SIMULATION OPTIMIZATION SYSTEMS
Research Laboratory

DESIGN TOOLS AND METHODOLOGY FOR HIGH-SPEED/HIGH-FREQUENCY CIRCUITS AND SYSTEMS

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SOS-95-6-V

May 1995

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Subproject C.3.C3

Design Tools and Methodology for High-Speed/High-Frequency Circuits and Systems

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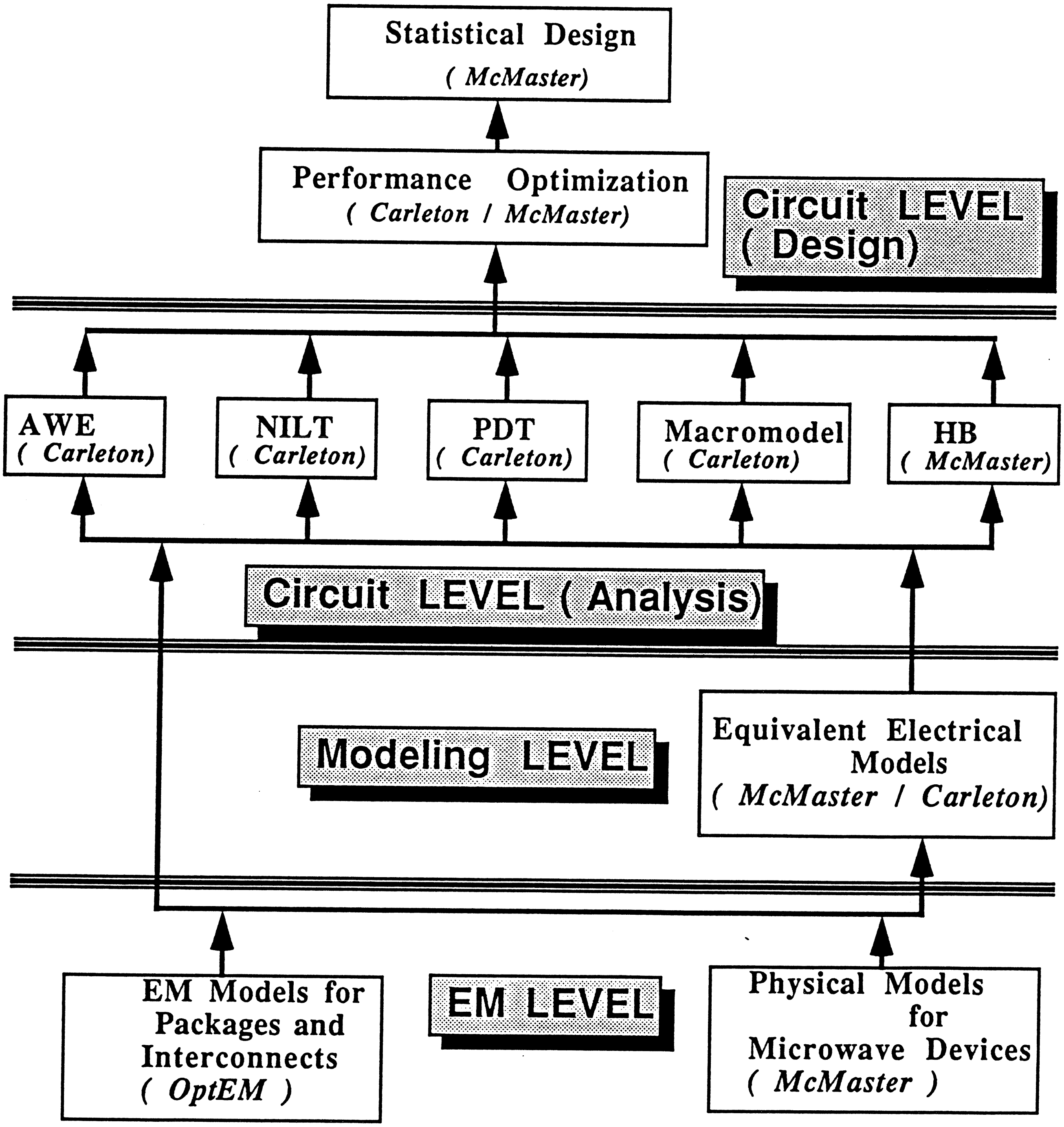
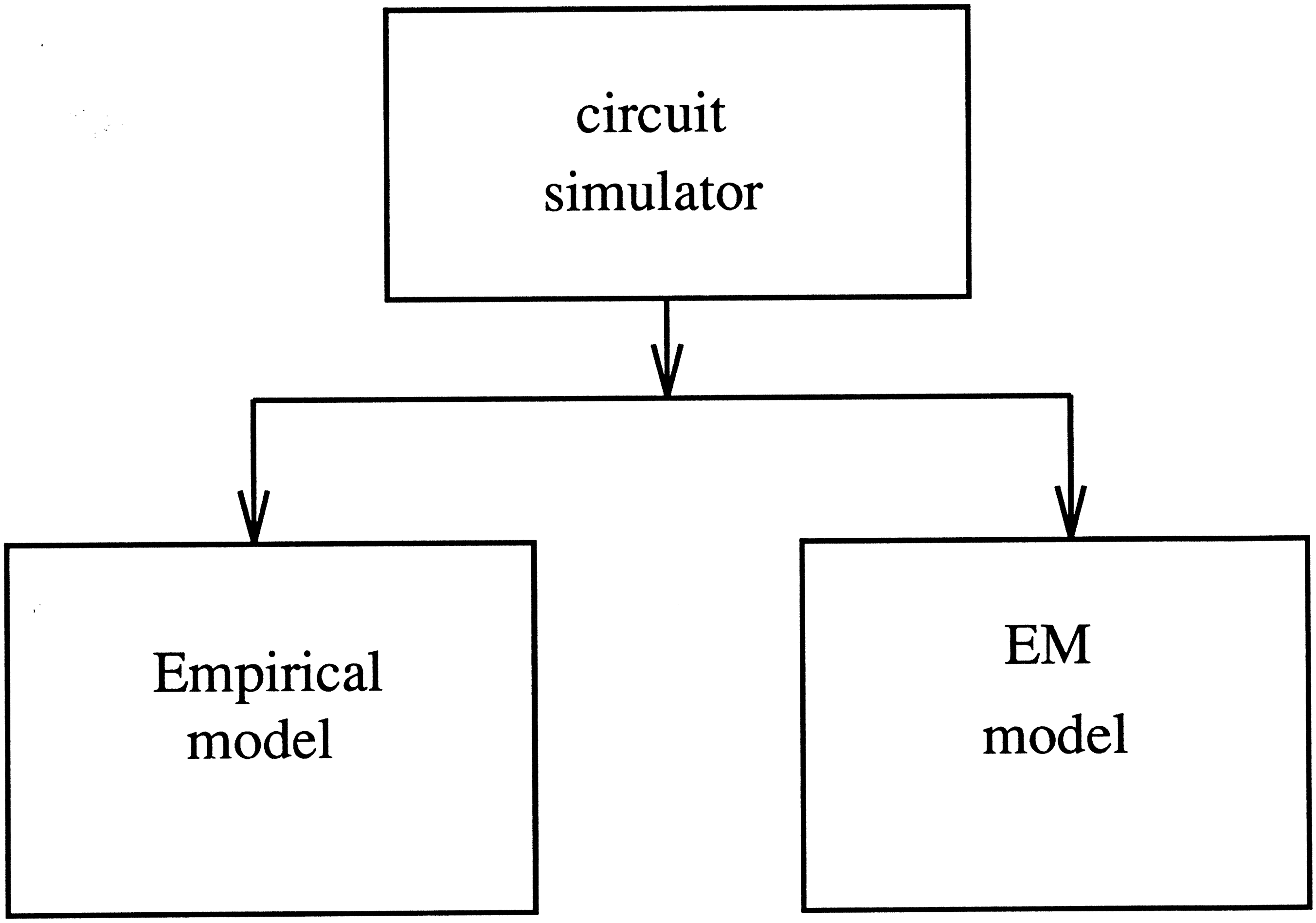
Overall Objectives

