Empipe3D TUTORIALS

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Empipe3D TUTORIALS

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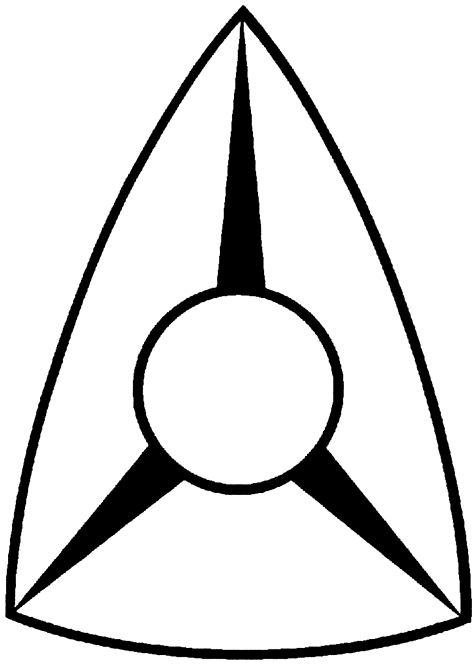
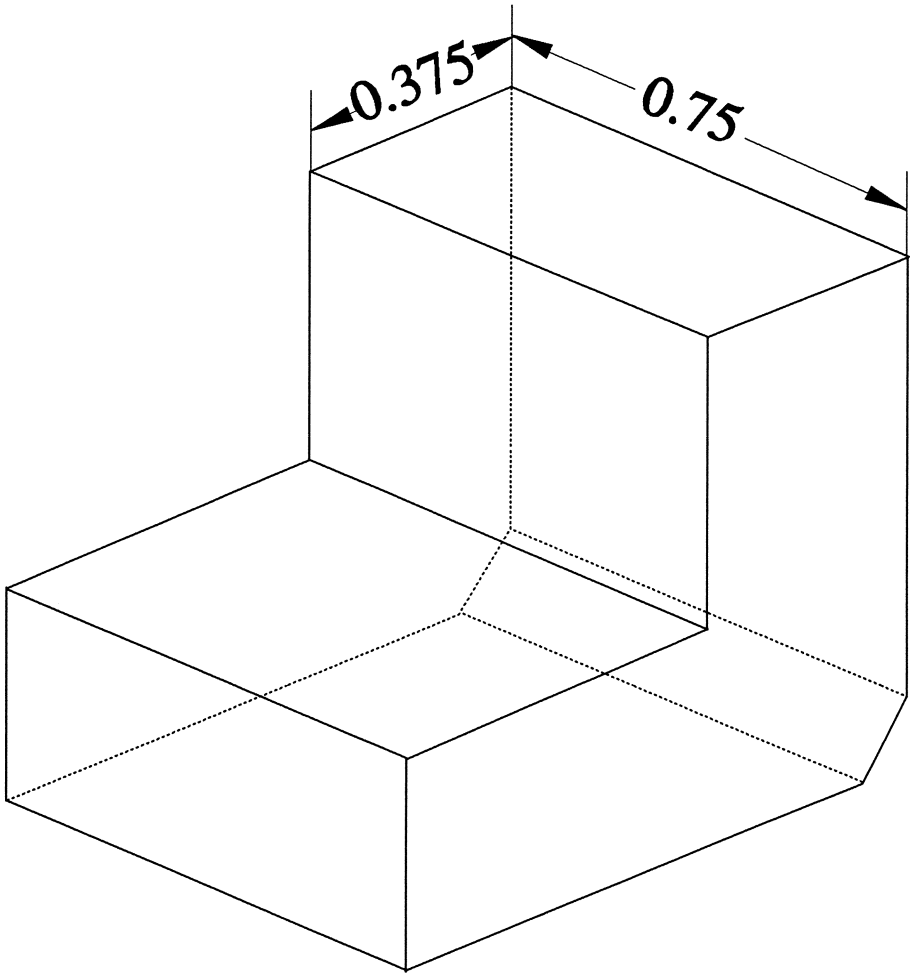


Waveguide Mitered Bend



single section miter

Outline

the basics of the user interface of Empipe3D

how to parameterize a geometrical dimension as an optimization variable

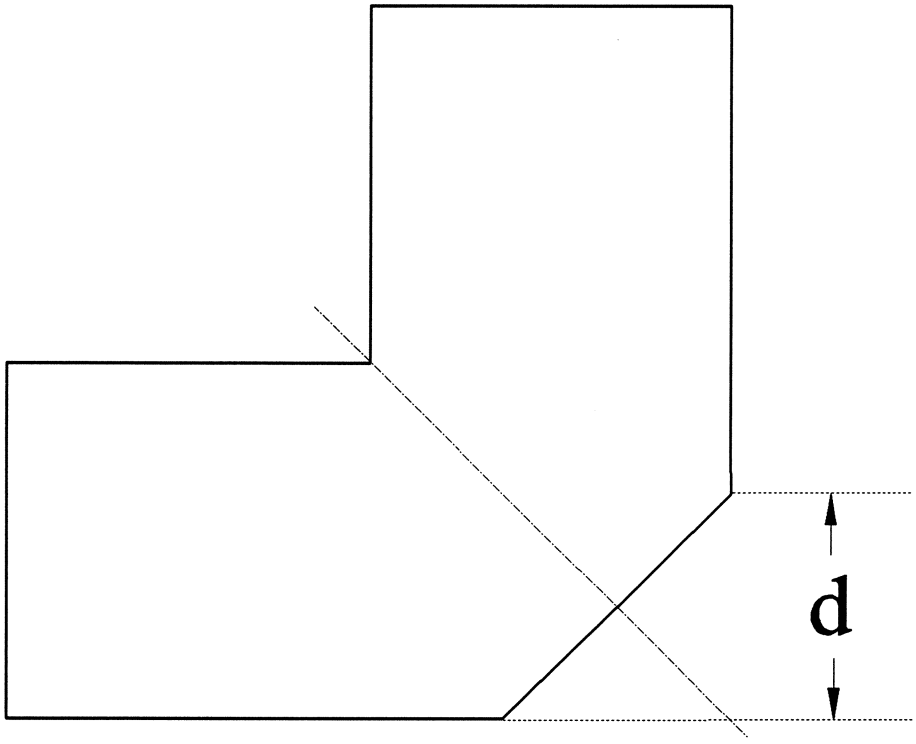
how to define a performance specification on the *S* parameters

how to start EM simulation through Empipe3D

how to start optimization

how to view and save the optimized solution

Definition of the Optimizable Parameter *d*



design specification

$$20\ log_{10}(|S_{11}|) < -30$$

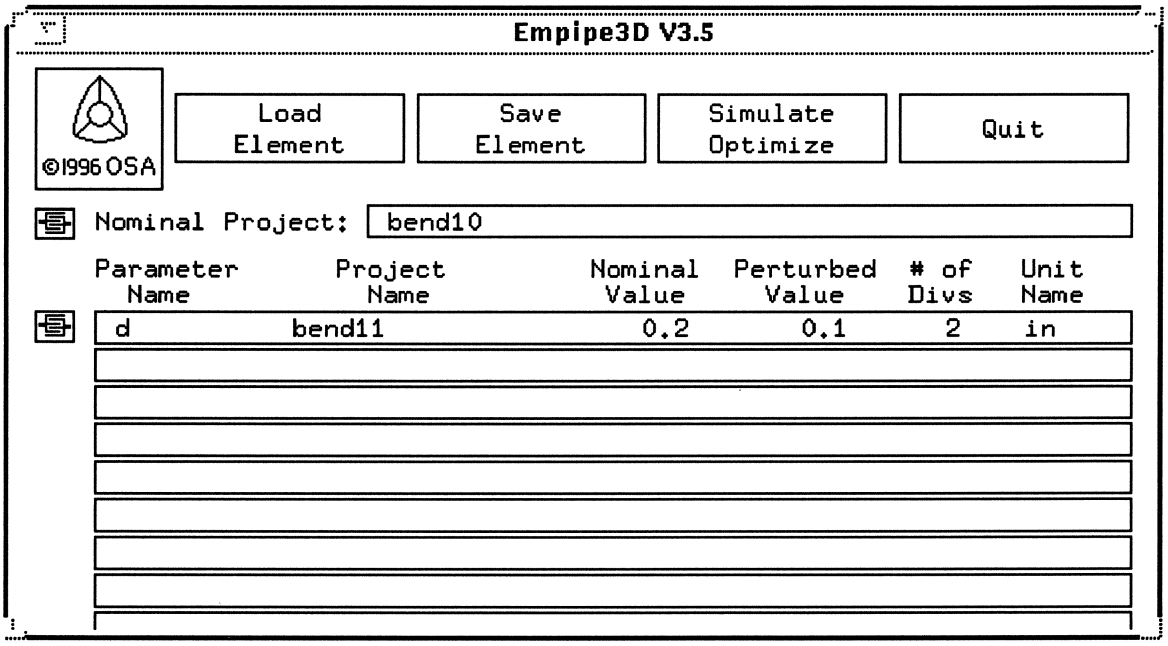
for frequencies from 9 to 15 GHz (with a 1 GHz step)

