SPACE MAPPING OPTIMIZATION OF WAVEGUIDE FILTERS USING FINITE ELEMENT AND MODE-MATCHING ELECTROMAGNETIC SIMULATORS

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Introduction

electromagnetic (EM) field simulators

- regarded as highly accurate at microwave frequencies
- increasingly available
- computationally intensive

it is very tempting to include EM simulators in performance-driven and even in yield-driven circuit optimization

EM simulations invoked directly within the optimization loop

commercial software already available (*Empipe 1992, Empipe3D 1996*)

Space Mapping facilitates practicality of design optimization with computationally very intensive simulators (*Bandler et al. 1994, 1995, 1996*)

Outline

EM optimization of an H-plane resonator filter with rounded corners

Space Mapping models

- finite-element (FEM)
- hybrid mode-matching/network theory

objective functions for parameter extraction

statistical parameter extraction

Space Mapping (SM)

to avoid direct optimization of computationally intensive models

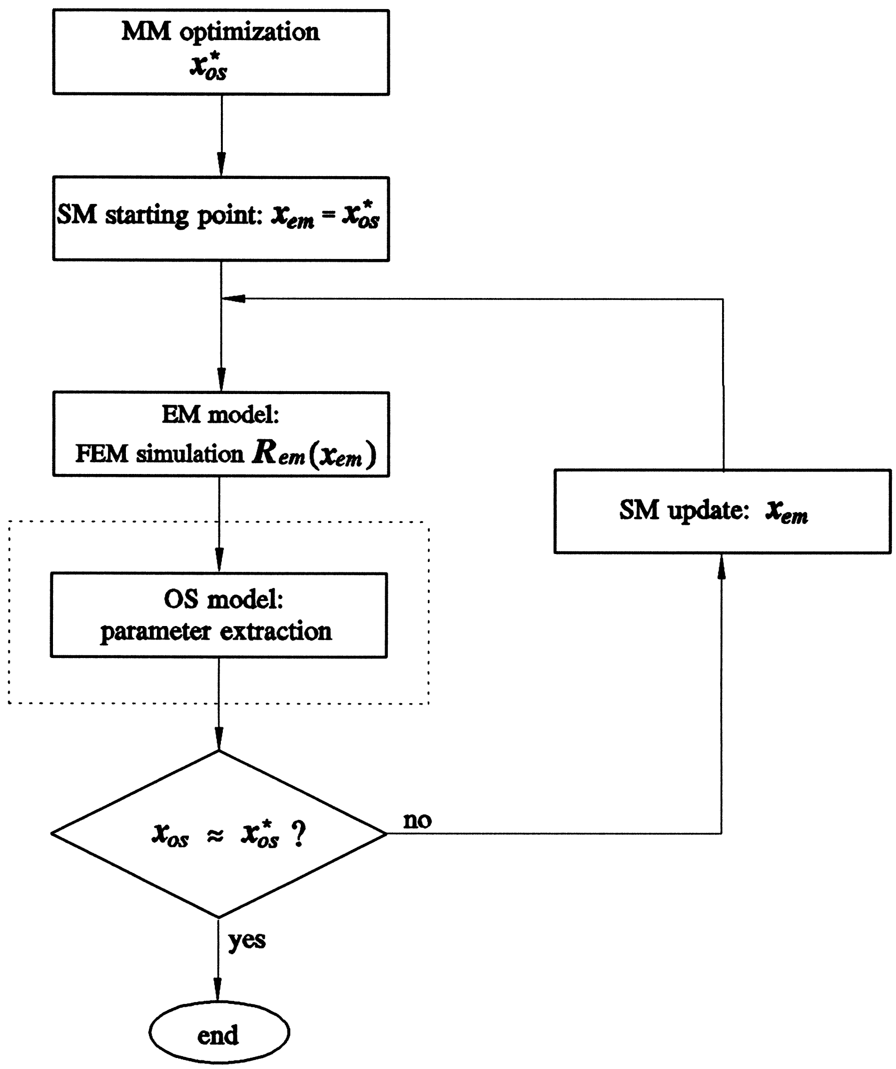
automatic alignment of two distinct models

two different EM simulators are used here

EM space or "fine" model - 3D FEM-based field simulator Maxwell Eminence (*Ansoft Corp.*)