Collaborative project aimed to develop tools and methodology for high-speed/high-frequency circuits and systems:

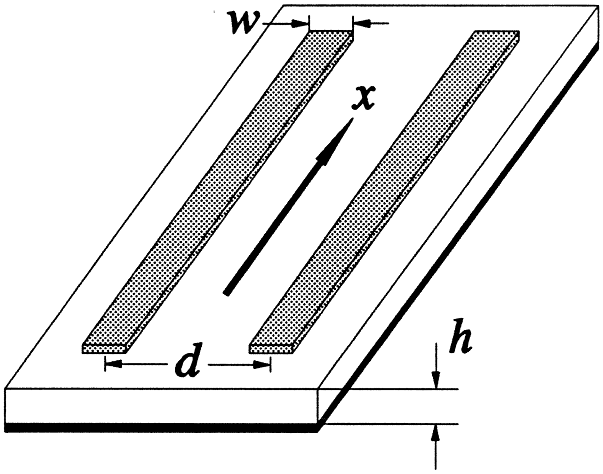
to address design hierarchy
- EM level, device level
- circuit level
- MCM, PCB, backplanes

to integrate CAD approaches
- modeling
- simulation
- optimization
- statistical design


Statistical Design
(McMaster)
Performance Optimization
(Carleton / McMaster)
Circuit LEVEL
(Design)
AWE
(Carleton)
NILT
(Carleton)
PDT
(Carleton)
Macromodel
(Carleton)
HB
(McMaster)
Circuit LEVEL (Analysis)
Modeling LEVEL
Equivalent Electrical Models
(McMaster / Carleton)
EM Models for Packages and Interconnects
(OptEM)
EM LEVEL
Physical Models for Microwave Devices
(McMaster)


circuit simulator
Empirical model
EM model

Two-Conductor Coupled Transmission Lines



Distributed LC Model for Lossless Lines

$$\frac{\partial \boldsymbol{v}(x)}{\partial x} = -j\omega \, \boldsymbol{L} \, \boldsymbol{i}(x)$$

$$\frac{\partial \boldsymbol{i}(x)}{\partial x} = -j\omega \, \boldsymbol{C} \, \boldsymbol{v}(x)$$

where L and C are the per-unit-length inductance and capacitance matrices, respectively.

TABLE I

Comparison of the Calculated LC Matrices

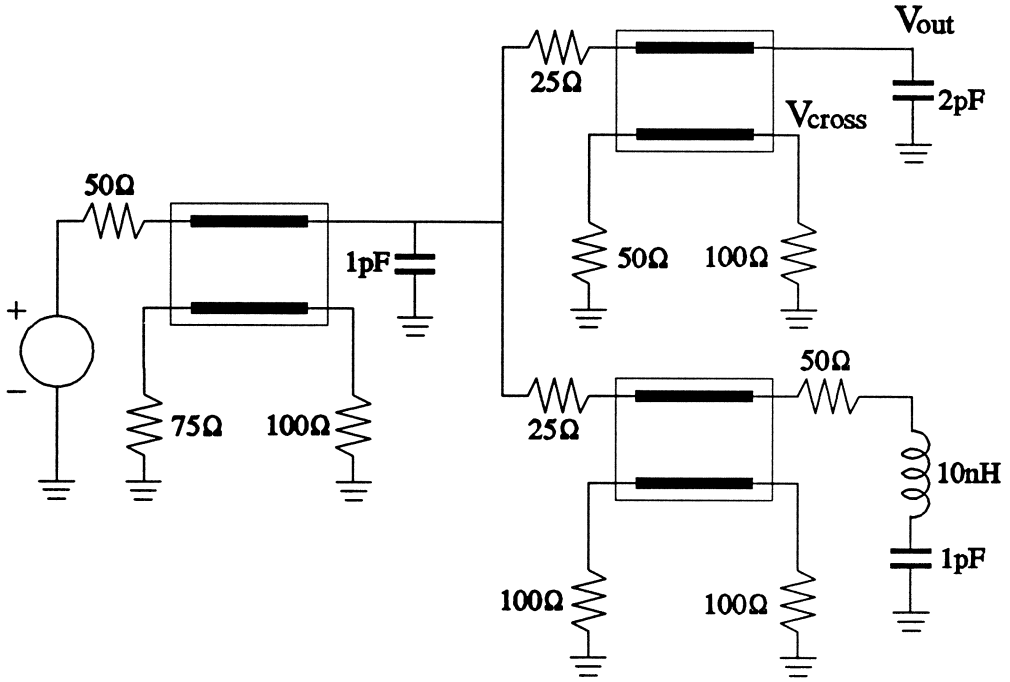
	Walker	*em*	IE3D
L_{11} (nH/m)	494.5	510.7	523.4
L_{12} (nH/m)	63.29	58.67	62.70
C_{11} (pF/m)	69.97	57.52	61.06
C_{12} (pF/m)	-7.13	-3.11	-3.06

TABLE II

Percentage Differences

	Walker	*em*	IE3D
L_{11} (%)	0	3.3	5.8
L_{12} (%)	0	-7.3	-0.9
C_{11} (%)	0	-17.8	-12.7
C_{12} (%)	0	-56.4	-57.1

Interconnect Circuit for Model Comparison
(*Lum, Nakhla and Zhang, 1991*)