Setting up the Projects

start Empipe3D using the command

```
empipe3d  bend1
```

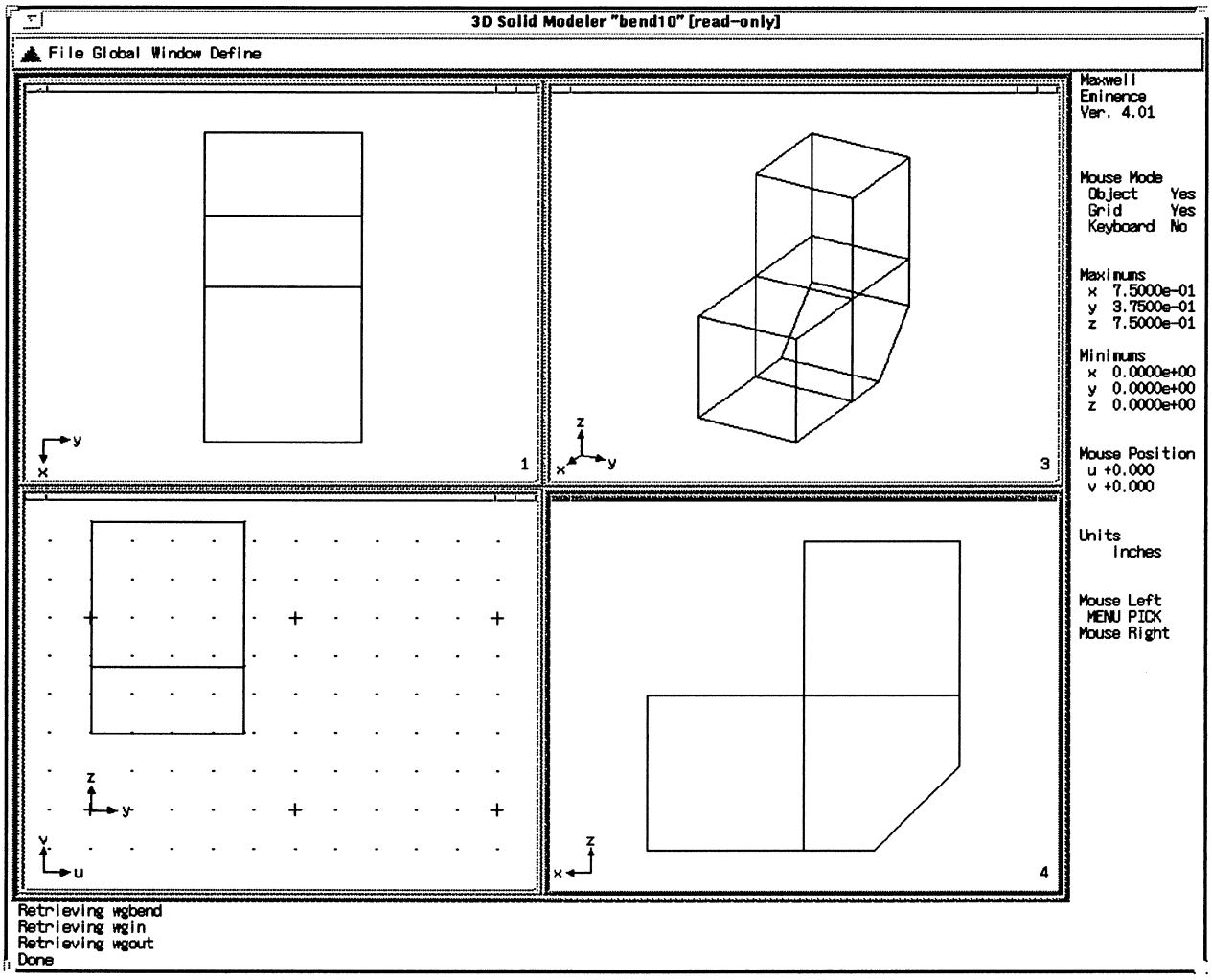
"bend1" represents the Empipe3D element name



"bend10" is the nominal project name

"bend11" is the name of another project

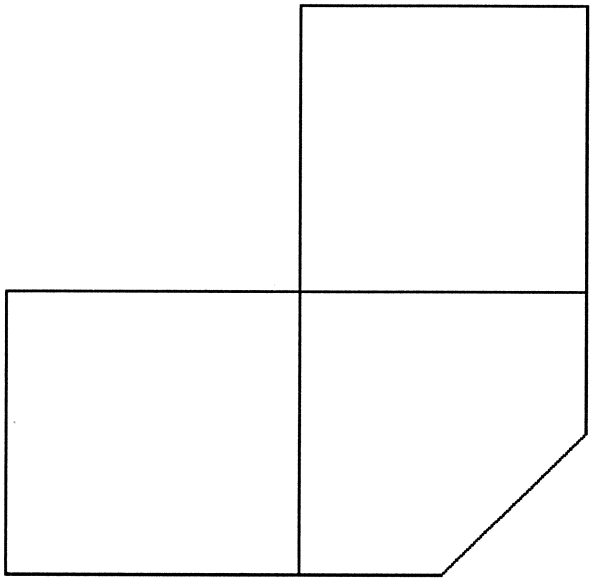
Solid Model for the Nominal Project



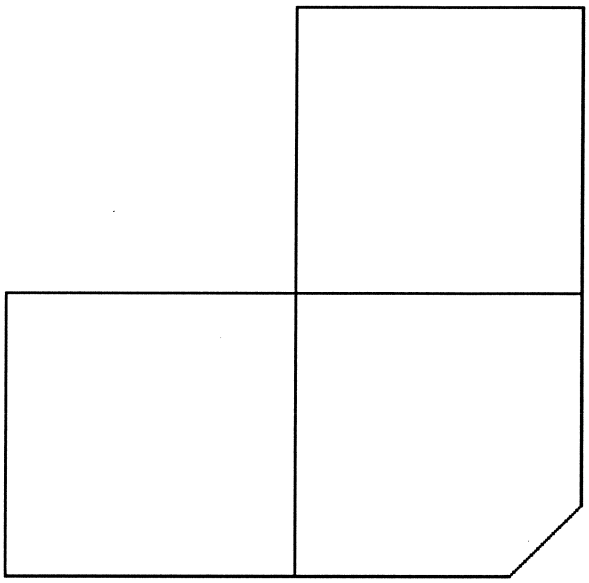
single section mitered waveguide bend

only half of the structure is drawn

Representing Incremental Change



nominal project
$d = 0.2$ inch

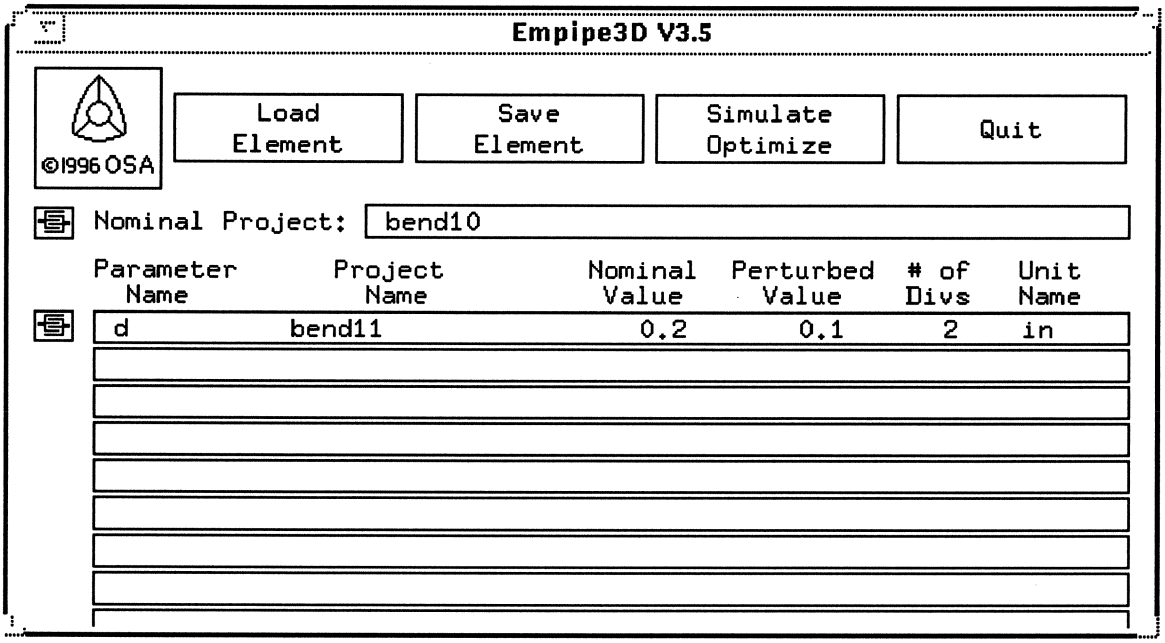


incremental change
$d = 0.1$ inch

by comparing the new project with the nominal project Empipe3D captures the information necessary for translating parameter values to a corresponding solid model

the basic topology of the structure cannot change

Details of the Geometry Capture Form Editor



"# of Divs"	the number of interpolation intervals	
"Unit Name"	IN (inch), MIL (milli-inch), etc.	
nominal project:	bend10	$d = 0.2$ inch
perturbed project:	bend11	$d = 0.1$ inch

