EM BASED MICROWAVE CAE

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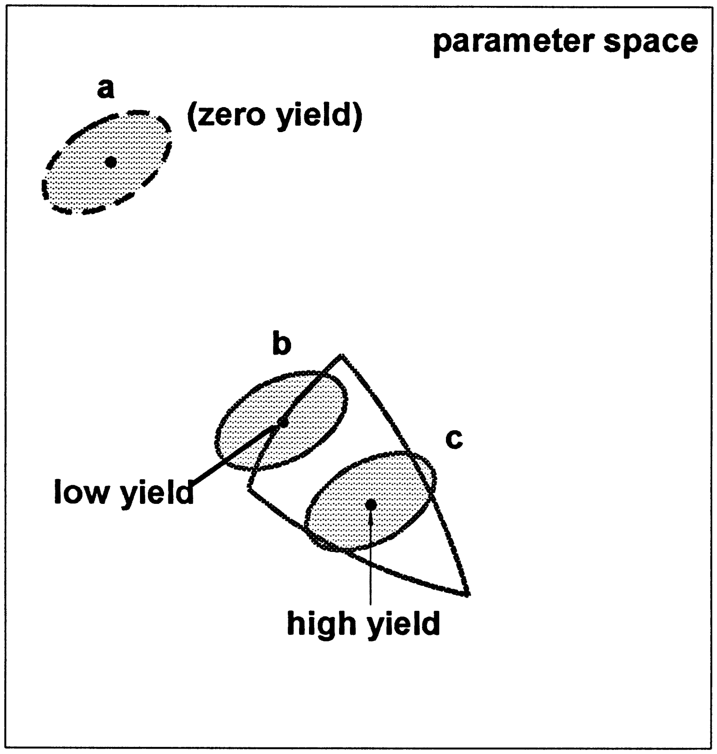


Yield interpretation in the parameter space

OSA Milestones

Optimization Systems Associates founded (1983)

introduction of powerful minimax optimizers into commercial CAD/CAE products such as EEsof's Touchstone (1985)

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

enhancements to commercial CAD/CAE products including Compact Software's Microwave Harmonica™ (1988)

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

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

OSA90™, world's first friendly optimization engine for performance- and yield-driven design (1990)

Datapipe™ Technology, OSA90's interprocess communication system (1990)

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

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

OSA Milestones (cont'd)

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

breakthrough Geometry Capture™ technique (1995)

aggressive Space Mapping™ for EM design (1995)

integrated harmonic balance and EM optimization (1995)

Datapipe™ connection of OSA90/hope™ with Arndt's waveguide component library (1995)

Empipe3D™ connection of OSA90/hope™ with Hewlett-Packard's HFSS and Ansoft's Maxwell® Eminence 3D full-wave simulators (1996)

EmpipeExpress™ and ***empath***™ connections to Sonnet Software's ***em***™ field simulator (1996)

Space Mapping™ optimization with finite element (FEM) and mode matching (MM) EM simulators (1997)

OSA90/hope™, Empipe™ and Empipe3D™ PC products for Microsoft Windows NT® and Windows 95® (1997)

HarPE™ Version 2.0

device characterization, simulation and optimization

FET, bipolar, HEMT, HBT, thermal modeling

parameter extraction, statistical modeling

cold and hot measurements

Huber optimization, Monte Carlo analysis

can be invoked from OSA90™ as a child process

OSA90/hope™
Version 4.0

general nonlinear circuit
simulation and optimization

comprehensive nonlinear
modeling, statistical analysis,
and design

automated Space Mapping
optimization

3D visualization
global optimization

Datapipe connections to user's
in-house simulators

Empipe™ Version 4.0

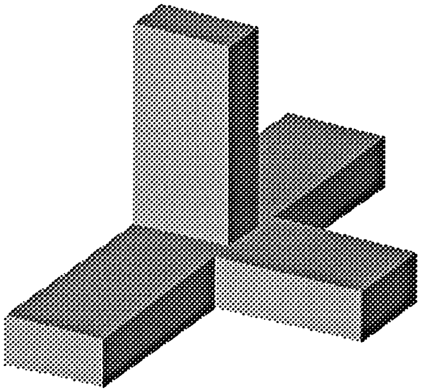
merges OSA90™ and Sonnet's *em*™ for direct EM optimization

captures and optimizes arbitrary geometries

integrates EM analysis into circuit-level optimization

maintains database of all EM simulation results

intelligent and efficient *S, Y or Z* response interpolation



Empipe3D

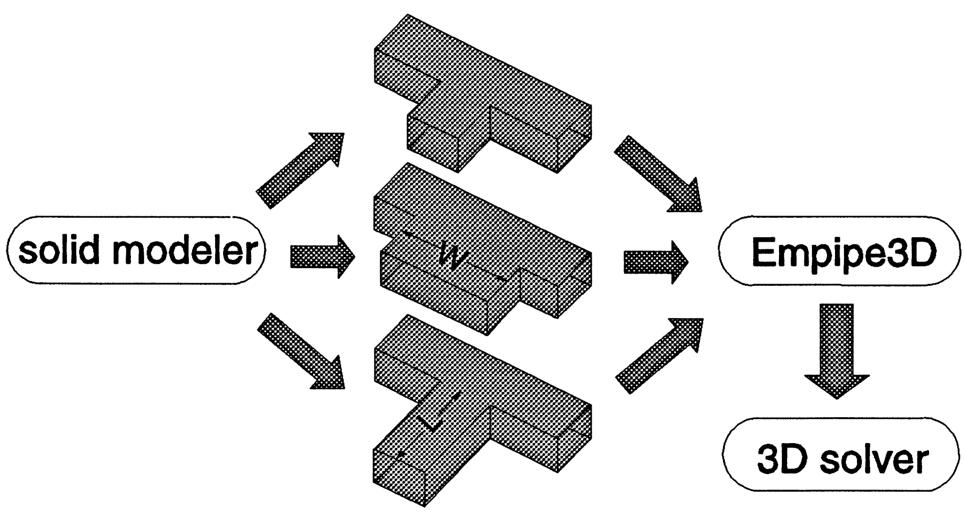
driving HFSS from ANSOFT

and HFSS from hp

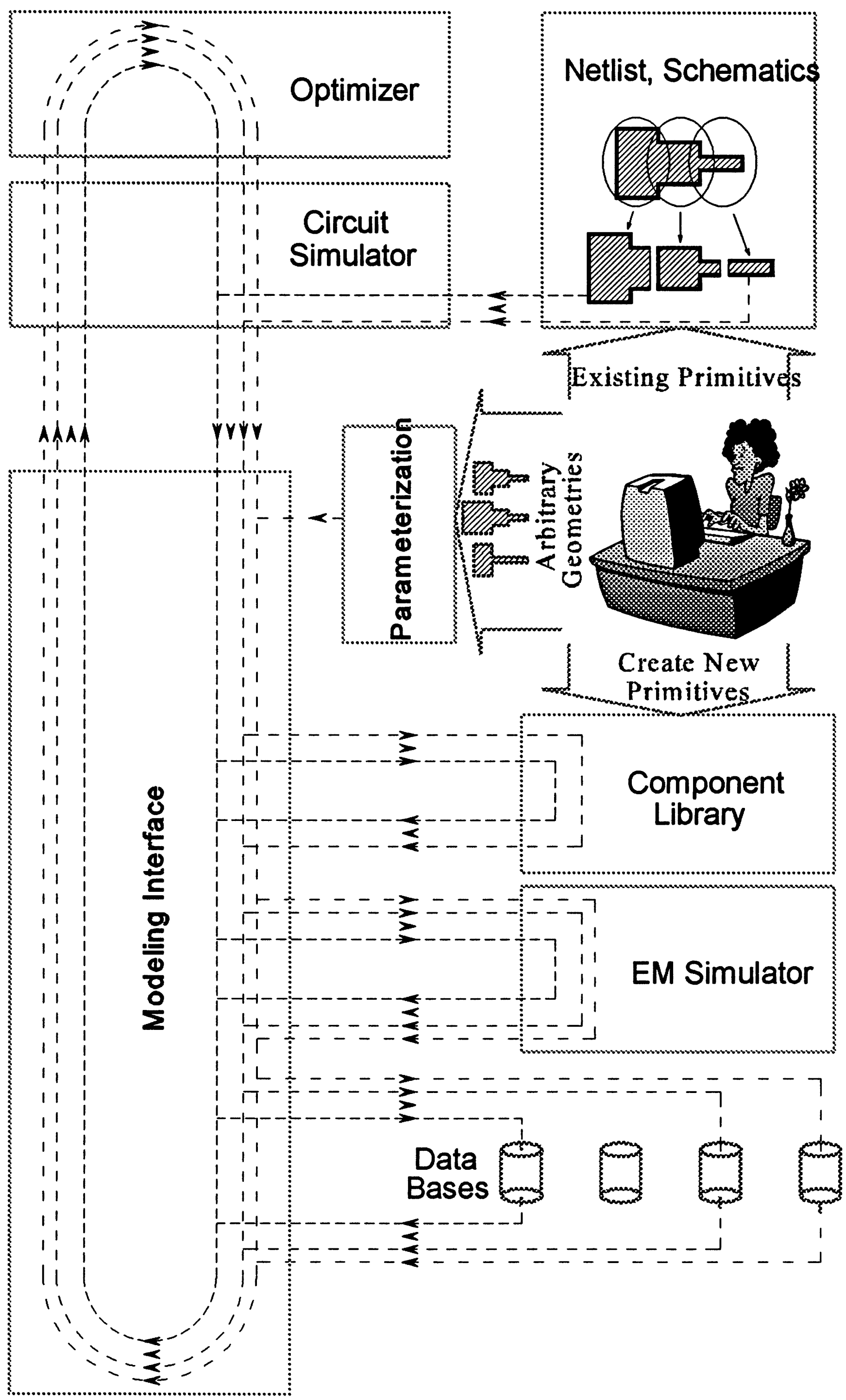
automated, efficient optimization

parameterization of arbitrary 3D

structures by Geometry Capture



EM Optimization Environment



Critical Issues of Automated EM Optimization

interfaces between gradient-based optimizers and discretized EM field solvers: interpolation and database

integration of EM analysis with circuit simulation, including harmonic balance simulation of nonlinear circuits

