A CAD ENVIRONMENT FOR PERFORMANCE AND YIELD DRIVEN CIRCUIT DESIGN EMPLOYING ELECTROMAGNETIC FIELD 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

feasibility of such optimization has already been shown (*Bandler et al. 1993*)

we use geometrical interpolation to reconcile inherent discretization of geometrical parameters with continuously varying optimization variables

we employ an efficient response modeling technique for computationally intensive statistical design centering (*Biernacki et al. 1986, 1989, 1991*)

Outline

we unify geometrical interpolation, response modeling and EM simulation with versatile optimization

we effectively create an open architecture CAD environment for EM driven design

implemented in Empipe (OSA) which interfaces the CAD system OSA90/hope (OSA) and the *em* field simulator (Sonnet)

we report new results on EM circuit design

> simulation of a microstrip line demonstrates the flexibility of our interpolation and modeling technique
>
> a 3-section microstrip impedance transformer illustrates nominal and yield-driven design optimization
>
> a frequency doubler illustrates various approaches to EM simulation and optimization of passive subcircuits

Efficient Interpolation/Modeling

numerical EM simulation requires discretized values of geometrical parameters (on-the-grid)

typical optimizers assume continuously varying parameters

to reconcile the two requirements we interpolate responses at off-the-grid points using multidimensional polynomials

$$q(\boldsymbol{x}) = a_0 + \sum_{i=1}^{n} a_i(x_i - r_i) + \sum_{\substack{i=1 \\ j \geq i}}^{n} a_{ij}(x_i - r_i)(x_j - r_j)$$

where

$\boldsymbol{x} = [x_1\, x_2 \ldots x_n]^T$ vector of circuit parameters

$\boldsymbol{r} = [r_1\, r_2 \ldots r_n]^T$ the reference point

EM simulation is invoked at some m base points

for a quadratic *Q-model* we use $n + 1 < m \leq 2n + 1$

for a linear *L-model* we use $m = n$

Discretization of the Model Parameter Space

we consider

simulation grid

modeling grid

the simulation grid $\delta_S = [\delta_{S1}\ \delta_{S2} \ldots \delta_{Sn}]^T$ is imposed by EM simulator; each δ_{Si} is a floating point number and has the same unit as the corresponding parameter

the modeling grid is implied by positive dimensionless integer multipliers $\delta_M = [\delta_{M1}\ \delta_{M2} \ldots \delta_{Mn}]^T$

the distance between adjacent modeling grid points is $\delta_{Mi}\delta_{Si}$

model parameters are discretized according to the modeling grid

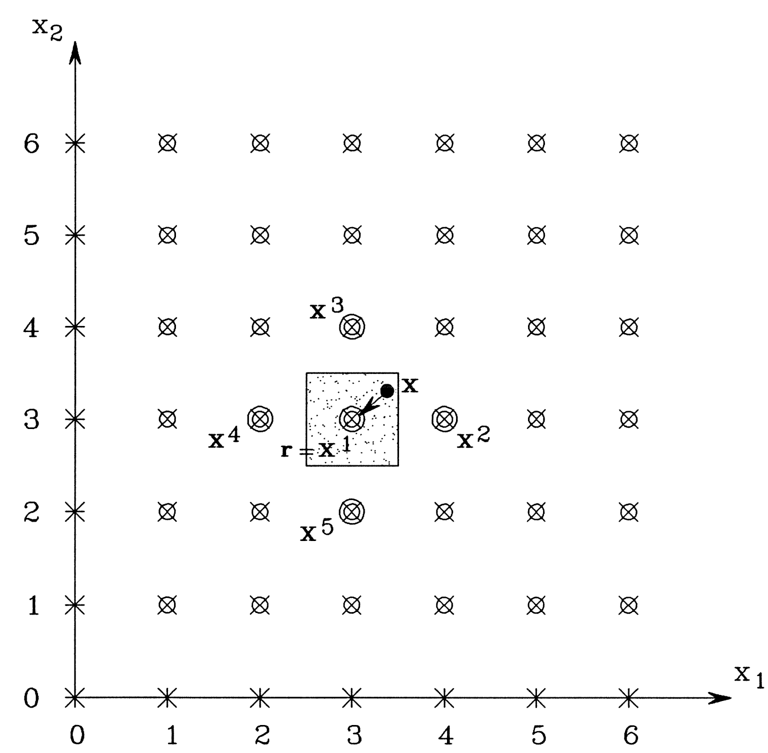
to create the interpolation models we invoke EM simulations at the modeling grid points only