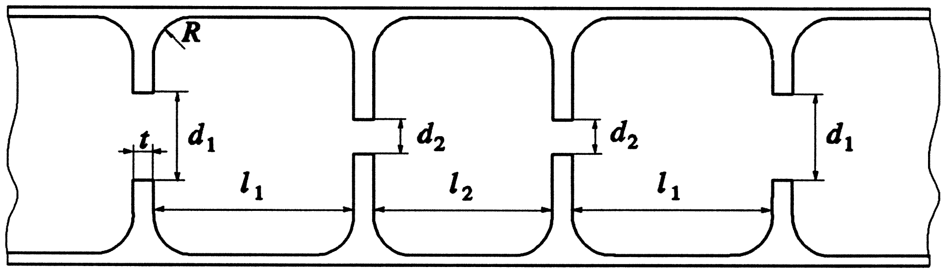
optimization space (OS) model - the RWGMM library of waveguide mode-matching (MM) models connected by network theory (*Fritz Arndt*)

Fully Automated SM Optimization



two-level Datapipe architecture

Optimization of the H-Plane Resonator Filter



the waveguide cross-section is 15.8 × 7.9 mm

t = 0.4 mm, R = 1 mm

optimization variables: d_1, d_2, l_1 and l_2

design specifications

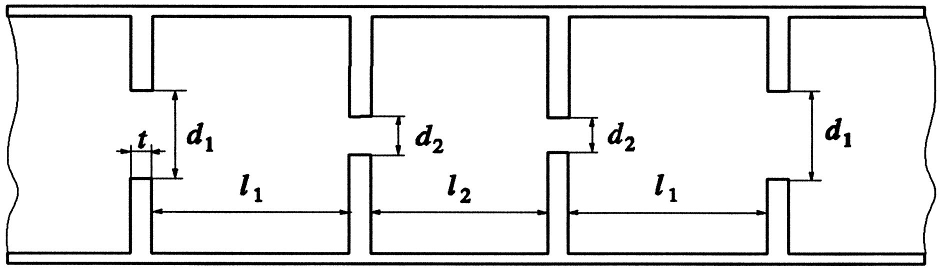
$|S_{21}| < -35$ dB for $13.5 \le f \le 13.6$ GHz
$|S_{11}| < -20$ dB for $14.0 \le f \le 14.2$ GHz
$|S_{21}| < -35$ dB for $14.6 \le f \le 14.8$ GHz

FEM analysis - fine model for Space Mapping

capable of analyzing arbitrary shapes

computationally very intensive

Coarse Model for Space Mapping Optimization



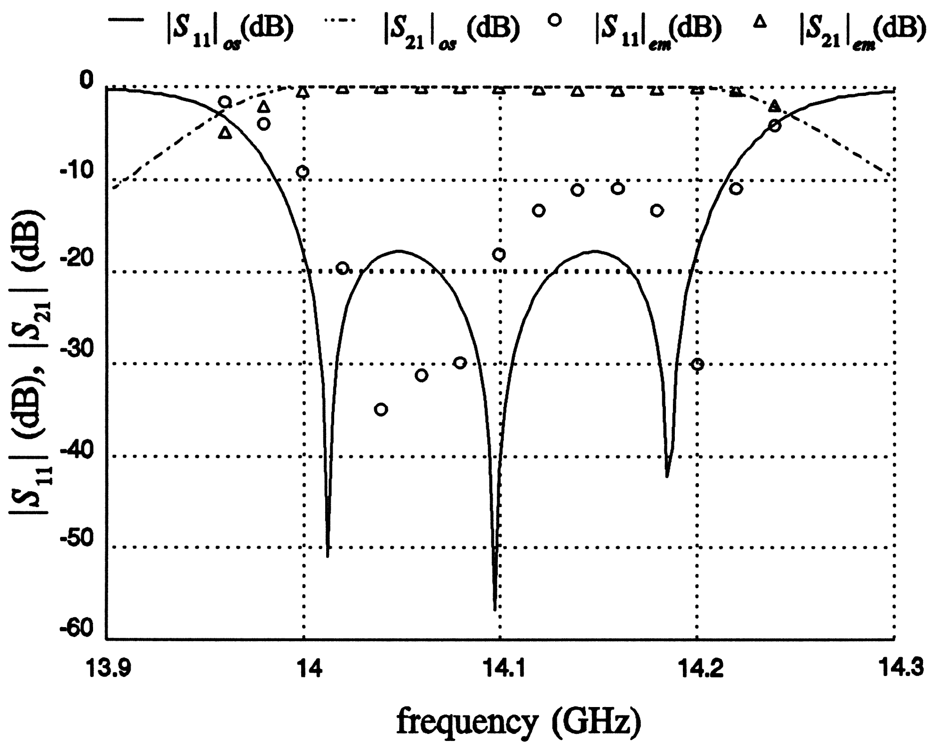
OS model (coarse model) for Space Mapping