Geometry Capture™: user-defined optimizable structures of arbitrary geometry

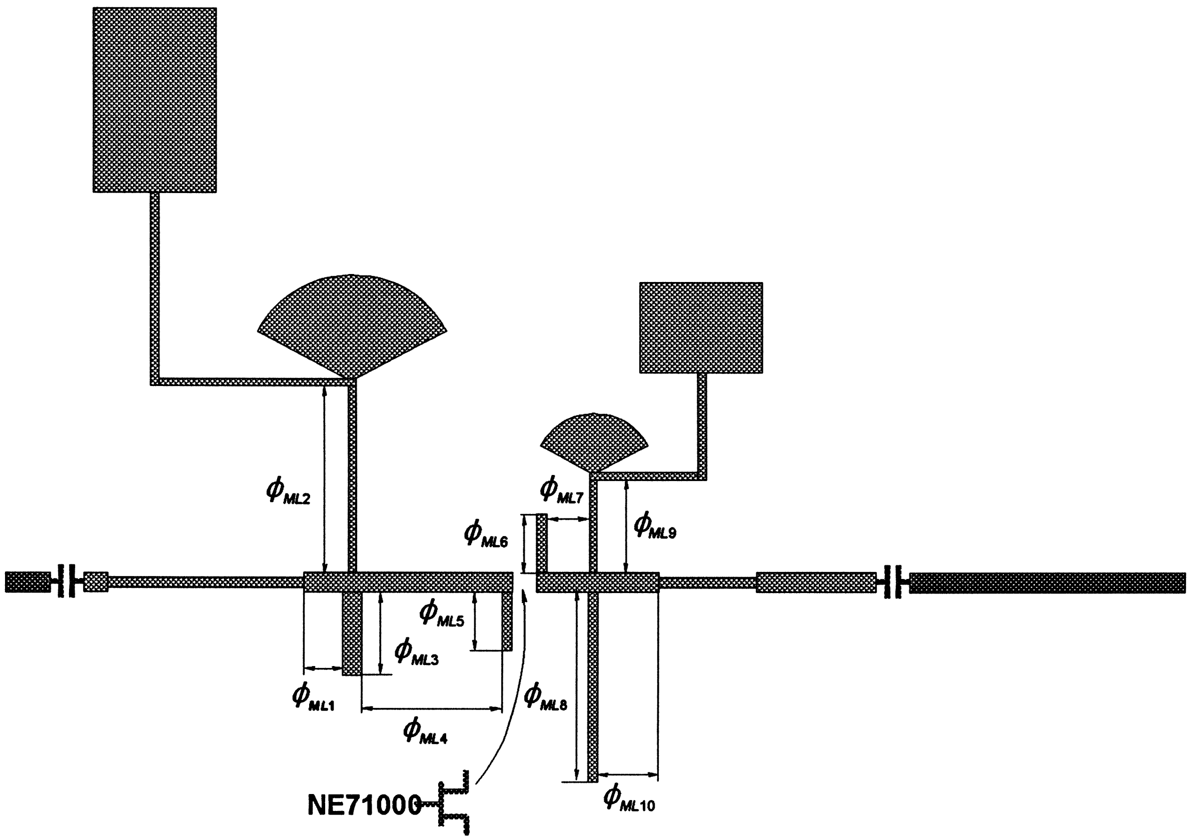
Space Mapping™ optimization: intelligent correlation between engineering models: EM models, empirical models and equivalent circuit models

smoothness and continuity of response interpolation

robustness of optimization algorithms and uniqueness of the solutions

parallel and massively parallel EM analyses

Nonlinear FET Class B Frequency Doubler
(*Microwave Engineering Europe, 1994*)

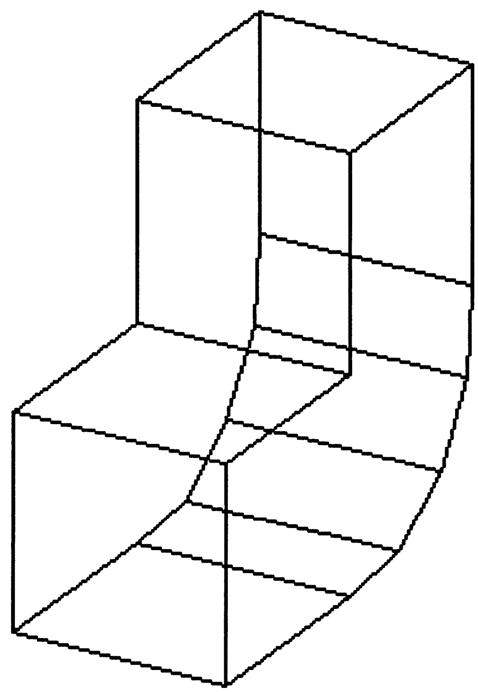


CAD benchmark example

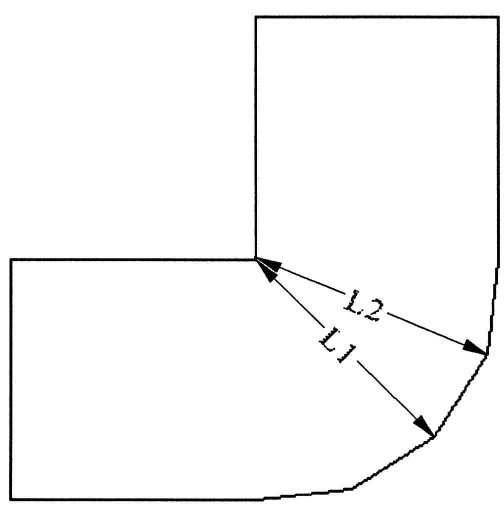
a single FET (NE71000) and a number of microstrip elements including two radial stubs and two large bias pads

significant couplings between the microstrip elements

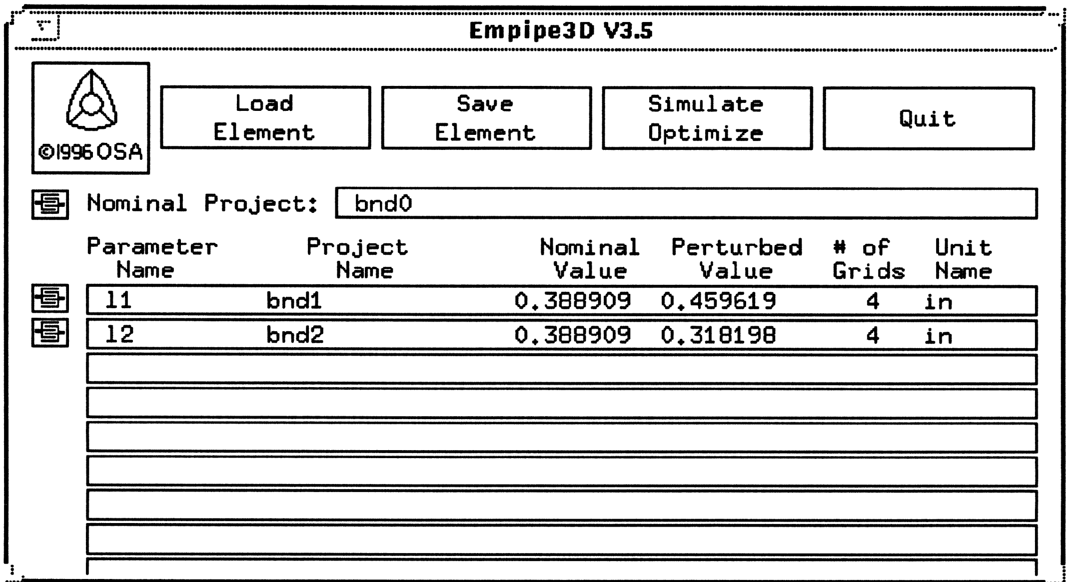
WR-75 Waveguide Bend
(only half of the structure is shown due to symmetry)



