SIMULATION OPTIMIZATION SYSTEMS
Research Laboratory

HETEROGENEOUS PARALLEL YIELD-DRIVEN ELECTROMAGNETIC CAD

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S.H. Chen, P.A. Grobelny and D.G. Swanson, Jr.

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Department of Electrical and Computer Engineering

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Introduction

the accuracy of EM models is a crucial contribution towards first-pass success design

extensive computational time is required for EM simulation to obtain accurate results

integration of EM models into automated design utilizing Sonnet's ***em***, OSA's optimizers and novel data base techniques

our previous work of EM optimization is restricted to a library of elements

OSA's novel Geometry Capture technique allows the designer to analyze and optimize a complicated structure as a whole to obtain more accurate simulation results

EM optimization of arbitrary geometries may exert a massive demand on computer resources, particularly for yield-driven design

parallel computation is an effective means of speeding up CPU intensive optimization tasks

EM Optimization with Geometry capture

challenges raised by automated EM optimization

- interpolation and modeling techniques to reconcile the discreteness of EM solvers and the continuity of gradient-based optimizers

- intelligent data bases to eliminate duplicate EM simulations

- geometrical parameterization to capture the design variables from the graphical editors of the EM simulators

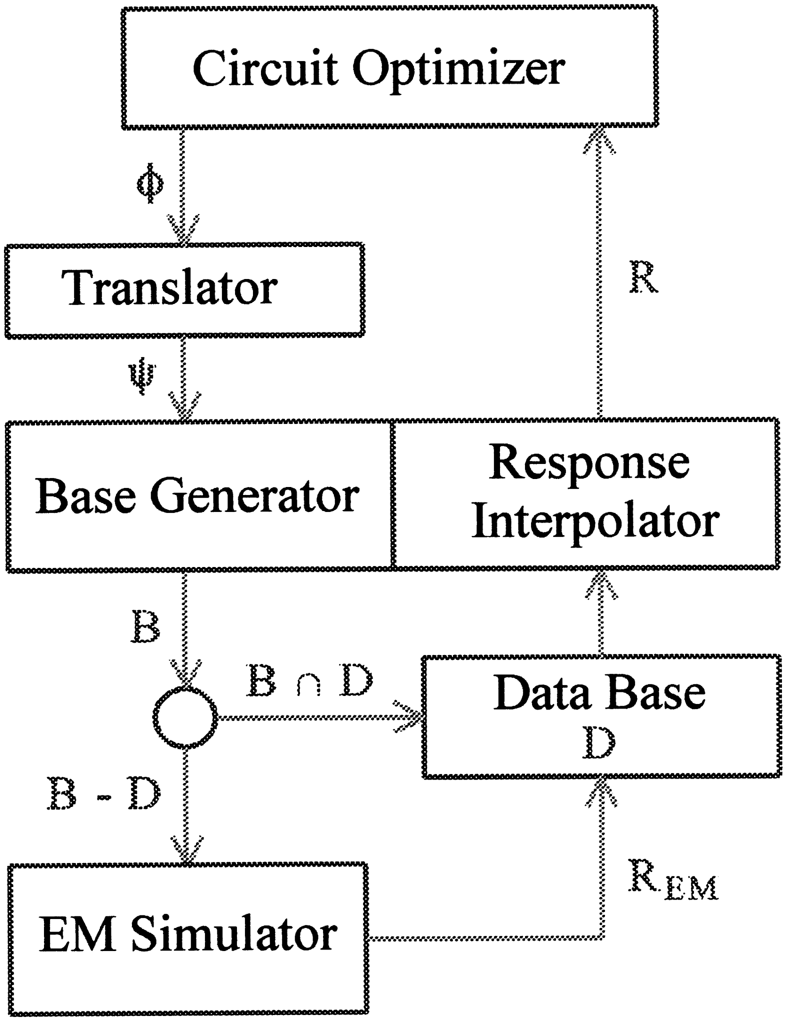
Geometry Capture of arbitrary structures

- establish the mapping between the designable parameter values and the geometrical coordinates

- automatic translate values of user-defined designable parameters to the layout description for EM simulators