Empipe3D Interpolation

to improve efficiency

to substantially reduce the number of calls to the 3D Solver during optimization

facilitates gradient calculation

interpolation interval =
    |*perturbed value* - *nominal value*| / *number of Divs*

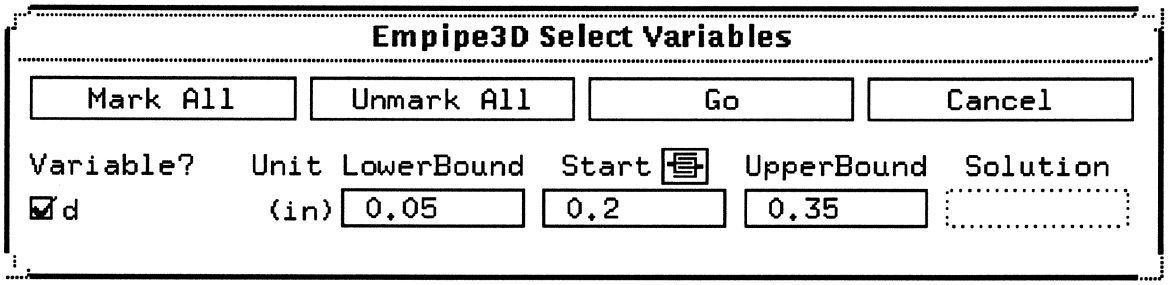
the choice of interpolation interval is problem dependent

too large an interval results in reduced accuracy

too small an interval may result in increased number of 3D EM simulations

recommendation: start with a coarse (large) interval and gradually refine the interval size as necessary

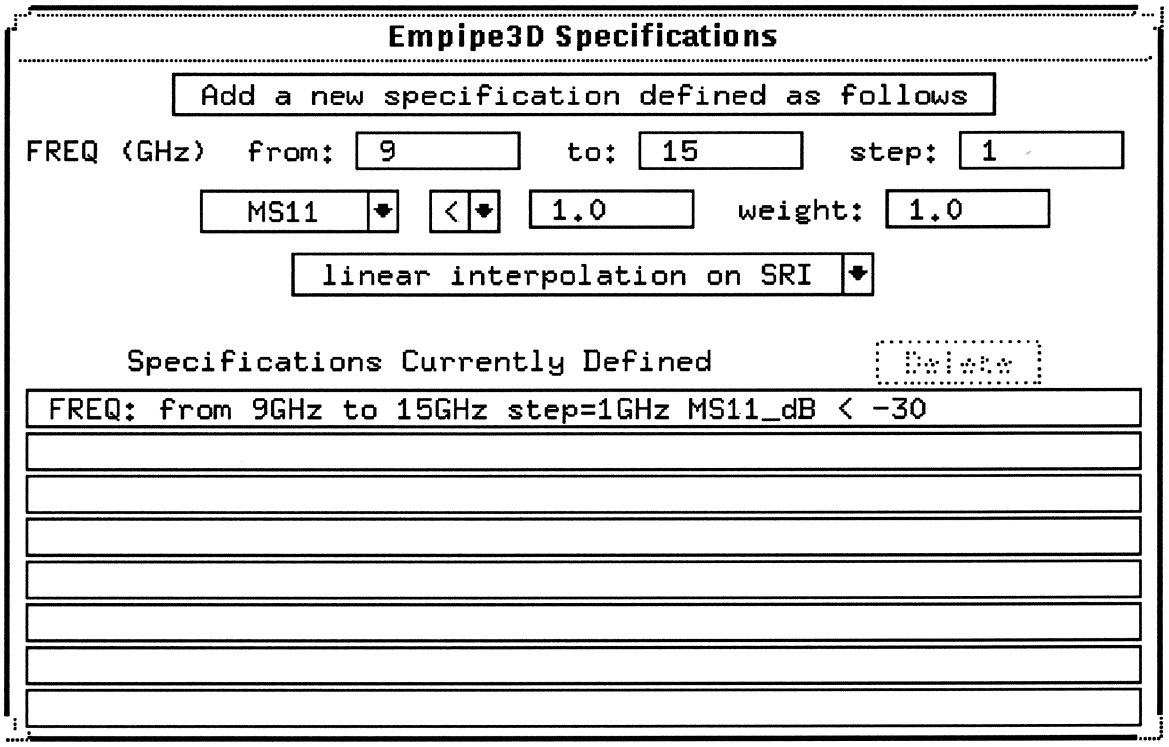
Window for Selecting Optimization Variables



"d" is assigned bounds of 0.05 and 0.35 inch

if bounds are not given explicitly, they will be determined by the program

Specifications for Optimization



select

frequency range (9 GHz to 15 GHz)
S-parameter response (e.g., $|S_{11}|$ in dB)
specification type (upper, lower or equality)
interpolation type (optional)

enter

numerical value as the goal (-30 dB)
weighting factor (optional)

OSA90 Simulation

OSA90_V3.5-0

File Parsing Completed | OSA Thu Jul 4 09:22:06 1996 /empipe3d_examples/bend1/bend1.ckt

