 GHz

optimizable parameters: length and height of each waveguide section

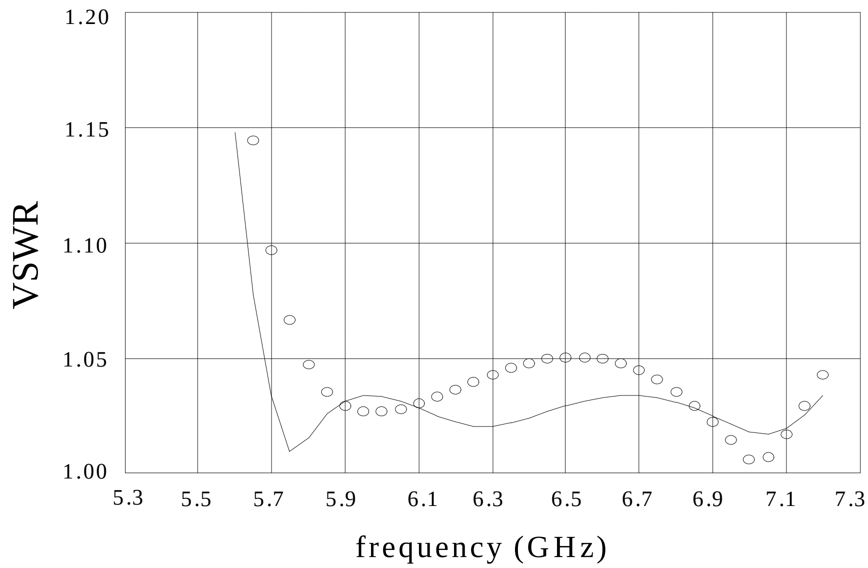
coarse model: an analytical model that neglects junction discontinuity

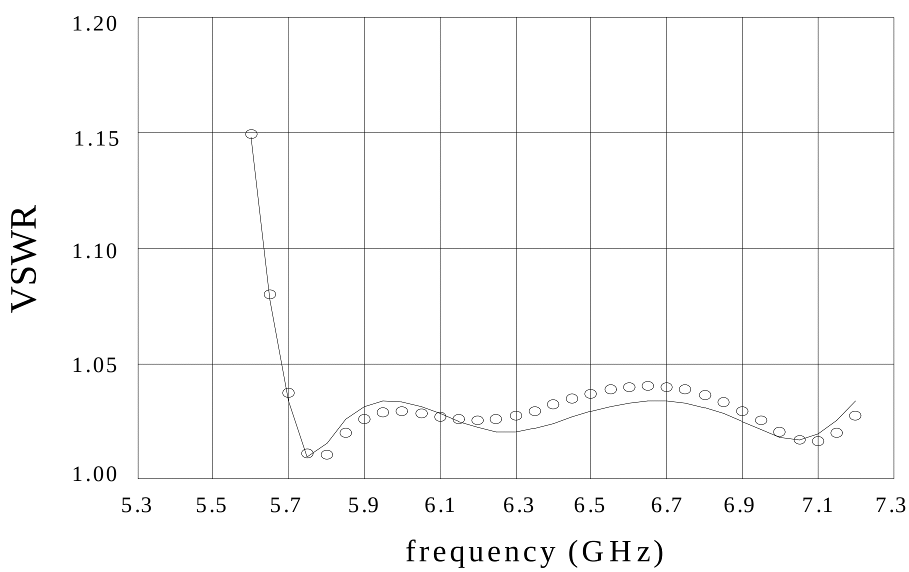
fine model exploits the 3D solver Maxwell Eminence

the optimal design is obtained in 2 TRASM iterations requiring 9 Maxwell Eminence simulations

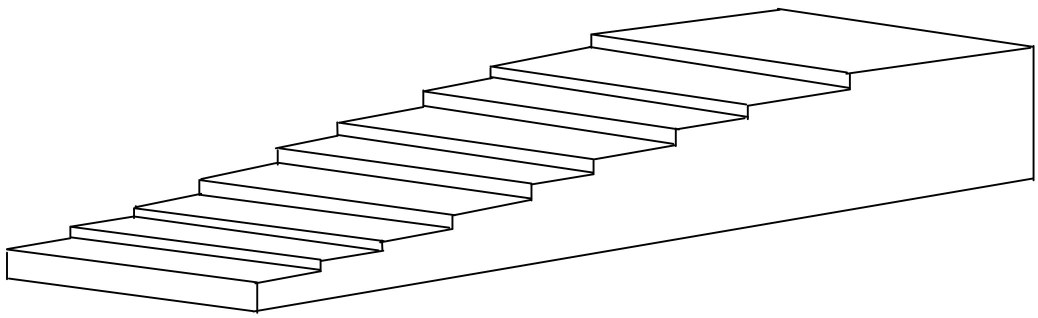
Three-Section Waveguide Transformer Responses