sharp corners

hybrid MM/network theory simulation

- computationally efficient
- accurately treats a variety of predefined geometries
- ideally suited for modeling complex waveguide structures decomposable into available library building blocks

Responses at the Starting Point

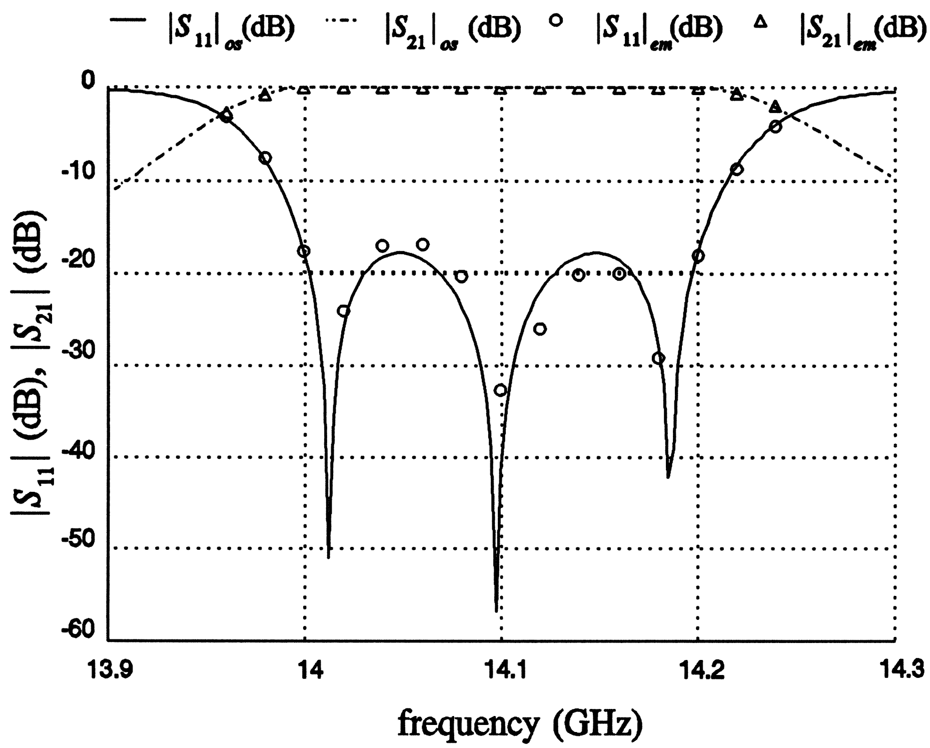


focus on the passband: 13.96 to 14.24 GHz

$d_1 = 6.04541$, $d_2 = 3.21811$, $l_1 = 13.0688$ and $l_2 = 13.8841$

the minimax solution in the OS space, x_{os}^*, yields the target response for Space Mapping