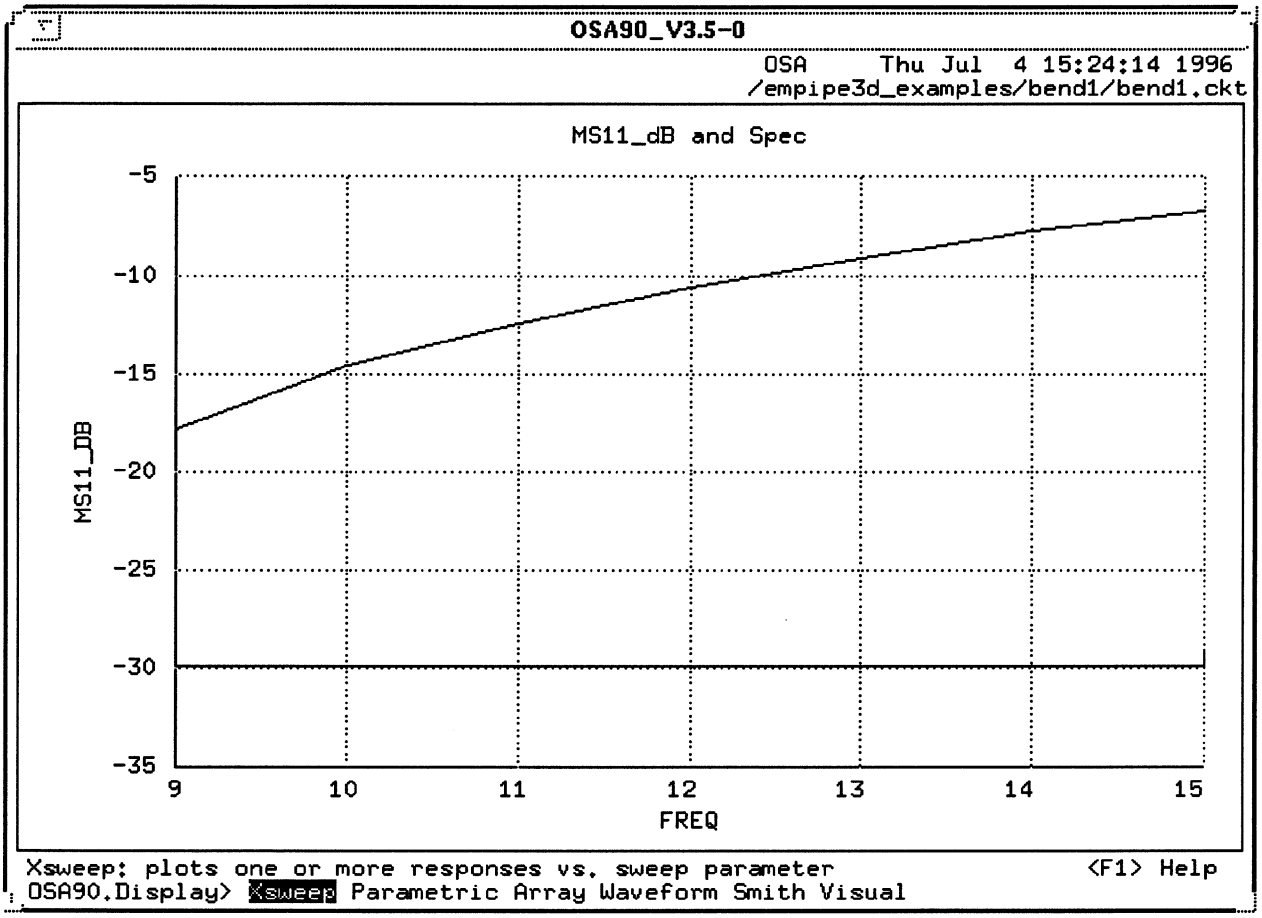
```
! Empipe3D user-defined structure BEND1

Model
#include "bend1_osa/bend1.inc";

   BEND1_d: ?0.05 0.2 0.35?;

   BEND1  1 2 0  model=7
      d=(BEND1_d * 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];
end

Sweep
   AC: FREQ: from 9GHz to 15GHz step=1GHz MS11_dB
      {XSWEEP title="MS11_dB and Spec" X=FREQ Y=MS11_dB
       SPEC=(from 9GHz to 15GHz, < -30)};

   AC: FREQ: from 9GHz to 15GHz step=1GHz MS MS_DB PS
      {Smith MP=(MS11,PS11).S11}
      {Polar MP=(MS21,PS21).S21};
end

Spec
   AC: FREQ: from 9GHz to 15GHz step=1GHz MS11_dB < -30;
end

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

File: reads, edits, parses and saves files <F1> Help

OSA90> File Display Optimize Macro Sensitivity monteCarlo Learn

this netlist is automatically generated from the data entered in the Empipe3D form editor windows

EM Simulation at the Starting Point



the specification of -30 on the MS11_DB response (magnitude of S_{11} in dB) is not satisfied

Optimization

to start optimization, click on the menu option "Optimize"

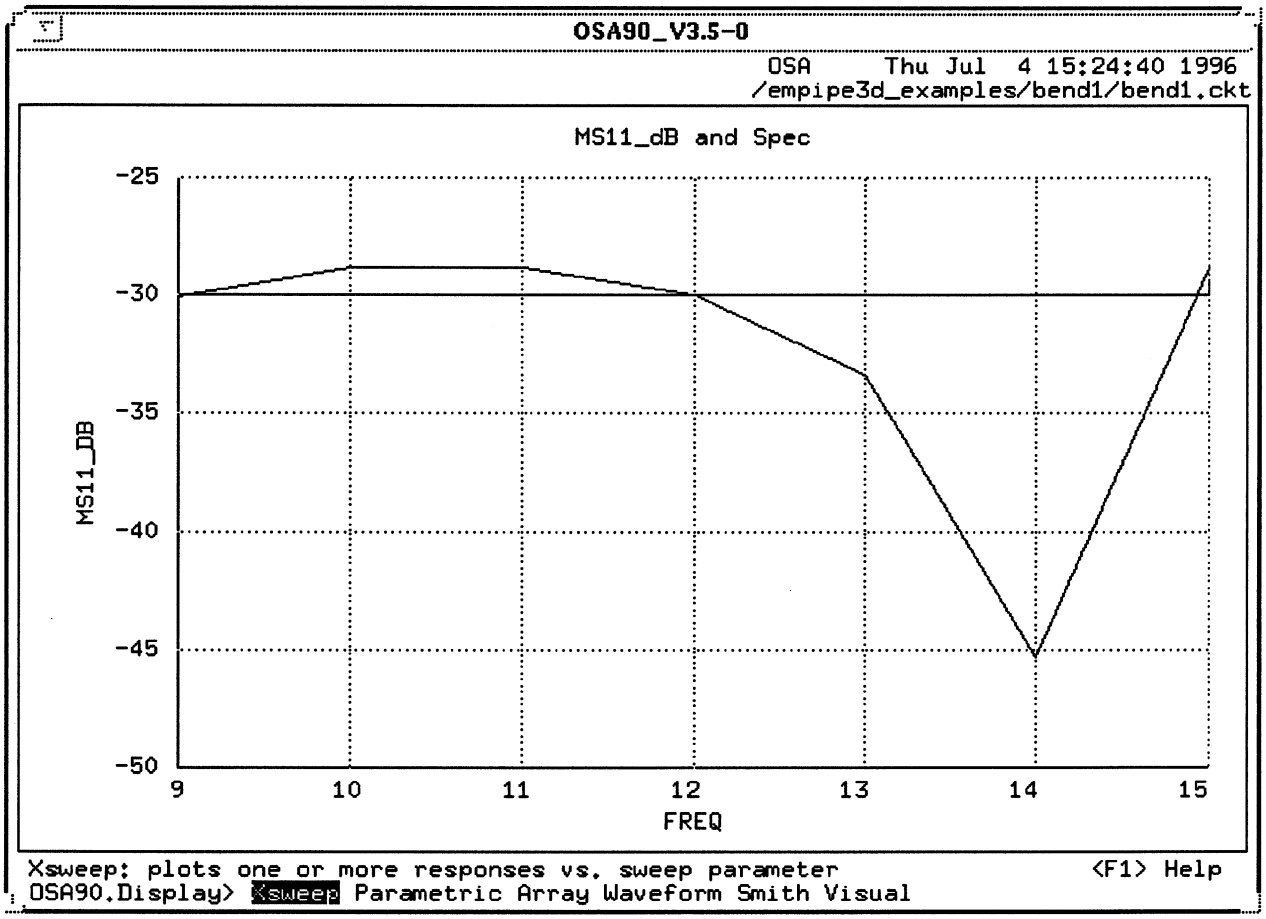
the progress of optimization is reported on the screen