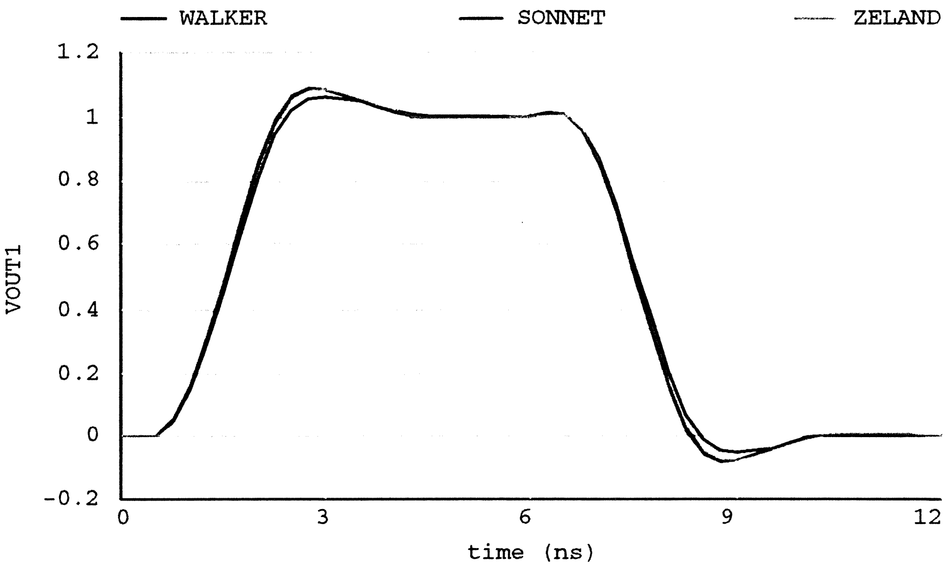


Circuit Simulator

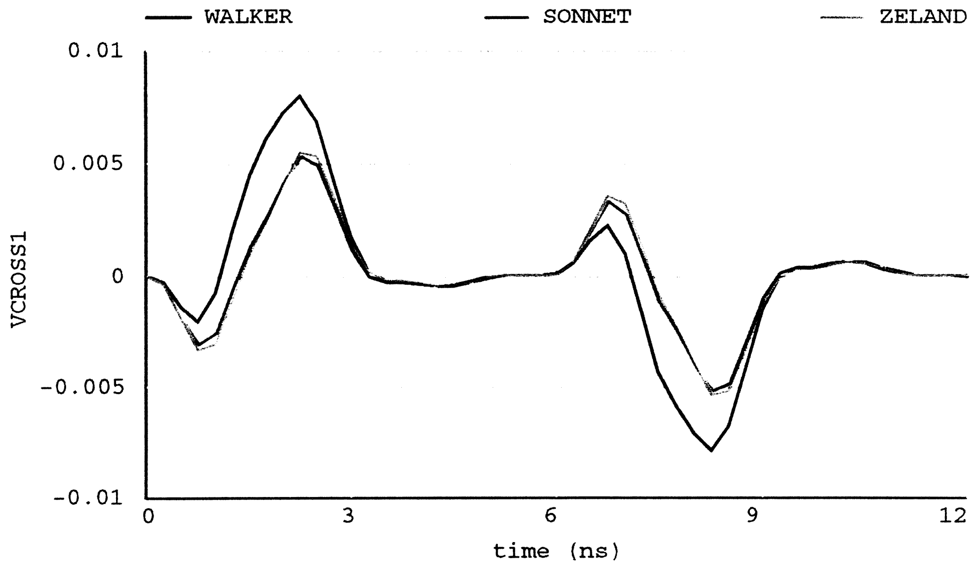
The AWE simulator COFFEE from Carleton University driven by OSA90/hope™ from Optimization Systems Associates Inc. through Datapipe™.

The input is a 6 ns trapezoidal voltage signal.