SM Optimized FEM Responses



only 4 Maxwell Eminence simulations

$d_1 = 6.17557$, $d_2 = 3.29058$, $l_1 = 13.0282$ and $l_2 = 13.8841$

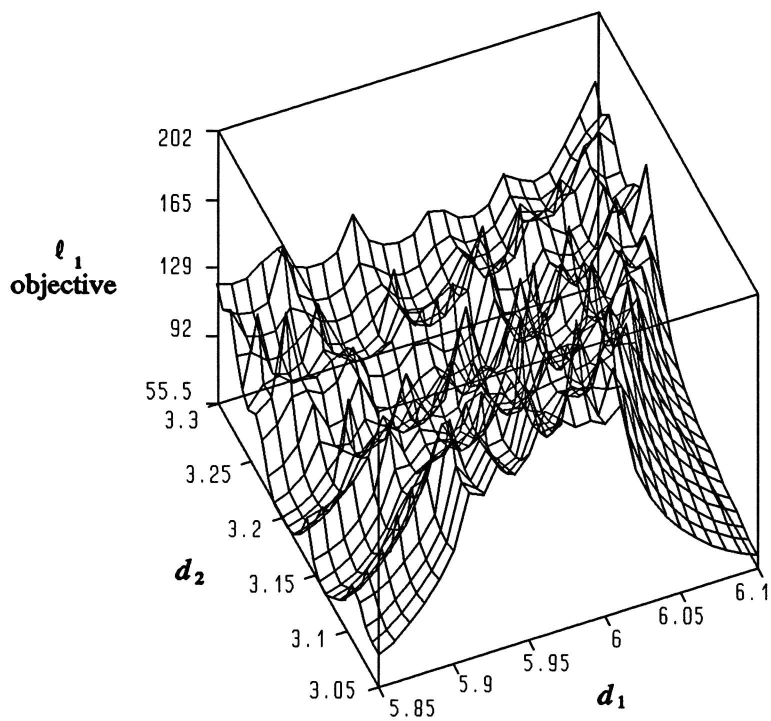
direct optimization using Empipe3D confirms that the Space Mapping solution is optimal

Objective Functions for Parameter Extraction

design specifications in the passband were formulated using $|S_{11}|$ (dB)

a natural choice is to use $|S_{11}|$ (dB) for parameter extraction

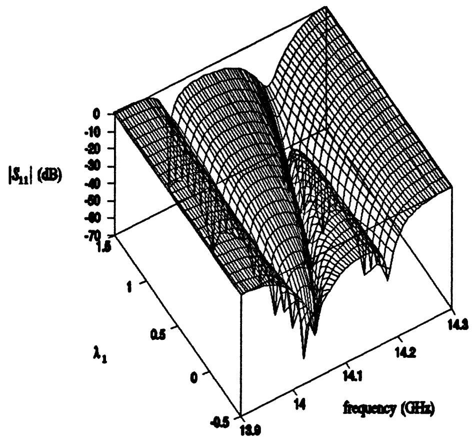
ℓ_1 objective in terms of $|S_{11}|$ (dB) in the second step of SM

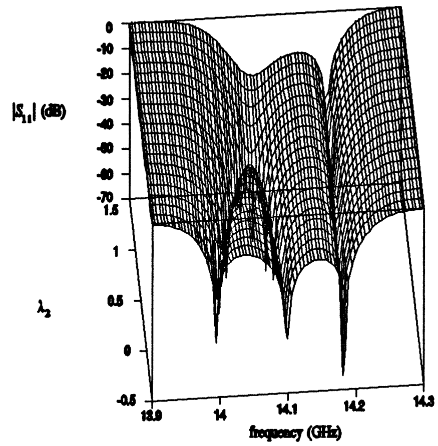


an excellent example to investigate the uniqueness of the parameter extraction process

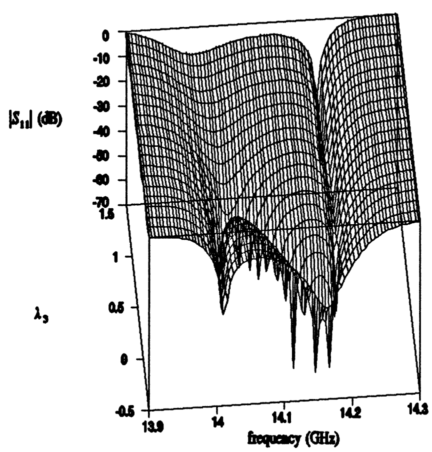
Variation of Responses Defined by the First SM Step