- capable of parameterizing geometrical, dielectrical, metallization parameters

Interface Between Optimizer and EM Solver



EM Optimization Environment

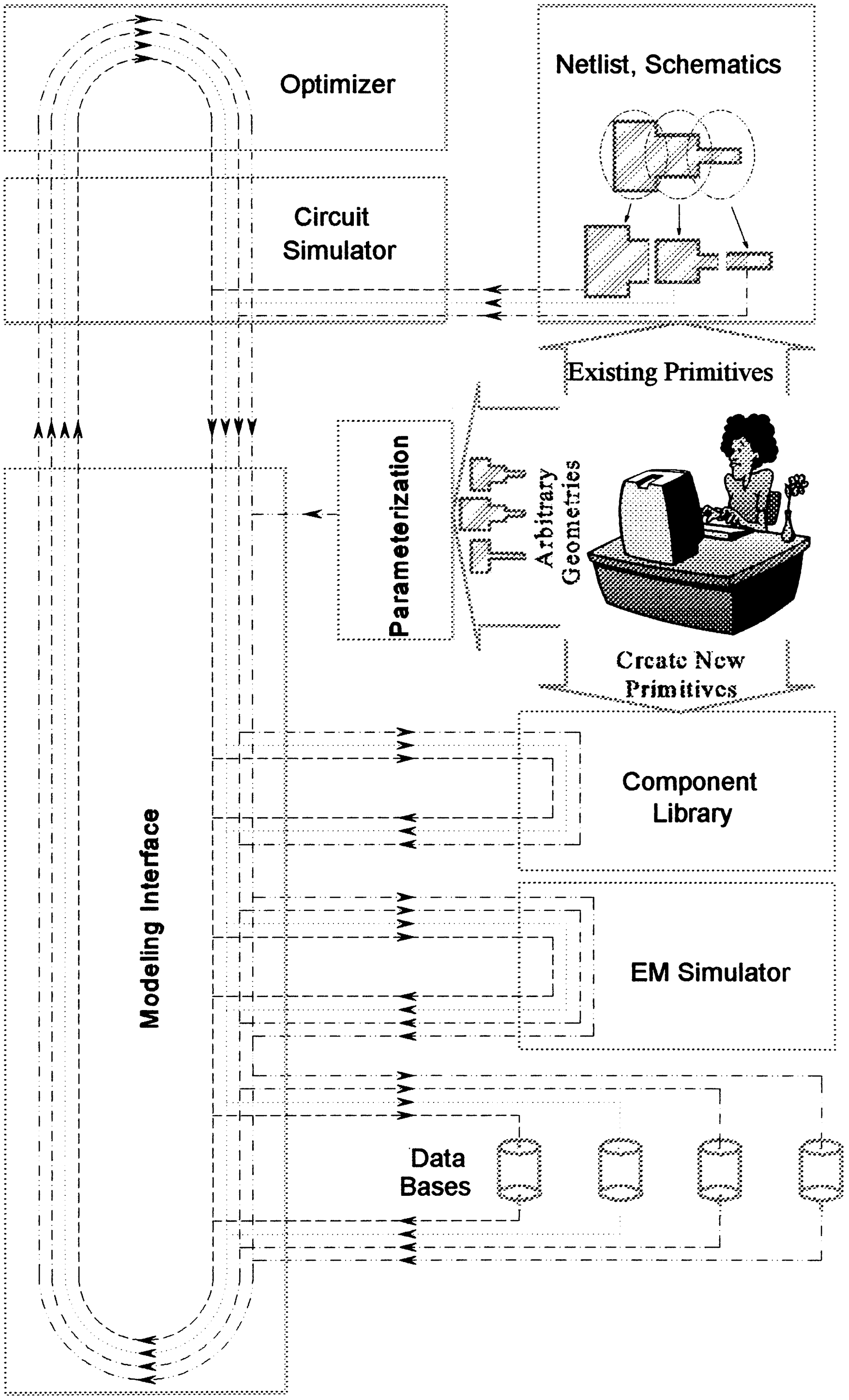
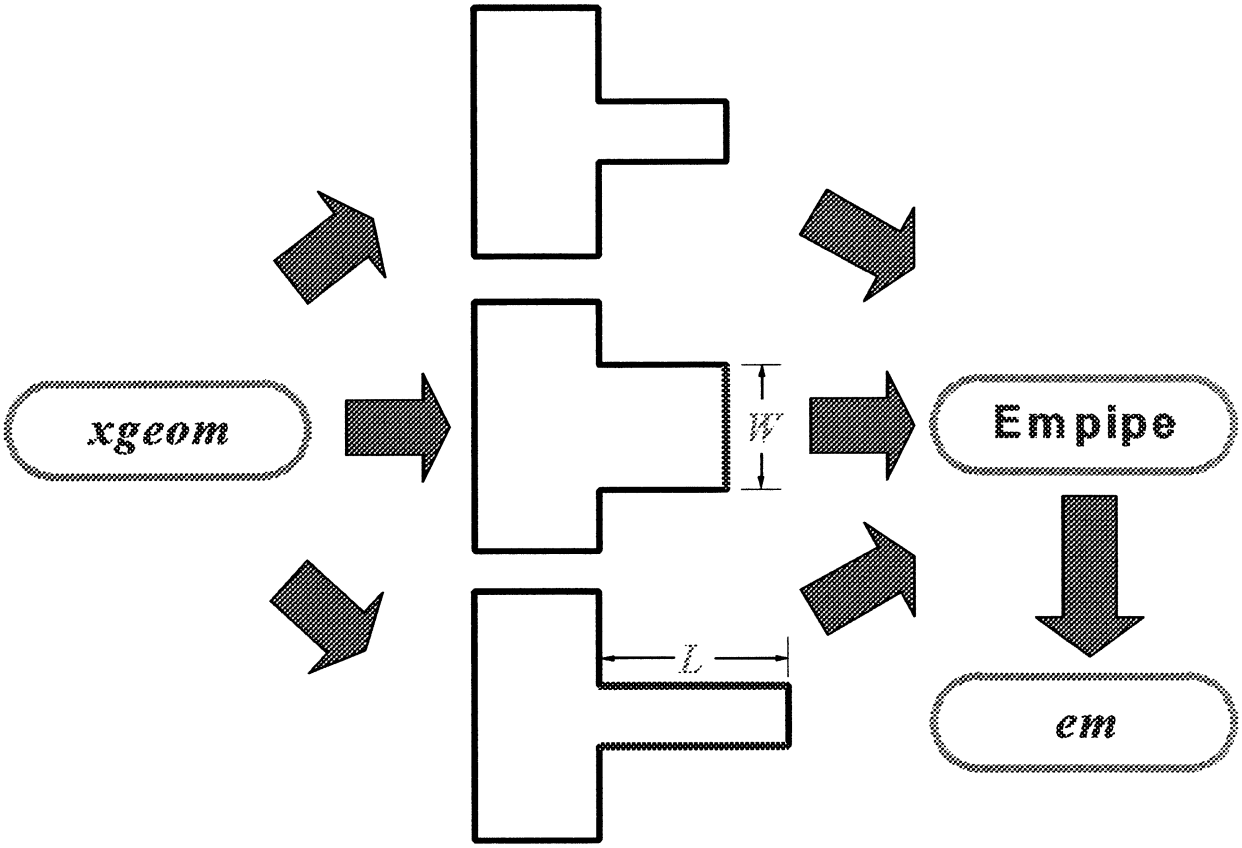