The Model Validity Region

for each model we define a validity region V

one possible choice for V in the case of Q-models is given by

$$V = \{ \boldsymbol{x} \mid \frac{-\delta_{Si}\delta_{Mi}}{2} < (x_i - r_i) \leq \frac{\delta_{Si}\delta_{Mi}}{2} \},\ i = 1, 2, \ldots, n$$



if $\boldsymbol{x} \in V$ than we assume that $q(\boldsymbol{x}) \approx f(\boldsymbol{x})$

Data Base/Modeling Integration

during optimization the nominal point and statistical outcomes may move outside the current model validity region *V*

if any point falls outside the current *V* then we

generate new base points

perform EM simulation at the new base points

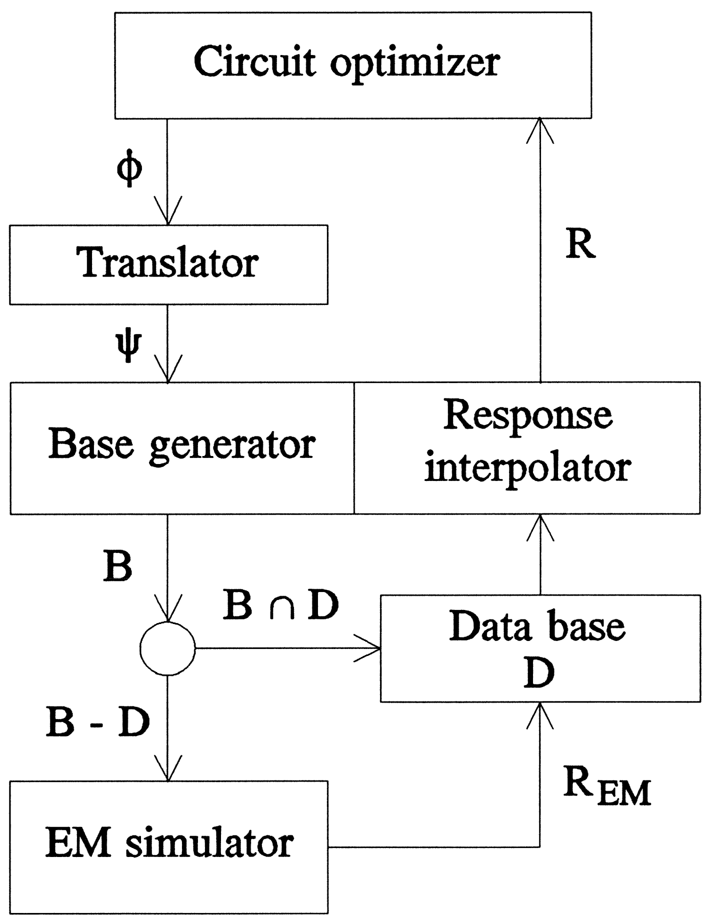
update the models

any additional EM simulation is performed only if no prior simulation has been performed at the new base points

to facilitate this we maintain and automatically update a data base of base points with the corresponding responses

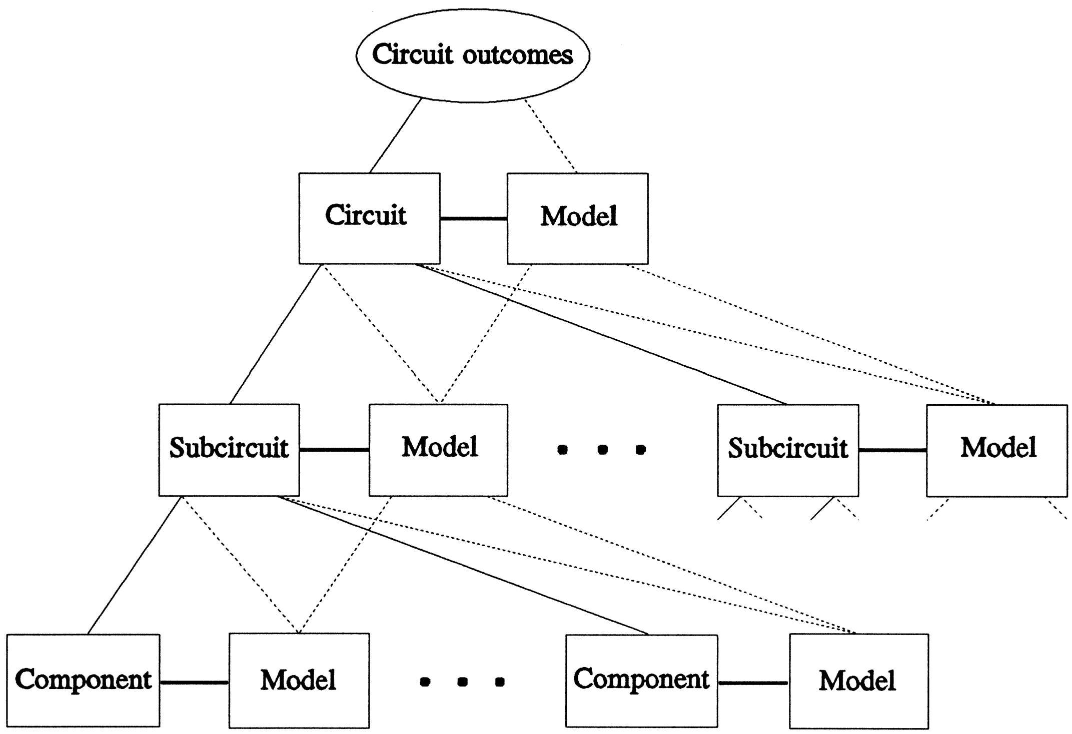
our scheme dynamically integrates interpolation models and data base updating in real optimization time