Two Design Variables

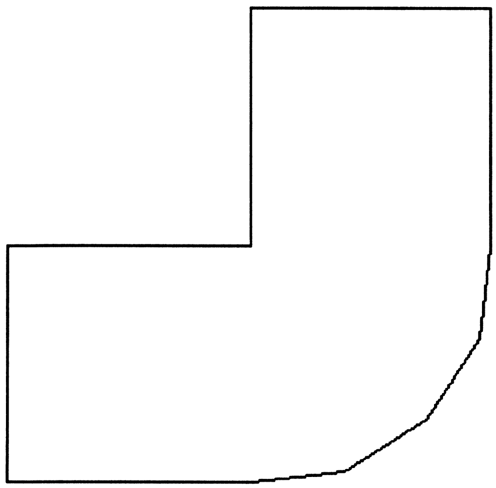


Empipe3D Geometry Capture

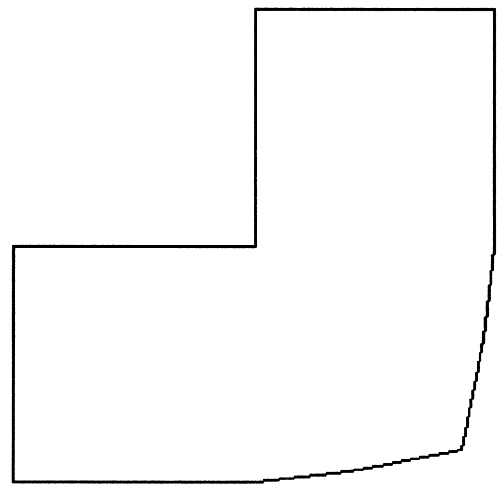


gateway to HFSS and Maxwell® Eminence

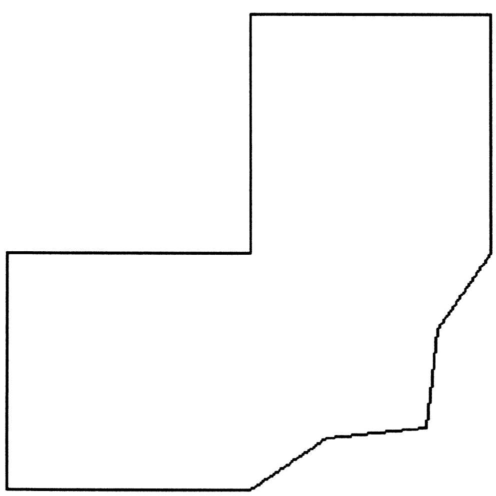
Geometries Representing the Parameters "L1" and "L2"



L1 = 0.3889 inch
L2 = 0.3889 inch

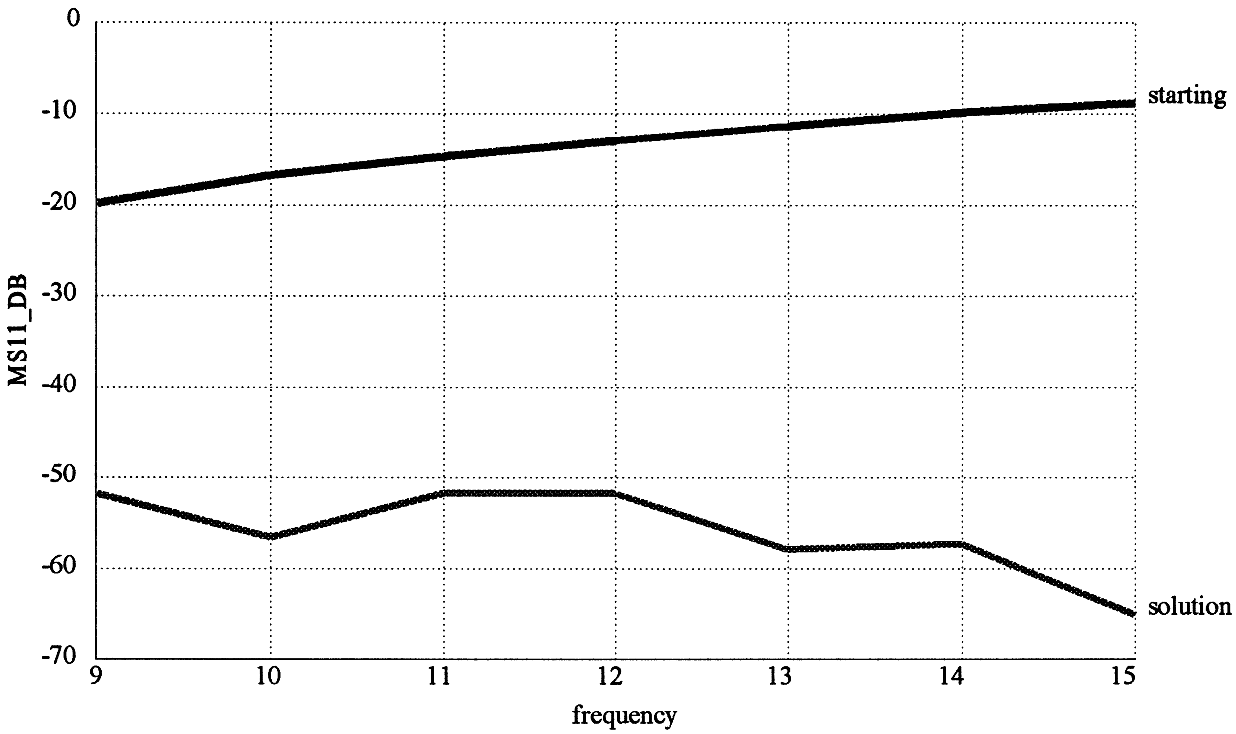


L1 = 0.4596 inch
L2 = 0.3889 inch



L1 = 0.3889 inch
L2 = 0.3182 inch

Automated Minimax Optimization

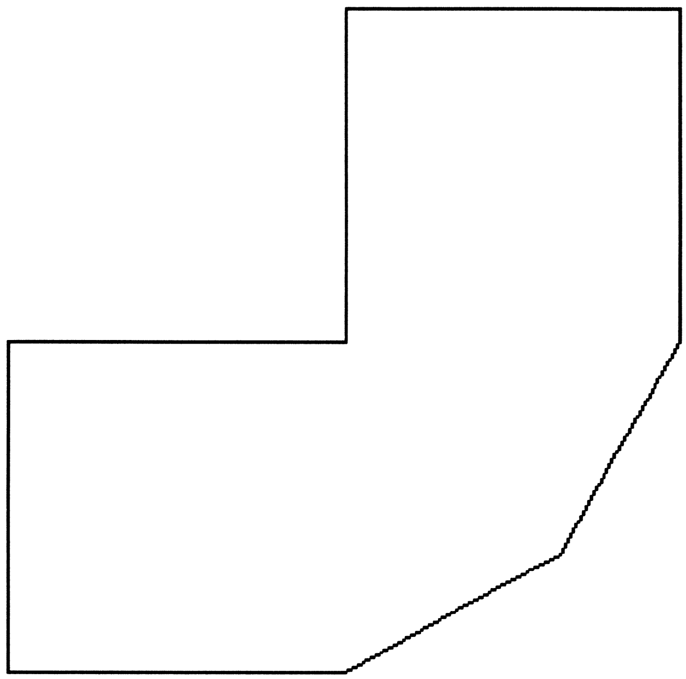


specification: return loss ≥ 40 dB from 9 to 15 GHz

starting point: *L1* = 0.3889 inch
L2 = 0.3889 inch
solution: *L1* = 0.343185 inch
L2 = 0.330018 inch

12 minimax iterations, 18 simulations by Maxwell Eminence

The Optimized Bend



this solution is virtually identical to the two-face bend optimized solution

Optimization Systems Associates Inc.

Extract From:
EM Field Simulators Made Practical
2 Day Short Course

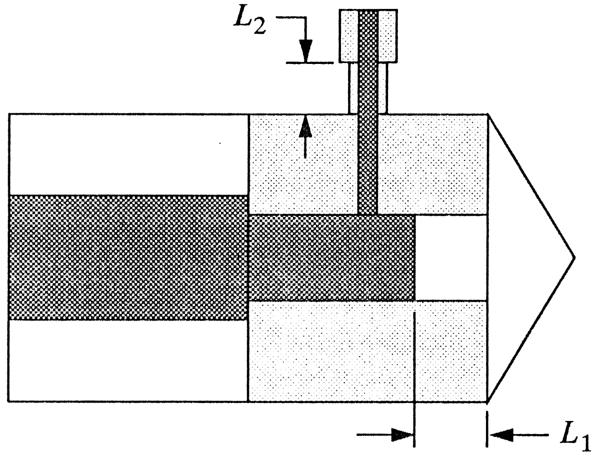
Daniel G. Swanson, Jr.

Besser Associates
4600 El Camino Real, suite 210
Los Altos, CA 94022
USA

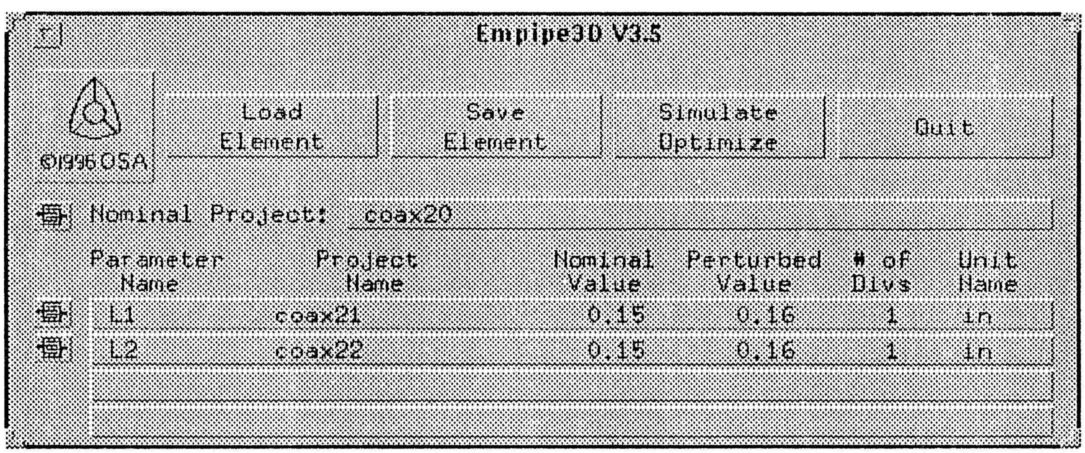
97-05-17

PCS Band Coax-to-Coax Transition (cont.)

