

**OPTIMIZATION TECHNOLOGY FOR
MICROWAVE CIRCUIT
MODELING AND DESIGN**

J.W. Bandler, R.M. Biernacki and S.H. Chen

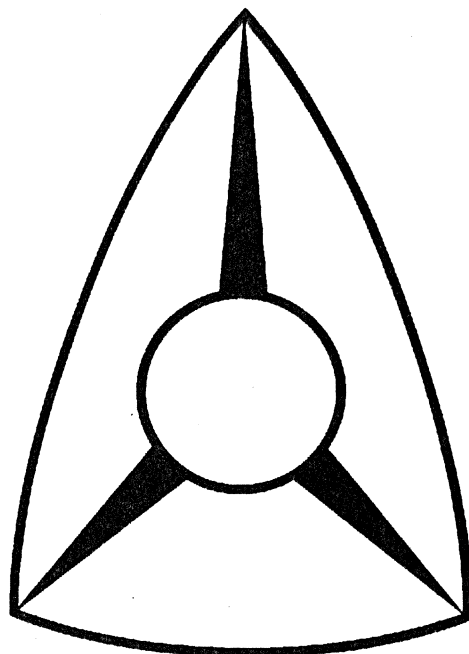
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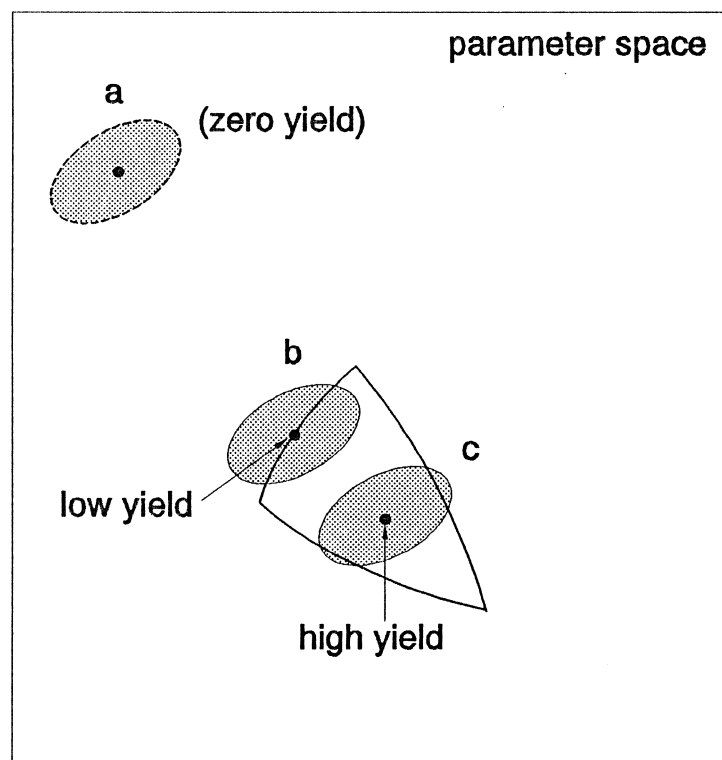
presented at

the 25th European Microwave Conference
Bologna, Italy, September 4-8, 1995



Optimization Technology for Microwave Circuit Modeling and Design

three decades of personal perspectives (1965-1995)



Yield-driven design: 25 years of research



Optimization Systems Associates Inc.

PIONEERS IN

yield and tolerance optimization

circuit performance optimization

parametric design centering

statistical device modeling

robust parameter extraction

harmonic balance simulation

physics based design

EM based design

large-scale optimization

benchmark CAD technology

software architecture for IC design



Areas of Expertise

RF/microwave circuit simulation, design and optimization

harmonic balance simulation techniques

robust and statistical modeling of active and passive devices

automated processing of DC, RF and spectrum data

device modeling, statistical estimation of production yield

powerful performance and yield optimization algorithms

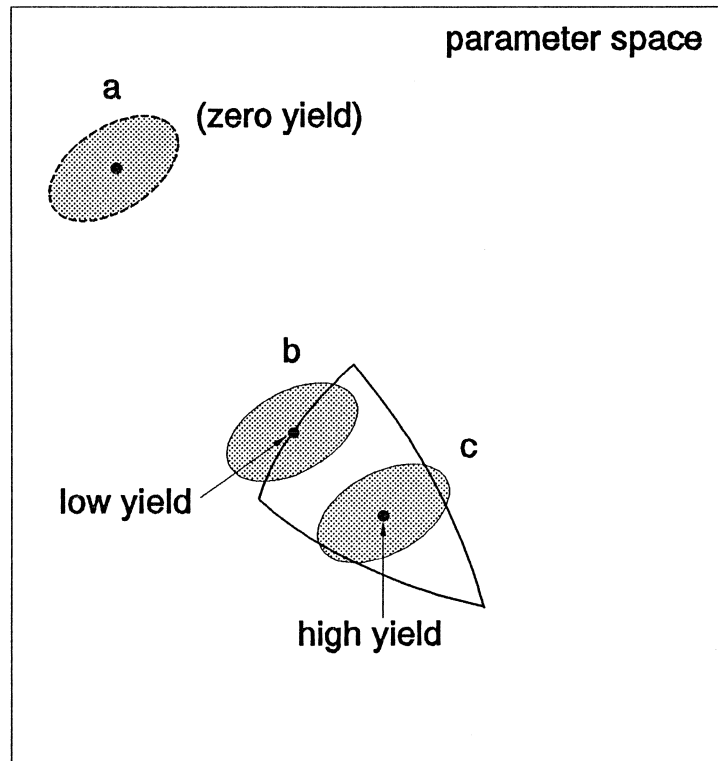
manufacturing tolerance assignment and cost minimization

customized optimizers for large-scale problems

computer optimization of linear and nonlinear networks

algorithms for automated production alignment and tuning

software architectures for integrated approach to design



Yield interpretation in the parameter space



Milestones I

computerized Smith chart plots (1966)

performance-driven optimization (1968)

optimization of waveguide circuits (1969)

adjoint sensitivities (1970)

cost-driven worst-case design with optimized tolerances
(1972)

centering, tolerance assignment integrated with tuning at the
design stage (1974)

integrated approach to microwave design with tolerances and
uncertainties (1975)

yield-driven optimization for general statistical distributions
(1976)

new results for cascaded circuits (1978)



Milestones II

optimal tuning and alignment at the production stage (1980)

fault diagnosis and parameter extraction (1980)

world's fastest multiplexer optimizer (1984)

introduction of powerful minimax optimizers into commercial CAD/CAE products (1985)

large-scale microwave optimization (1986)

foundation of multi-circuit ℓ_1 modeling (1986)

world's first yield-driven design for Super-Compact® (1987)

computational enhancements of commercial CAD/CAE products (1988)

parameter extraction using novel large-scale concepts (1988)



Milestones III

nonlinear adjoint (harmonic balance) exact sensitivities
(1988)

RoMPETM, world's first commercial product for FET
parameter extraction featuring S-parameters and/or DC data
(1988)

yield-driven design of nonlinear microwave circuits (1989)

FASTTM, novel technique for high-speed nonlinear
sensitivities (1989)

efficient large-signal FET parameter extraction using
harmonics (1989)

HarPETM, world's first commercial product for harmonic
balance driven FET parameter extraction (1989)

combined discrete/normal statistical modeling of active
devices (1989)



Milestones IV

efficient quadratic approximation for statistical design (1989)

nonlinear circuit optimization with dynamically integrated physical device models (1990)

analytically unified DC/small-signal/large-signal circuit design (1990)

OSA90TM, world's first friendly optimization engine for performance- and yield-driven design (1990)

DatapipeTM Technology, OSA90's interprocess communication system (1990)

OSA90/hopeTM, the microwave and RF harmonic optimization system (1991)

design optimization with external simulators, circuit-theoretic and field-theoretic (1991)



Milestones V

statistical modeling of GaAs MESFETs (1991)

gradient quadratic approximation for yield optimization (1991)

physics-based design and yield optimization of MMICs (1991)

Spicepipe™ connection of OSA90/hope™ with Zuberek's SPICE-PAC simulator (1992)

Empipe™ connection of OSA90/hope™ with Sonnet's *em*™ field simulator (1992)

predictable yield-driven circuit optimization (1992)

integrated physics-oriented statistical modeling, simulation and optimization (1992)

"fulfills the requirement of microwave engineers to model and simulate nonlinear active and passive systems without having a thorough knowledge of analysis, and optimization methods" - MEE 1992



Milestones VI

DatapipeTM connection of OSA90/hopeTM with Hoefer's TLM electromagnetic field simulators (1993)

DatapipeTM connection of OSA90/hopeTM with Nakhla/Zhang VLSI interconnect simulators (1993)

microstrip filter design using direct EM field simulation (1993)

yield-driven direct electromagnetic optimization (1993)

robustizing modeling and design using Huber functions (1993)

"CAD review: Non-linear CAD benchmark" by MEE (1993)

EM design of HTS microwave filters (1994)

CDF approach to statistical modeling (1994)

Space MappingTM - a fundamental new theory for design with CPU intensive simulators (1994)

"CAD review: the 7 GHz doubler circuit" by MEE (1994)

optimization of structures with arbitrary geometry (1994)



Milestones VII

breakthrough Geometry Capture™ (1995)

aggressive Space Mapping™ for EM design (1995)

cost-driven physics-based large-signal simultaneous device and circuit design (1995)

integrated harmonic balance and EM optimization (1995)

novel heterogeneous parallel yield-driven EM CAD (1995)

mixed-domain multi-simulator statistical parameter extraction and yield-driven design (1995)



Milestones VIII

full-day MTT-S workshop on Automated Circuit Design Using Electromagnetic Simulators (Arndt, Bandler, Chen, Hoefer, Jain, Jansen, Pavio, Pucel, Sorrentino, Swanson, 1995)

explosion of development and use of optimization-based technology for automated circuit design with EM simulators (1994, 1995)

Network DatapipeTM connection of OSA90/hopeTM with Hoefer's TLM electromagnetic field simulators on massively parallel computers (1995)

DatapipeTM connections of OSA90/hopeTM with Sorrentino's mode-matching electromagnetic field simulators with adjoint sensitivities (1995)

DatapipeTM connection of OSA90/hopeTM with Arndt's waveguide component library (1995)