Illustration of Geometry Capture



intuitive and totally flexible

graphical description of parameters and constraints

Parallel Computing

realization of parallel computing

- multiprocessor computers
- specialized compilers
- distribution of tasks over a computer network

distribution of EM simulations by Empipe

- utilize standard UNIX protocols (remote shell and equivalent hosts)

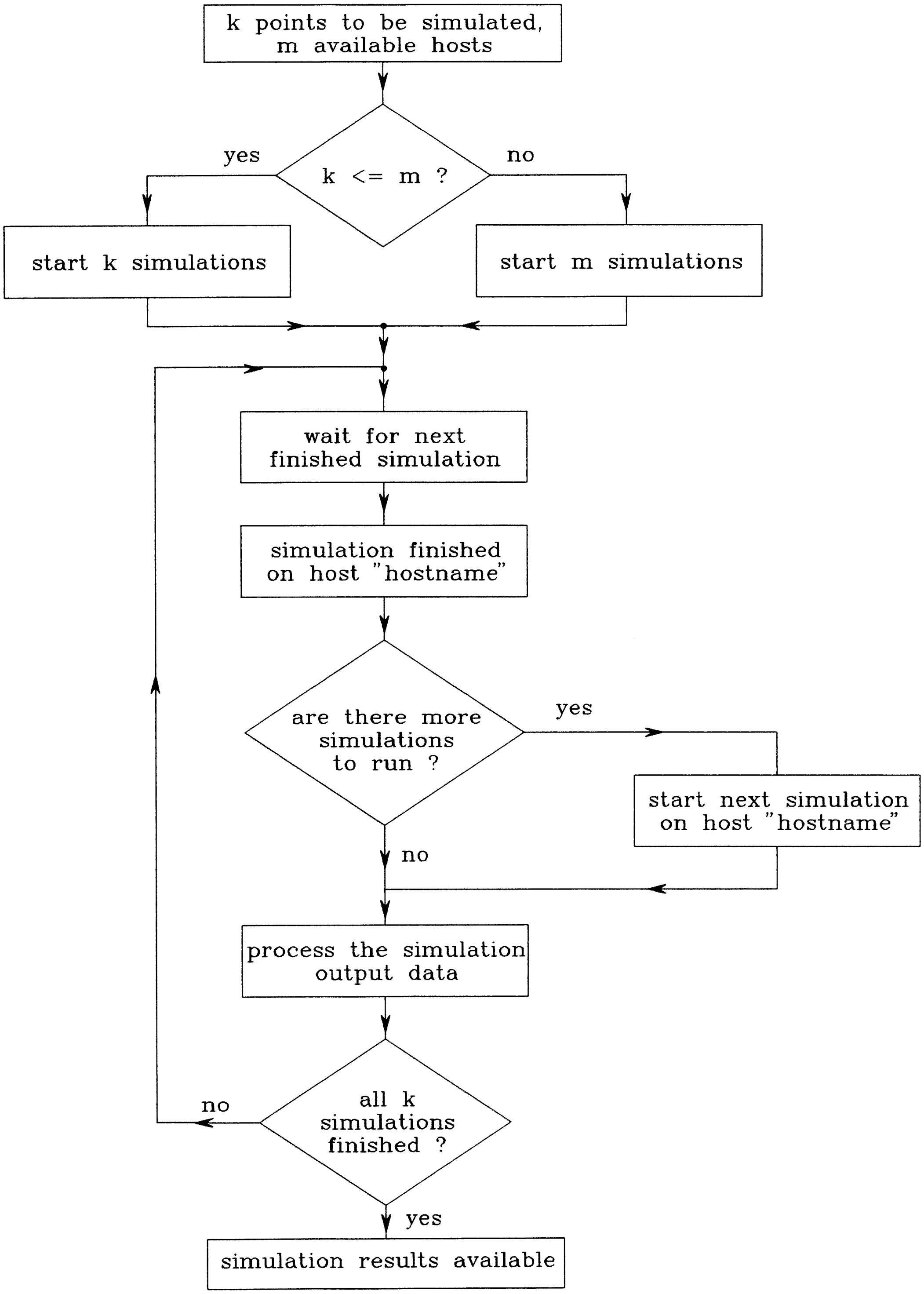
- allow to apply the concept to both local and wide area networks of heterogeneous workstations