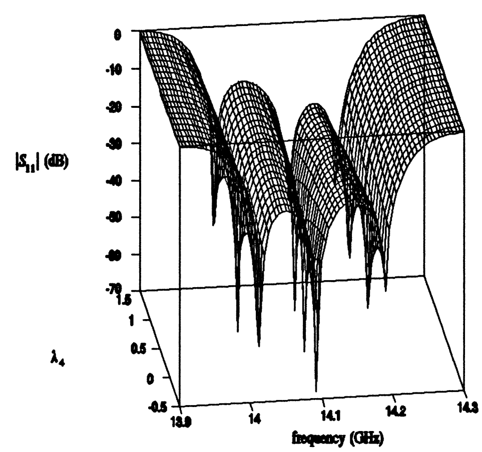
openings of irises varied





lengths of resonators varied

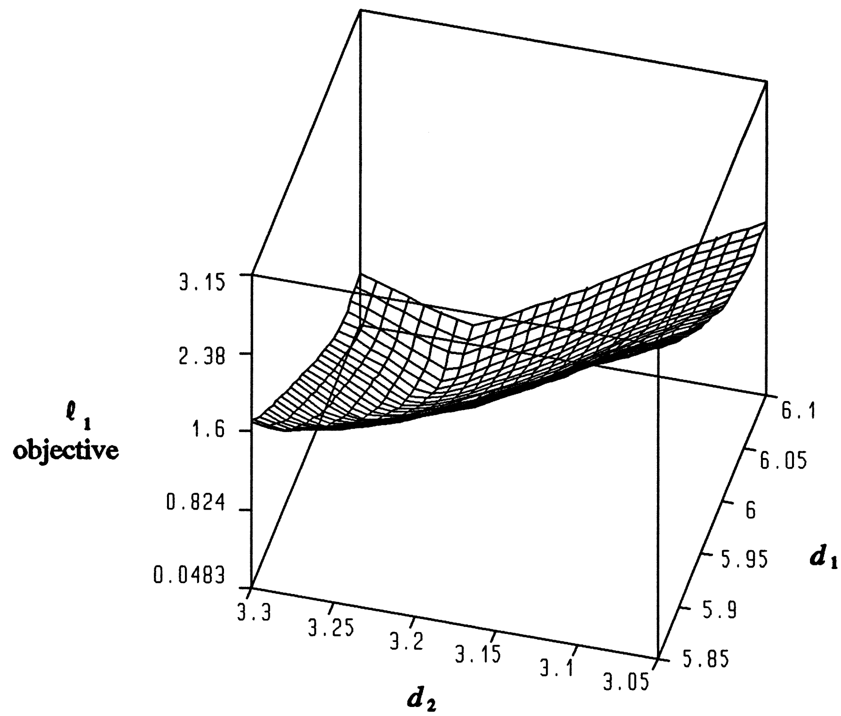




parameters varied in the range of the first aggressive SM step: $\lambda_i = 0$ at x_{os}^* and $\lambda_i = 1$ at x_{os}^1

Alternative Error Functions for Parameter Extraction

errors formulated in terms of $|S_{21}|$ (the second step of SM)



no difficulty in parameter extraction

the Space Mapping iterations proceeded flawlessly

Statistical Parameter Extraction

to overcome potential pitfalls

inaccurate solutions

nonunique solutions

first, attempt the standard ℓ_1 parameter extraction starting from x_{os}^*

if the optimized response of the coarse model matches well the fine model response, continue Space Mapping iterations