EmpipeTM Version 3.1

powerful and friendly software system for automated EM design optimization

driving Sonnet's *em*TM field simulator

employing the sophisticated optimizers of OSA90TM

breakthrough Geometry CaptureTM allows you to designate geometrical and material parameters as variables for optimization

any arbitrary structures that can be simulated by *em*TM can be optimized using EmpipeTM

automatic off-grid interpolation integrated with intelligent database management

intuitive and extremely user-friendly

a significant step towards the required integrated approach for interprocessing circuit/field/measurement data



OSA90/hope™ Version 3.1

general nonlinear circuit simulation and optimization
analytically unified DC, small-signal and large-signal
harmonic balance analysis
statistical analysis and yield optimization
comprehensive optimization/nonlinear modeling
interconnects external simulators
Empipe™ merges *em*™, even for arbitrary geometry!
Spicepipe™ merges SPICE
Space Mapping breakthrough in EM optimization
3D visualization

HarPE™ Version 2.0

device characterization, simulation and optimization
FET, bipolar, HEMT, HBT, thermal modeling
parameter extraction
cold measurement processing
statistical modeling, Monte Carlo analysis
Huber optimization
cumulative probability distribution fitting
can be invoked from OSA90/hope™ as a child process



OSA90/hopeTM Optimization

state-of-the-art gradient-based optimizers with a proven track record in electrical circuit and system optimization

- L1
- L2 (least squares)
- Huber
- minimax
- quasi-Newton
- conjugate gradient
- simplex
- random
- simulated annealing
- yield (design centering)

exact or approximate gradient

specification and goal definition

quadratic modeling of functions and gradients

sensitivity displays help the user to select the most crucial variables for optimization

Space MappingTM for CPU intensive optimization

automated Aggressive Space MappingTM



OSA90/hopeTM Circuit Features

general nonlinear circuit simulation and optimization
physics-based yield optimization

analytically unified simulation:
DC/small-signal/large-signal harmonic balance

arbitrary topology
multitone, multisource excitations
nonlinear sources controlled by voltages and currents

symbolic subcircuit definition: linear and nonlinear
voltage and current labels (probes)

comprehensive device library
empirical microstrip models
*em*TM parameterized microstrip models
user-definable models



OSA90/hope™ Math Features

variable definition

expressions including conditional *if else* structures

extensive math library

vector and matrix operations

- multiplication

- transposition

- inverse

- LU factorization

- eigenvalues and eigenvectors

- solving linear equations

vector and matrix elements fully optimizable

Space Mapping™ functions

built-in transformations, including DFT, splines,
piecewise linear interpolation, etc.

operation control block



OSA90/hope™ Graphics

continuous, point, bar plots

parametric and multiple plots

histograms, run charts and scatter diagrams

sensitivity displays

waveforms

Smith chart and polar plots

3D visualization including scaling, rotating and smoothing

contours with trace of optimization variables

user-defined legends, colors, views

graphics zoom

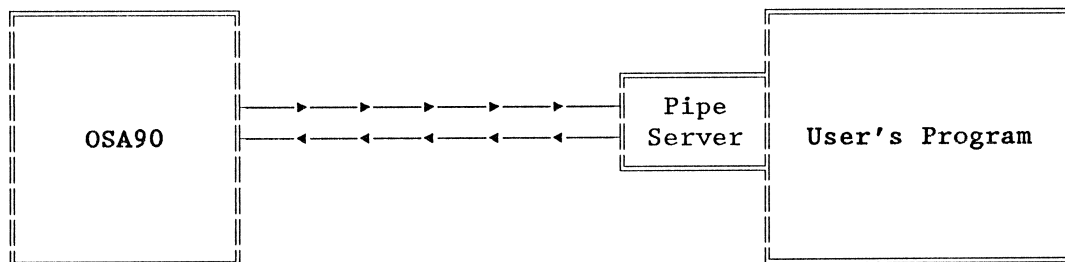
HPGL and PostScript files



OSA90/hope™ Datapipe™

Datapipe™: predefined protocols for UNIX pipes

ready-to-use to facilitate high-speed data connections to and from the user's software; over networks



typical READ and WRITE statements are used to receive and send data

a small pipe server (about 350 lines) establishes the protocols; OSA provides the source code of the pipe server

maintains complete security of user's software: OSA does not need access to the user's source code



OSA90/hope™ Connections

Empipe™ merges *em*™

from Sonnet Software, Inc.

for direct field-level optimizable microstrip designs
under circuit-level linear/nonlinear analysis

optimization of structures with arbitrary geometries

Spicepipe™ merges SPICE

for time-domain simulation, noise analysis, etc.
multidomain (frequency and time) specifications
nominal optimization
yield optimization

OSA90™ can call OSA90™

OSA90™ can call HarPE™



HarPE™ Version 2.0

characterize devices

extract parameters

- simulation-driven
- data-driven

build equivalent circuit models

build physics-based models

simulate and optimize

- single device circuits at DC, small-signal and large-signal harmonic balance

statistically model devices

estimate Monte Carlo yield

cumulative probability distribution and histogram matching

HEMT models (*M. Golio, Motorola*)

HBT thermal modeling of self-heating



Minimax Design Optimization

$$\underset{\phi}{\text{minimize}} \{ \underset{j}{\text{max}} (e_j(\phi)) \}$$

where

ϕ the vector of optimization variables

$R_j(\phi)$ $j=1,2,..$ - the circuit responses (S parameters, return loss, insertion loss, etc.)

S_{uj}, S_{lj} upper/lower specification on $R_j(\phi)$

the individual errors $e_j(\phi)$ are of the form

$$e_j(\phi) = R_j(\phi) - S_{uj}$$

or

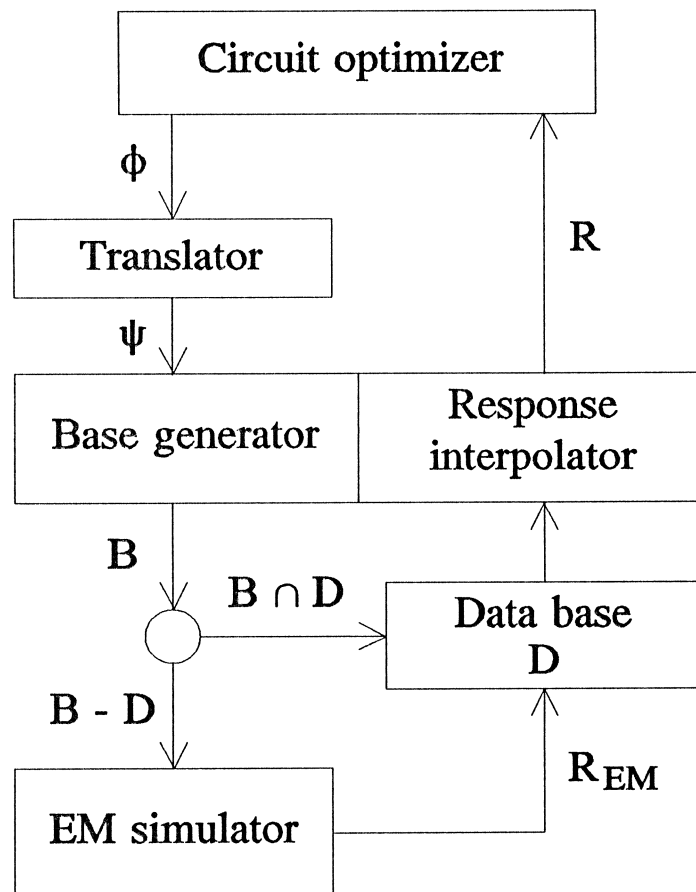
$$e_j(\phi) = S_{lj} - R_j(\phi)$$

negative/positive error value indicates that the corresponding specification is satisfied/violated

effective minimax optimization requires a dedicated optimizer and accurate gradients of individual errors w.r.t. the optimization variables ϕ

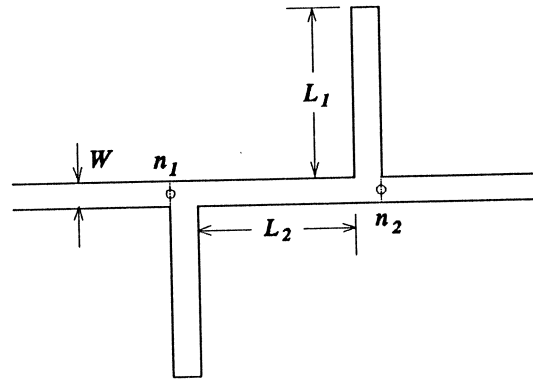


Interconnection Between a Circuit Optimizer and a Numerical EM Simulator



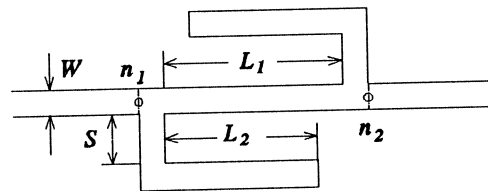


Conventional Double Stub Microstrip Structure



for band-stop filter applications

Double Folded Stub Microstrip Structure (Rautio, 1992)



substantially reduces the filter area while achieving the same goal as the conventional double stub structure

can be described by 4 parameters: width, spacing and two lengths W , S , L_1 and L_2



Design of the Double Folded Microstrip Structure

minimax optimization to move the center frequency of the stop band from 15 GHz to 13 GHz

W fixed at 4.8 mils

L_1 , L_2 and S - variables (designable parameters)

design specifications

$$|S_{21}| > -3 \text{ dB} \quad \text{for } f < 9.5 \text{ GHz and } f > 16.5 \text{ GHz}$$

$$|S_{21}| < -30 \text{ dB} \quad \text{for } 12 \text{ GHz} < f < 14 \text{ GHz}$$

substrate thickness - 5 mils

relative dielectric constant - 9.9

*em*TM driven by the minimax gradient optimizer of OSA90/hopeTM through EmpipeTM

optimization was carried out in two steps

(1) $\Delta x = \Delta y = 2.4 \text{ mils}$

(2) the grid size was reduced to $\Delta x = \Delta y = 1.6 \text{ mils}$ for fine resolution