One way to create the additional capacitance we need near port two is to reduce the diameter of the output coaxial line for a short distance. Just for good measure we will also vary the length of the open stub.



Empipe3D was used in conjunction with *Maxwell Eminence* to optimize this structure. To set up the problem we first draw the base or reference structure. Then we draw one new structure for each of variables that have been defined. In the new models, small changes are made to the dimensions that correspond to the variables. We are not allowed to change the number or names of the objects in the model. Our “game plan” for drawing the model that was developed earlier comes in handy at this point. After we have drawn the models we need, a simple procedure captures the information for *Empipe3D*.



Notes:

PCS Band Coax-to-Coax Transition (cont.)

Another set of menus help us set up the optimization problem. The result is a circuit net list that we can easily interpret. Our 3D field-solver project becomes another circuit element and can be combined with other library elements if desired.

```
! Empipe3D user-defined structure COAX2

Model
#include "coax2_osa/coax2.inc";

   COAX2_L1: ?0.05 0.15 0.2?;
   COAX2_L2: ?0.05 0.15 0.3?;

   COAX2  1 2 0  model=7
      L1=(COAX2_L1 * 1in)  L2=(COAX2_L2 * 1in);

   PORTS 1 0 2 0;

   CIRCUIT;

   MS_DB[2,2] = if (MS > 0) (20 * log10(MS)) else (NAN);
   MS11_DB = MS_DB[1,1];
   MS22_DB = MS_DB[2,2];
end

Sweep
   AC: FREQ: from 1.8GHz to 2GHz step=0.1GHz MS22_dB MS11_dB
      {XSWEEP title="MS11_dB and Spec" X=FREQ Y=MS11_dB
       SPEC=(from 1.8GHz to 2GHz, < -40)};
end

Spec
   AC: FREQ: from 1.8GHz to 2GHz step=0.01GHz MS11_dB < -40;
end

Control
   Perturbation_Scale=1.0e-4;
   Optimizer=Minimax;
end
```

Notes:

PCS Band Coax-to-Coax Transition (cont.)

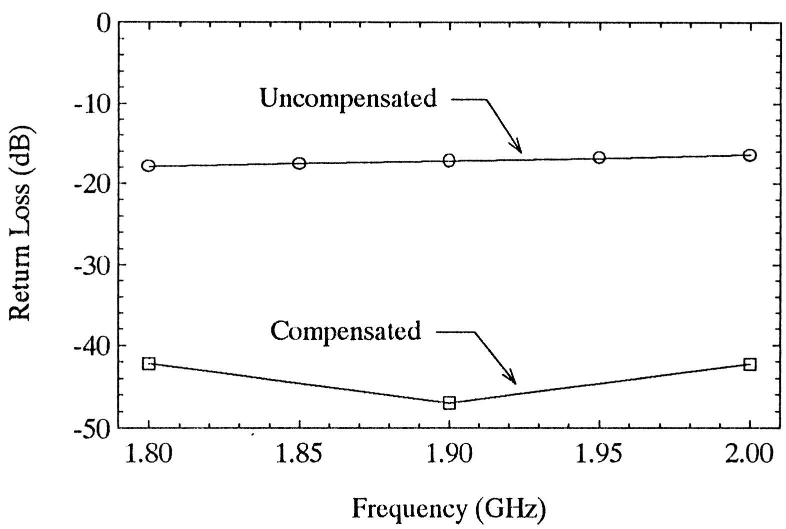
The optimization of this structure proceeded quite quickly; the total time was 1 hour, 48 minutes. The starting values and optimized values for both variables are shown below.

Variable	Start Point	End Point
L_1	.150	.137
L_2	.150	.139

A total of 10 field-solver solutions were computed. It is interesting to look at the "trajectory" of the field-solver solutions. We specified 10 mil steps in both variables for the field-solver solutions. Notice that the final solution falls off this "grid" of known solutions because the software can interpolate between known solutions.

Solution No.	1	2	3	4	5	6	7	8	9	10
L_1	.15	.16	.15	.14	.15	.14	.13	.12	.13	.14
L_2	.15	.15	.16	.14	.14	.15	.13	.13	.14	.13

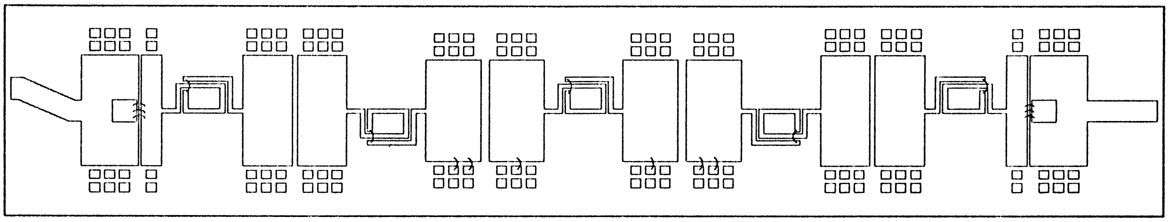
Below we have plotted the return loss of the original transition and the return loss of the compensated transition.



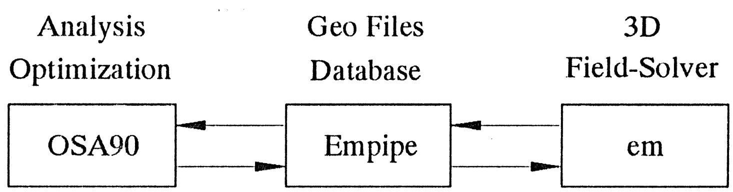
Notes:

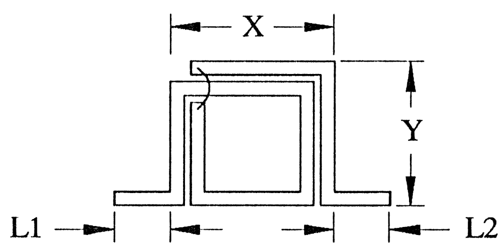
Pseudo-Lumped 3.7 GHz Bandpass Filter

This filter is a lower frequency version of the previous example. The two key parameters for this design were insertion loss and the width of the spurious free stopband. Printed spiral inductors were used to achieve the higher inductance values needed at this frequency. The final layout for this filter is shown below. The substrate is 20 mil thick alumina, 945 mil long by 190 mil wide. A more complete description of this filter can be found in [33].



This example demonstrates how the field-solver can now be used to optimize planar circuits. The filter was subdivided into three unique pi-network elements and one spiral inductor element. The analysis and optimization of these circuit elements were controlled by a linear simulator, *OSA/90*, with an auxiliary interface to the field-solver, *Empipe*.