otherwise, turn to statistical exploration of the coarse model

Statistical Exploration Region

the key is to establish the exploration region

*k*th Space Mapping step

determine the multidimensional interval $\boldsymbol{\delta}$

$$\boldsymbol{\delta} = \boldsymbol{x}_{os}^{k-1} - \boldsymbol{x}_{os}^{*}$$

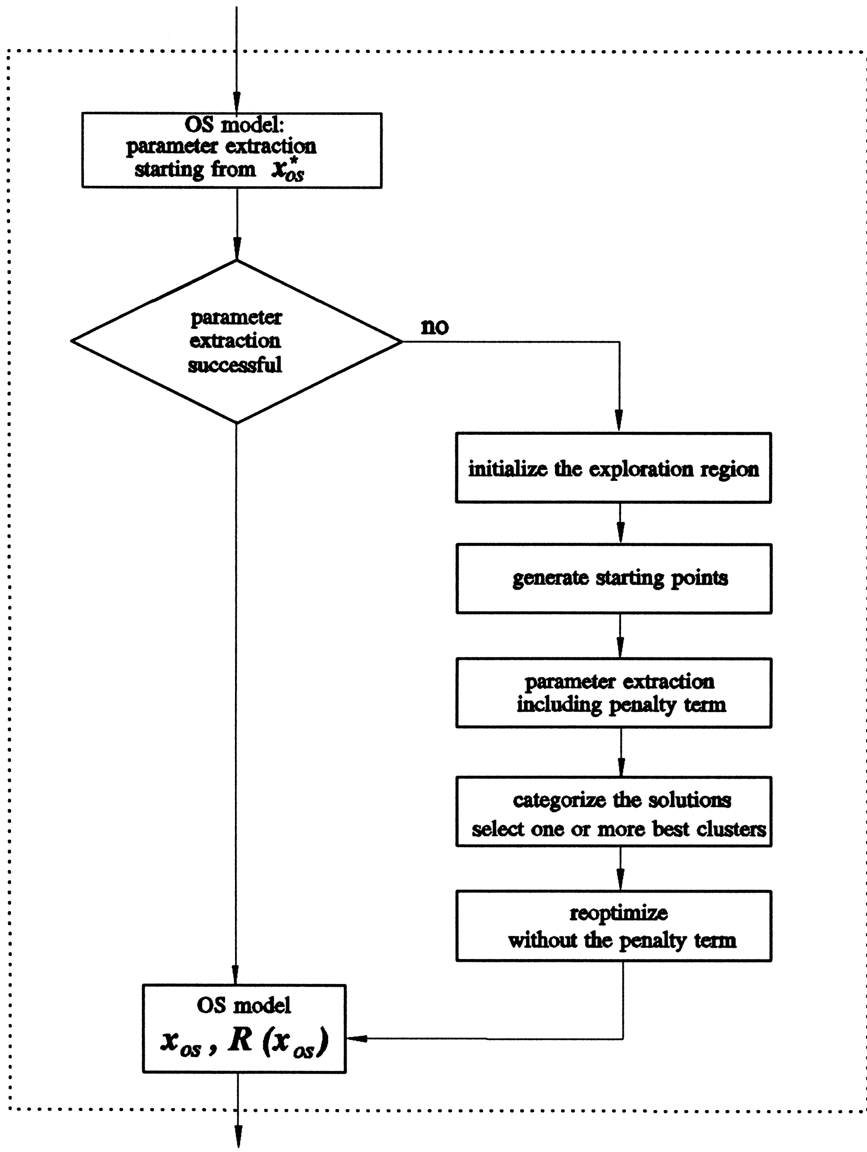
the statistical exploration may be limited to the region

$$x_{osi} \in [\, x_{osi}^{*} - 2\,|\delta_i|,\, x_{osi}^{*} + 2\,|\delta_i|\,]$$