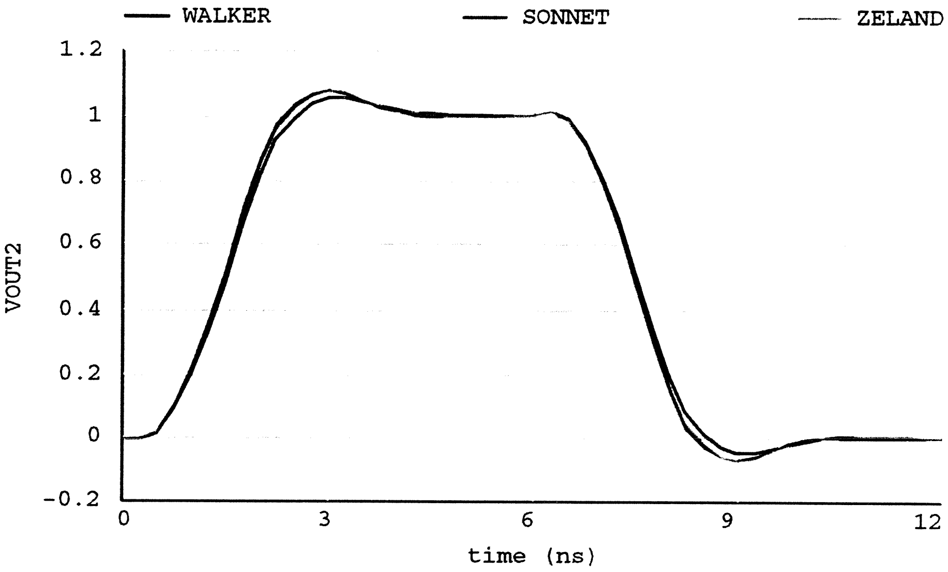
Comparison of the Response V_{out1}



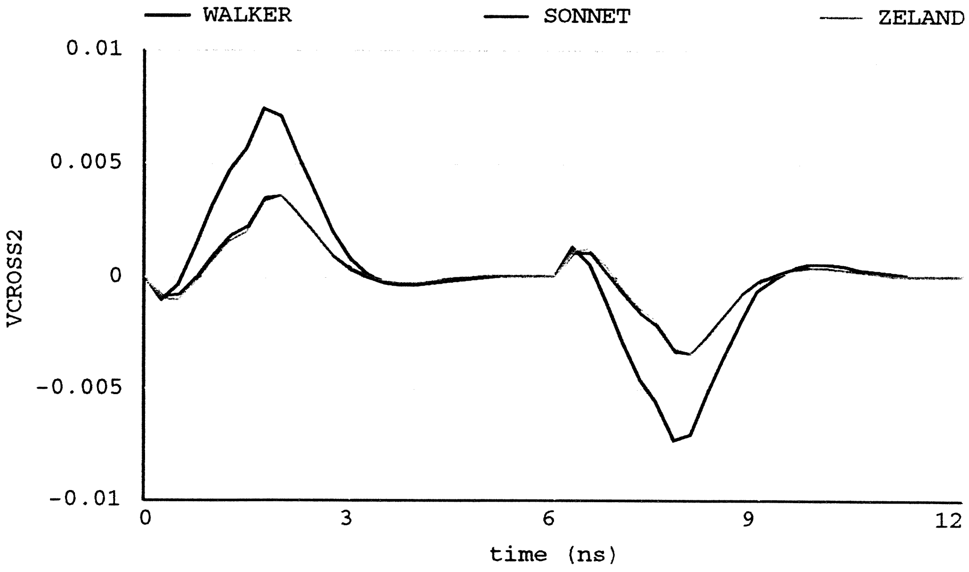
Comparison of the Response V_{cross1}

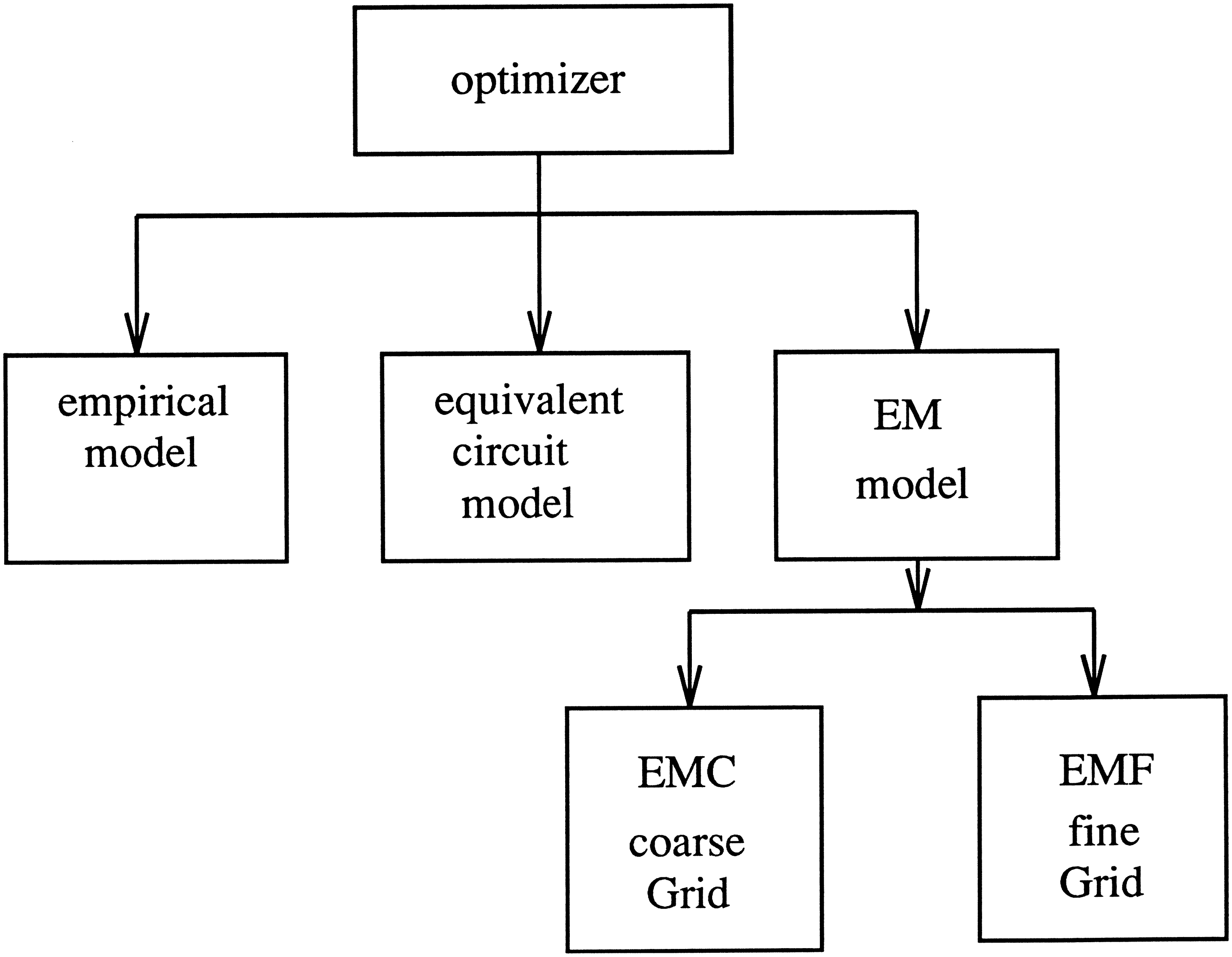


Comparison of the Response V_{out2}



Comparison of the Response V_{cross2}




optimizer
empirical model
equivalent circuit model
EM model
EMC coarse Grid
EMF fine Grid

The Space Mapping Technique

particularly attractive for designs involving CPU intensive simulators

it substantially decreases the number of necessary exact EM simulations

we create and iteratively refine a mapping from the EM simulator input space onto the parameter space of the model used by the optimizer

the initial mapping is found using a preselected set of k points in the EM input space

the set of corresponding points in the optimizer parameter space is determined by fitting the EM simulation results to the model used by the optimizer