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





Seven-Section Waveguide Transformer
(*Bandler et al., 1996*)



design specifications: $VSWR \leq 1.01$ for $1.06 \text{ GHz} \leq f \leq 1.8 \text{ GHz}$

optimizable parameters: length and height of each waveguide section

coarse model: an analytical model that neglects junction discontinuities

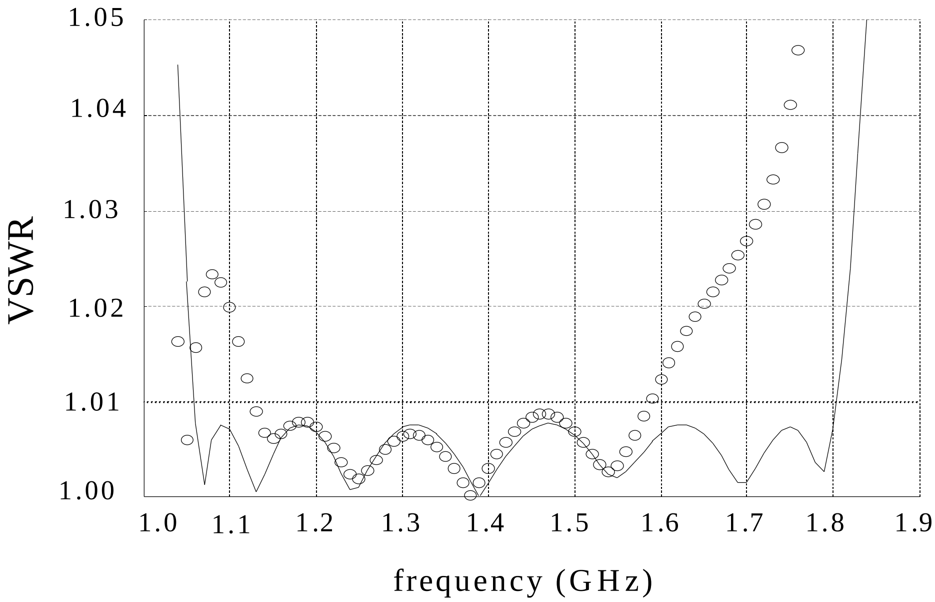
fine model : an analytical model that considers junction discuntinuities

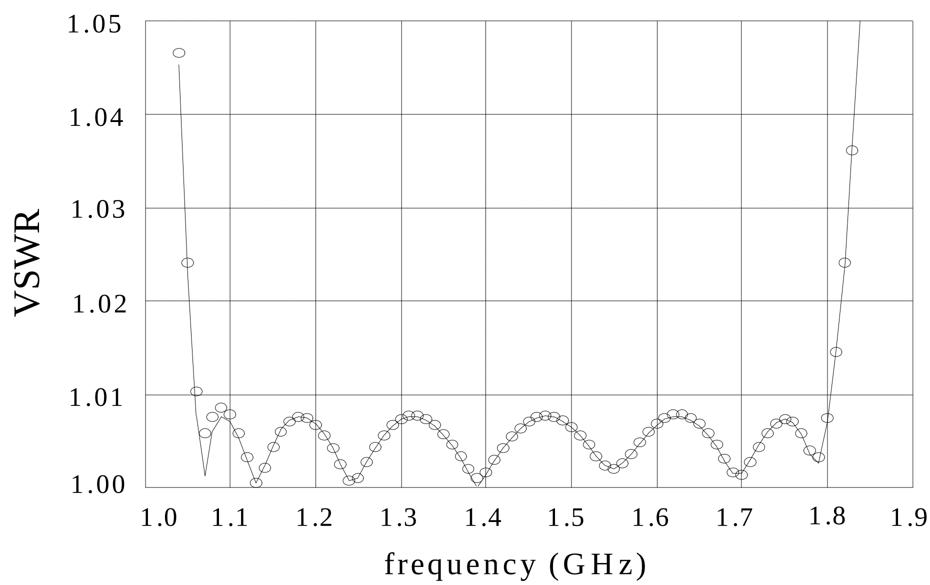
the optimal design is obtained in 3 TRASM iterations requiring 6 fine model simulations

21 frequency points were used per simulation

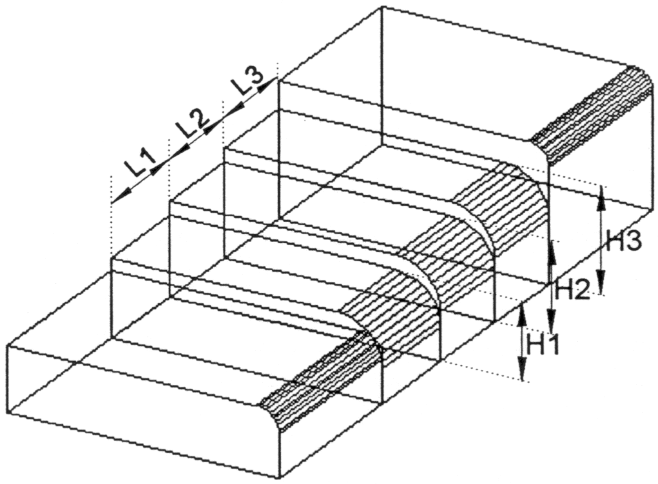
Seven-Section Waveguide Transformer Responses