elliptical multidimensional domain with semiaxes $2|\delta_i|$

$$\sum_i \,(x_{osi} - x_{osi}^{*})^2 / |\delta_i|^2 \leq 4$$

Flow-Chart of Statistical Parameter Extraction

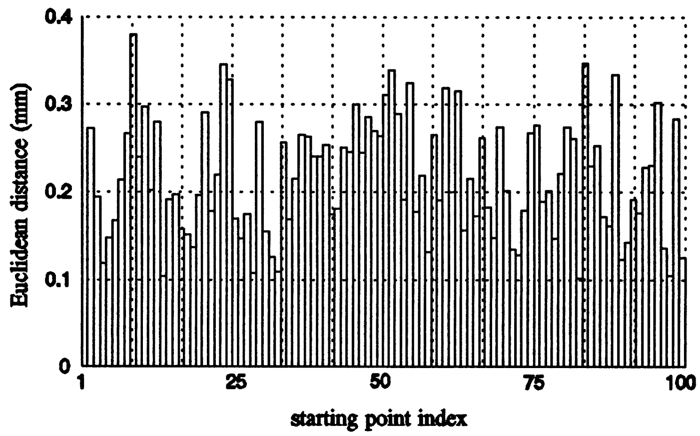


automated using three-level Datapipe architecture

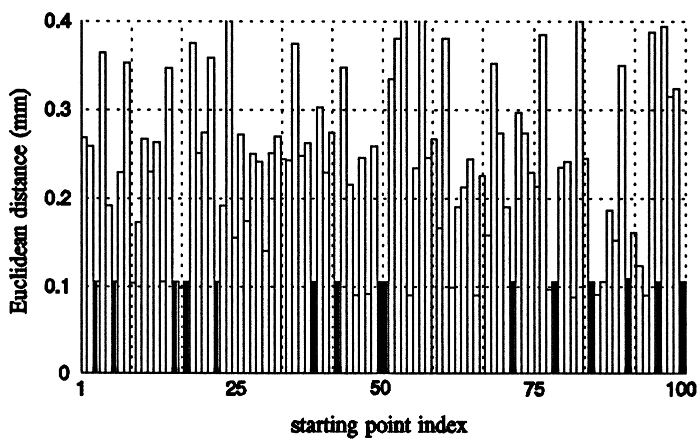
potential for parallelization

Euclidean Distances in Statistical Parameter Extraction

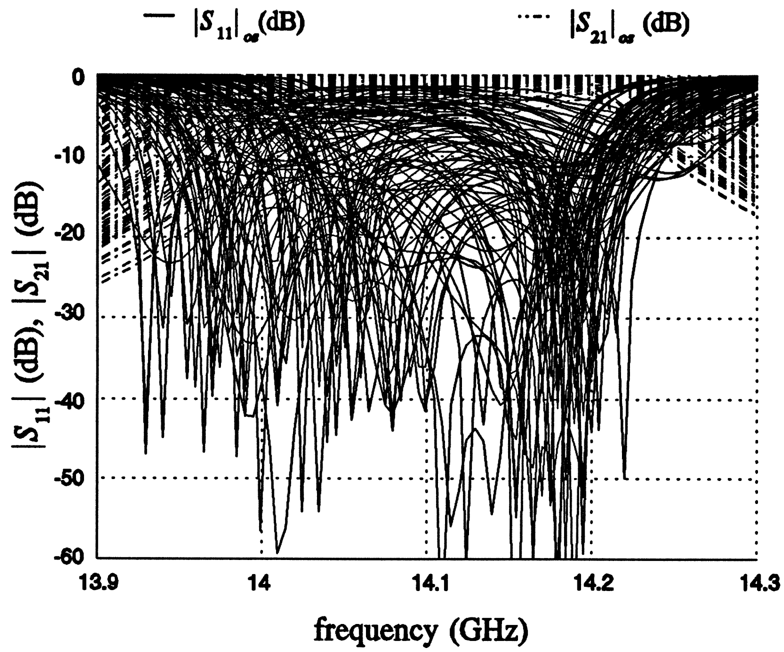
randomly generated starting points w.r.t. x^*_{os}