Exploitation of Coarse Grid for EM Optimization

we exploit coarse-grid EM field simulations for rapid

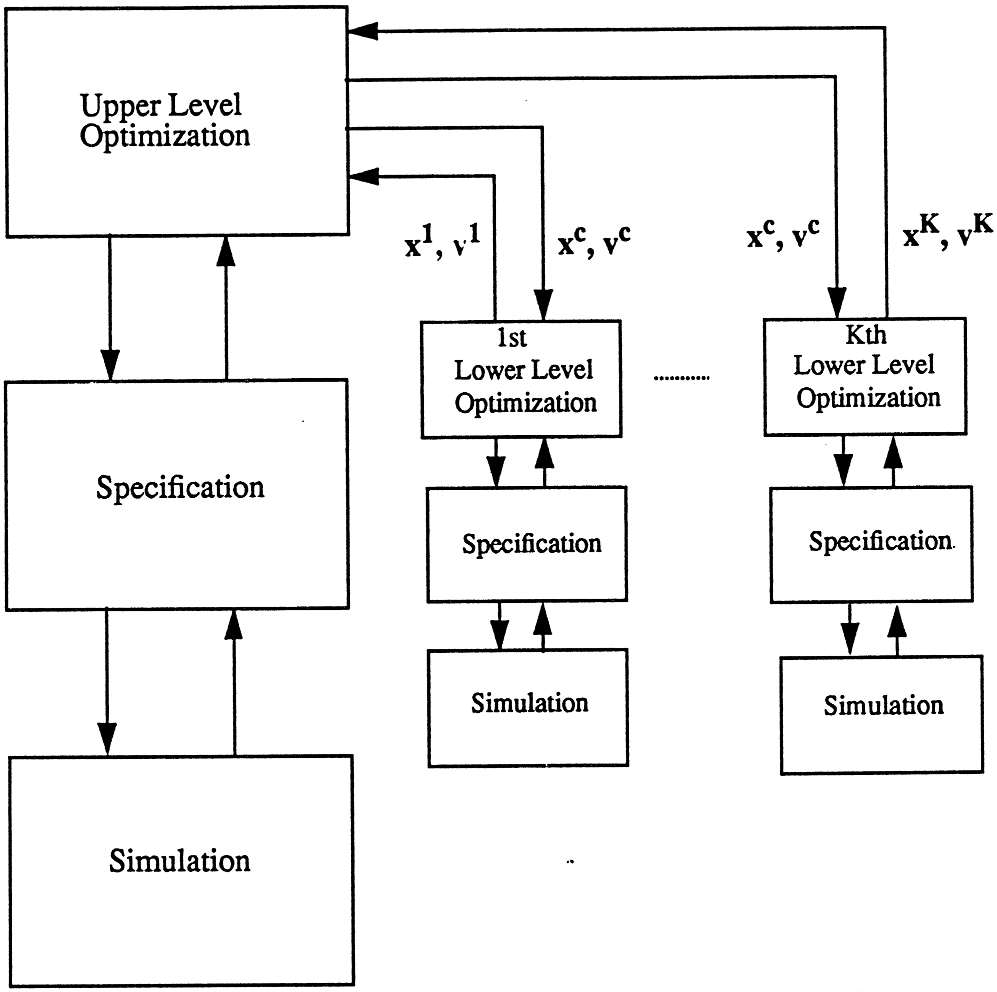
- performance driven design optimization
- yield optimization
- robustness analysis of optimal solutions

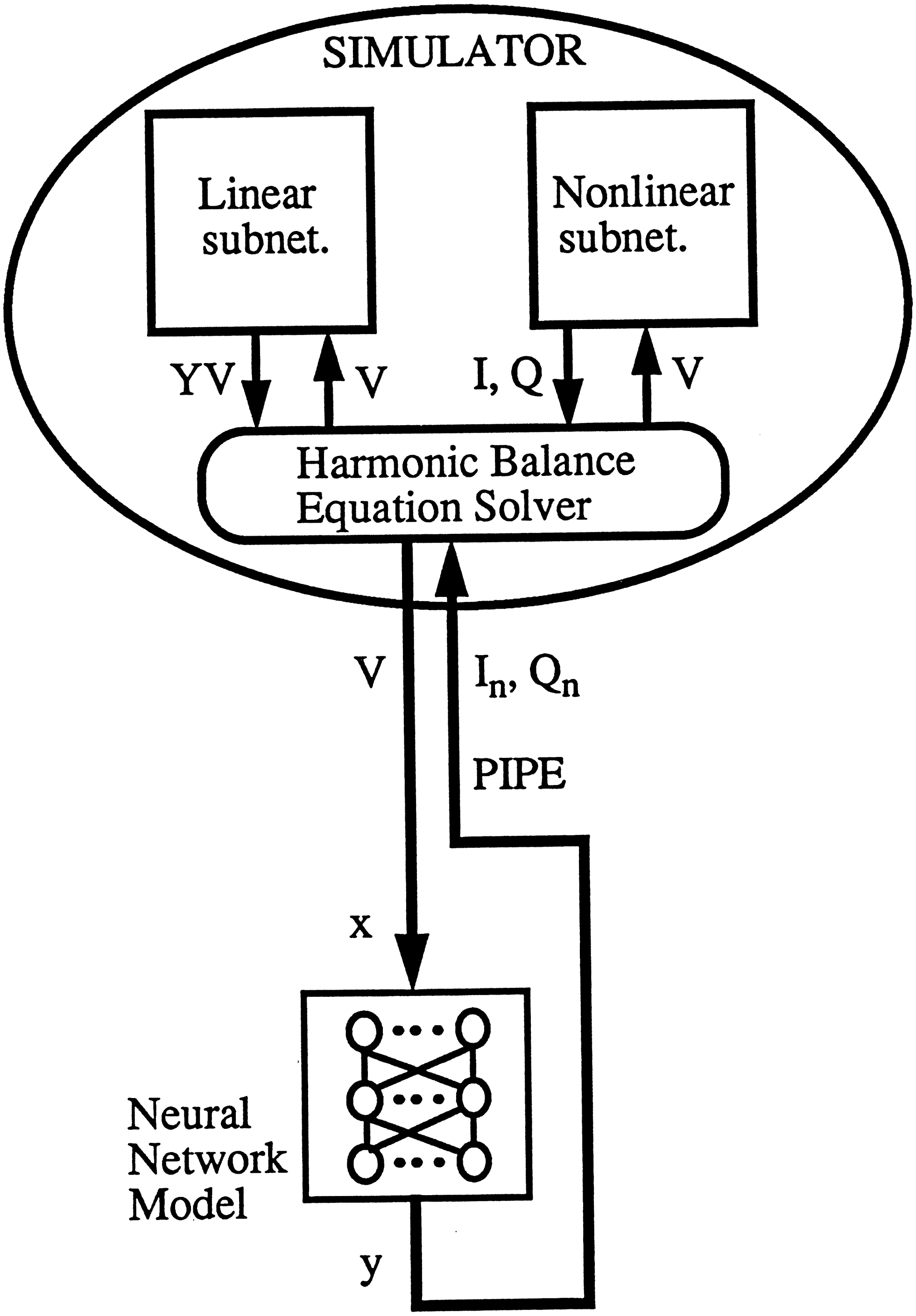
it is demonstrated that coarse grid models can provide substantive circuit performance information in a practical time frame

very few fine-grid EM simulations are needed to align the EMC model with the ultimately accurate EMF model