- split the load of EM analyses on the component/subcircuit level

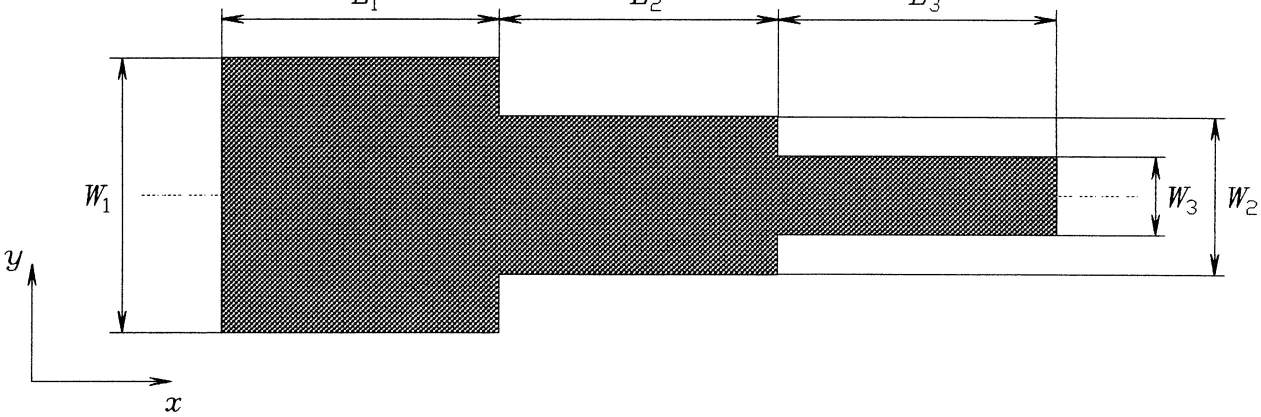
- organize and dispatch the jobs intelligently

- suitable for the operational flow of interpolation, optimization and statistical analysis

Distribution of EM Analysis Over a Network



Yield Optimization of a Microstrip Impedance Transformer



a 3-section 3:1 impedance transformer built on a 0.635 mm thick substrate with relative dielectric constant 9.7

the source and load impedances: 50 and 150 Ω

design specification

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

Simulation and Optimization of the Transformer

using Geometry Capture, the transformer is analyzed by ***em*** as one piece (if it is decomposed into three Empipe library elements any couplings between the three pieces would be omitted)

approximately 3 CPU minutes is required to analyze the transformer at a single frequency on a Sun SPARCstation 1+

three designable parameters: W_1, W_2 and W_3 are considered

six statistical variables assumed normal distributions are considered in yield optimization

- W_1, W_2 and W_3, with a standard deviation of 5 μm
- L_1, L_2 and L_3, with a standard deviation of 2% of the nominal values

the linear interpolation model of Empipe is used during optimization

Parallel Computing in Nominal Design of the Transformer

a maximum of 4 EM analyses (the number of designable parameter + 1) may be parallelized

31 EM analyses were performed during optimization, with an average of 3.1 analyses run in parallel

the CPU time needed to obtain the solution is cut by 2/3 through parallel computing assuming comparable computing power available from each of the 4 workstations

Parallel Computing in Statistical Design of the Transformer

100 statistical outcomes are used in optimization and 250 statistical outcomes are used in statistical analysis

up to 7 EM analyses can be parallelized (the number of designable/statistical parameters + 1)