```
Iteration  1/30 Max Error=23.2428
Iteration  2/30 Max Error=22.0957
Iteration  3/30 Max Error=19.2298
Iteration  4/30 Max Error=9.69842
Iteration  5/30 Max Error=19.0108
Iteration  6/30 Max Error=1.45415
Iteration  7/30 Max Error=1.14845
Iteration  8/30 Max Error=1.14157
Solution  Max Error=1.14157
```

the 3D Solver simulation results are saved in a database

the optimization of the single section mitered bend required 4 simulations by the 3D Solver

Waveguide Bend Response After Optimization

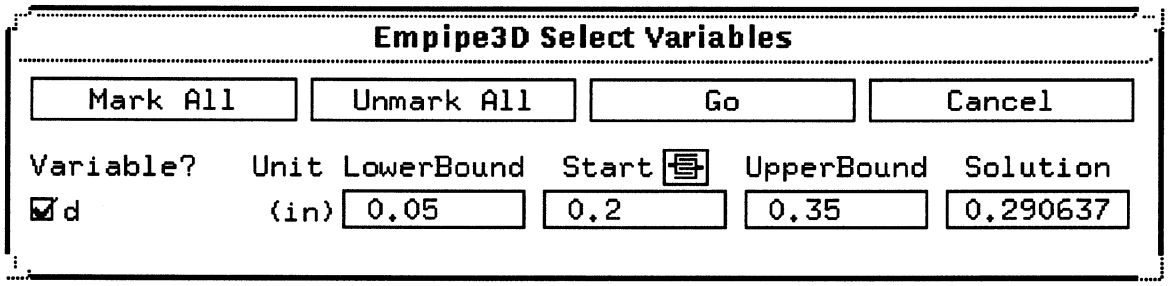


the MS11_DB response is greatly improved from that of the starting point

the responses of the optimized waveguide bend can be viewed instantly: they are retrieved from the database

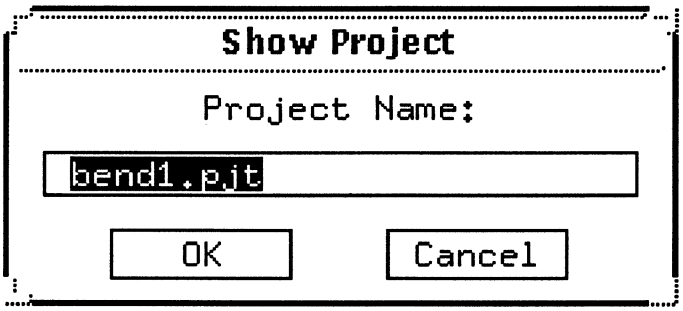
The Optimized Parameter Value(s)

after optimization is finished the "Empipe3D Select Variables" window reappears on the screen



Viewing the Optimized Bend

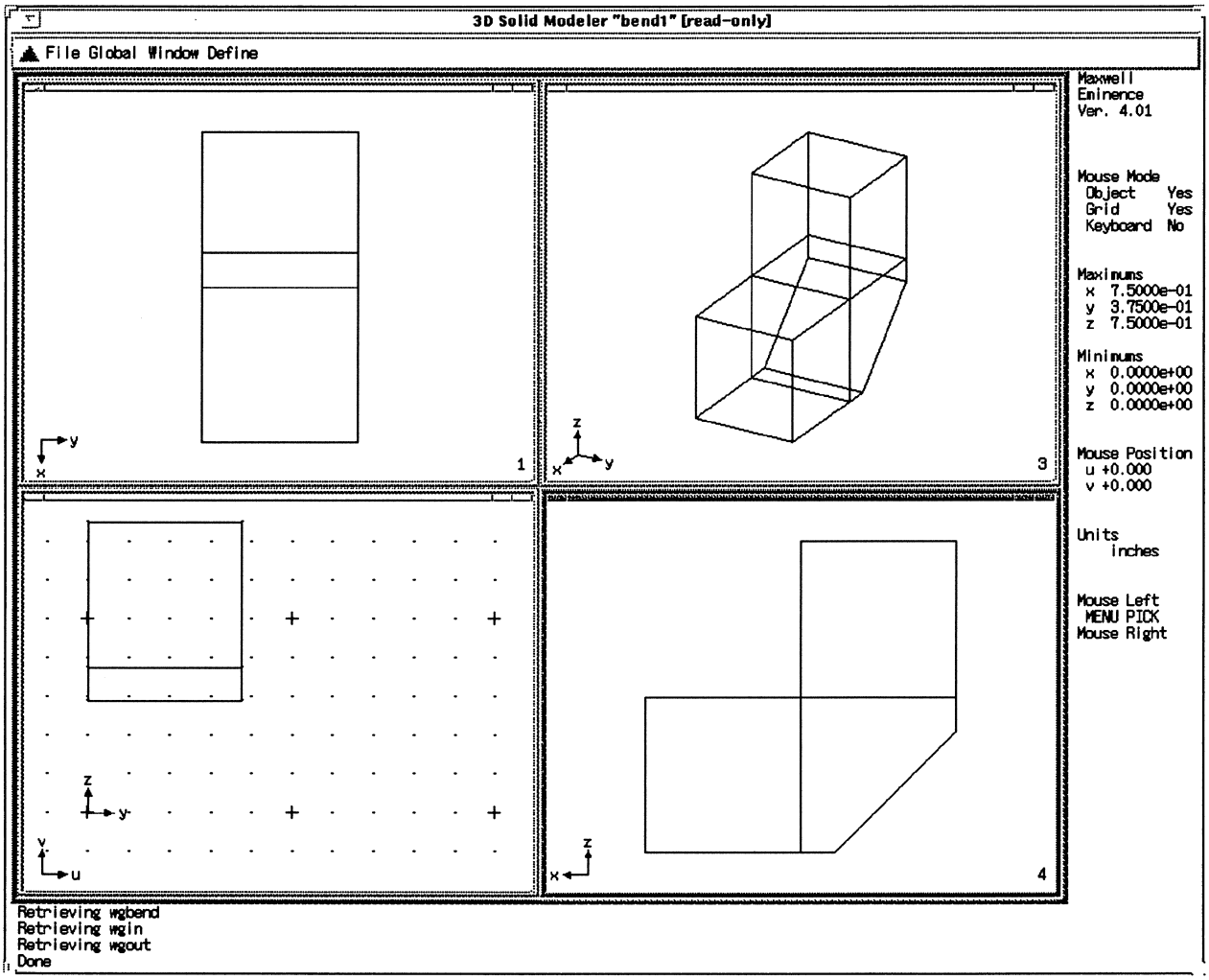
click on the entry box under the heading "Start" and type in the optimized parameter value "0.290637"



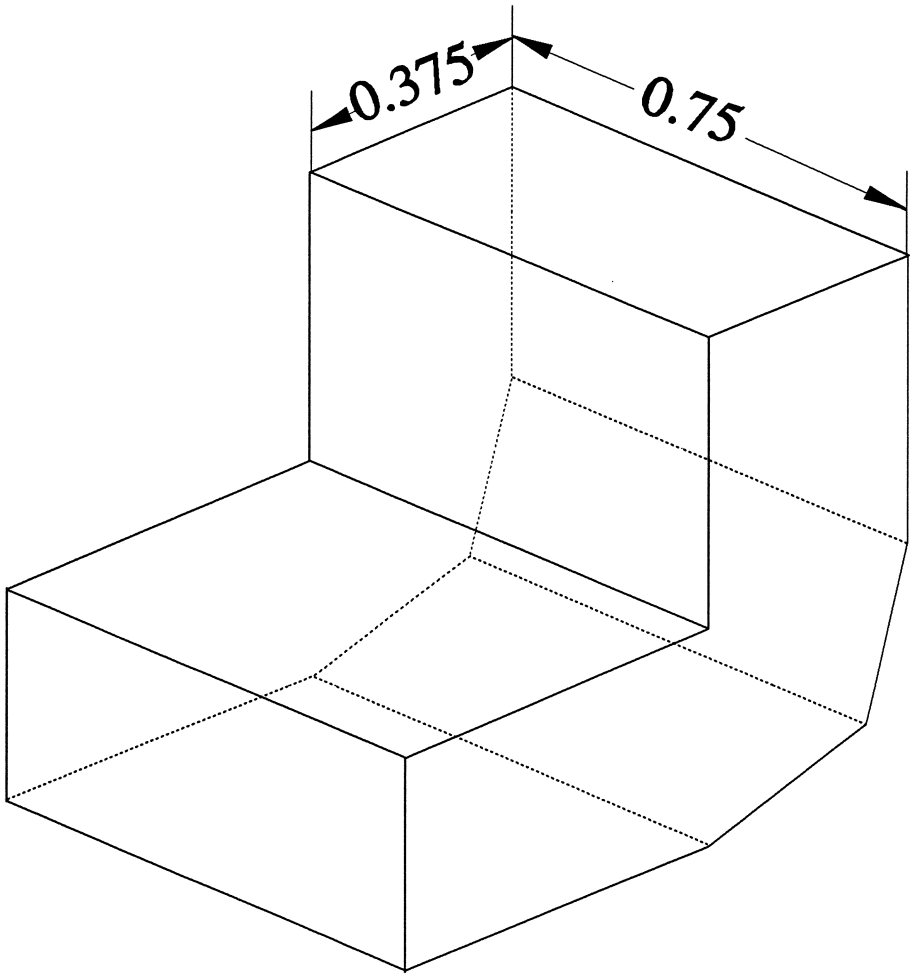
the optimized structure will be saved in the project directory "bend1.pjt"

The Solid Model of the Optimized Bend

the button invokes the 3D Solid Modeler to view the optimized bend structure



Waveguide Mitered Bend



two-section miter

Outline

how to parameterize the two-section bend

how to select variables and define specifications

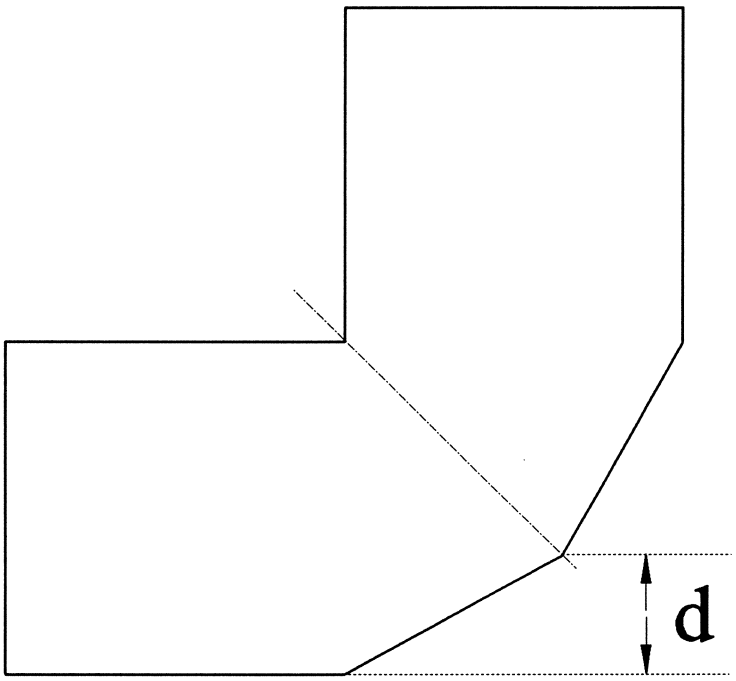
how to start simulation and optimization

how to view the Smith Chart and Polar Plot

how to verify the optimized solution

how to generate projects with arbitrary parameter values using Empipe3D

Definition of the Optimizable Parameter d



design specification

$$20\ log_{10}(|S_{11}|) < -40$$

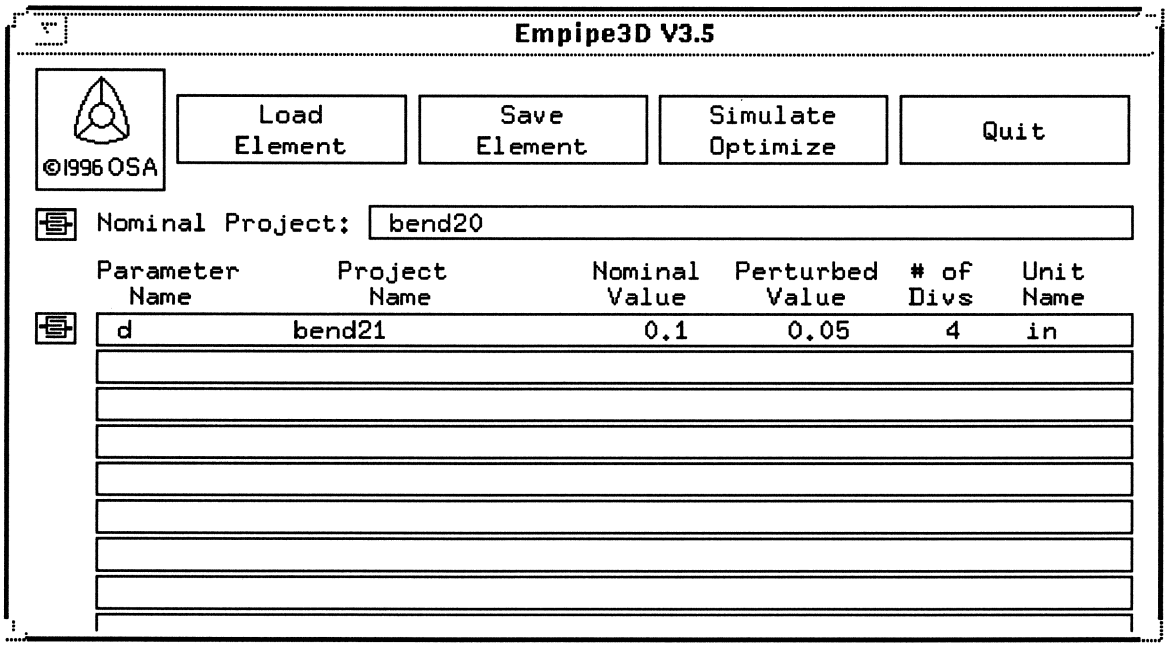
for frequencies from 9 to 15 GHz (with a 1 GHz step)

Setting Up The Projects

start Empipe3D using the command