Minimax Optimization of the Double Folded Microstrip Structure

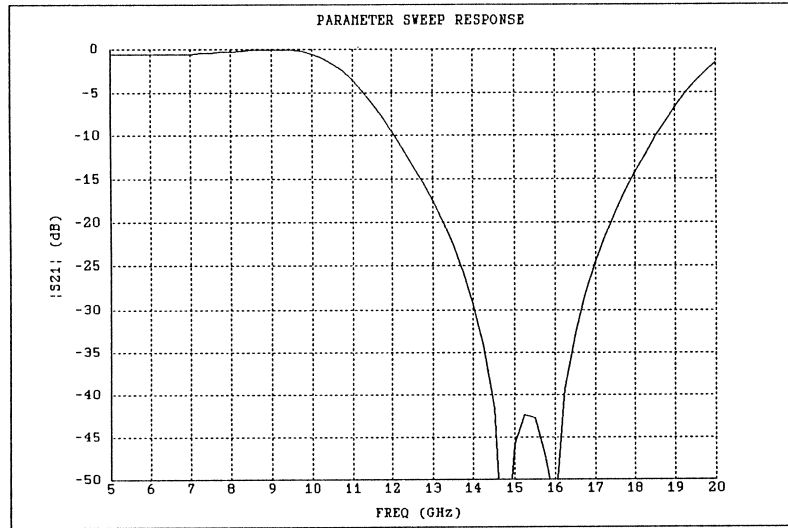
PARAMETER VALUES FOR THE DOUBLE FOLDED STUB
BEFORE AND AFTER OPTIMIZATION

Parameter	Before optimization (mils)	After optimization (mils)
L_1	74.0	91.82
L_2	62.0	84.71
S	13.0	4.80

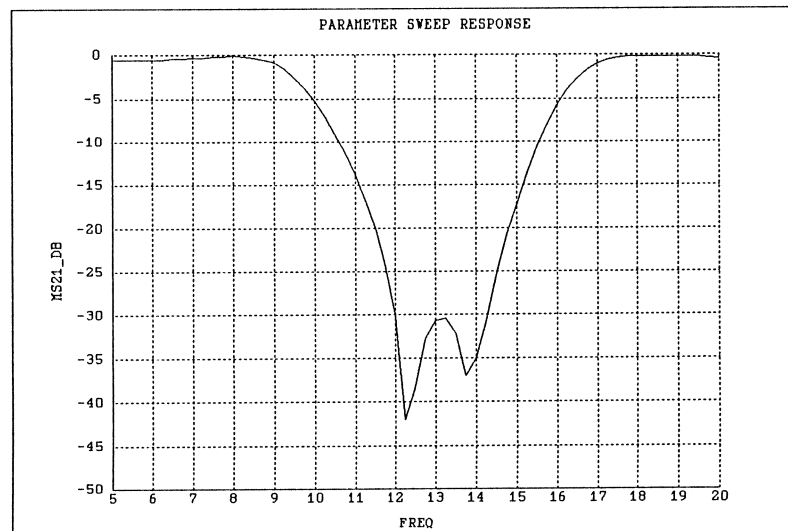


Results for the Double Folded Microstrip Structure

Before Optimization

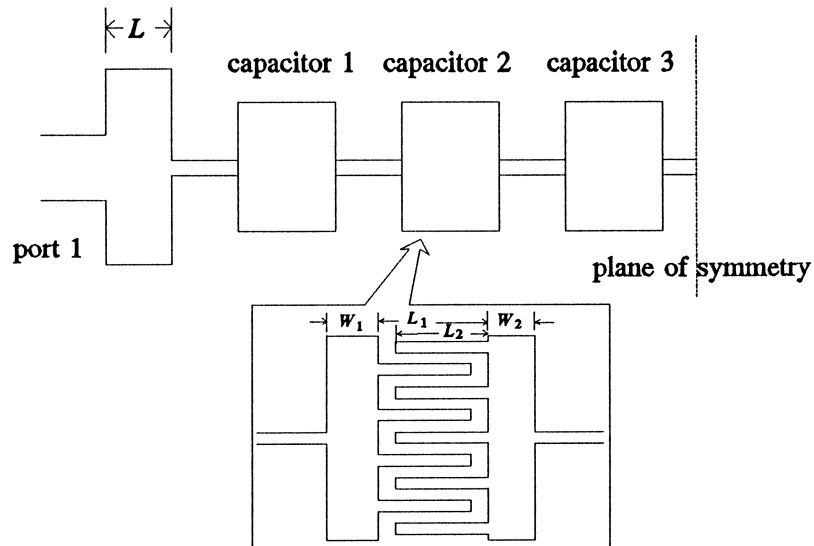


After Optimization





26-40 GHz Interdigital Microstrip Bandpass Filter



utilizes thin microstrip lines and interdigital capacitors to realize inductances and capacitances of a synthesized lumped ladder circuit

the original microstrip design was determined by matching the lumped prototype at the center frequency using *em*TM

when the filter was simulated by *em*TM in the whole frequency range the results exhibited significant discrepancies w.r.t. the prototype

it necessitated manual adjustment and made a satisfactory design very difficult to achieve



Design of the 26-40 GHz Interdigital Microstrip Filter

a total of 13 designable parameters including the distance between the patches L_1 , the finger length L_2 and two patch widths W_1 and W_2 for each of the three interdigital capacitors, and the length L of the end capacitor

the second half of the circuit, to the right of the plane of symmetry, is assumed identical to the first half, so it contains no additional variables

the transmission lines between the capacitors were fixed at the originally designed values

design specifications

$$|S_{11}| < -20 \text{ dB} \quad \text{and} \quad |S_{21}| > -0.04 \text{ dB}$$

$$\text{for } 26 \text{ GHz} < f < 40 \text{ GHz}$$

substrate thickness - 10 mils

dielectric constant - 2.25

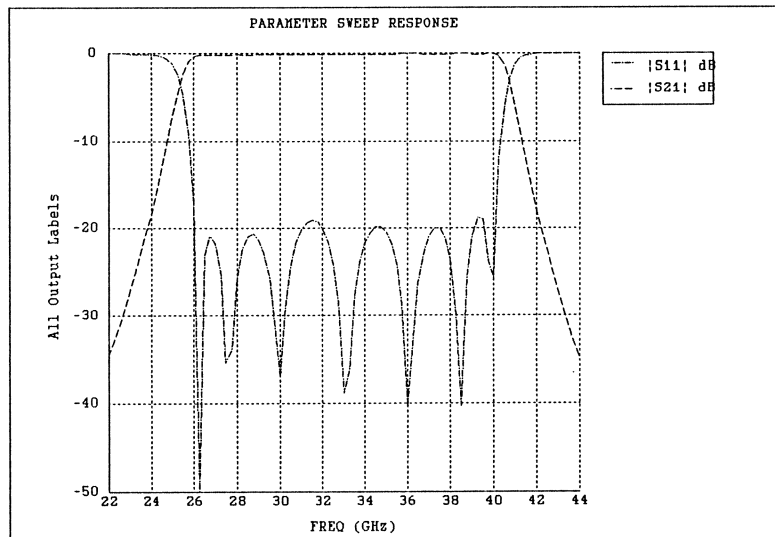
shielding height - 120 mils

*em*TM driven by the minimax gradient optimizer of OSA90/hopeTM through EmpipeTM



Simulation of the 26-40 GHz Interdigital Capacitor Filter After Optimization

filter response after optimization



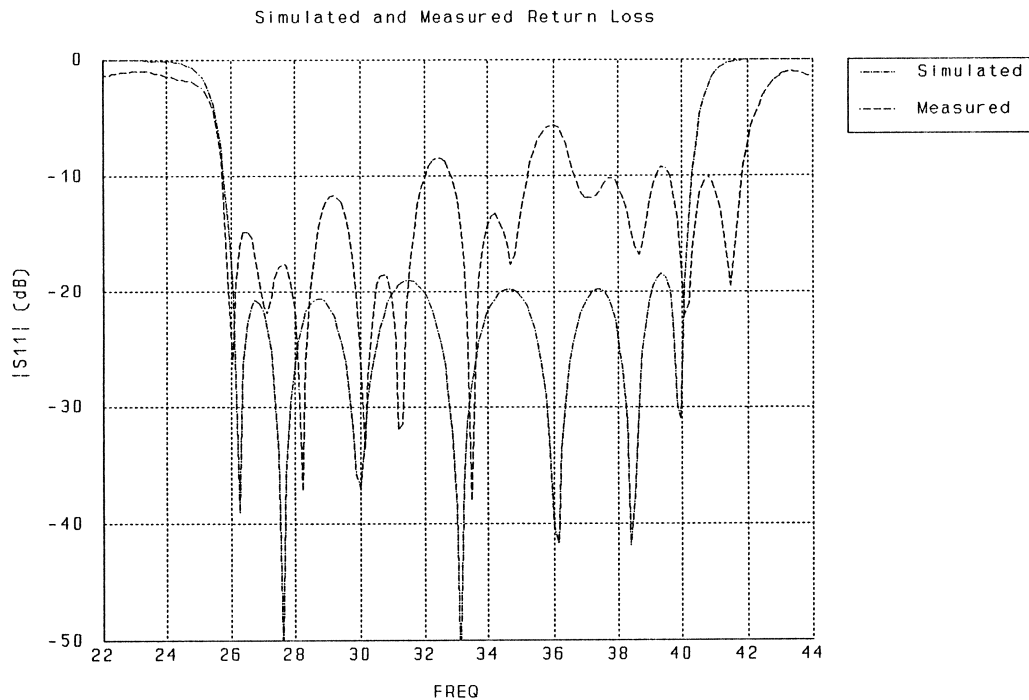
a typical minimax equal-ripple response of the filter was achieved after a series of consecutive optimizations with different subsets of optimization variables and frequency points

the resulting geometrical dimensions were finally rounded to 0.1 mil resolution



Measurements of the 26-40 GHz Interdigital Capacitor Filter - Return Loss After Optimization