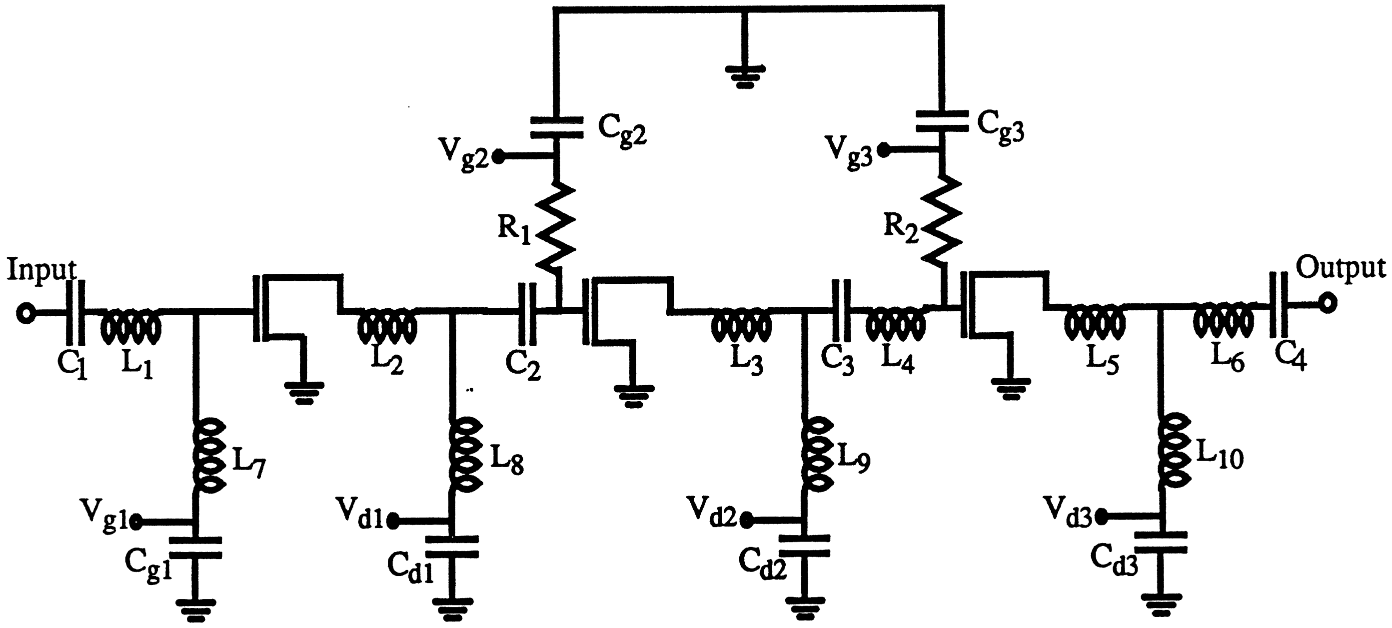
Space Mapping is used for model alignment; it leads to solutions otherwise obtainable only by extremely CPU intensive direct fine-grid optimization

IMPLEMENTATION OF PARALLEL OPTIMIZATION

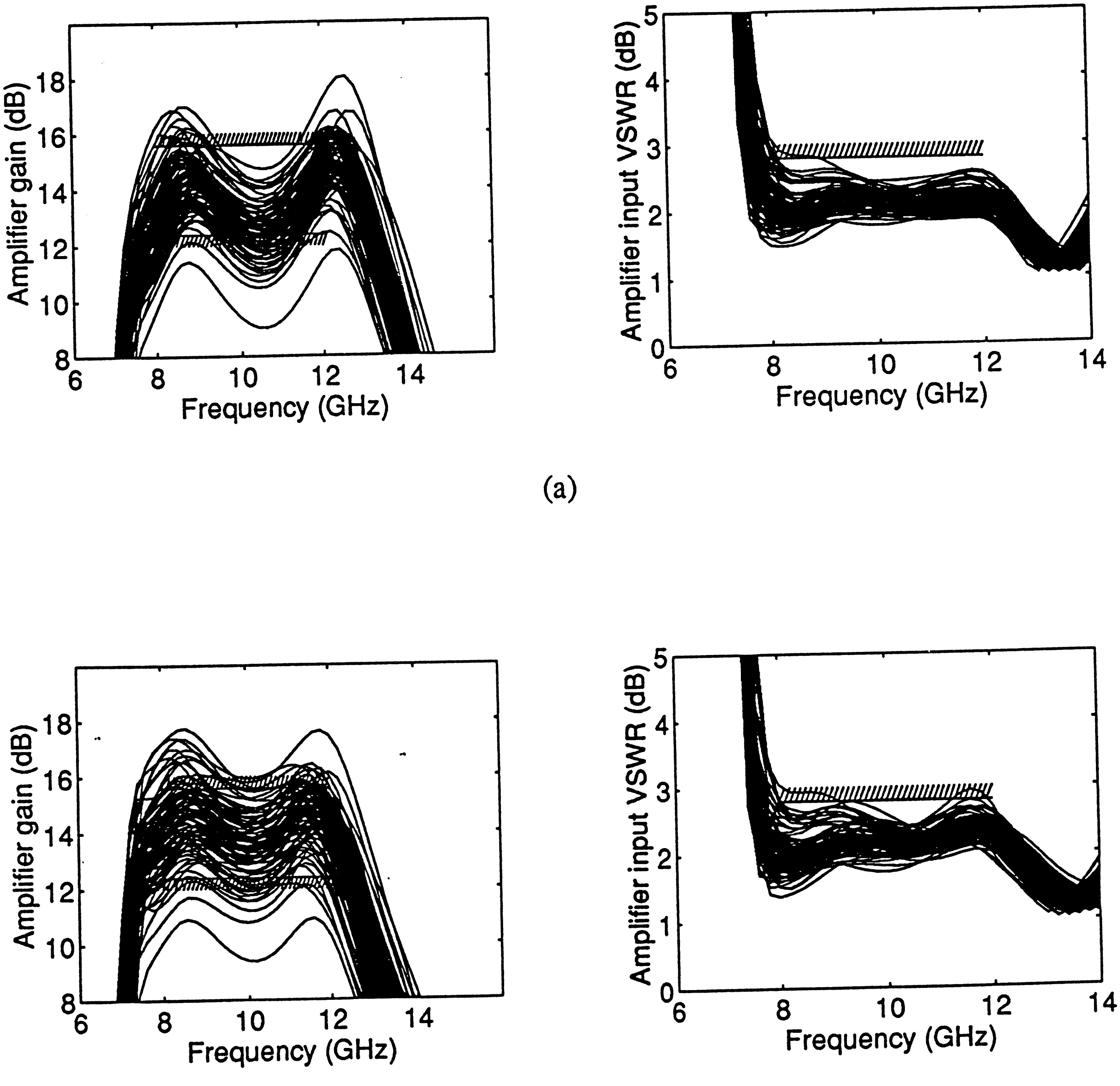




Implementation of neural network models into circuit simulator.