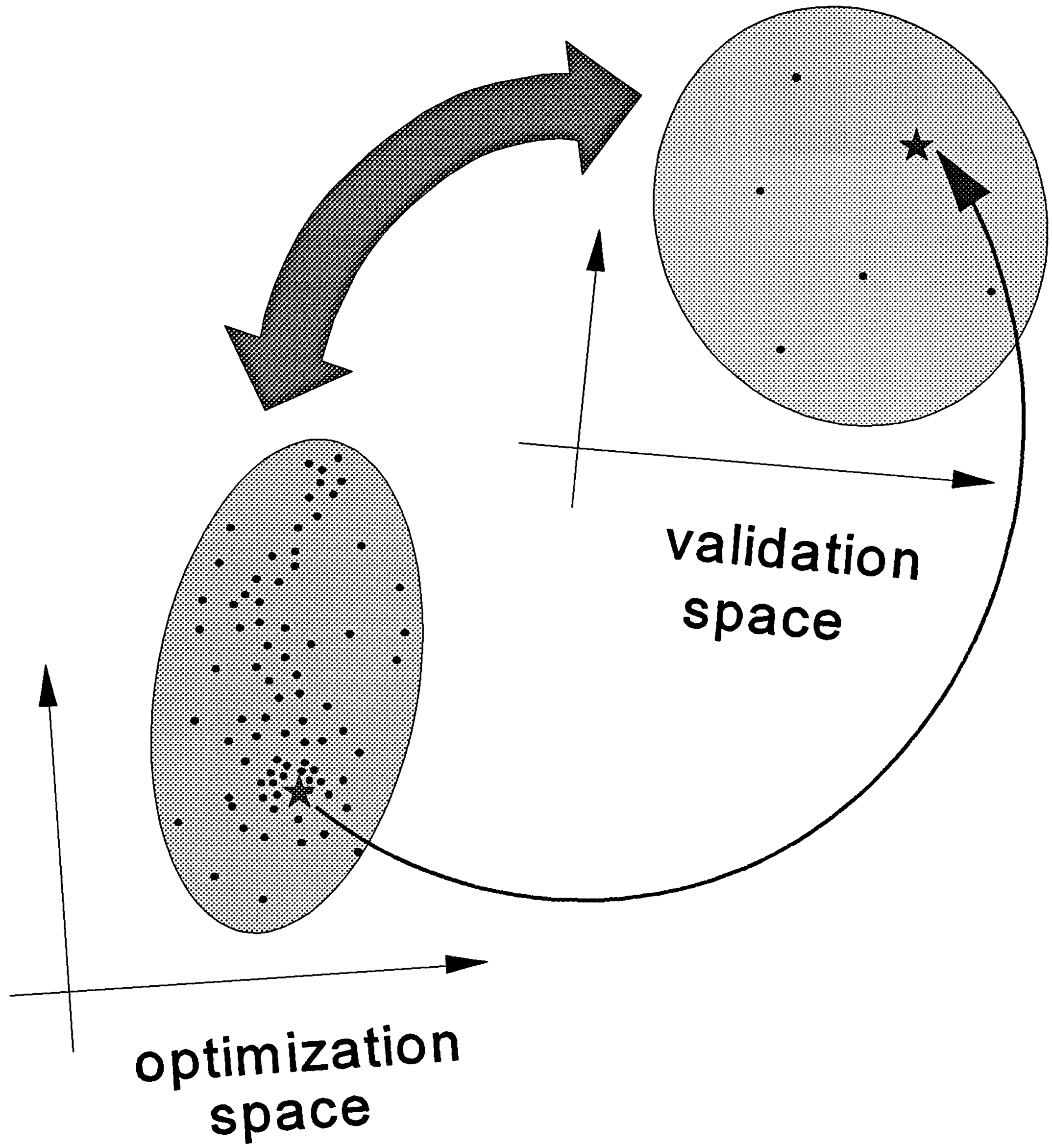




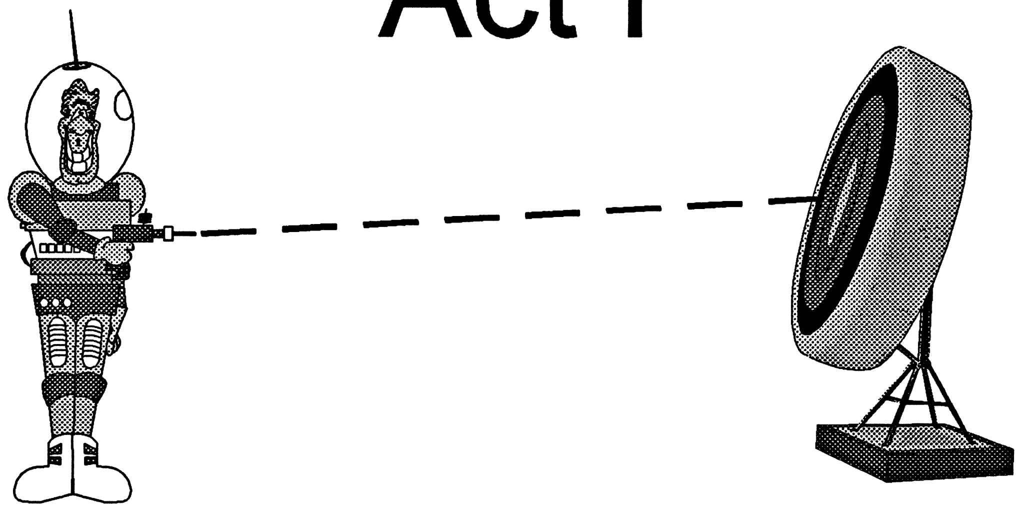
The analysis and optimization proceed by first building a database of field-solver solutions around the starting point and then interpolating in the existing database or adding new solutions to the database. One side benefit of this approach is that it frees the user from the fixed grid. That is, solutions can be found with dimensions that do not fall on the analysis grid. More details on direct driven em optimization can be found in [34],[35].

Notes:

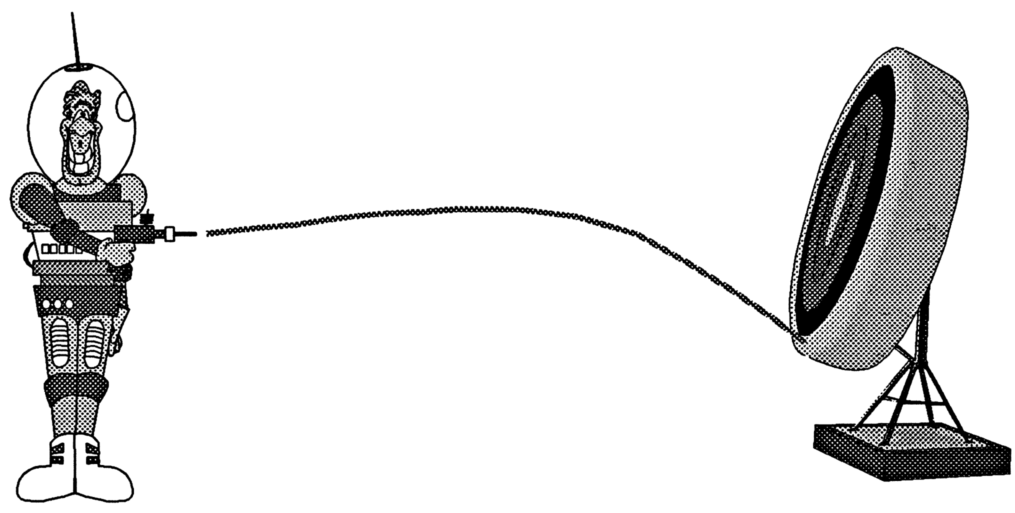
Space Mapping™
(Bandler et al., 1994)