```
empipe3d  bend2
```

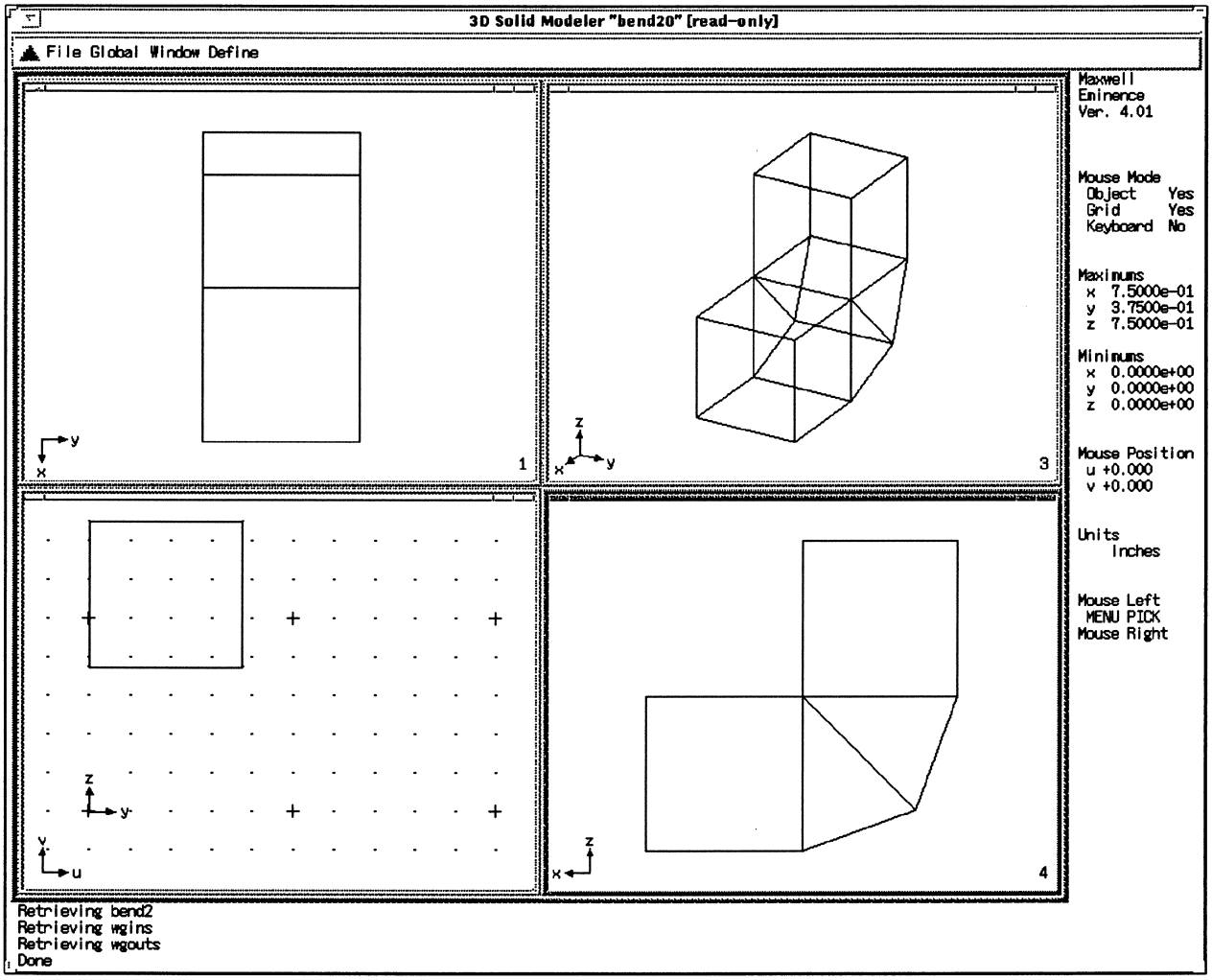
"bend2" represents the Empipe3D element name



"bend20" is the nominal project name

"bend21" is the name of another project

Solid Model for the Nominal Project



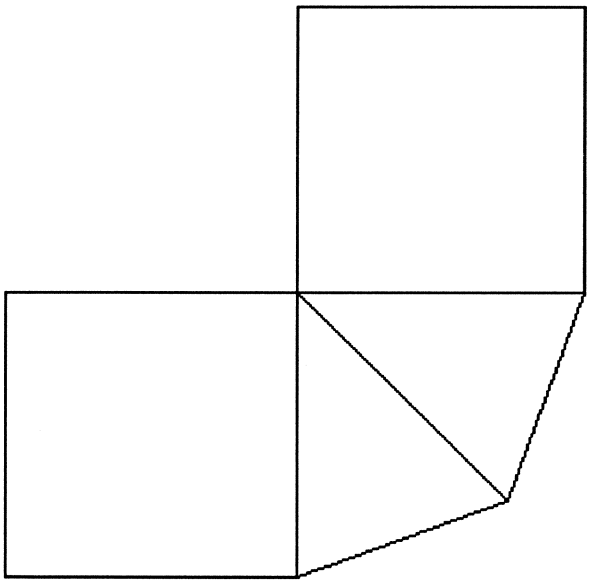
can be a design obtained by synthesis, from experience, or through optimization of an empirical model

only half of the structure is drawn

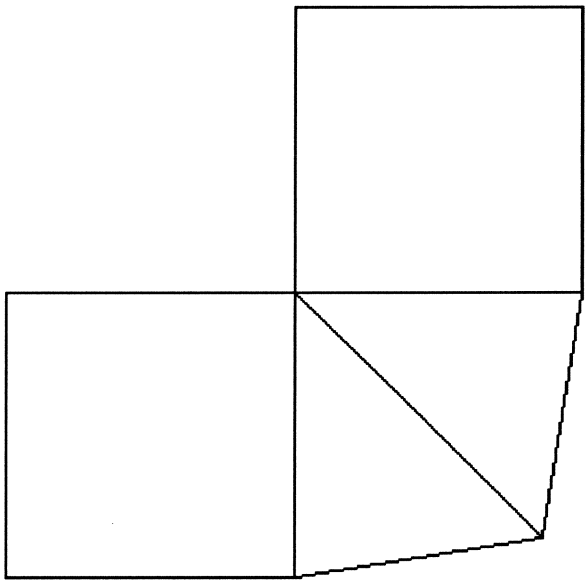
Representing Incremental Change

to parameterize the structure for optimization

we create a new project representing an incremental change in a parameter



nominal project
d = 0.1 inch

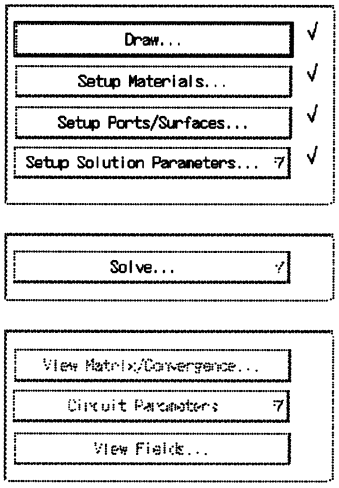


incremental change
d = 0.05 inch

by comparing the new project with the nominal project Empipe3D captures the information necessary for translating parameter values to a corresponding solid model

Guidelines for Preparing the 3D Solver Projects

the nominal project should include the complete setup of material, ports, boundaries and solution parameters



do not solve or mesh the projects (avoid option "Boundary Display" in the "Setup Ports/Surfaces" menu)

create a new project by copying and modifying the nominal project

the number of 3D solid objects and the number of vertices must remain the same

to modify a 3D object, delete the existing object and redraw a new one, keeping the same object name

the order of the vertices of the redrawn object must remain the same

Verifying the Consistency Between Projects

using the utility program "cmpjt" supplied with Empipe3D