measured and simulated $|S_{11}|$ of the filter after manufacturing

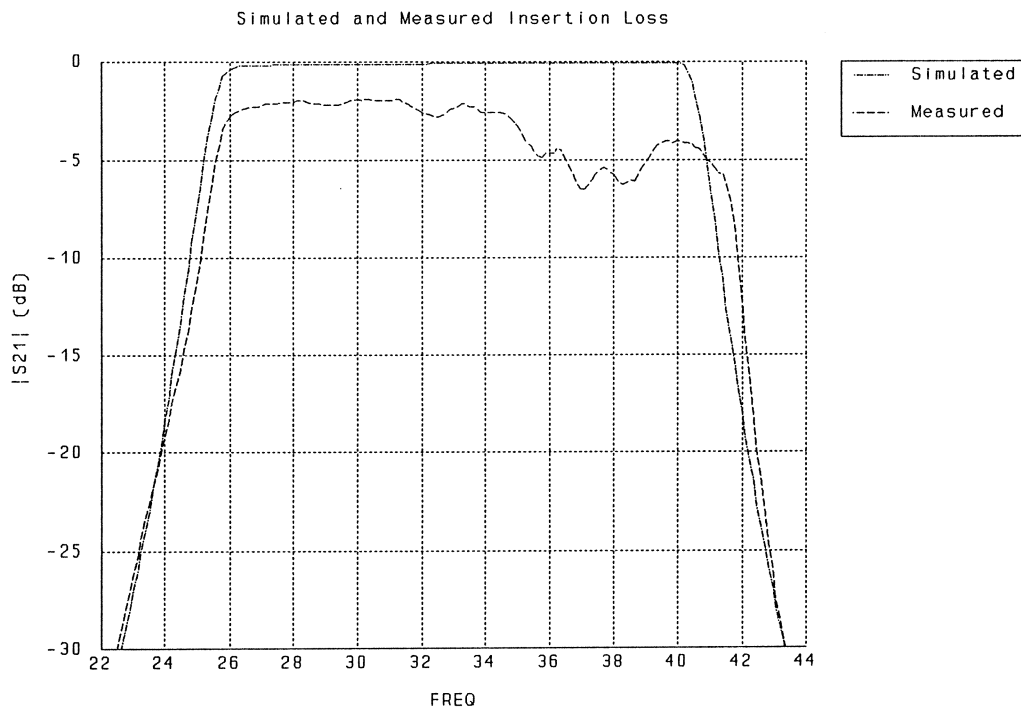


recent improvements in the field solver analysis of interdigital capacitors will improve the accuracy of the bandwidth prediction



Measurements of the 26-40 GHz Interdigital Capacitor Filter - Insertion Loss After Optimization

measured and simulated $|S_{21}|$ of the filter after manufacturing



the insertion loss flatness will clearly improve after return loss has been tuned



Yield Optimization

the problem of yield optimization can be formulated as

$$\underset{\phi^0}{\text{maximize}} \{ Y(\phi^0) = \int_{R^n} I_a(\phi) f_{\phi}(\phi^0, \phi) d\phi \}$$

where

ϕ^0 nominal circuit parameters

ϕ actual circuit outcome parameters

$Y(\phi^0)$ design yield

$f_{\phi}(\phi^0, \phi)$ probability density function of ϕ around ϕ^0

$$I_a(\phi) = \begin{cases} 1 & \text{if } \phi \in A \\ 0 & \text{if } \phi \notin A \end{cases}$$

A acceptability region

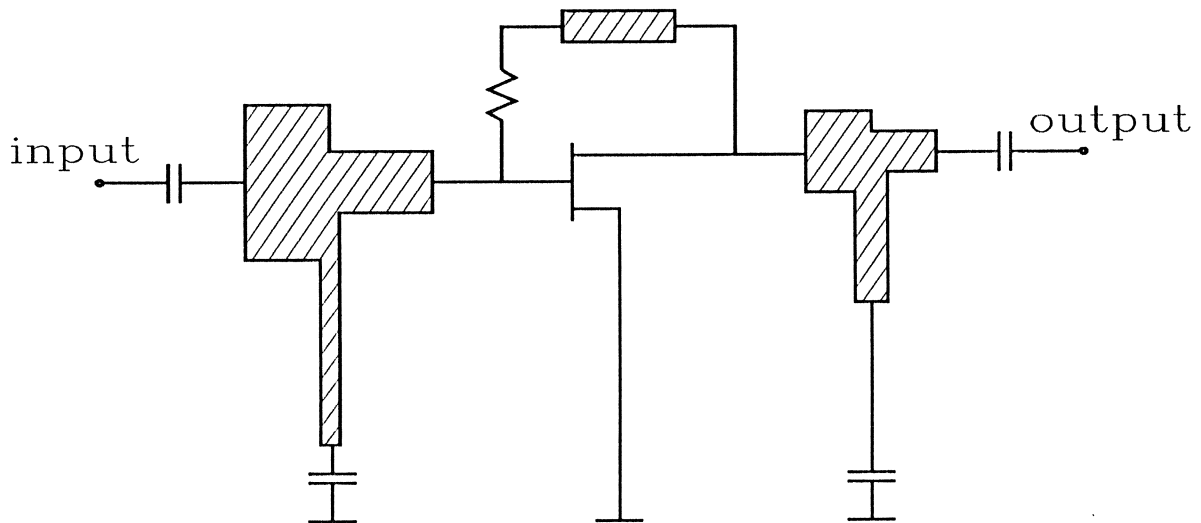
in practice, the integral is approximated using K Monte Carlo circuit outcomes ϕ^i and yield is estimated by

$$Y(\phi^0) \approx \frac{1}{K} \left(\sum_{i=1}^K I_a(\phi^i) \right)$$

the outcomes ϕ^i are generated by a random number generator according to $f_{\phi}(\phi^0, \phi)$



Optimization of a Small-Signal Amplifier



the specifications for yield optimization of the amplifier are

$$7 \text{ dB} \leq |S_{21}| \leq 8 \text{ dB} \quad \text{for} \quad 6 \text{ GHz} < f < 18 \text{ GHz}$$

the gate and drain circuit microstrip T-junctions and the feedback microstrip line are built on a 10 mil thick substrate with relative dielectric constant 9.9

the microstrip components of the amplifier are simulated using component level Q-models built from EM simulations

we used *em*TM from *Sonnet Software* for EM simulations

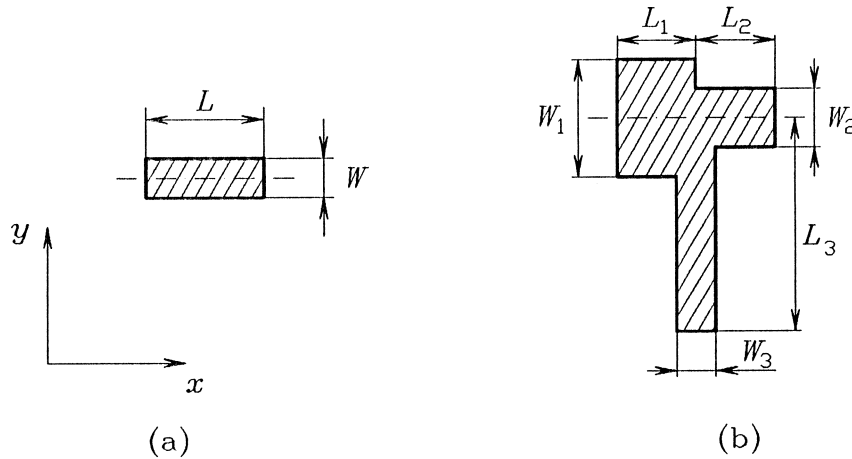


Optimization Variables

$W_{g1}, L_{g1}, W_{g2}, L_{g2}$ of the gate circuit T-junction and $W_{d1}, L_{d1}, W_{d2}, L_{d2}$ of the drain circuit T-junction are the optimization variables

W_{g3}, L_{g3}, W_{d3} and L_{d3} of the T-junctions, W and L of the feedback microstrip line, as well as the FET parameters are not optimized

parameters of the microstrip line (a) and the T-junctions (b)



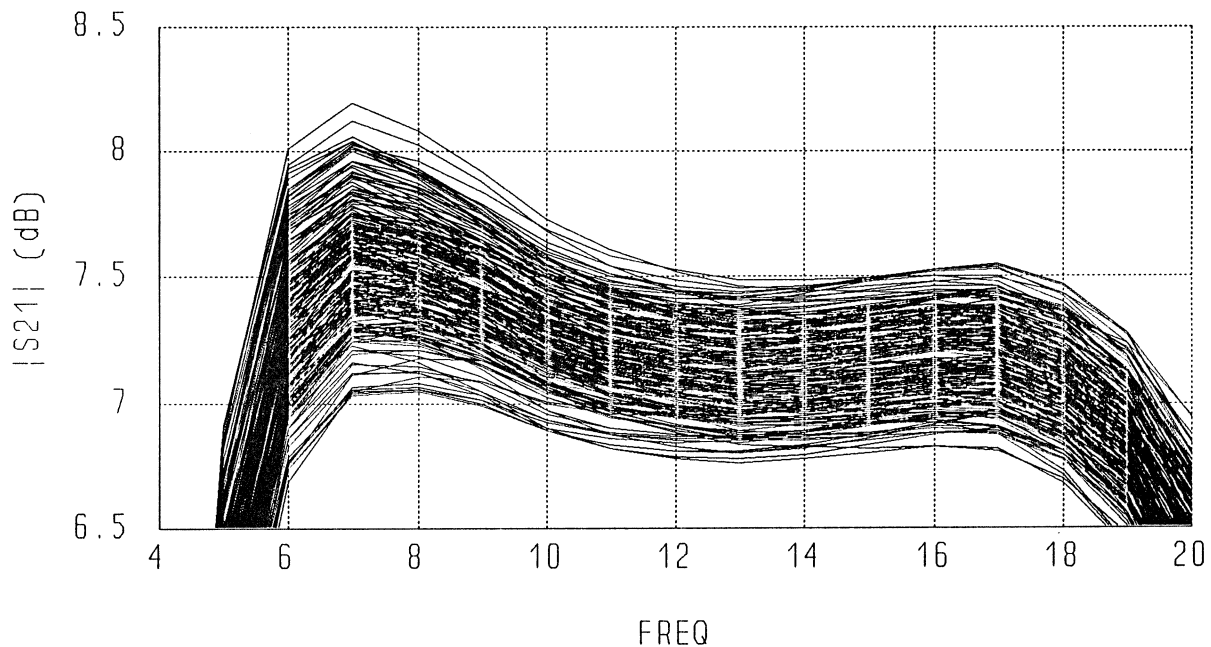
we assumed 0.5 mil tolerance and uniform distribution for all geometrical parameters of the microstrip components

the statistics of the small-signal FET model were extracted from measurement data



Small-Signal Amplifier Yield Before Optimization

the starting point for yield optimization was obtained by nominal minimax optimization using analytical/empirical microstrip component models