Space Mapping
Act I



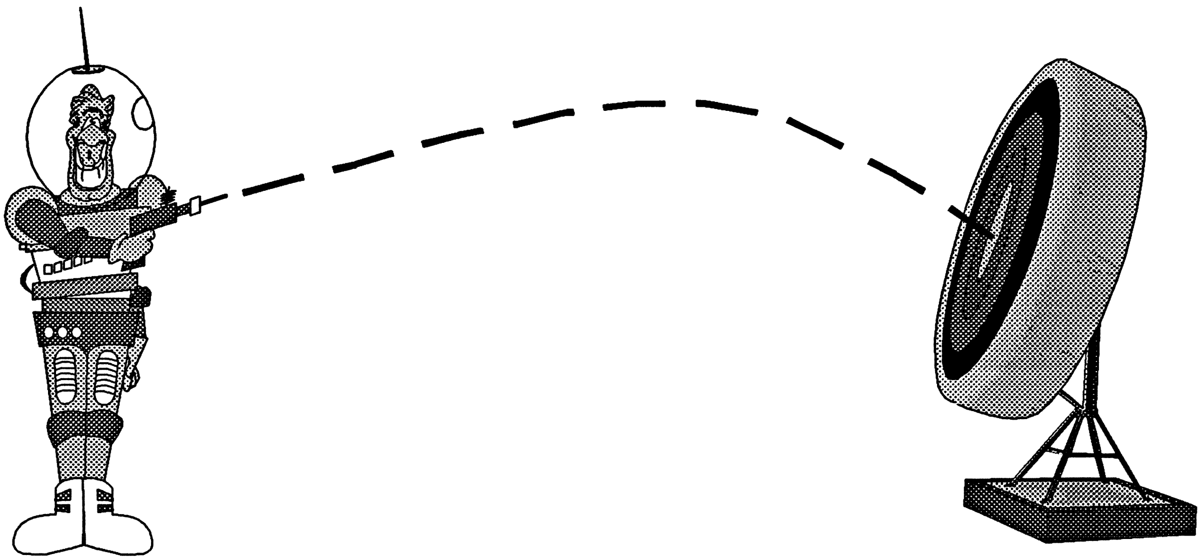
ideal aim



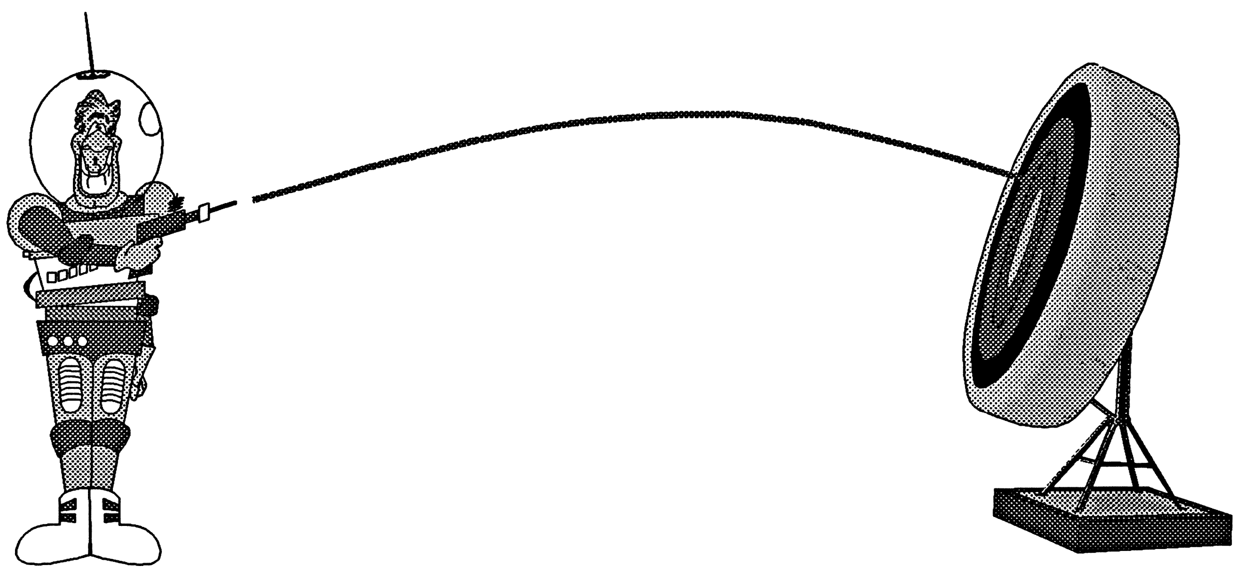
reality check ... oops

97-05-23

Space Mapping
Act II



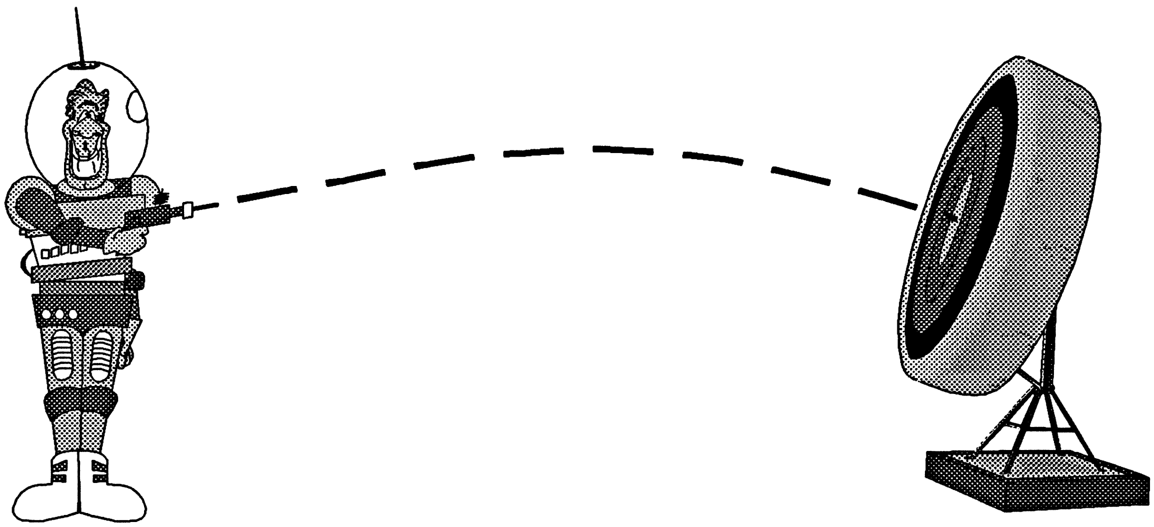
Broyden update



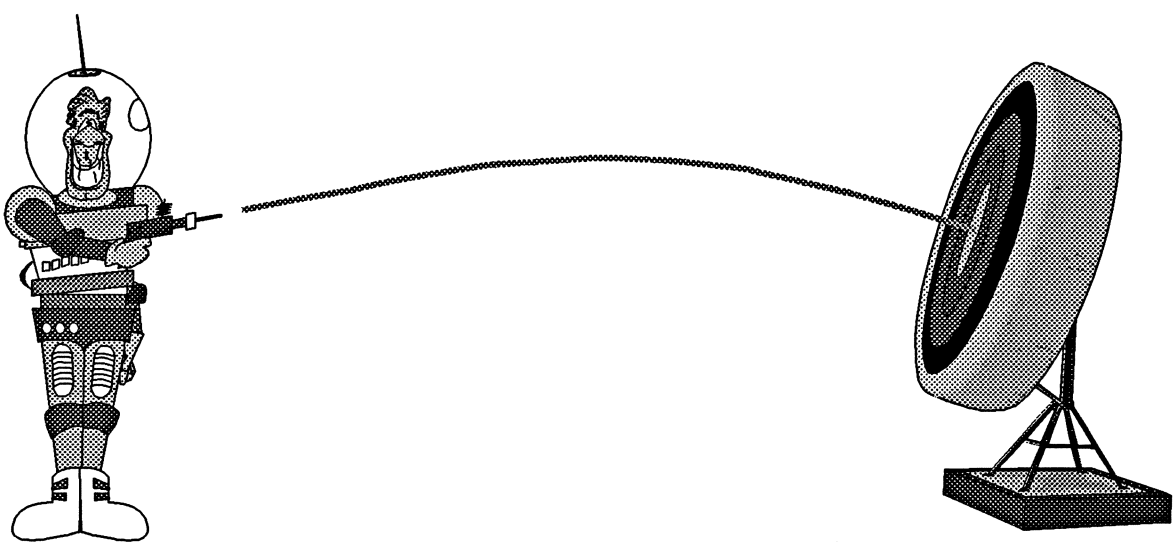
almost there

97-05-24

Space Mapping Act III

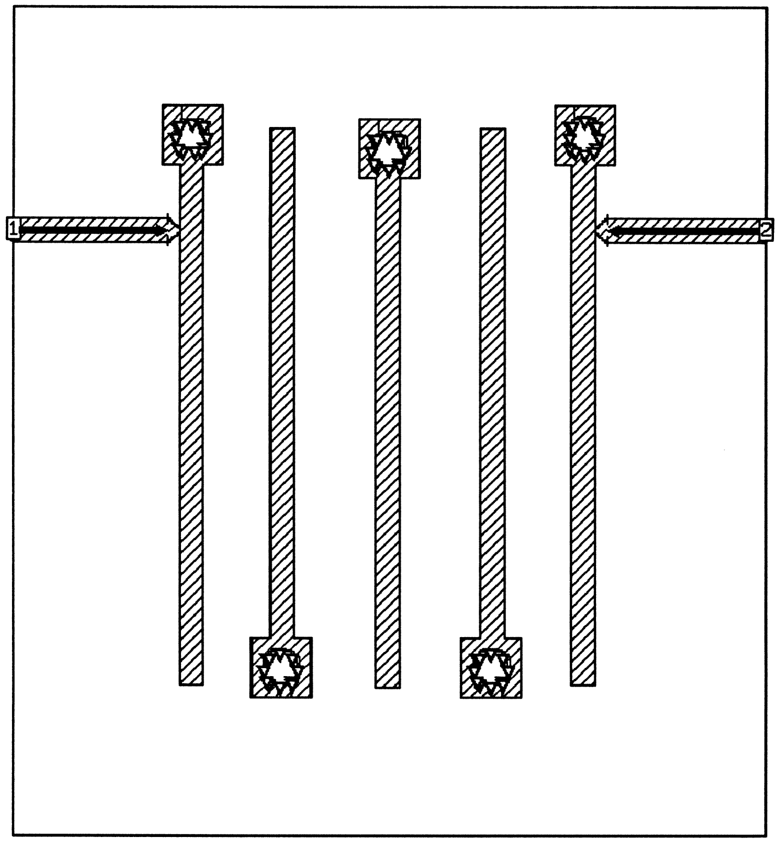


I licensed OSA



Hey, SM works!!

A Five-Pole C-Band Interdigital Filter



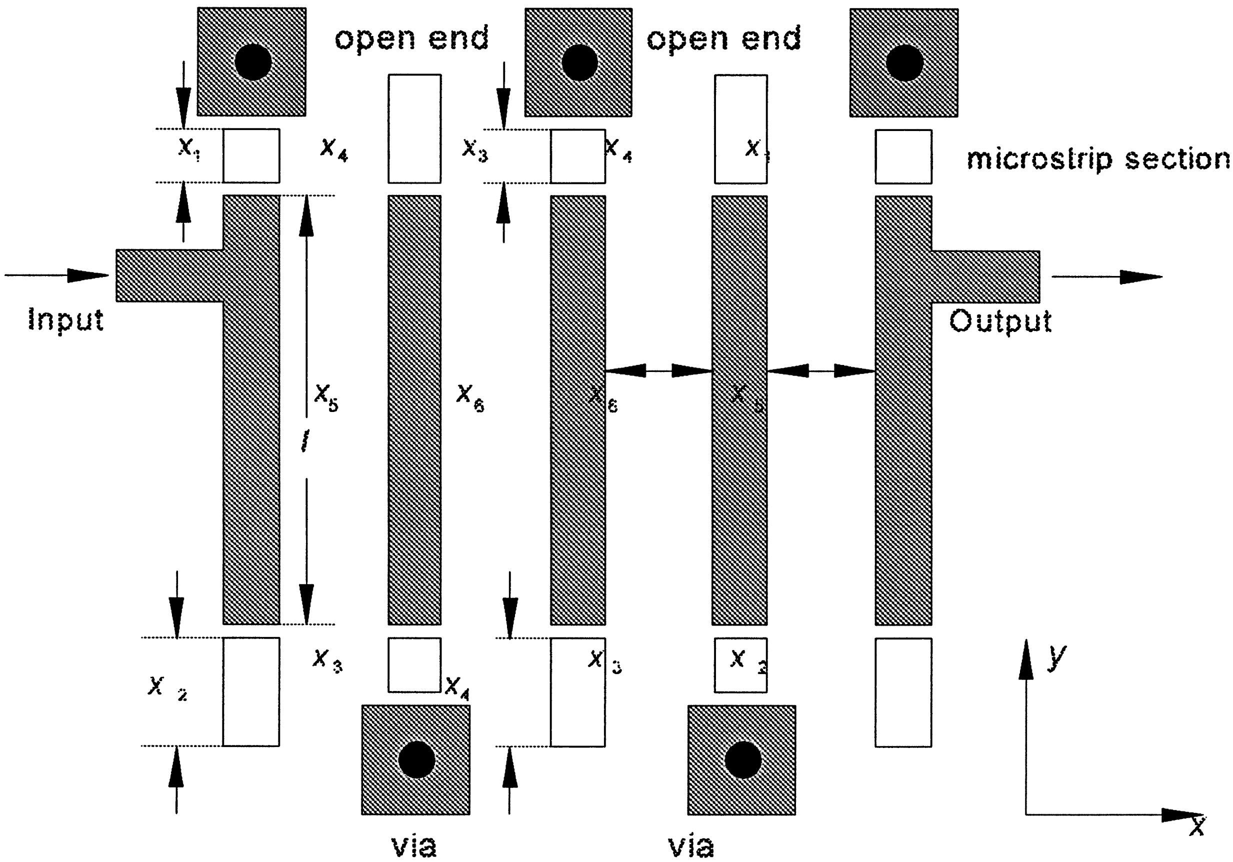
15 mil thick alumina substrate with $\varepsilon_r = 9.8$.