Interconnection Between a Circuit Optimizer and a Numerical EM Simulator



Multilevel Quadratic Modeling

(*Bandler et al. 1993*)



a Q-model can be established at any level for some or all subcircuits and components

the models are built from simulations of the corresponding components, subcircuits, or the overall circuit

many Q-models may exist changing the path of calculations as indicated by different links in the figure

A Microstrip Line Study

a microstrip line with

- the width fixed at $W = 25$ mil

- the length L varied from 100 to 202.5 mils with a 2.5 mil step for different simulation and modeling grids

reference data is obtained with fine simulation (δ_{SL}=2.5 mil) and modeling (δ_{ML}=1) grids; no interpolation is needed

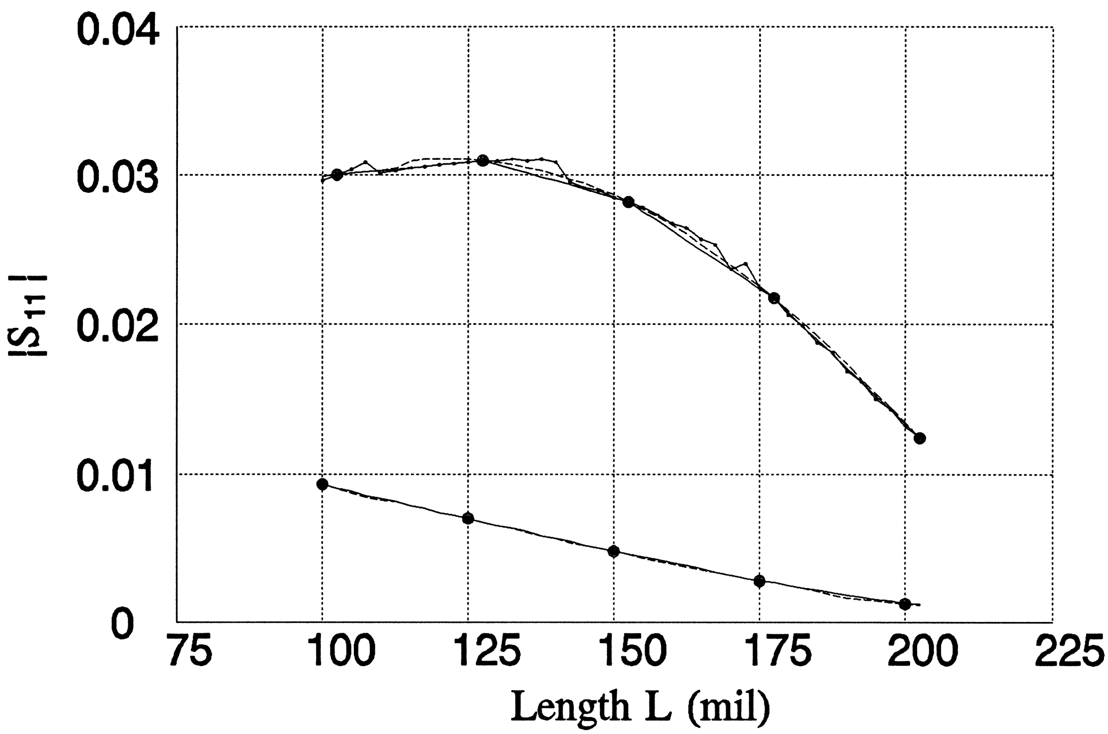
two experiments

- coarse simulation (δ_{SL} = 25 mil) grid and small modeling multiplier (δ_{ML} = 1)