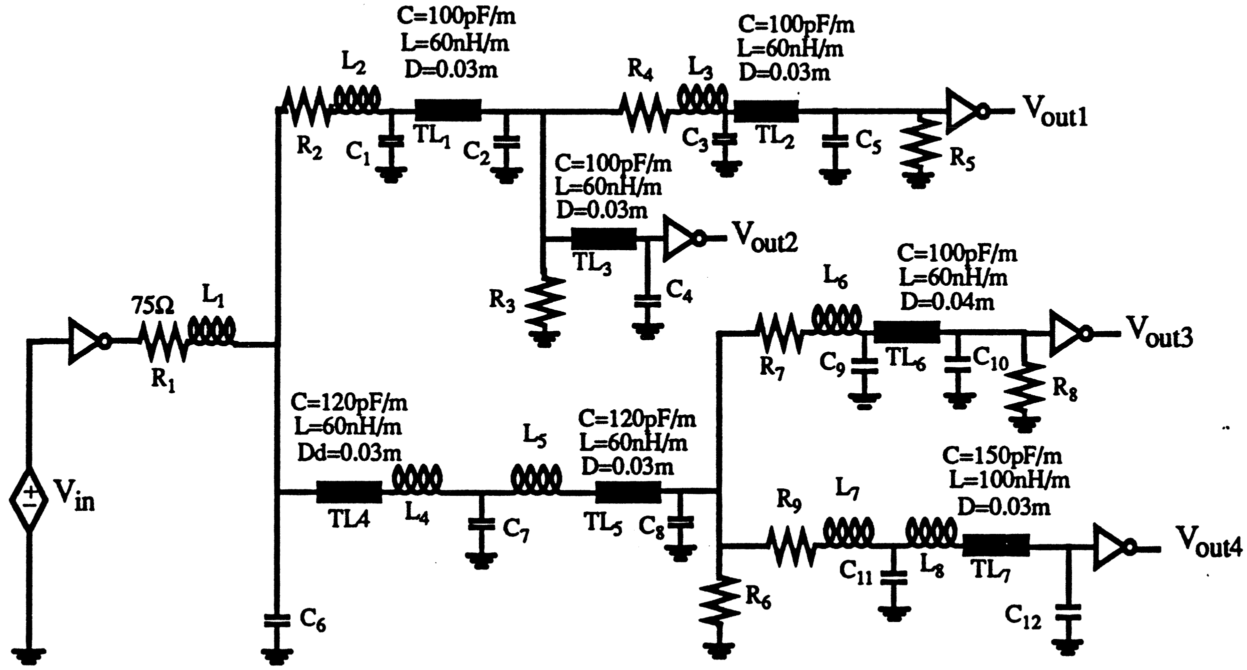
Circuit diagram of an X-band amplifier



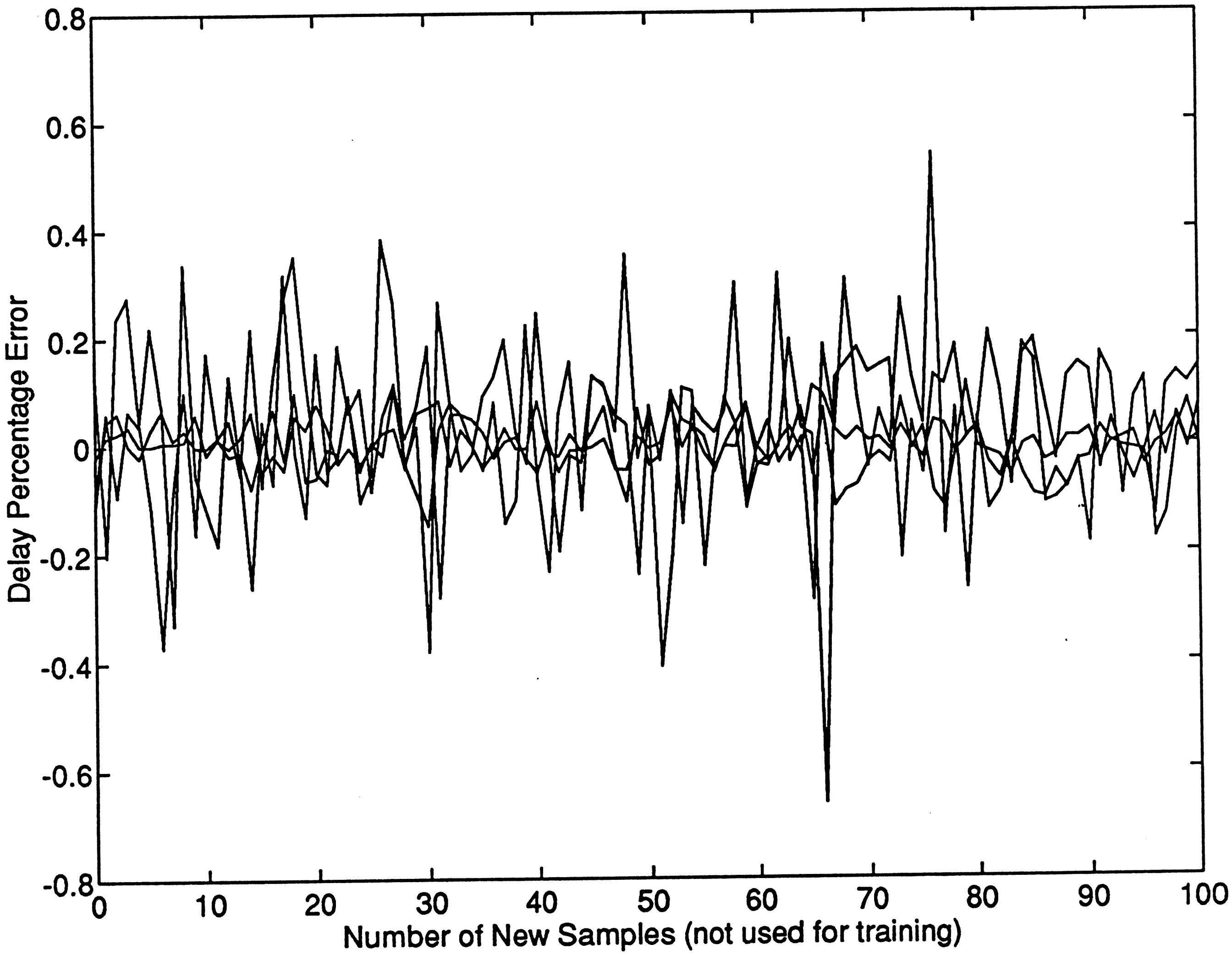
(a)

(b)

Monte Carlo sweep of gain and input VSWR of the X-band amplifier using neural network model (a) before and (b) after yield optimization.



A high-speed VLSI interconnect network represented by a 7 transmission line circuit with nonlinear terminations



The 7 transmission line example. Percentage errors between signal delays predicted from the neural network model and that from exact simulation for 100 randomly selected set of samples not used for training.