the width of each microstrip is chosen to be 10 mil

quarter wavelength resonators

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

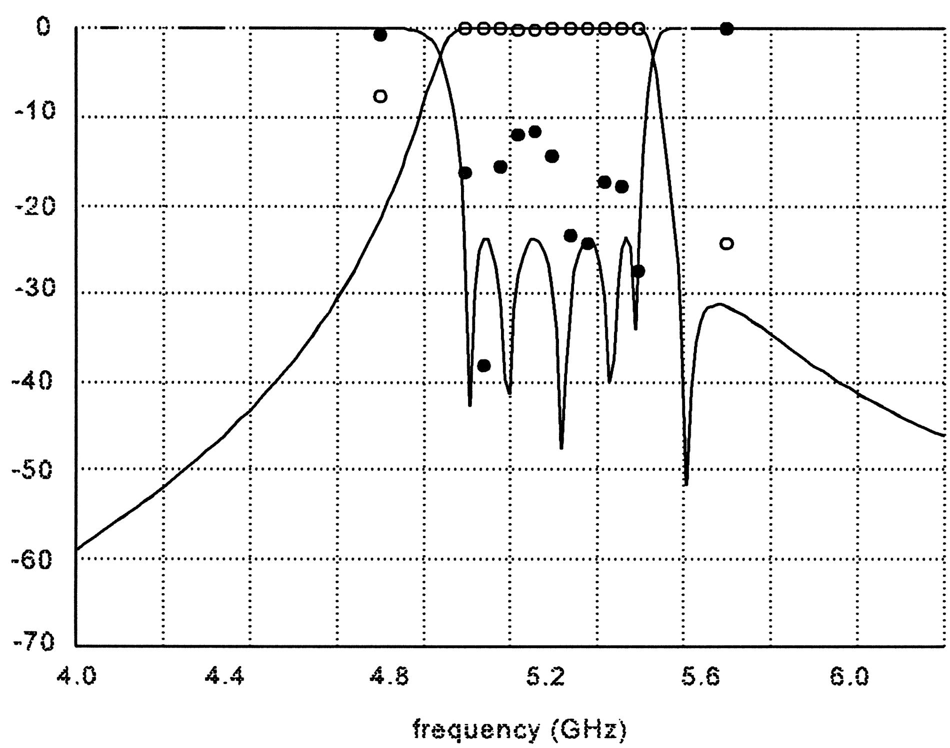
the partial results are then combined through circuit theory to obtain the response of the overall filter

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}^*

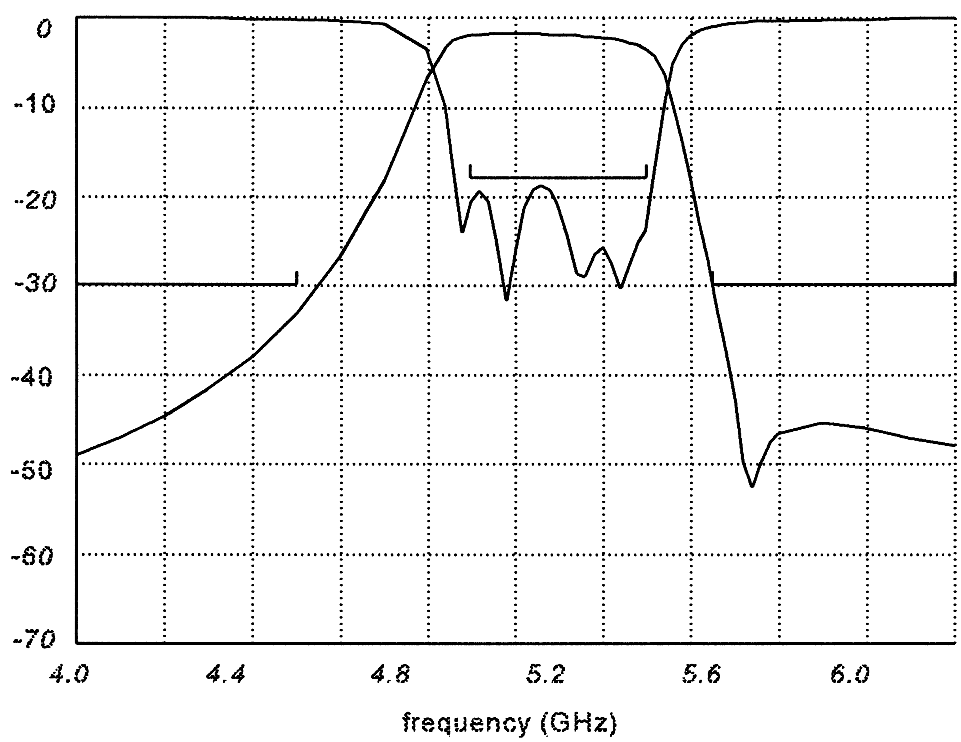
circles fine model responses at x_{os}^*

Final EM Validation

a dense frequency sweep is desired

here, simulation includes the conductor and dielectric losses

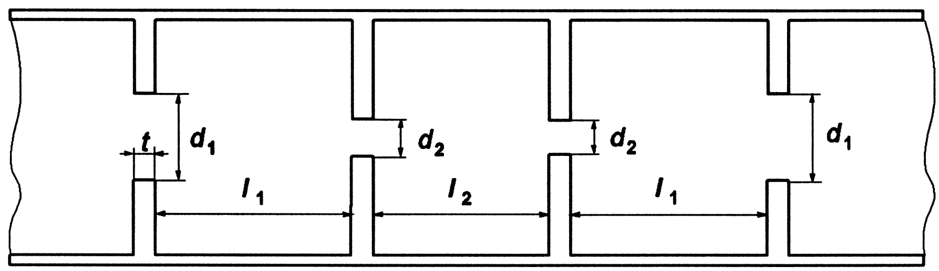
the fine model responses at $\boldsymbol{x}_{em}^{(3)}$



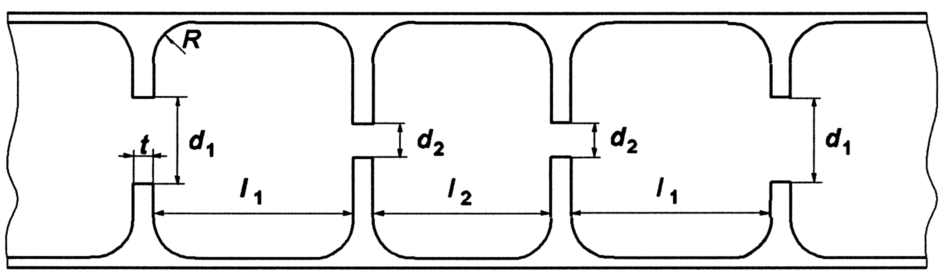
the passband return loss is better than 18.5 dB