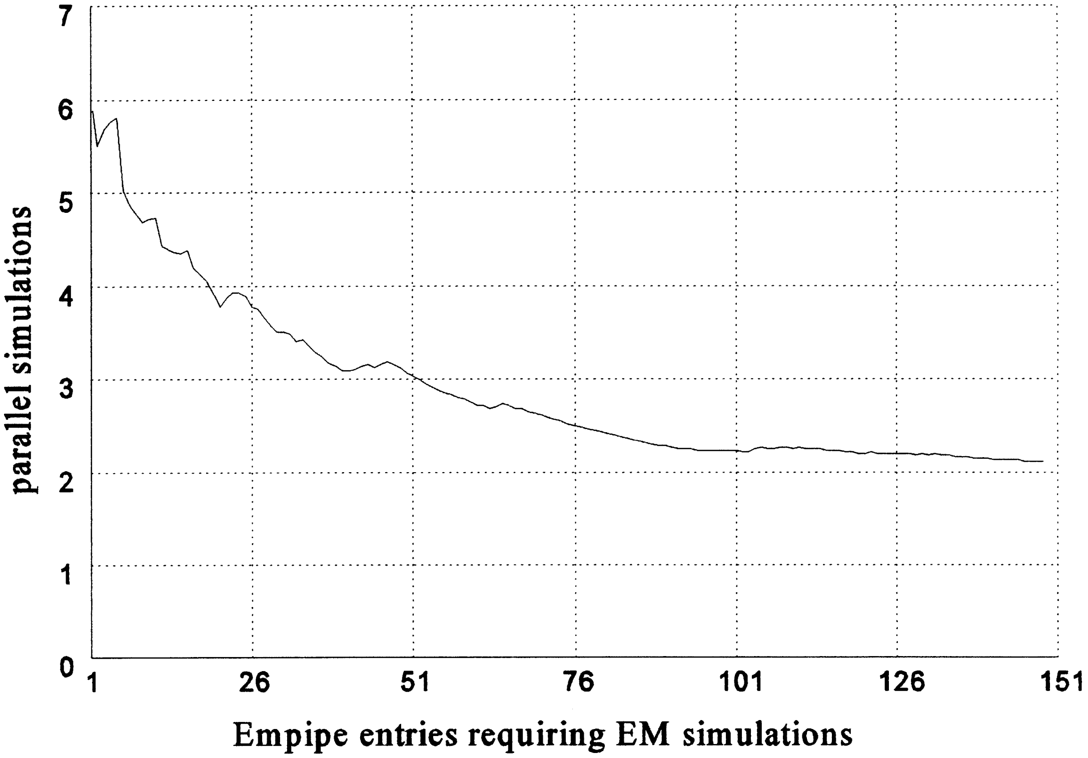
the average number of EM analyses run in parallel is high in the early stage (approximately 6)

fewer jobs are available for parallelization as the optimization converges due to the following reasons

> the parameter values mostly stay in the vicinity of the solution
>
> the interpolation/modeling techniques in Empipe enable the reuse of EM results stored in the data base and minimize the number of new EM analyses required

the CPU time required to obtain the solution is significantly reduced by parallel computing

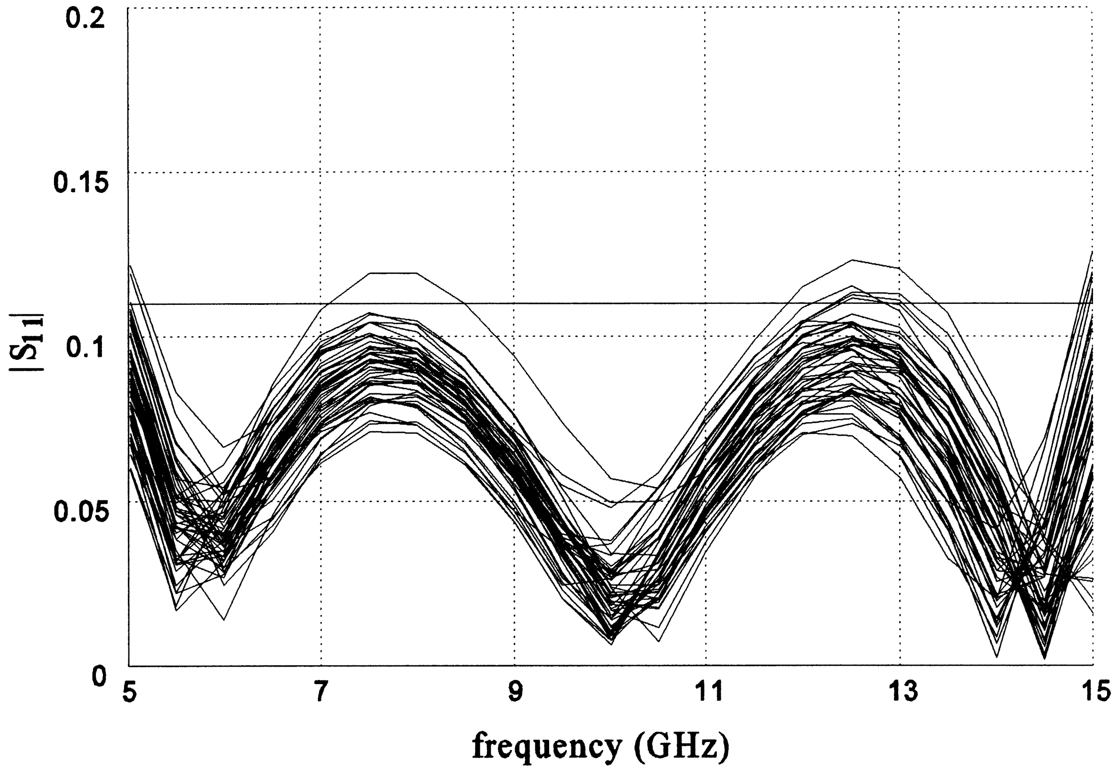
Illustration of Parallel Computation in Statistical Design



