AGGRESSIVE SPACE MAPPING WITH DECOMPOSITION: A NEW DESIGN METHODOLOGY

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OSA-96-RF-18-V

September 25, 1996

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presented at

M+RF96 Microwaves and RF Conference and Exhibition, Wembley, England, October 8-10, 1996

Introduction

advances in full-wave EM simulation techniques provide designers with the tools to accurately simulate passive microwave structures

it is commonly perceived that the practical utilization of EM simulators is limited by their heavy demand on computer resources

EM simulators are mostly employed to validate designs obtained using less CPU-intensive means

synthesis

circuit optimization with empirical models

we pioneered direct EM optimization for microwave/RF circuits (*Bandler et al., 1993*)

in direct EM optimization of larger structures the CPU time may be prohibitive

EM simulations are carried out by Sonnet's *em*

Overview

a new design methodology: a coherent strategy combining two powerful techniques

decomposition

Space Mapping™ (SM)

applied to design optimization of an interdigital filter

"fine" model for accurate simulations

"coarse" model for fast simulations

steps and progress of Space Mapping iterations

Decomposition

partitions a complex structure into a few smaller substructures

each substructure is analyzed separately

the results are combined to obtain the response of the overall structure

2D analytical methods or even empirical formulas can be used for some non-critical regions

full-wave 3D models are adopted for the analysis of the key substructures

The Space Mapping Technique
(Bandler et al., 1994)

models in two distinct spaces

the EM space (X_{em}) - fine models: rigorous and accurate, but their simulation is CPU intensive

the optimization space (X_{os}) - coarse models: less accurate but faster to compute; can be coarse EM, empirical, or a combination of both types of models

designable parameters in these two spaces are denoted by $\boldsymbol{x}_{em}$ and $\boldsymbol{x}_{os}$, respectively

we want to establish a mapping $\boldsymbol{P}$ between these two spaces

$$\boldsymbol{x}_{os} = \boldsymbol{P}(\boldsymbol{x}_{em})$$

such that

$$\boldsymbol{R}_{os}(\boldsymbol{P}(\boldsymbol{x}_{em})) \approx \boldsymbol{R}_{em}(\boldsymbol{x}_{em})$$

where

$\boldsymbol{R}_{em}(\boldsymbol{x}_{em})$	responses of the fine model
$\boldsymbol{R}_{os}(\boldsymbol{x}_{os})$	responses of the coarse model

The Advantages of Space Mapping

the aim is to avoid direct optimization in the CPU-intensive X_{em} space

the bulk of the computation involved in optimization is carried out in the X_{os} space

the optimal solution is mapped from the X_{os} space to the X_{em} space using the inverse mapping P^{-1}