Optimization of the H-Plane Resonator Filter

OS model, for hybrid MM/network theory simulation



fine model, for analysis by FEM



the waveguide cross-section is 15.8 × 7.9 mm

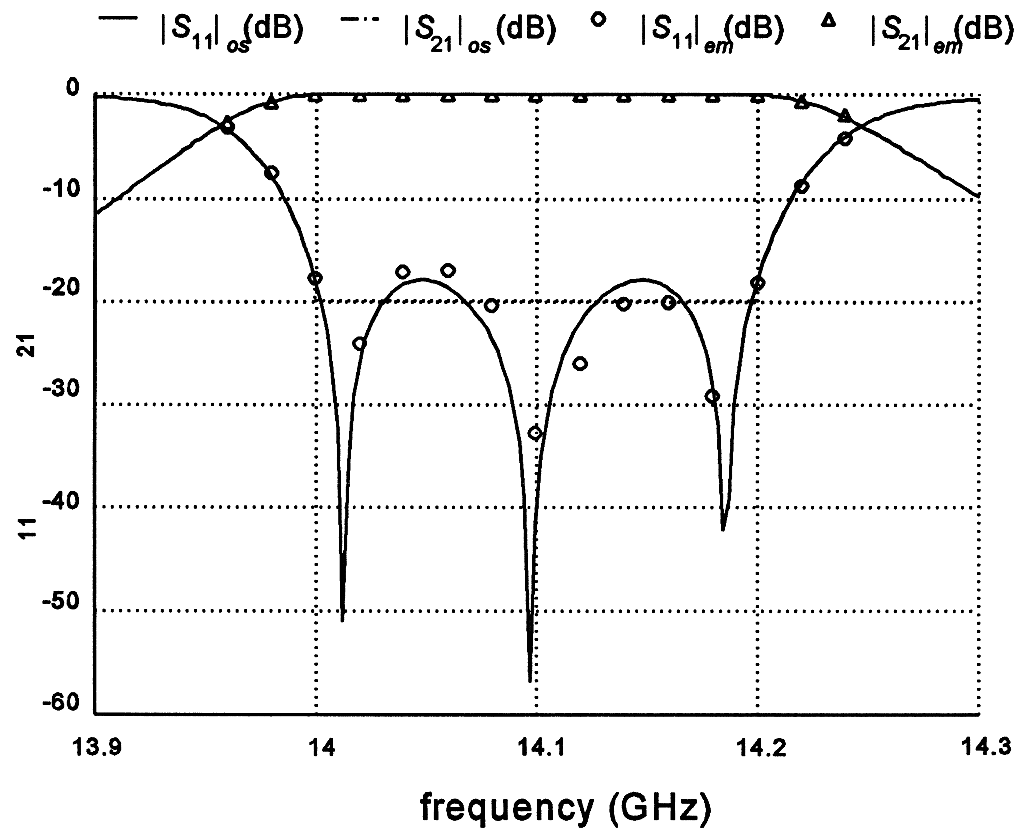
$t = 0.4$ mm, $R = 1$ mm

optimization variables: d_1, d_2, l_1 and l_2

design specifications

$|S_{21}|$ (dB) < -35 for $13.5 \leq f \leq 13.6$ GHz
$|S_{11}|$ (dB) < -20 for $14.0 \leq f \leq 14.2$ GHz
$|S_{21}|$ (dB) < -35 for $14.6 \leq f \leq 14.8$ GHz

SM Optimized FEM Response

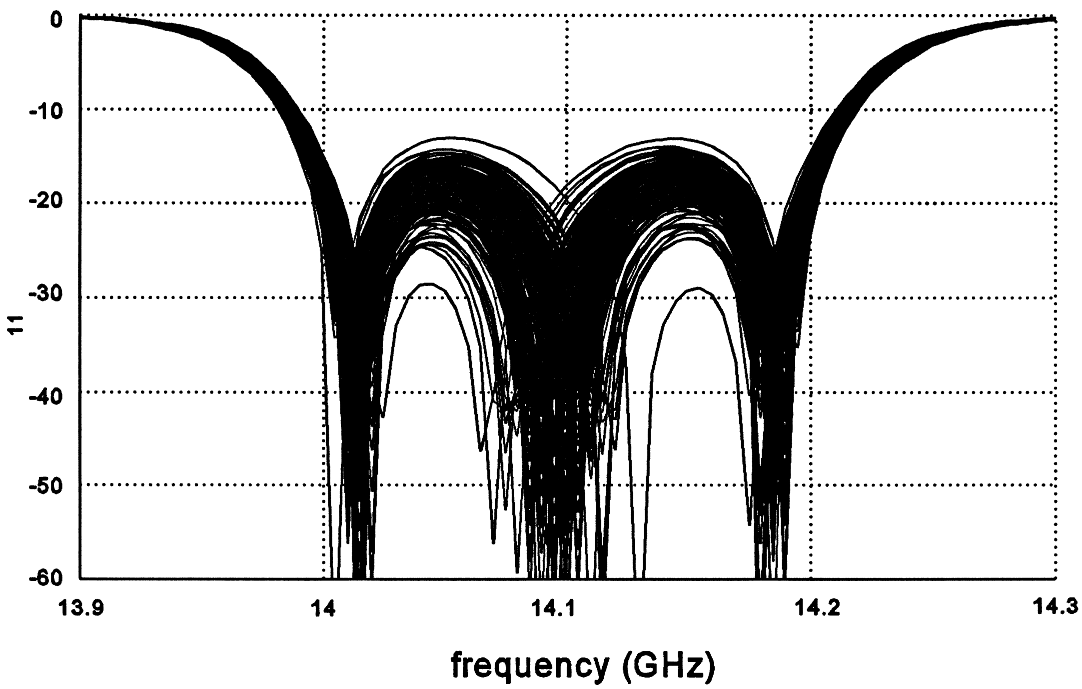


only 4 Maxwell Eminence simulations lead to the optimal solution

$d_1 = 6.17557$, $d_2 = 3.29058$, $l_1 = 13.0282$ and $l_2 = 13.8841$

direct optimization using Empipe3D confirms that the SM solution is optimal

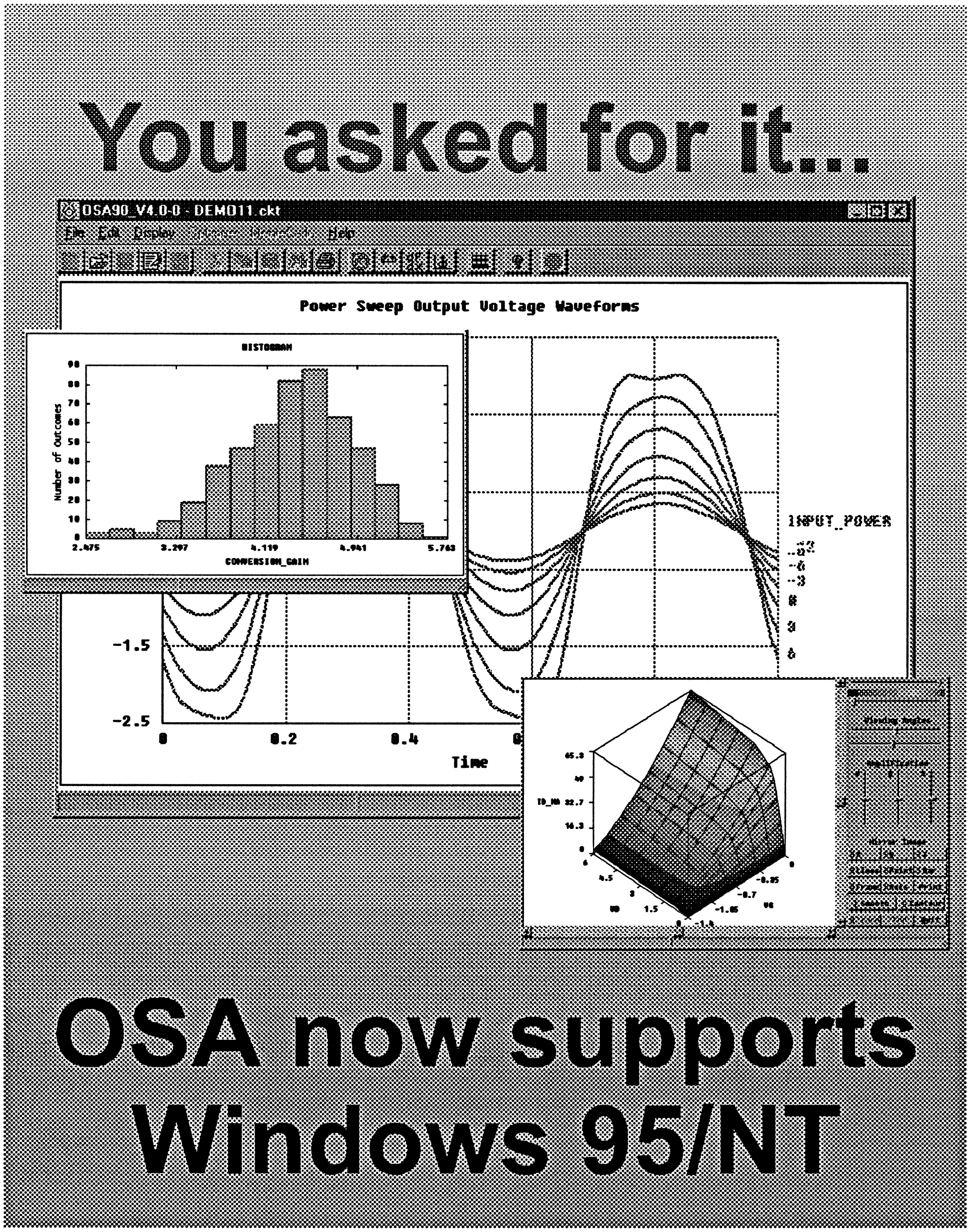
Monte Carlo Analysis of the H-Plane Filter



the statistical outcomes were randomly generated from normal distribution with a standard deviation of 0.0333%

the yield estimated from 200 outcomes is 88.5% w.r.t. the specification of $|S_{11}| < -15$ dB in the passband

increasing the standard deviation to 0.1% results in yield dropping to 19% for 200 outcomes


You asked for it...
OSA90_V4.0-0 - DEMO11.ckt
File Edit Display Help
Power Sweep Output Voltage Waveforms
HISTOGRAM
Number of Outcomes
2.475 3.297 4.119 4.941 5.763
CONVERSION_GAIN
INPUT_POWER
-1.5
-2.5
0 0.2 0.4
Time
OSA now supports
Windows 95/NT

97-05-33

Selected Users of OSA Technology

Alcatel	AMTEL
Ansoft	Alenia
BNR	Boeing
British Telecom	ComDev
Compact Software	COMSAT
CRC (Canada)	Daimler Benz
EEsof	France Telecom
GE	Hewlett Packard
Hughes	IMST (Germany)
Loral	M/A-COM
MIT Lincoln Labs	Micronet
NAWC	Nortel
Philips	Raytheon
Rockwell	Schrack Aerospace
Siemens	Sonnet
Sumitomo	Texas Instruments
Telettra	TRIO
TRW	VTT
Watkins-Johnson	

University Users of OSA Technology

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Belgium

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