- fine simulation (δ_{SL} = 2.5 mil) grid and large modeling multiplier (δ_{ML} = 10)

we build and examine the L-models as well as the Q-models

A Microstrip Line Study - Results



upper curves: the reference data and the responses of the *L*- and *Q*-models built using the fine simulation and coarse modeling grids

lower curves: the responses of the *L*- and *Q*-models built using the coarse simulation grid

L-models (——), *Q*-models (- - -), EM simulations (•)

A Microstrip Line Study - Conclusions

responses of the models built using the fine simulation grid are much closer to the reference data, even if the modeling grid is coarse

the loss of accuracy in using interpolation models is likely to be due to too coarse simulation grid

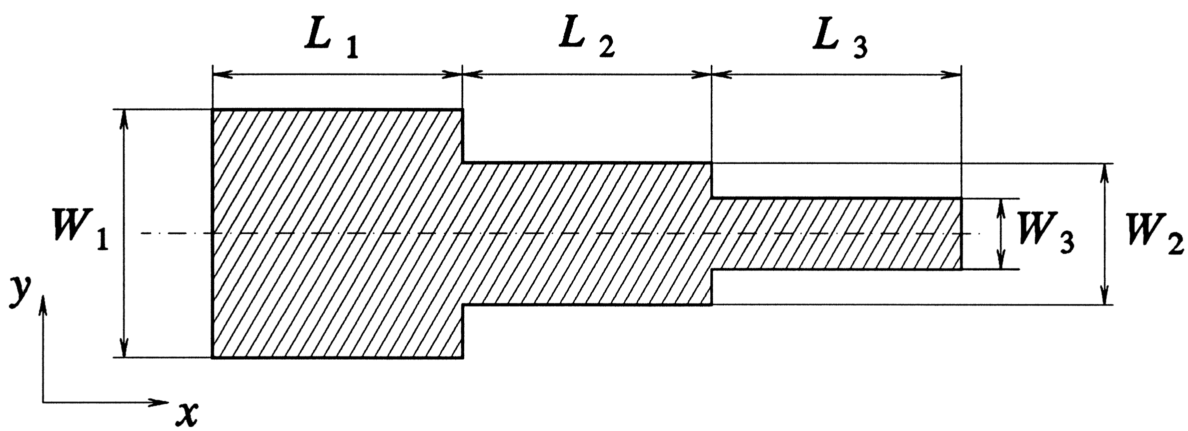
a specific modeling technique may not be critical for the accuracy of the model as long as the validity region is not too large