we expect to obtain a rapidly improved design after each fine model simulation

significantly more efficient than the "brute force" direct EM optimization

a fundamentally new concept in engineering-oriented optimization practice

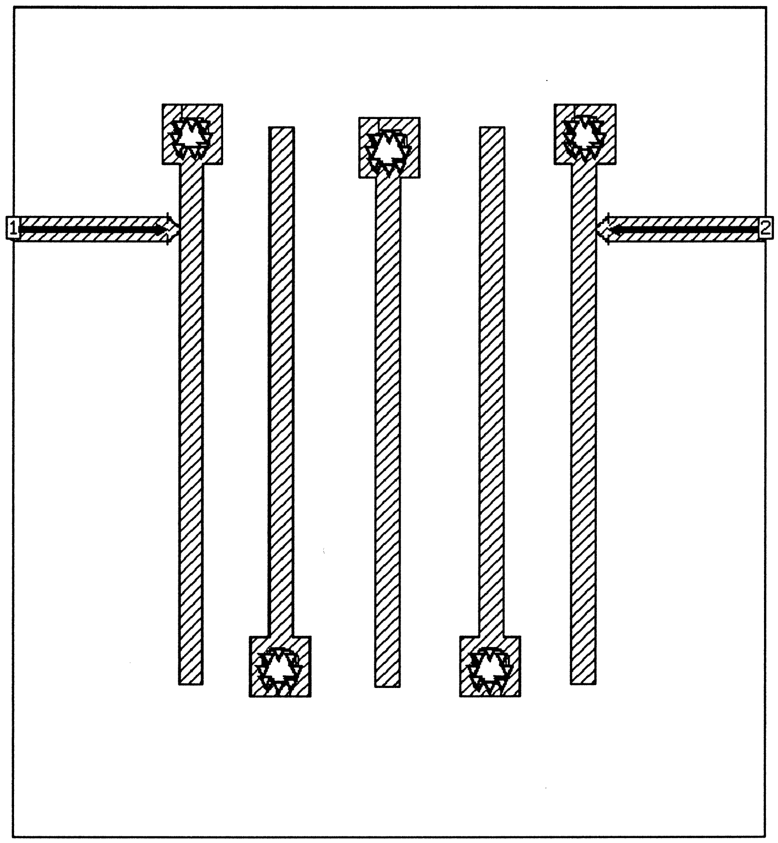
Aggressive Space Mapping
(*Bandler et al., 1995*)

the mapping function is updated employing a quasi-Newton iteration

first-order derivative approximations based on the Broyden formula

fully automated within a two-level Datapipe™ architecture
(*Bandler et al., 1996*)

A Five-Pole C-Band Interdigital Filter



15 mil thick alumina substrate with $\varepsilon_r = 9.8$.

the width of each microstrip is chosen to be 10 mil

quarter wavelength resonators

Interdigital Filter Design

specifications

passband cutoff	f_1 = 4.9 GHz, f_2 = 5.3 GHz
passband ripple	r = 0.1 dB
isolation bandwidth	BWI = 0.95 GHz
isolation	DBI = 30 dB

the order of the filter is determined as 5

all other dimensions including the gaps and the positions of the tapped lines are obtained by synthesis (*Matthaei et al., 1964*)

design variables include two gaps between the resonators and four lengths of microstrip lines from an appropriate position of each resonator to its ends

the size of the vias is fixed

The Fine Model of the Interdigital Filter

full-wave EM simulations of the whole structure using Sonnet's *em*

for good accuracy the grid size has to be sufficiently small

selected grid size: 1×1 mil

about 1.5 CPU hours per frequency point on a Sun SPARCstation 10

much longer if losses are included

this translates into considerable EM simulation time for fine frequency sweeps

direct optimization would require many EM analyses and consequently excessive CPU time