Monte Carlo simulation

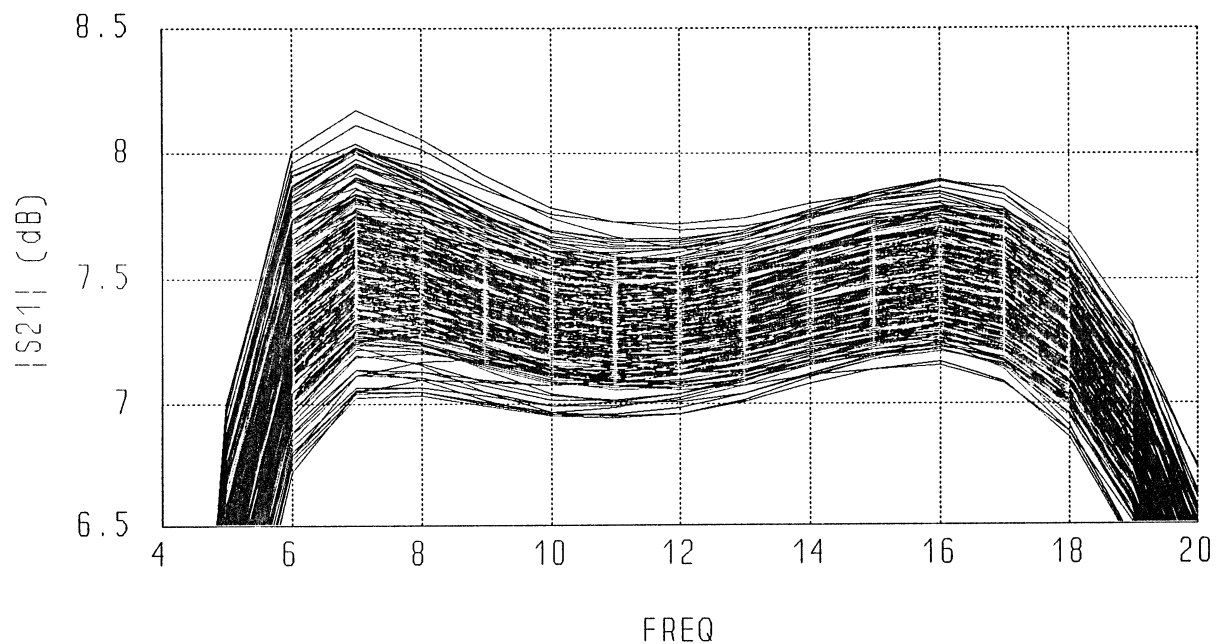
250 outcomes

55% yield



Small-Signal Amplifier Yield After Optimization

the component level Q-models were used in yield optimization



yield estimated by 250 Monte Carlo simulations increased to 82%

optimization was performed by OSA90/hopeTM with EmpipeTM driving *em*TM



Optimization Results

MICROSTRIP PARAMETERS OF THE AMPLIFIER

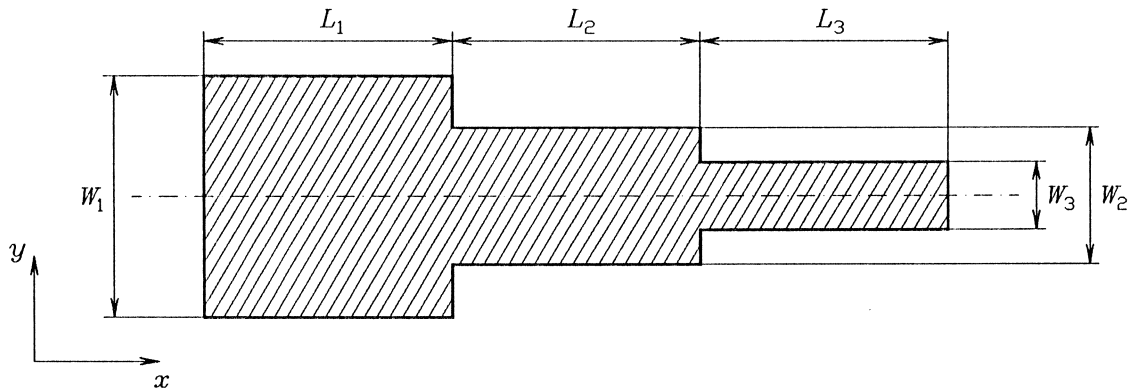
Parameters	Nominal design	Centered design
W_{g1}	17.45	19.0
L_{g1}	35.54	34.53
W_{g2}	9.01	8.611
L_{g2}	30.97	32.0
W_{g3}	3.0*	3.0*
L_{g3}	107.0*	107.0*
W_{d1}	8.562	7.0
L_{d1}	4.668	6.0
W_{d2}	3.926	3.628
L_{d2}	9.902	11.0
W_{d3}	3.5*	3.5*
L_{d3}	50.0*	50.0*
W	2.0*	2.0*
L	10.0*	10.0*
Yield (250 outcomes)	55%	82%

* Parameters not optimized.

Dimensions of the parameters are in mils. 50 outcomes were used for yield optimization. 0.5 mil tolerance and uniform distribution were assumed for all the parameters.



Three-Section 3:1 Microstrip Impedance Transformer



designed on a 0.635 mm thick substrate with relative dielectric constant of 9.7

the source and load impedances are 50 and 150 ohms

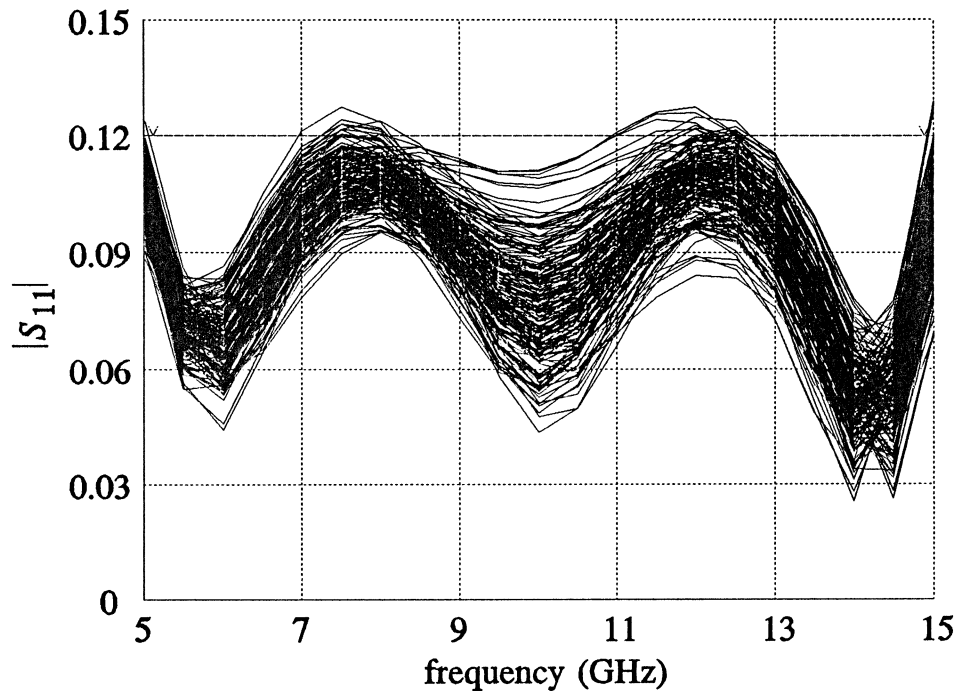
design specification set for the input reflection coefficient

$$|S_{11}| \leq 0.12, \text{ from 5 GHz to 15 GHz}$$

normal distributions with 2% standard deviations assumed for W_1 , W_2 and W_3 and 1% standard deviations assumed for L_1 , L_2 and L_3



Three-Section Microstrip Transformer After Yield Optimization



modulus of the reflection coefficient vs. frequency

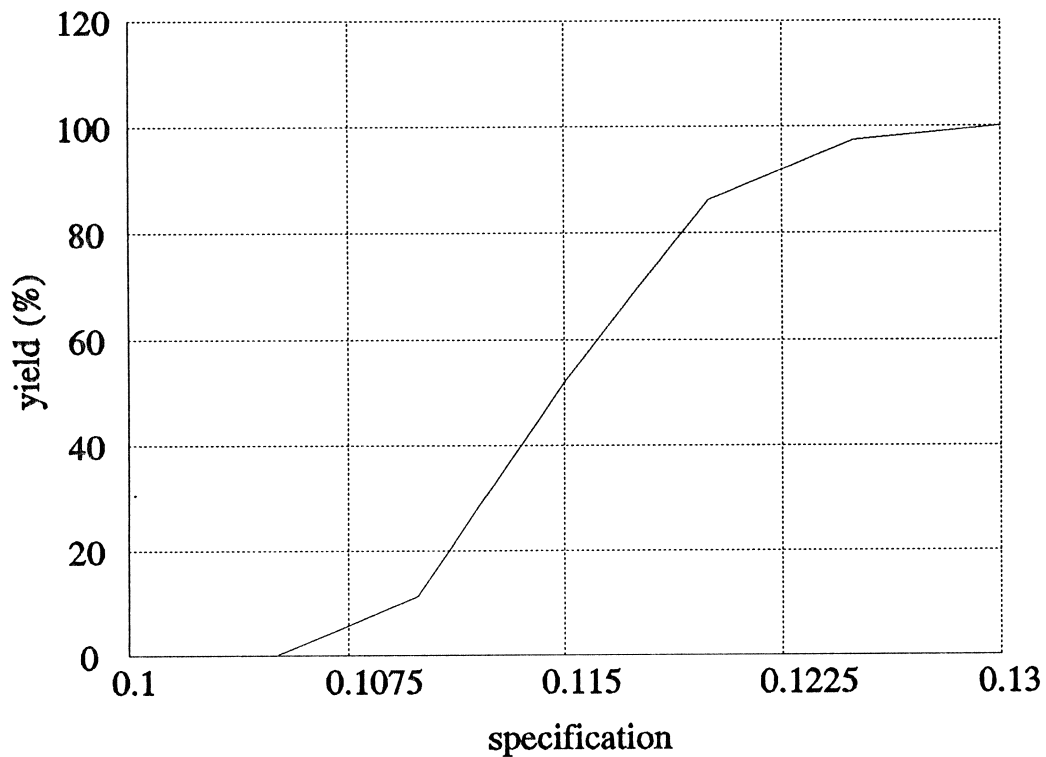
optimization using single-level (component) Q-models