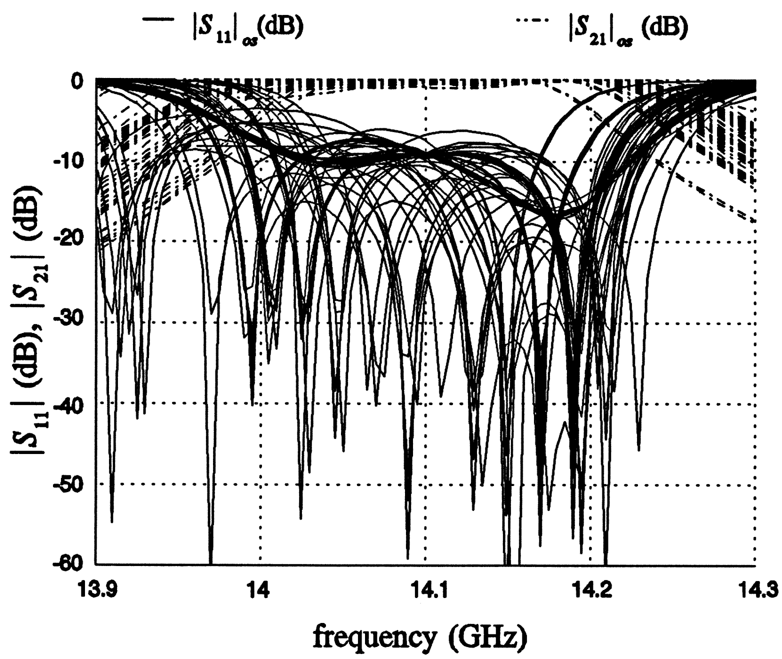


converged points

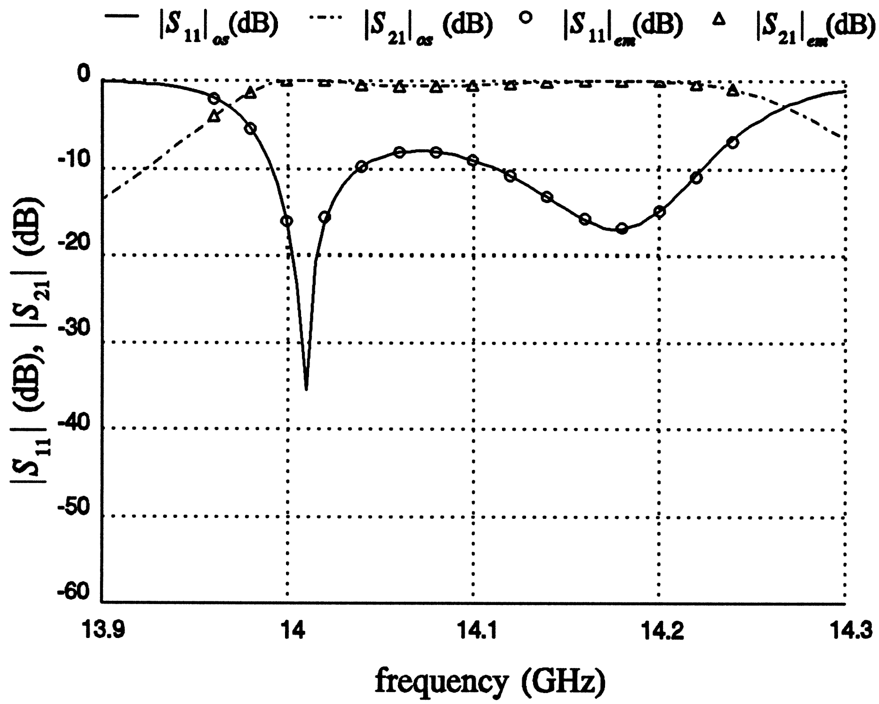


Responses Before and After Statistical Parameter Extraction





Responses After Successful Parameter Extraction

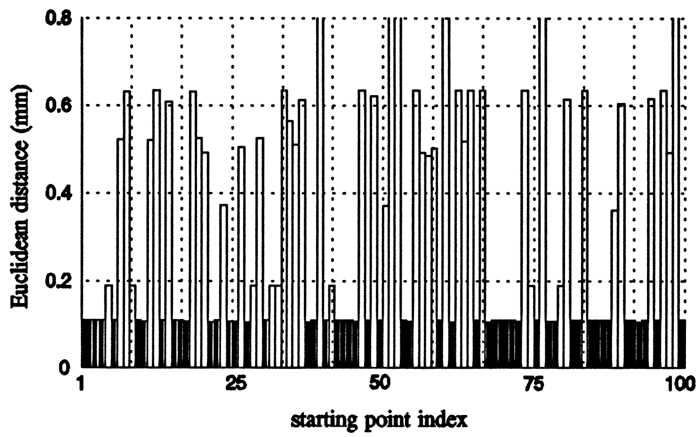


responses corresponding to the cluster of 15 points which converged to the same solution

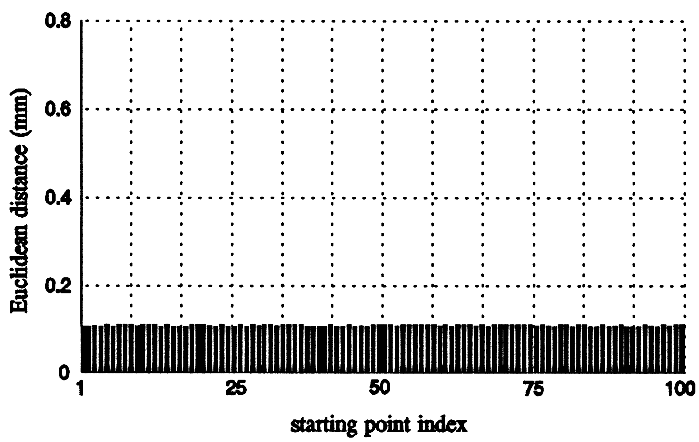
Error Function Defined in Terms of $|S_{21}|$

starting from the default point, x_{os}^{*}, yields good result

52% success when no penalty term is used



inclusion of penalty term yields 100% success



Conclusions

new applications of aggressive Space Mapping

filter optimization using network theory, MM and FEM

addressing uniqueness of parameter extraction

statistical parameter extraction incorporating

- the ℓ_1 errors
- penalty function concepts

further work

- highly efficient means for Monte Carlo analysis of microwave circuits carried out with the accuracy of FEM simulation
- Space Mapping optimization based on coarse and fine MM models with different numbers of modes