Dimensions and Material Parameters of the Filter

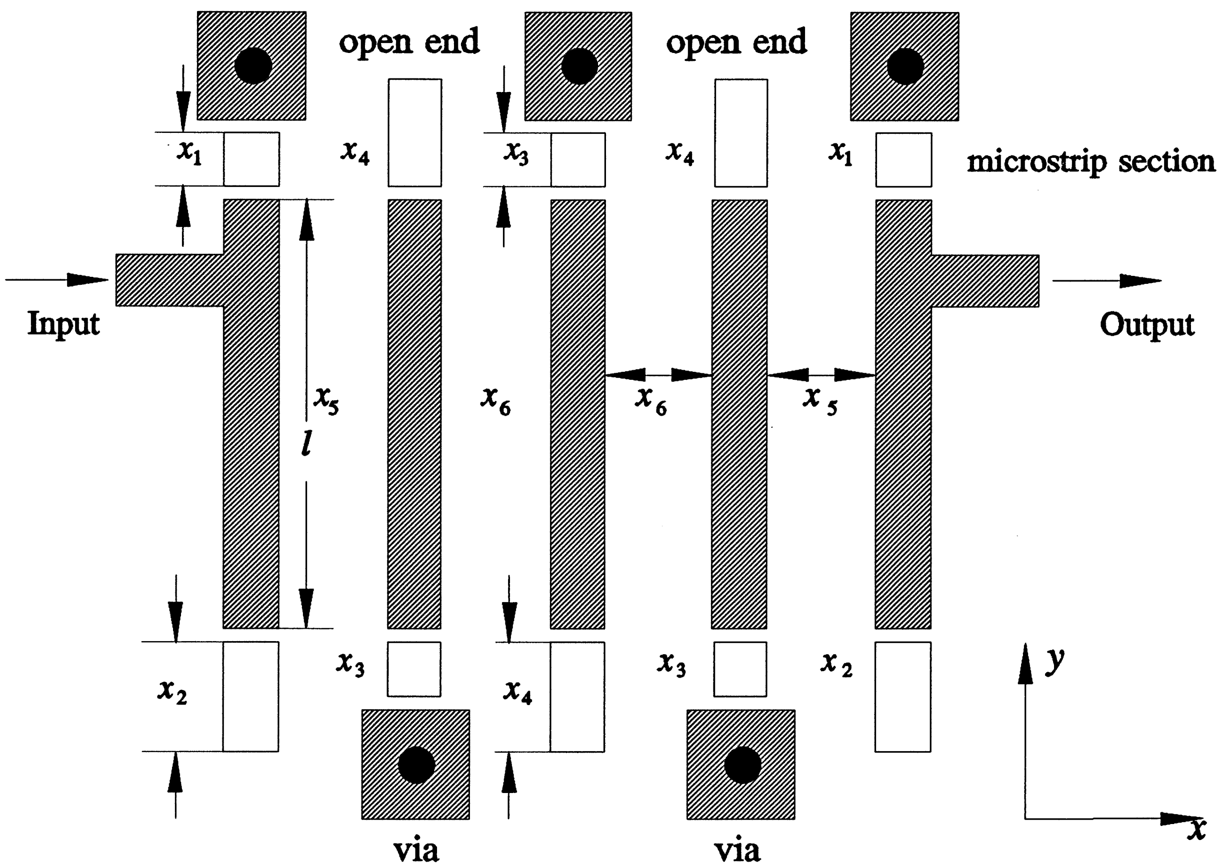
FILTER MATERIAL PARAMETERS AND GEOMETRICAL DIMENSIONS

Parameter	Value
substrate dielectric constant	9.8
substrate thickness (mil)	15
conducting metal thickness (mil)	0
substrate dielectric loss tangent	0/0.001*
conductivity of the metal	$\infty/5.8\times10^{7}$*
shielding cover height (mil)	75
width of input/output lines (mil)	10
width of each resonator (mil)	10
via diameter (mil)	13
via pad dimensions (mil × mil)	25 × 25

* loss tangent and conductivity for simulations without and with losses, respectively

Decomposition of the Interdigital Filter

the coarse model is constructed using decomposition



the substructures are analyzed separately using either EM models with a coarse grid or empirical models

the partial results are then combined through circuit theory to obtain the response of the overall filter

The Coarse Model of the Interdigital Filter

the center shaded 12-port network is analyzed by ***em*** with a very coarse grid: 5×10 mil

the vias have fixed dimensions - one via is analyzed by ***em*** with a grid of 1×1 mil only once; in subsequent simulations all vias are represented by their reflection coefficient

all other parts including the microstrip line sections and the open ends are analyzed using the empirical models of OSA90/hope

less than 1 CPU minute per frequency point on a Sun SPARCstation 10

off-grid responses, when needed during optimization, are obtained by interpolation