100 statistical outcomes used for yield optimization

yield is increased to 86%



Yield Sensitivity of the Microstrip Transformer



yield vs. specification on $|S_{11}|$

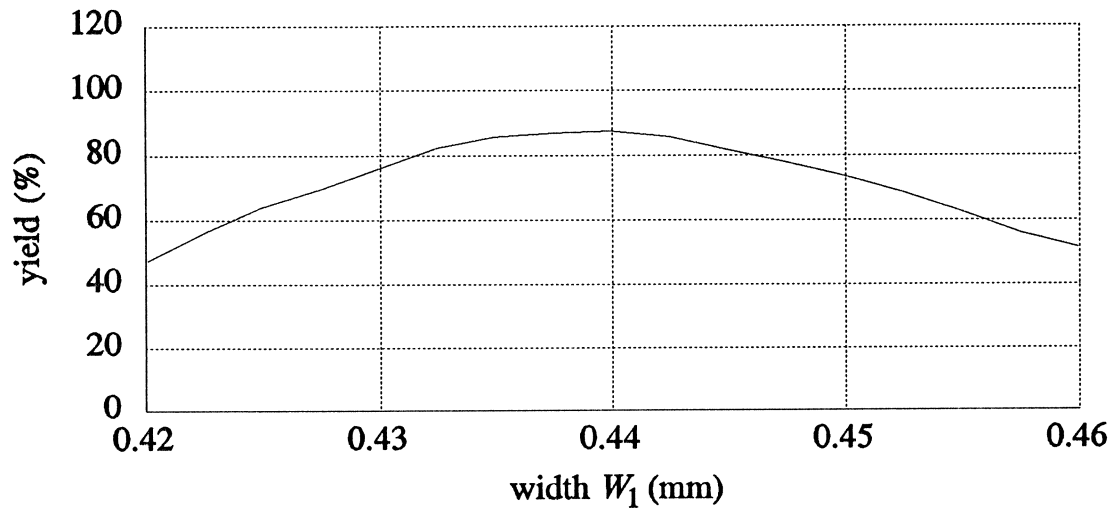
high sensitivity of yield w.r.t. the specification

yield varies from 0% to 100% over a very small range of the specification

yield estimated with 250 Monte Carlo outcomes



Yield Sensitivity of the Microstrip Transformer



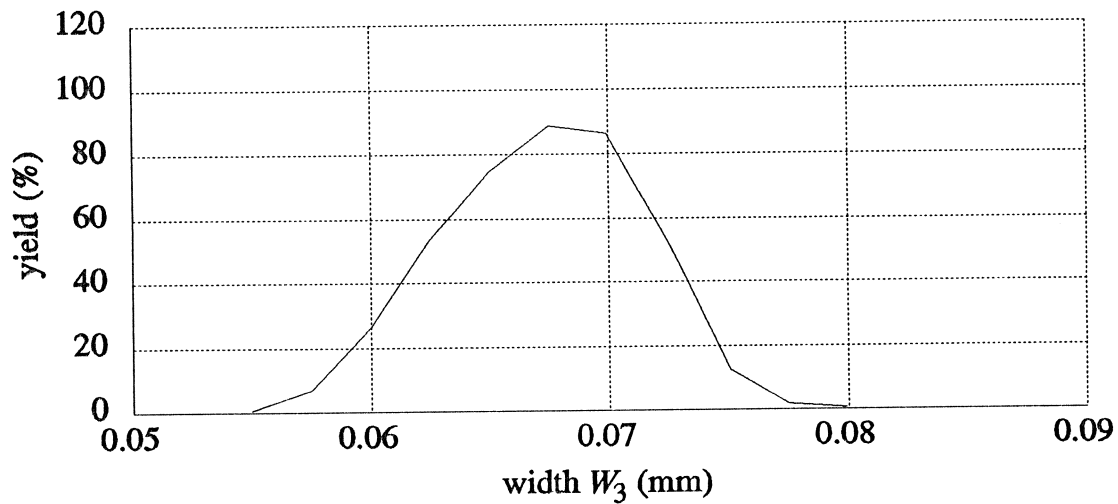
yield vs. W_1

relatively high sensitivity of yield w.r.t. W_1

yield estimated with 250 Monte Carlo outcomes



Yield Sensitivity of the Microstrip Transformer



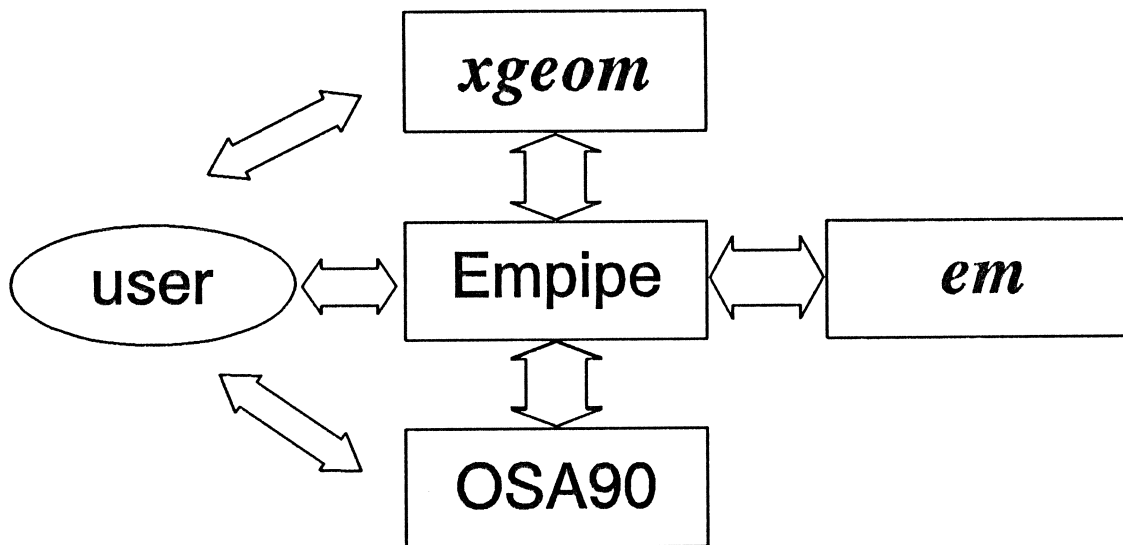
yield vs. W_3

high sensitivity of yield w.r.t. W_3

yield estimated with 250 Monte Carlo outcomes



Data Flow in Empipe™ Version 3.1





**Parameterized (Optimizable)
Microstrip Library of Empipe™**

bend
cross junction
coupled line filter
double patch capacitors
interdigital capacitors
microstrip line
mitered bend
open stub
overlay double patch capacitors
rectangular structure
spiral inductors
step junction
symmetrical and asymmetrical folded double stubs
symmetrical and asymmetrical gaps
symmetrical and asymmetrical double stubs
T junction



Electromagnetic Design of HTS Microwave Filters

available low-loss and narrow-bandwidth (0.5 - 3 %) filter banks are of very large size which in some satellite and airborne applications is intolerable

small conventional microstrip filters are too lossy for narrow-band applications

low-loss, narrow-bandwidth microstrip filters can be made using HTS technology with relatively inexpensive cooling

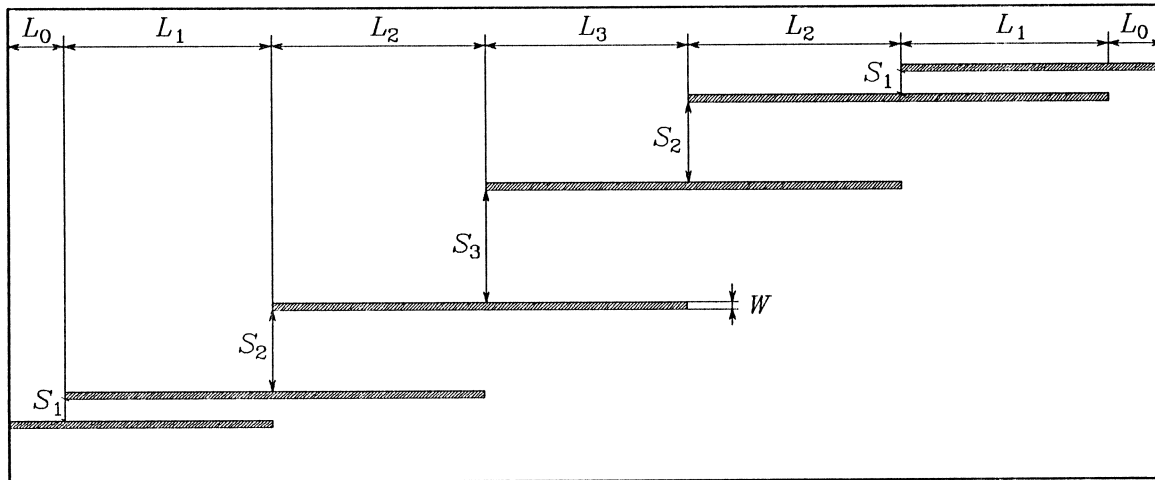
the dielectric constant of substrate materials used in HTS technology is too large to be accurately treated by traditional microwave circuit design software packages with analytical/empirical models

we employ electromagnetic field simulation which can provide results in good agreement with experimental data

high sensitivity requires a very fine grid in numerical EM simulations



The HTS Quarter-Wave Parallel Coupled-Line Filter



20 mil thick lanthanum aluminate substrate

the dielectric constant is 23.4

the x and y grid sizes for *em* simulations are 1.0 and 1.75 mil

100 elapsed minutes are needed for *em* analysis at a single frequency on a Sun SPARCstation 10