Sun SPARCstation 10

0.3 CPU seconds per frequency point for coarse grid simulation

5 CPU seconds per frequency point for fine grid simulation

A 3-Section Microstrip Impedance Transformer



W_1, W_2 and W_3 are optimization variables

L_1, L_2 and L_3 are fixed

substrate is 0.635 mm thick

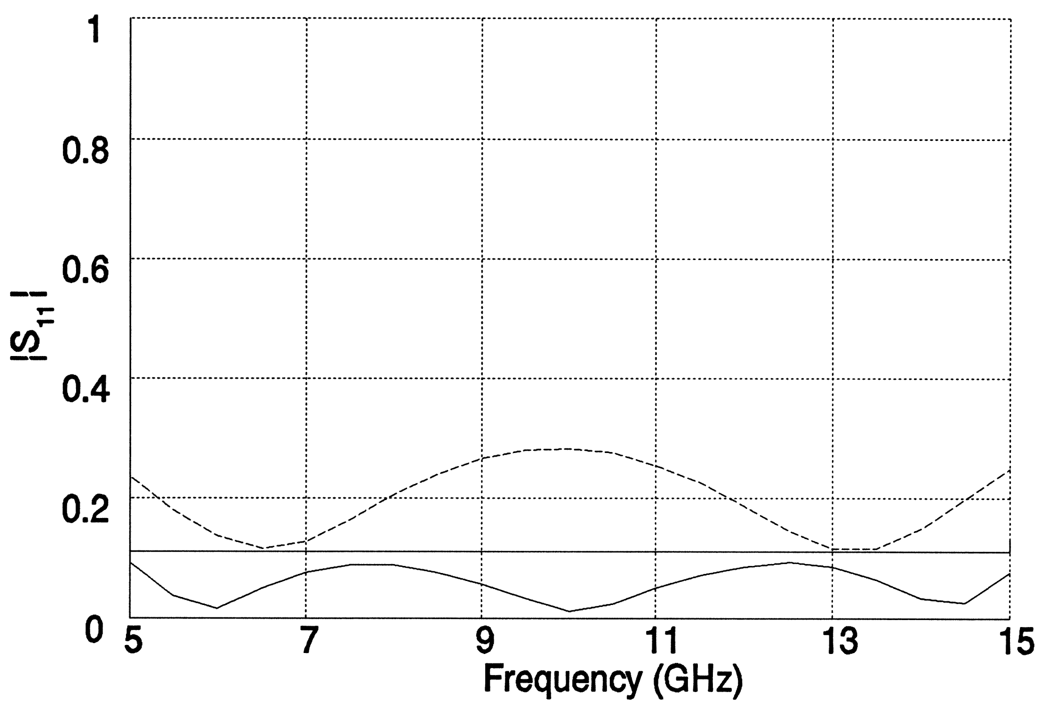
ϵ_r is 9.7

source and load impedances are 50 and 150 Ω, respectively

Minimax Design of the Microstrip Transformer

design specifications

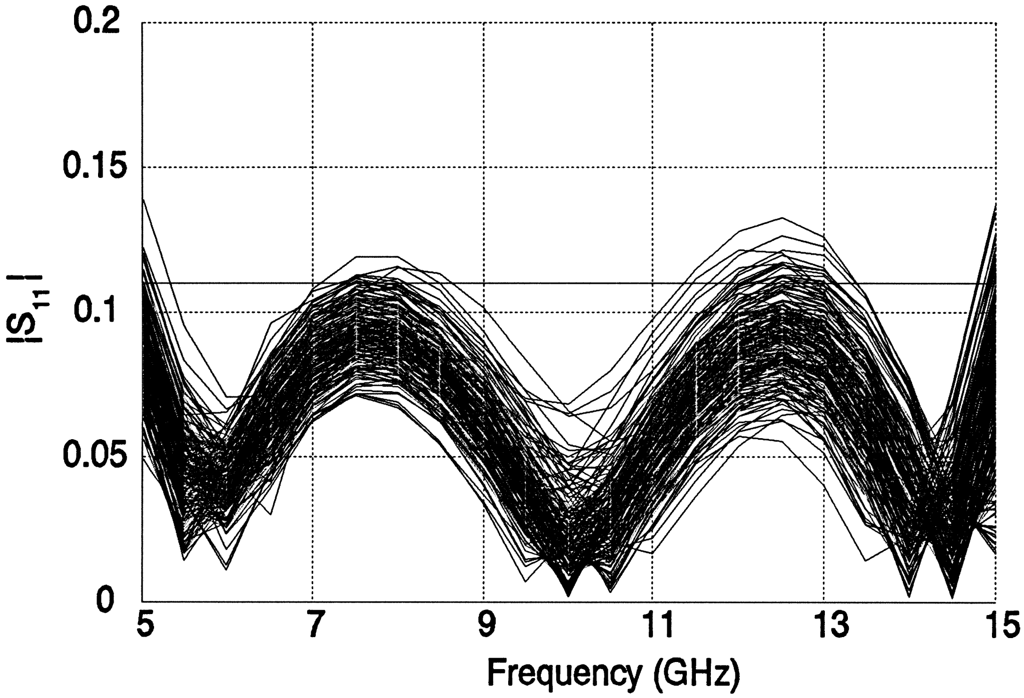
$|S_{11}| \leq 0.11$, from 5 GHz to 15 GHz



$|S_{11}|$ before (- - -) and after (——) optimization

Yield-driven Design of the Impedance Transformer

Monte Carlo sweep at the centered solution



yield is increased from 61% (at the minimax solution) to 77% at the centered solution

yields are estimated from 250 Monte Carlo outcomes

Yield-driven Design of the Microstrip Transformer - Results

Parameter	Starting point (mm)	Minimax solution (mm)	Centered solution (mm)
W_1	0.65	0.349	0.373
W_2	0.35	0.139	0.165
W_3	0.15	0.039	0.049
Yield	-	61%	77%

L_1, L_2 and L_3 are fixed at 3 mm.

normal distributions of all six geometrical parameters

standard deviations of 0.005 mm and 2% for the lengths and widths, respectively

100 outcomes used in yield optimization

Conclusions

a CAD environment for circuit design employing accurate EM field simulations within the optimization loop

efficient modeling is now combined and unified with geometrical interpolation imposed by EM simulation

the data base system is intergral to the modeling techniques and absolutely essential for efficient EM design

multilevel modeling offers additional computational savings

recent studies lead to breakthrough space mapping technique which allows effective utilization of coarse EM models without loss of accuracy offered by fine EM models

recent developments allow for automated EM optimization of structures of arbitrary geometry