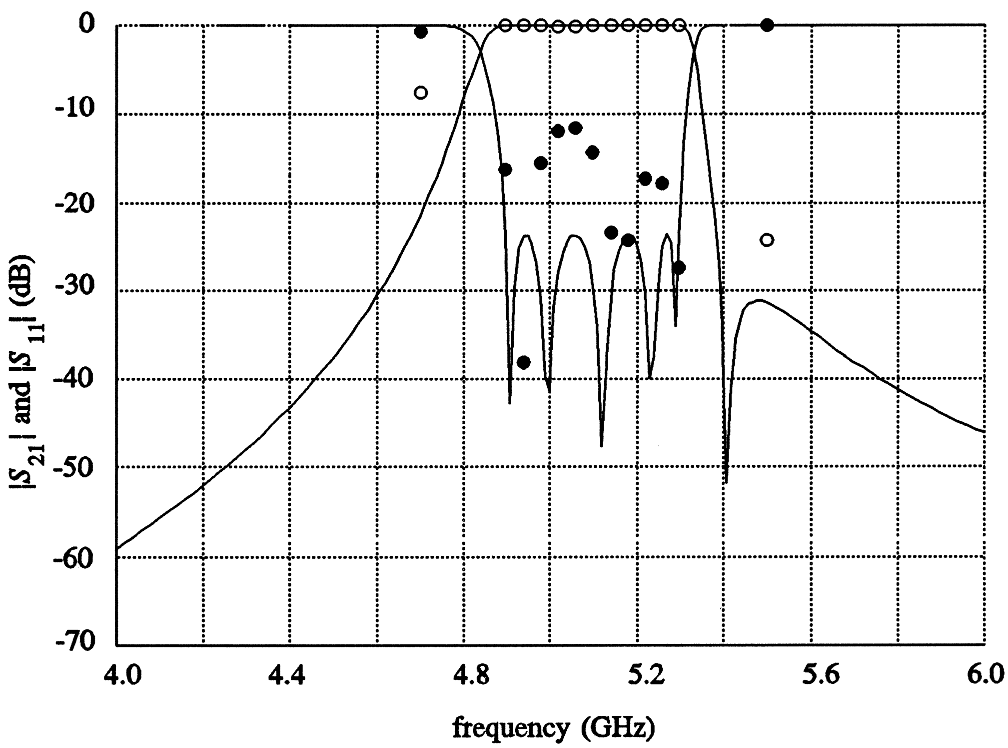
the coarse model retains most of the adjacent and non-adjacent couplings, thus it provides reasonably accurate results at dramatically faster speed

Design Procedure

first, we optimize the filter using the coarse model

minimax solution x^*_{os} is obtained

we check this coarse model solution using the fine model at a few selected frequencies



solid curves — optimized $|S_{11}|$ and $|S_{21}|$ responses of the coarse model at the optimal point x^*_{os}

circles — fine model responses at x^*_{os}

Results of EM Validation

the fine model responses deviate significantly from the optimized coarse model responses

the passband return loss is only about 11 dB and the bandwidth is wider than specified

discrepancies may be due to the coarse grid and some couplings not taken into account by the coarse model

WHAT'S NEXT?

typically, engineers manually tune the design and try to meet design specifications