Design Specifications for the HTS Filter

$$|S_{21}| < 0.05 \quad \text{for } f < 3.967 \text{ GHz and } f > 4.099 \text{ GHz}$$

$$|S_{21}| > 0.95 \quad \text{for } 4.008 \text{ GHz} < f < 4.058 \text{ GHz}$$

narrow 1.2 % bandwidth

the lengths of the line sections: L_1 , L_2 and L_3 and the gaps between the sections: S_1 , S_2 and S_3 are the design parameters

the line width W is the same for all sections and is kept fixed

the length of the input and output lines L_0 is kept fixed

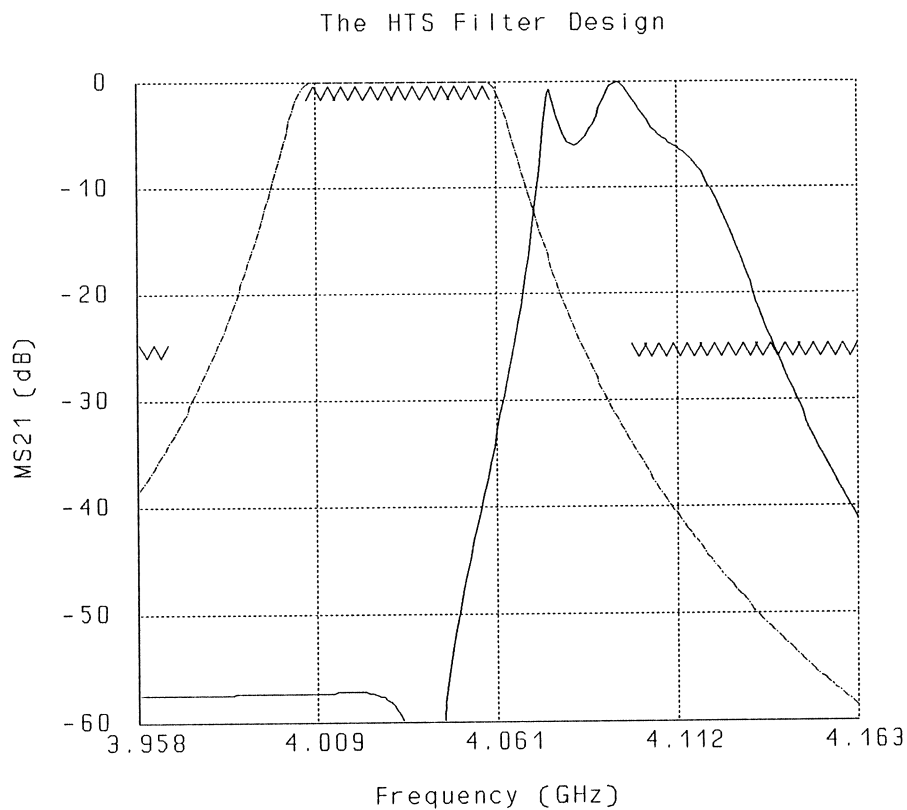
design carried out in cooperation with Westinghouse Science and Technology Center



Filter Design Using Traditional Simulators

we tested two commercial microwave CAD packages:
OSA90/hope and Touchstone

Touchstone Results:



em simulation results differ significantly from Touchstone results and do not satisfy the specifications



The Space MappingTM Technique

particularly attractive for designs involving CPU intensive simulators

it substantially decreases the number of necessary exact (EM) simulations

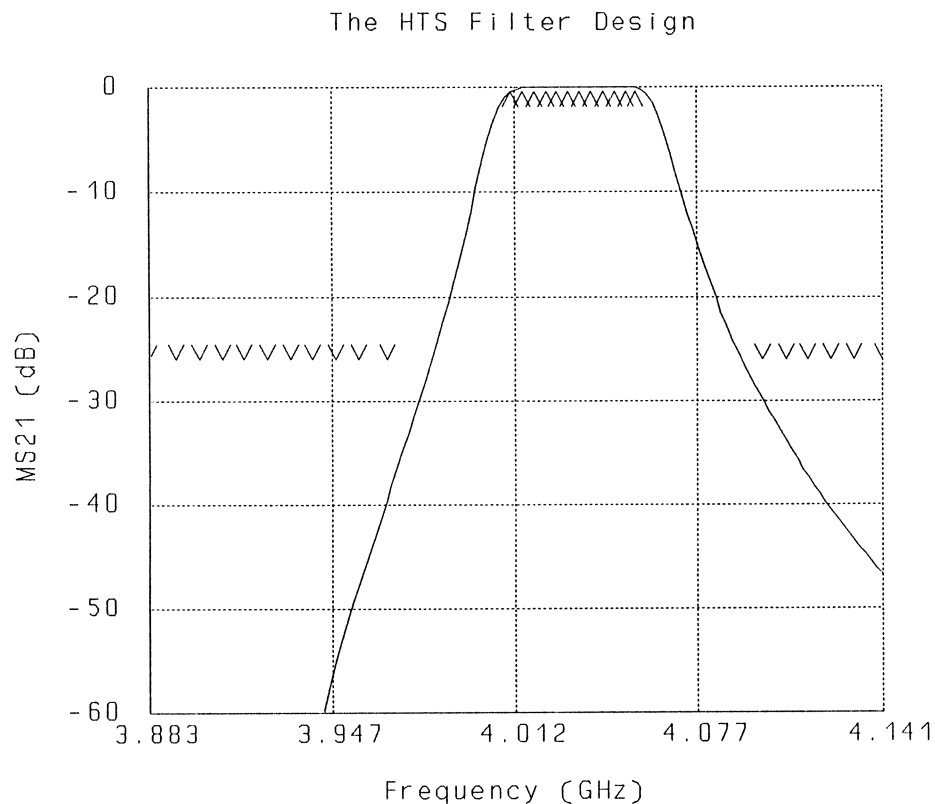
we create and iteratively refine a mapping from the EM simulator input space onto the parameter space of the model used by the optimizer

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



HTS Filter Design Using Space Mapping Optimization



em interfaced to OSA90/hope through Empipe

all the processing needed to establish the mapping was performed within the OSA90/hope environment

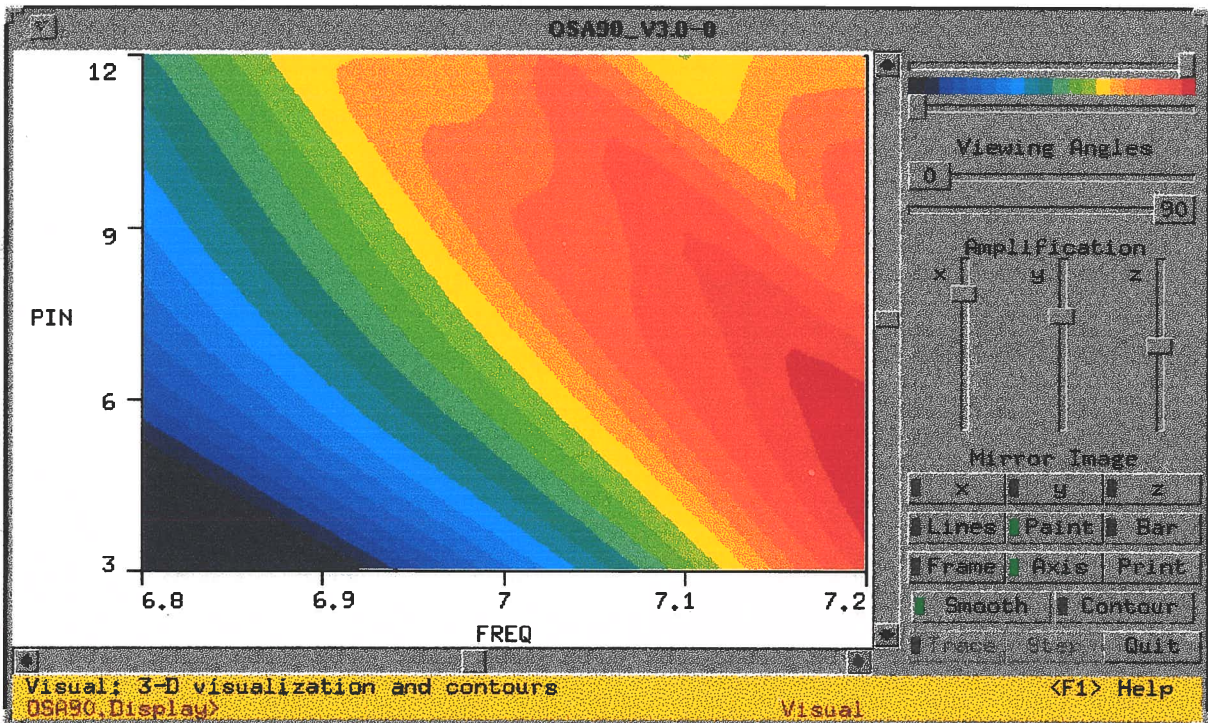
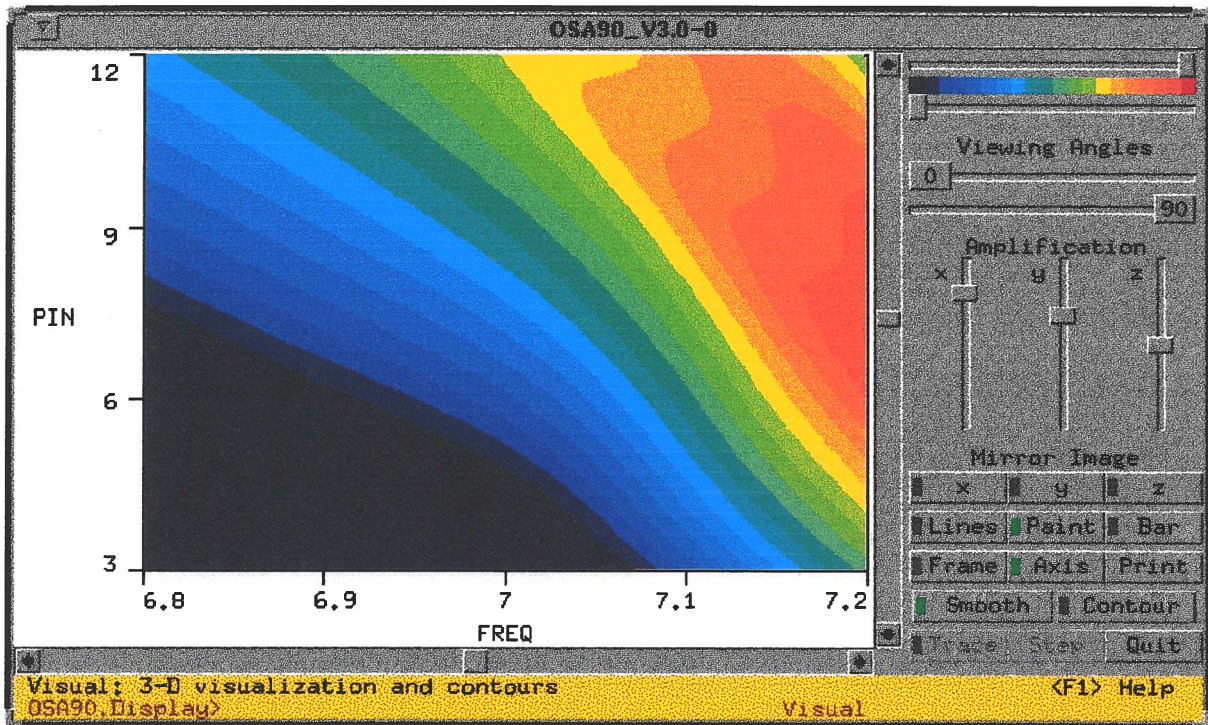
a total of 13 *em* simulations was sufficient to establish the mapping