```
cmpjt  bend20  bend21
```

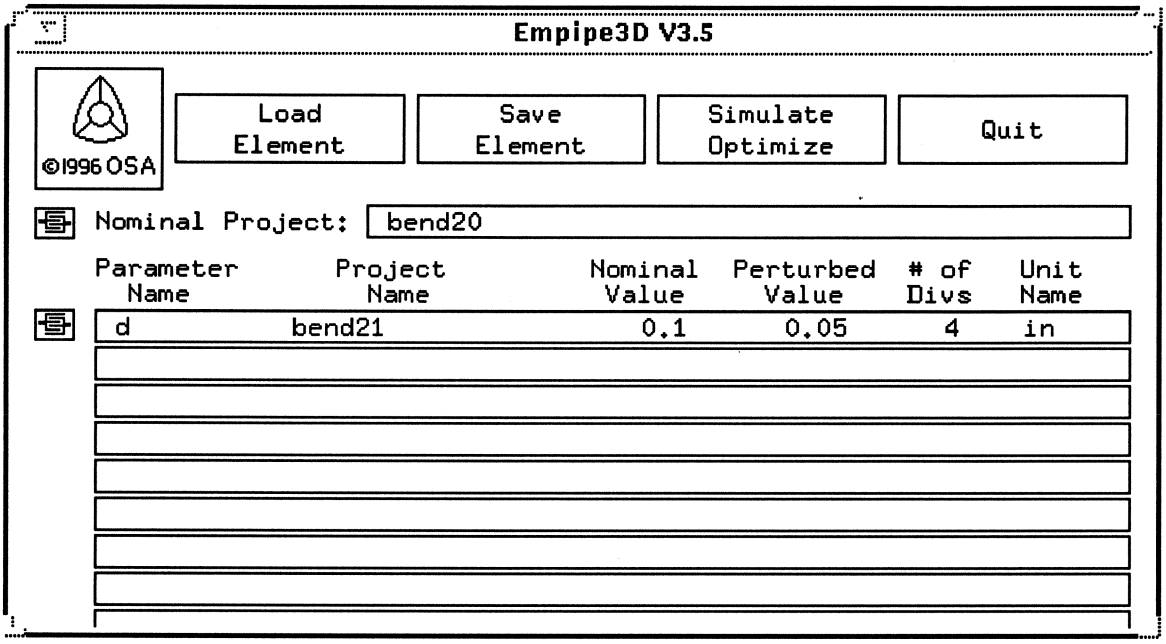
files being compared

the solid model files (*.sld)
the port/boundary and solution definition files (*.sat)
the material definition files (*.db)

typically, the incremental change in one parameter affects relatively few lines in these files

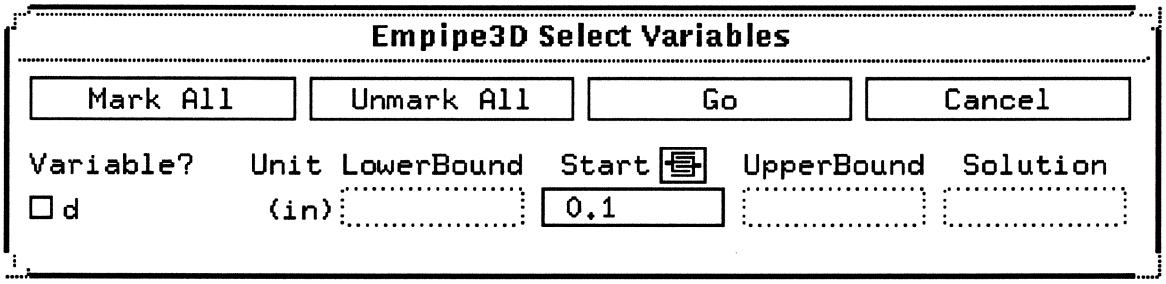
if the differences appear to be numerous then it is likely that the Geometry Capture procedures have been violated

Details of the Geometry Capture Form Editor



"# of Divs"	the number of interpolation intervals	
"Unit Name"	IN (inch), MIL (milli-inch), etc.	
nominal project:	bend20	d = 0.1 inch
perturbed project:	bend21	d = 0.05 inch

Window for Selecting Optimization Variables



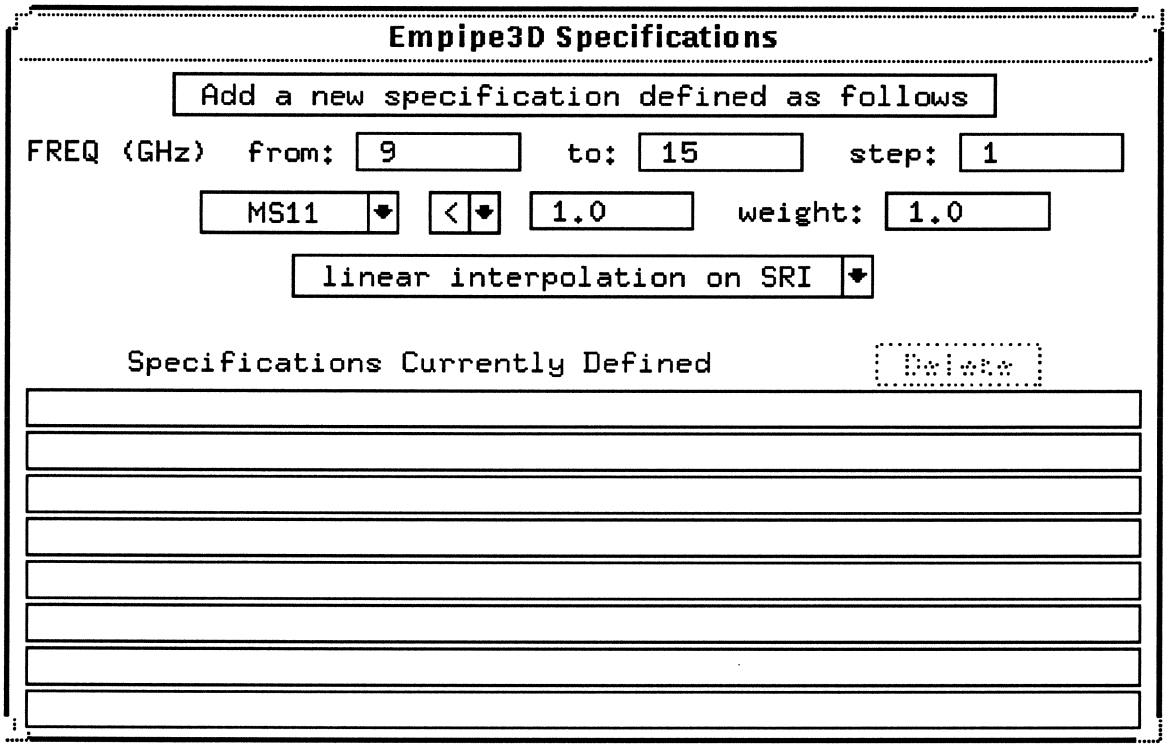