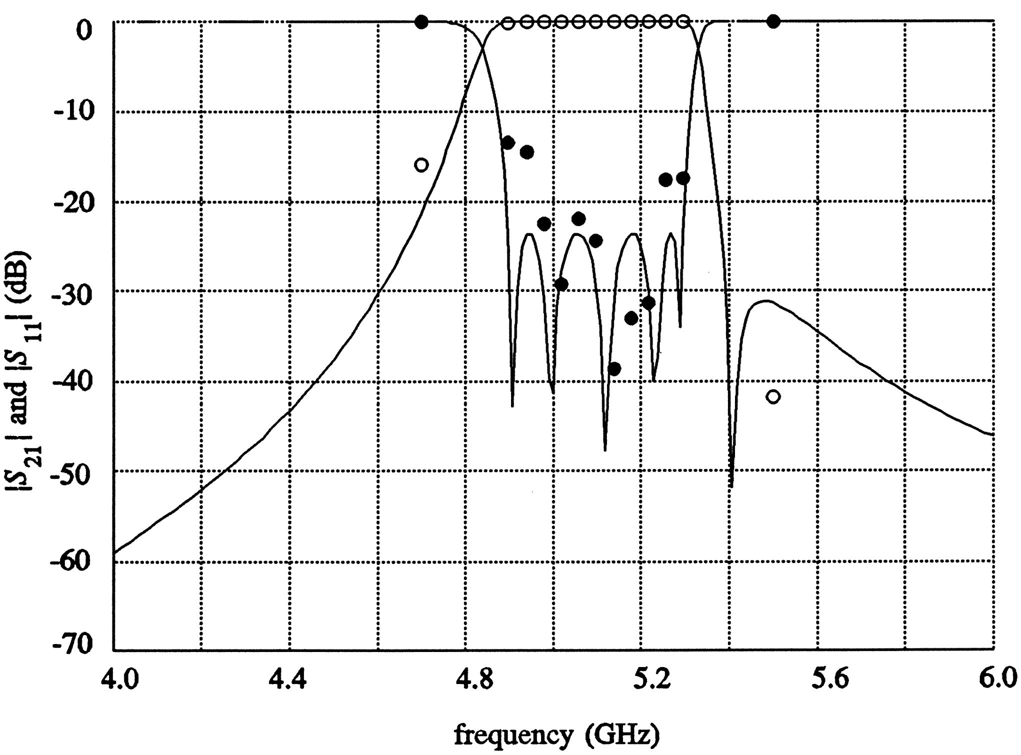
we offer an automated approach using Space Mapping

Space Mapping Optimization of the Interdigital Filter

SM optimization starts with $x_{em}^{(1)} = x_{os}^{*}$

after the first iteration, a new point $x_{em}^{(2)}$ in the X_{em} space is obtained

the fine model responses of this new point are compared with the coarse model optimal responses