a total of 311 EM analyses were performed for both statistical analysis and yield optimization with OSA's interpolation/modeling/data base techniques

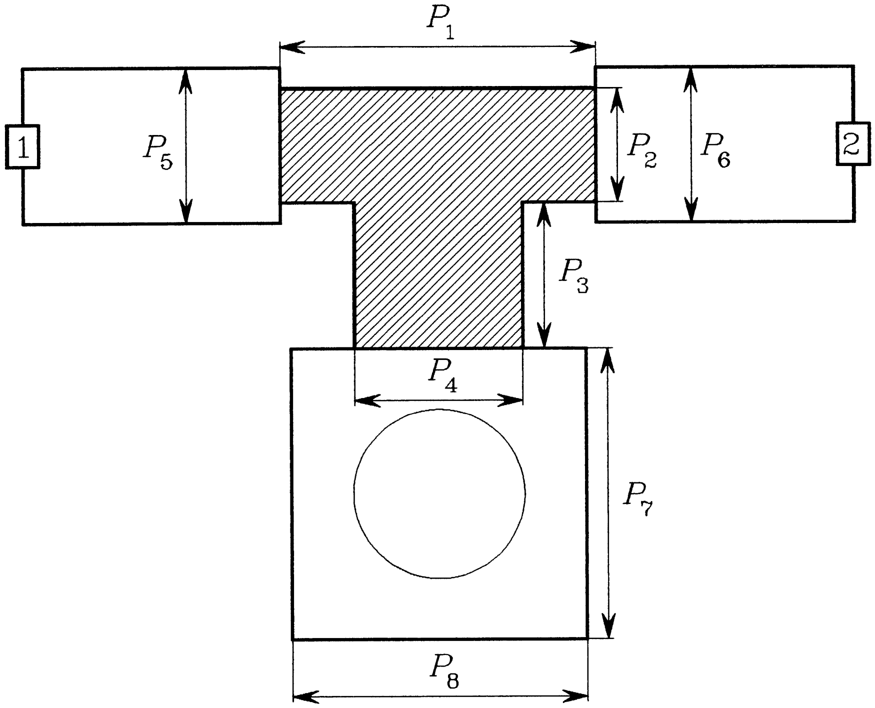
without interpolation/modeling/data base techniques 500 EM simulations for statistical analysis and 400 EM analyses *per iteration* during optimization would be required

Monte Carlo Sweep of $|S_{11}|$ After Yield Optimization



yield estimated from 250 statistical outcomes is increased from 61% at the nominal design to 77% after yield optimization

Statistical design of a 10 dB Distributed Attenuator



the distributed attenuator is built on a 15 mil substrate with a relative dielectric constant of 9.8

the structure is difficult, if not impossible, to be decomposed into Empipe library elements

Simulation and Optimization of the Attenuator

the attenuator is considered as one piece and captured by Empipe's Geometry Capture

out of 8 geometrical parameters, namely P_1, P_2, ..., P_8, 4 are assumed to be designable, i.e., P_1, P_2, P_3 and P_4

the attenuator is simulated by Sonnet's ***em*** and the results are returned to OSA90/hope for optimization through Empipe

EM simulation of the attenuator at a single frequency requires about 7 CPU minutes on a Sun SPARCstation 1+

design specification

$$-10.5 \text{ dB} \leq \text{insertion loss} \leq -9.5 \text{ dB}$$
$$\text{return loss} \leq -10 \text{ dB}$$

for the frequency range from 2 GHz to 18 GHz

Parallel Computing in the Design of the Attenuator

nominal design:

30 EM analyses with an average of 3.8 analyses run in parallel

it took about 168 minutes on the network of Sun SPARCstations 1+ compared to 630 minutes required on a single computer

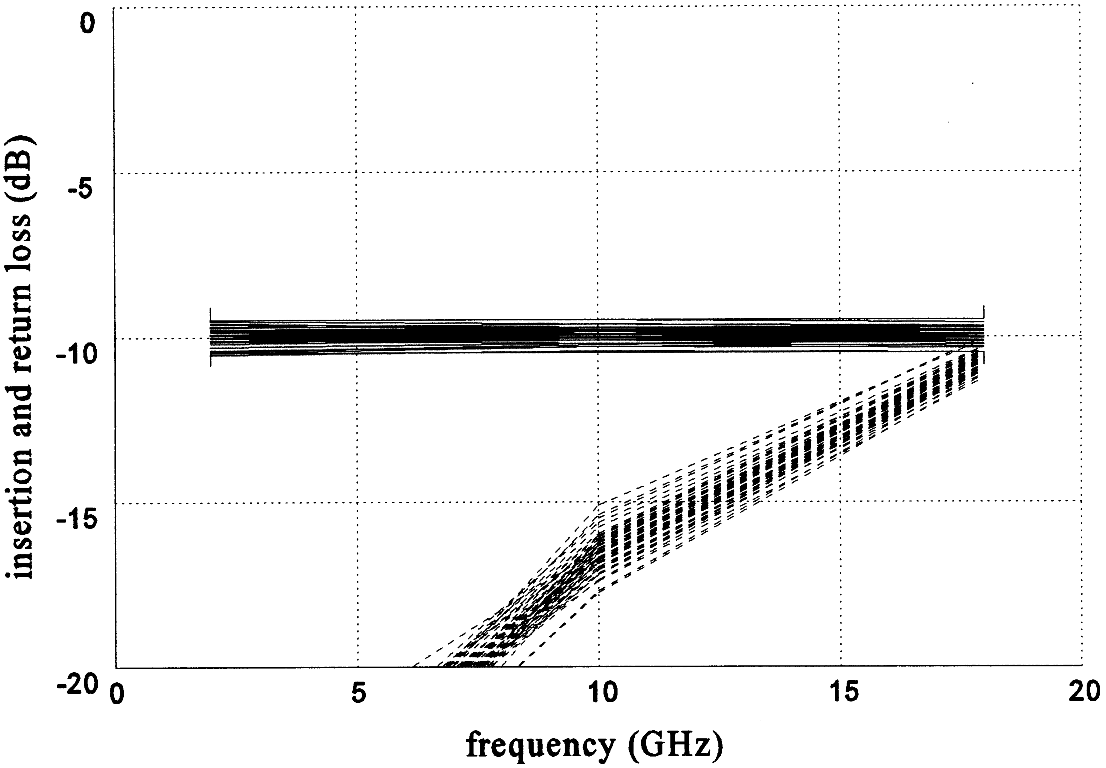
statistical design:

assume normal distributions with a standard deviation of 0.25 mil for all 8 geometrical parameters

yield estimated by 250 Monte Carlo outcomes

in addition to the nominal design, the statistical simulation and optimization called for 113 additional EM analyses, with an average of 2.5 analyses run in parallel

Monte Carlo Sweeps of the Attenuator Responses



yield estimated from 250 statistical outcomes is increased from 82% at the nominal design to 97% after yield optimization

Conclusions

within an integrated parallel optimization framework, we are able, for the first time, to apply EM optimization to the yield-driven design of microstrip circuits of arbitrary geometries

parallel optimization handles the massive demand on computer resources, due to the large number of designable parameters and of simulations involved in yield optimization

integrating parallel computing with interpolation, response function modeling and data base techniques can immensely reduce the overall design time

our approach consolidates a network of moderately powered workstations into an optimization environment of tremendous potential

our approach is one of the most cost-effective ways to utilize the available computer resources

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