Huber Optimization

circuit optimization must take into account model/measurement/statistical errors, variations and uncertainties

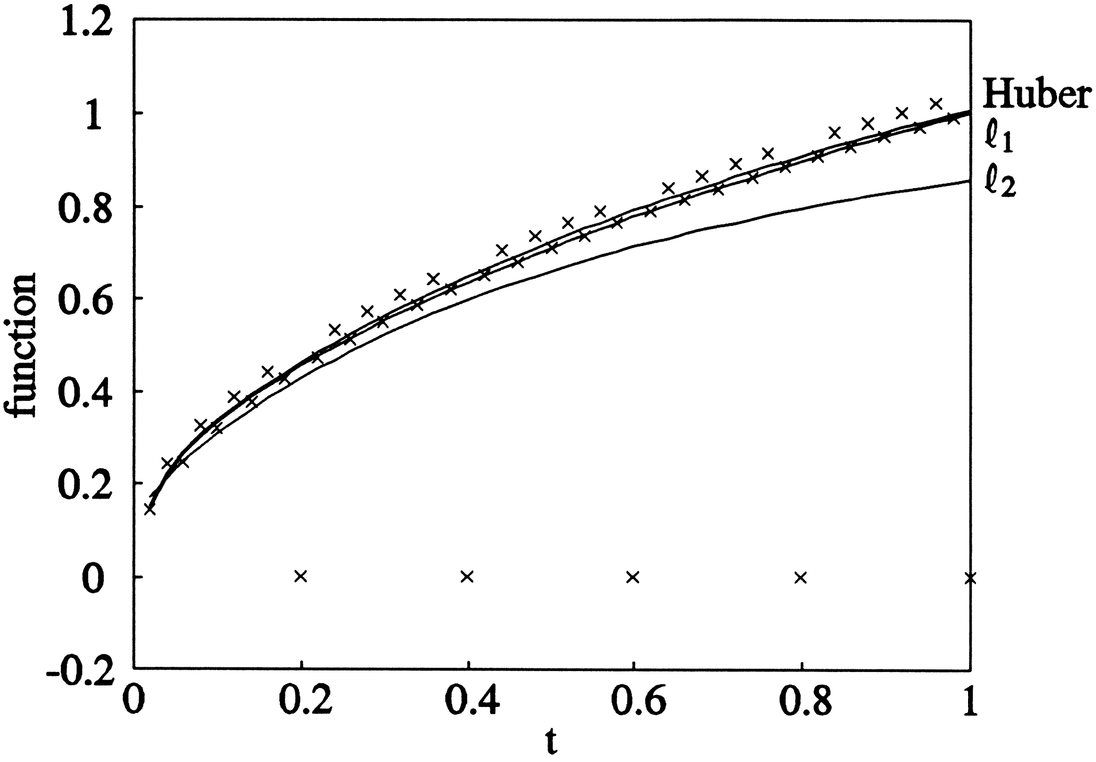
least-squares (ℓ_2) solutions are notoriously susceptible to the influence of gross errors: just a few "wild" data points can alter the results significantly

the ℓ_1 method is robust against gross errors; however, it inappropriately treats small variations in the data

neither the ℓ_1 nor ℓ_2 alone is capable of providing solutions which are robust against large errors *and* flexible w.r.t. small variations in the data

the Huber solution can provide a smooth model from data which contains many small variations and such a model is also robust against gross errors

ℓ_1, ℓ_2 and Huber Data Fitting



ℓ_1, ℓ_2 and Huber solutions for data fitting in the presence of large and small errors

One-sided Huber Formulation for Yield Optimization

we present a one-sided Huber approach to yield optimization of linear and nonlinear circuits

we consider a number of statistical outcomes of circuit parameters denoted by $\boldsymbol{\phi}^i$

for each outcome we create a generalized ℓ_p function $v(\boldsymbol{\phi}^i)$

we have formulated yield optimization as a one-sided ℓ_1 problem (*Bandler and Chen, 1988*)

here we formulate yield optimization as a one-sided Huber problem: the objective function is defined as

$$U(\boldsymbol{\phi}^0) = \sum_{i=1}^{N} \rho_k^+(\alpha_i v(\boldsymbol{\phi}^i))$$

where

$\boldsymbol{\phi}^0$ the nominal circuit parameters

α_i a positive multiplier associated with the ith outcome

N the total number of outcomes

MOMENT METHOD

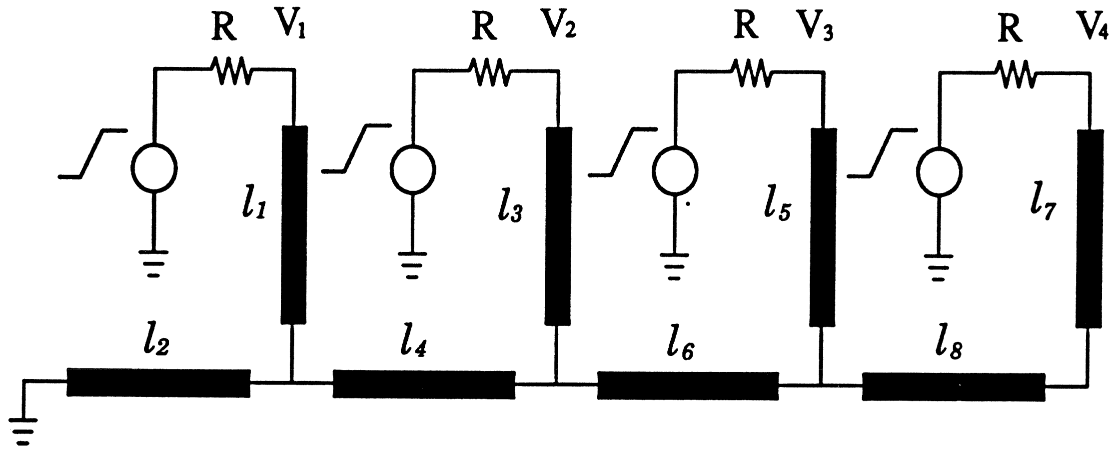
Fast statistical analysis based on statistical moments

An analytical and explicit relationship between X and y

Much fewer circuit simulations required

Useful for statistical design of high-speed circuits and systems

GROUND NOISE EXAMPLE



		Monte-Carlo	proposed method
moments of V_4	h_1	3.2291	3.2265
	h_2	10.4287	10.4121
	h_3	33.6866	33.6064
	h_4	108.8322	108.4882
mean	$\overline{y}$	3.2291	3.2265
stand. dev.	σ	4.2029e-02	4.2917e-02
test of skewness	s	0.03926	0.07593
test of kurtosis	k	3.0188	3.1085

Collaboration with Industry

Bell-Northern Research

Optimization Systems Associates

OptEM Engineering

Summary

signal integrity optimizations carried out

statistical design methods developed

fast modelling approaches for circuit optimization introduced

EM models used in simulation and optimization

results achieved through collaboration between two universities and by cooperation with industry