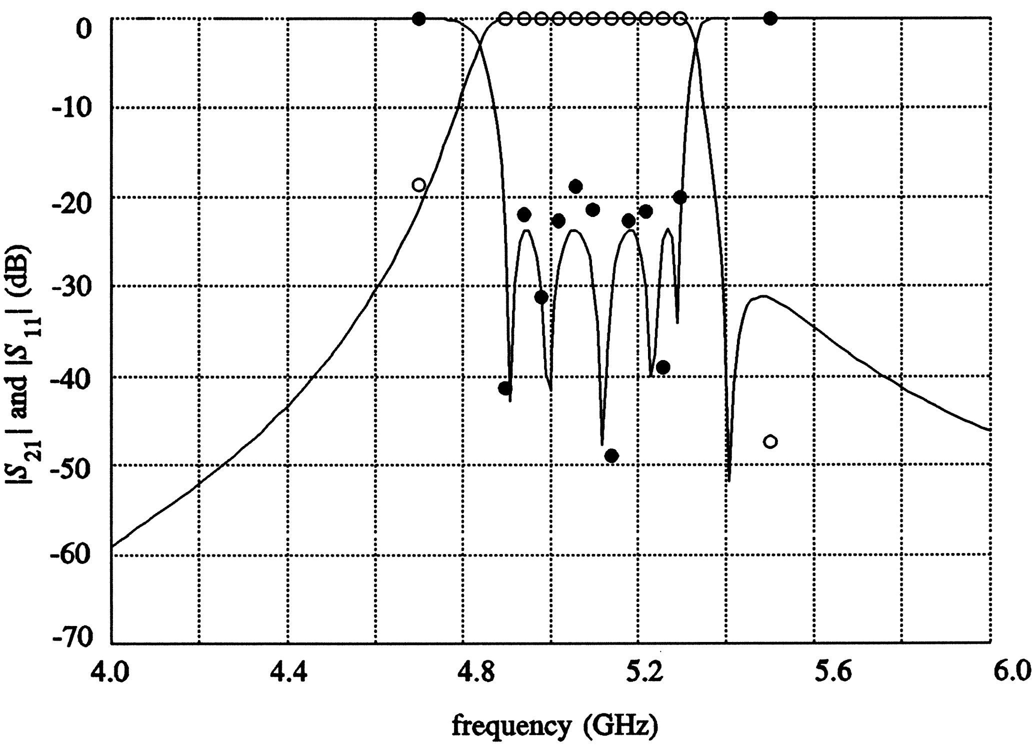


return loss is improved and the bandwidth is reduced at the lower frequency end

Second Iteration of Space Mapping

another iteration of SM produces $x_{em}^{(3)}$

the fine model responses at $x_{em}^{(3)}$ at 13 frequency points are compared with the coarse model optimal responses



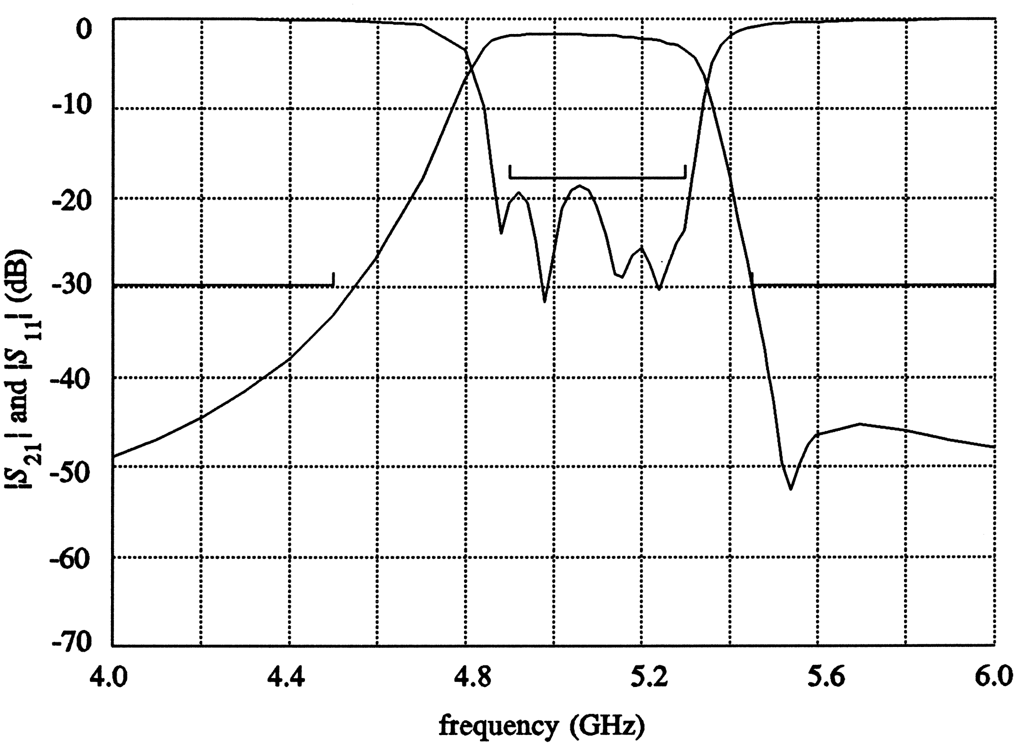
only three EM simulations of the fine model were needed

Final EM Validation

a dense frequency sweep is desired

here, simulation includes the conductor and dielectric losses

the fine model responses at $\boldsymbol{x}_{em}^{(3)}$



the passband return loss is better than 18.5 dB

Conclusions

we have presented a new design methodology for EM optimization

a coherent framework combines the power of aggressive SM with decomposition

accurate but computationally intensive fine model calibrates computationally efficient coarse models

decomposition further accelerates the coarse model simulation

rapid and significant improvements have been achieved after each Space Mapping iteration

for interdigital filter design, a desirable filter response emerges after only three EM fine model simulations

we used only 13 frequency points for fine model simulations

the total EM simulation effort in our design is equivalent to a single fine model EM simulation with 39 frequency points