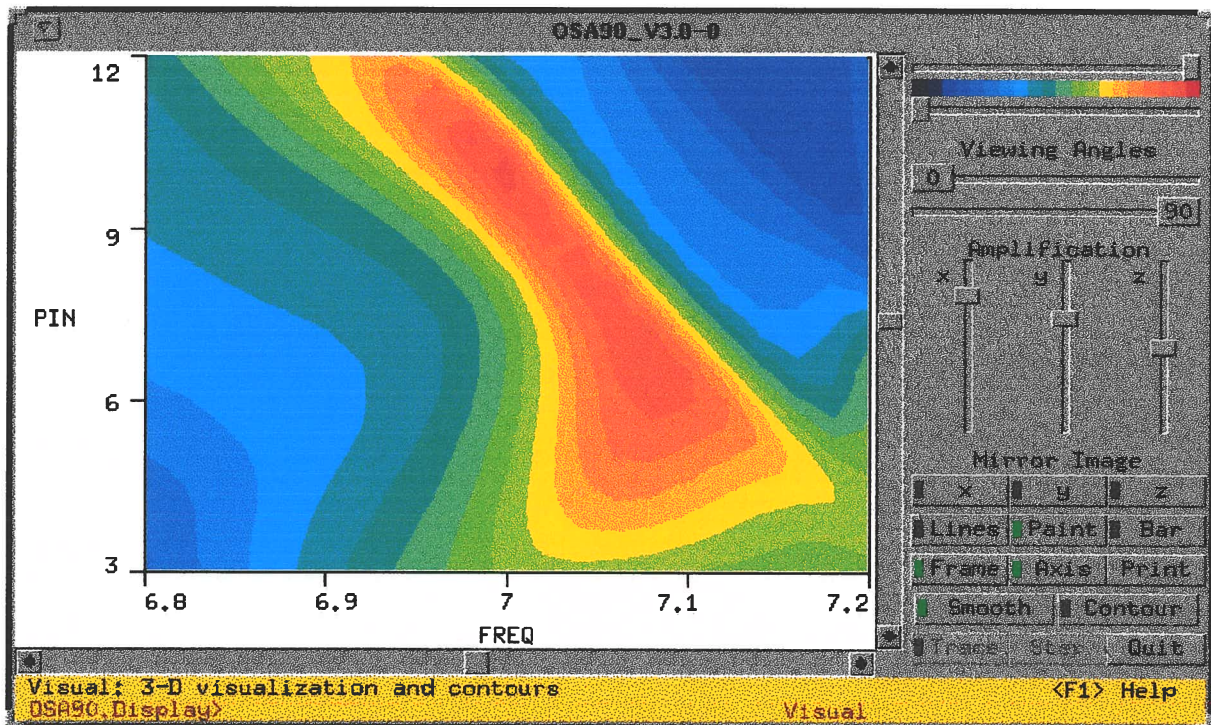
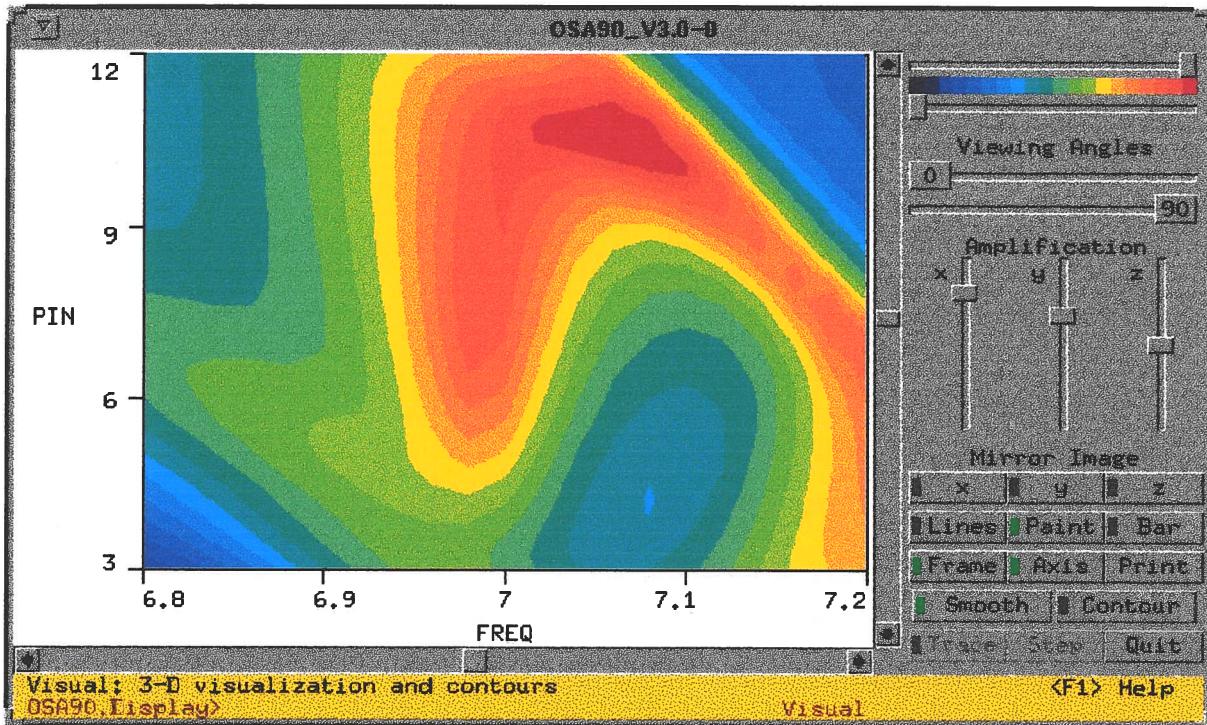
$|S_{21}|$ at the solution well exceeds the design specifications



Selected Users of OSA Technology

Alcatel	AMTEL
Alenia	BNR
British Telecom	ComDev
Compact Software	COMSAT
CRC	Daimler Benz
EEsof	French Telecom
GE	Hughes
IMST	M/A-COM
MIT Lincoln Labs	NAWC
Raytheon	Rockwell
Schrack Aerospace	Siemens
Telettra	TRW
Watkins-Johnson	







Optimization Systems Associates Inc.

J. W. Bandler, President

Empipe™

EXECUTIVE SUMMARY

Empipe™ is the only design optimization system for components and subcircuits simulated by the electromagnetic simulator *em*™ from Sonnet Software, Inc. Empipe provides RF and microwave designers with a powerful tool for direct optimization-driven field simulations. Empipe includes a comprehensive library of *em*-ready components, fully parameterized and ready for optimization. Empipe's unique capabilities are particularly powerful due to OSA's *exclusive* Geometry Capture technique which lets the user optimize any structure of *arbitrary* geometry that can be simulated using *em*. By automatically adjusting the structure the optimizer finds the best solution for design specifications. Discretization requirements of *em* are internally handled by the Empipe interpolator. Empipe's capabilities can be fully exploited in circuit-level design if it is acquired together with OSA90/hope™ CAD system from OSA. In such cases both systems are seamlessly integrated and allow the user to perform, for example, large-signal harmonic balance analysis of a nonlinear circuit with active devices and the overall circuit simulated by OSA90/hope and with passive components or subcircuits simulated by *em*. Such a circuit can then be optimized in its entirety by adjusting designable parameters, including geometrical dimensions of those passive components.



Optimization Systems Associates Inc.

J. W. Bandler, President

OSA90/hope™

EXECUTIVE SUMMARY

OSA90/hope™ is a state-of-the-art general purpose RF/Microwave CAD software system offering simulation, modeling, statistical analysis, and nominal and yield optimization for linear and nonlinear analog circuits. Derived from decades of archival research and continually enhanced, OSA90/hope features many techniques and algorithms unchallenged by other vendors. This comprises powerful and robust gradient-based optimizers: ℓ_1 , ℓ_2 , Huber, minimax, quasi-Newton, conjugate gradient, as well as non-gradient simplex and random optimizers including simulated annealing. Built-in simulators handle DC, small-signal AC, large-signal harmonic balance and two-tone spectral analyses. OSA90/hope is equipped with several Datapipe protocols ready to attach external programs for high-speed data connections, even across networks. Available built-in responses include DC and AC voltages, currents and output powers at all external ports, voltages at designated nodes and currents in designated branches. Small-signal analysis produces S , Y and Z parameters, and group delay. Using expressions the user can create his/her own responses for graphical or numerical output, and for optimization. OSA90/hope contains a comprehensive library of linear and nonlinear models, including discontinuities. OSA90/hope is well complemented by the Empipe™ and HarPE™ CAD software systems from OSA.



Optimization Systems Associates Inc.

J. W. Bandler, President

HarPE™

EXECUTIVE SUMMARY

Introduced in 1989, HarPE™ was the first parameter extraction software for active device modeling from harmonic measurement data. It offers complete linear and nonlinear device characterization including statistical modeling. HarPE provides the user with small- and large-signal simulation and design optimization for single device circuits. The built-in nonlinear models include MESFETs: Curtice (both symmetrical and asymmetrical), Statz, Materka and Kacprzak, Khatibzadeh and Trew, KTL (Trew/Ladbroke); four HEMT models (Golio, Motorola); the Gummel and Poon bipolar transistor; an HBT model; semiconductor diode; and user-defined models. HarPE can extract parameters from any combination of large-signal measurements, small-signal S parameters taken over a number of bias conditions, and DC data. HarPE models are fully compatible with those in OSA90/hope™ (the general purpose RF/Microwave CAD system from OSA). Using model parameters extracted by HarPE from measurements the user can enhance the accuracy of simulations performed by OSA90/hope. This can be achieved without leaving OSA90/hope's environment since HarPE can be invoked from within OSA90/hope as a child process via a Datapipe connection.