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





Three-Section Waveguide Transformer, Rounded Corners
(*Empipe3D manual, 1997*)



design specifications: $|S_{11}| \leq -30\,\text{dB}$ for $9.5\text{ GHz} \leq f \leq 15\text{ GHz}$

impedance matching between WR-75 half height and WR-75 full height waveguides

designable variables: the height and length of each section

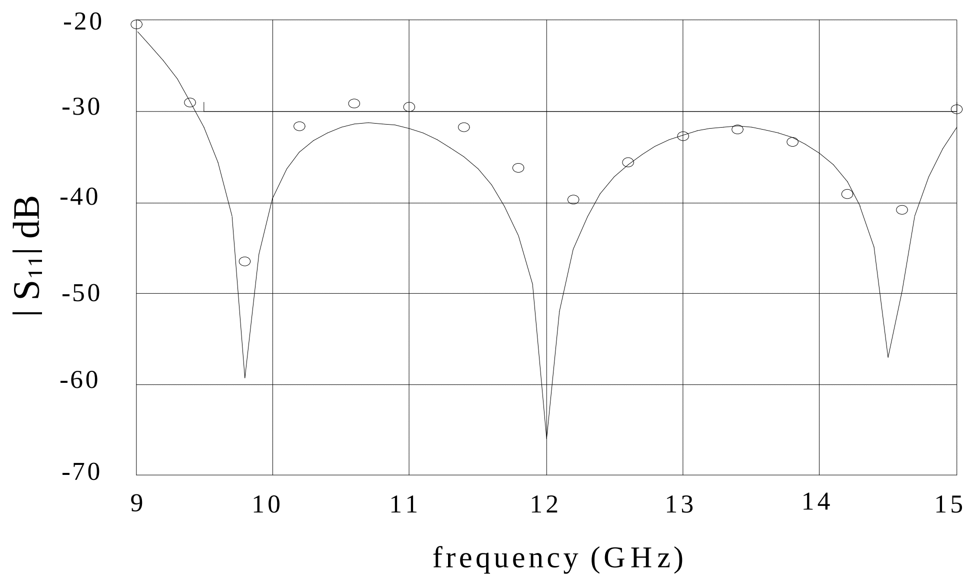
fine (EM) model: HP HFSS Version 5.0

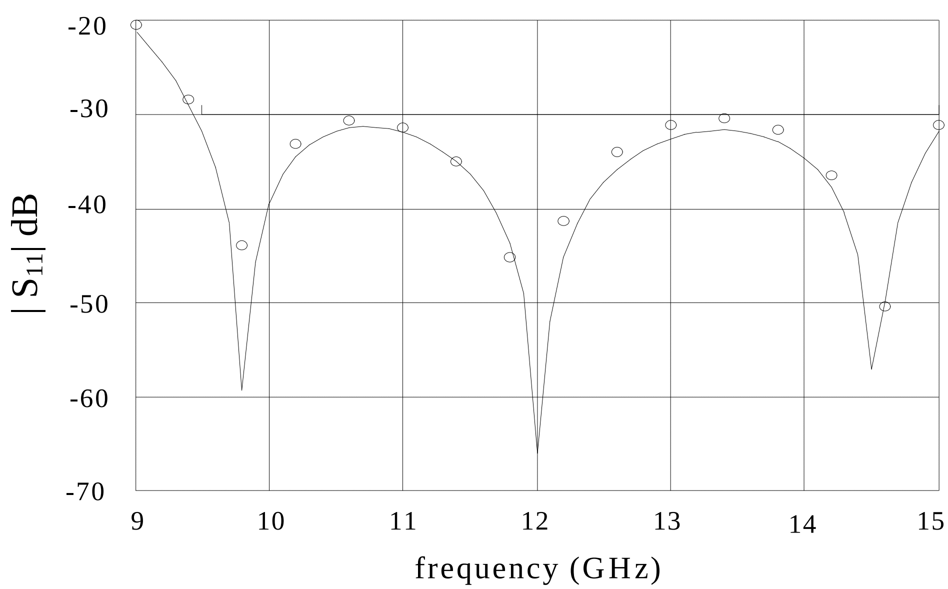
coarse model: ideal analytical model (*Bandler, 1969*)

the optimal design was obtained in 1 TRASM iteration, requiring 7 fine model simulations by HP HFSS

Three-Section Waveguide Transformer, Rounded Corners

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





Conclusions

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

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

a number of examples were successfully optimized using the proposed algorithm

the algorithm is currently implemented in MATLAB