by default, the nominal project value(s) are offered as the starting value(s)

upper and/or lower bound may also be specified

setting suitable bounds on all the variables is advisable to prevent the optimizer from changing the structure beyond what can be realized physically

for the two-section mitered bend it is desired to enter 0.025 and 0.35 inch as the bounds

Specifications for Optimization



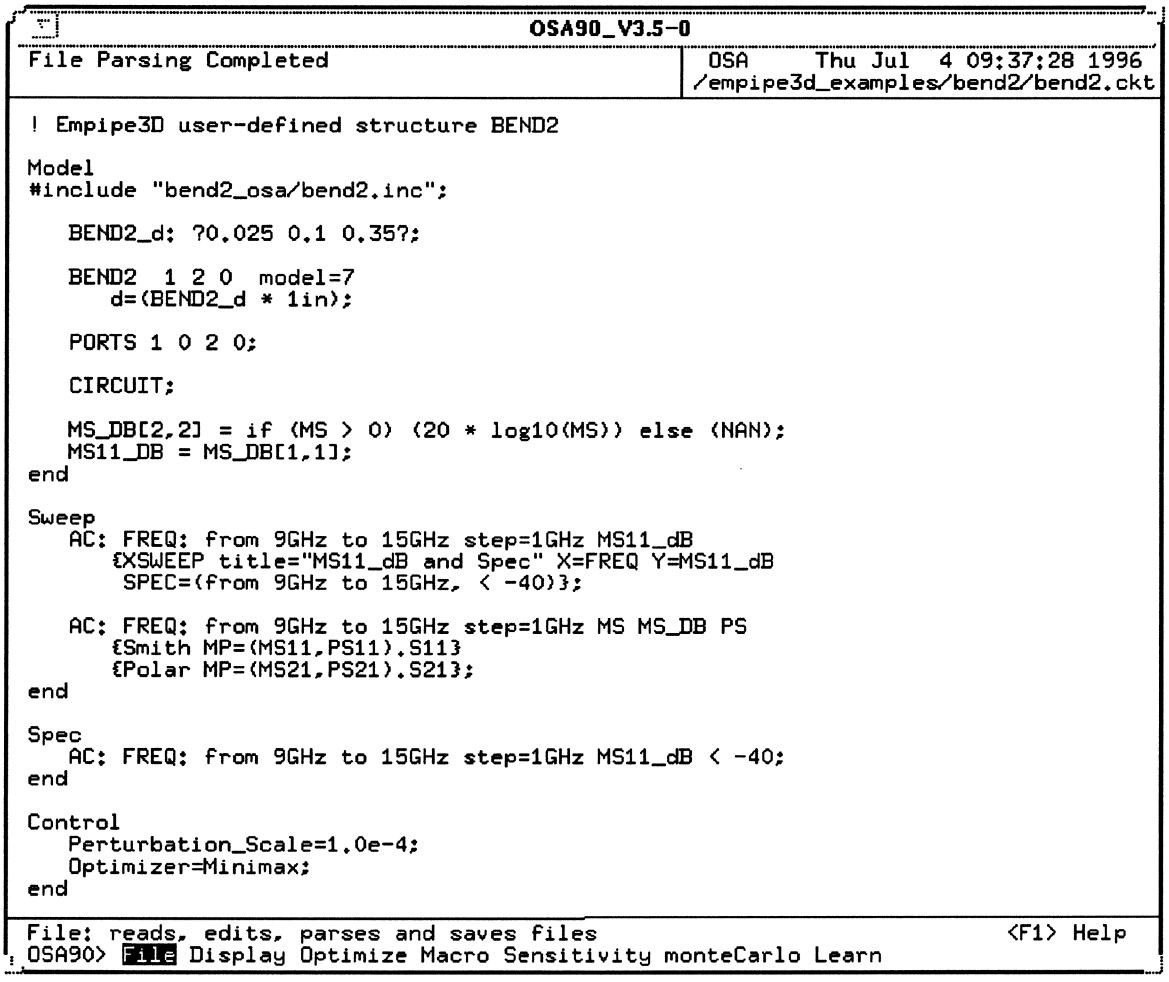
select

frequency range (9 GHz to 15 GHz)
S-parameter response (e.g., $|S_{11}|$ in dB)
specification type (upper, lower or equality)
interpolation type (optional)

enter

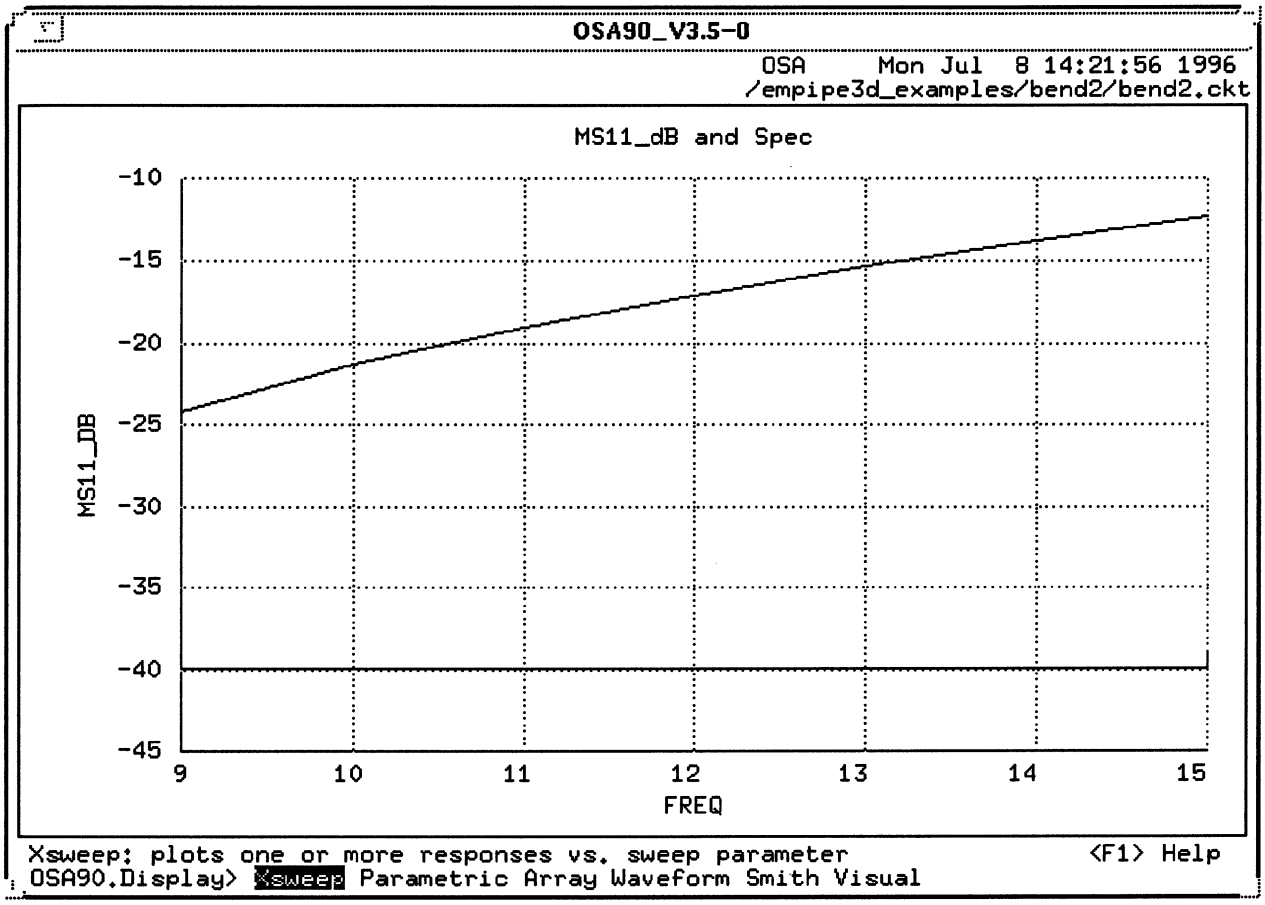
numerical value as the goal (e.g., -40 dB)
weighting factor (optional)

OSA90 Simulation



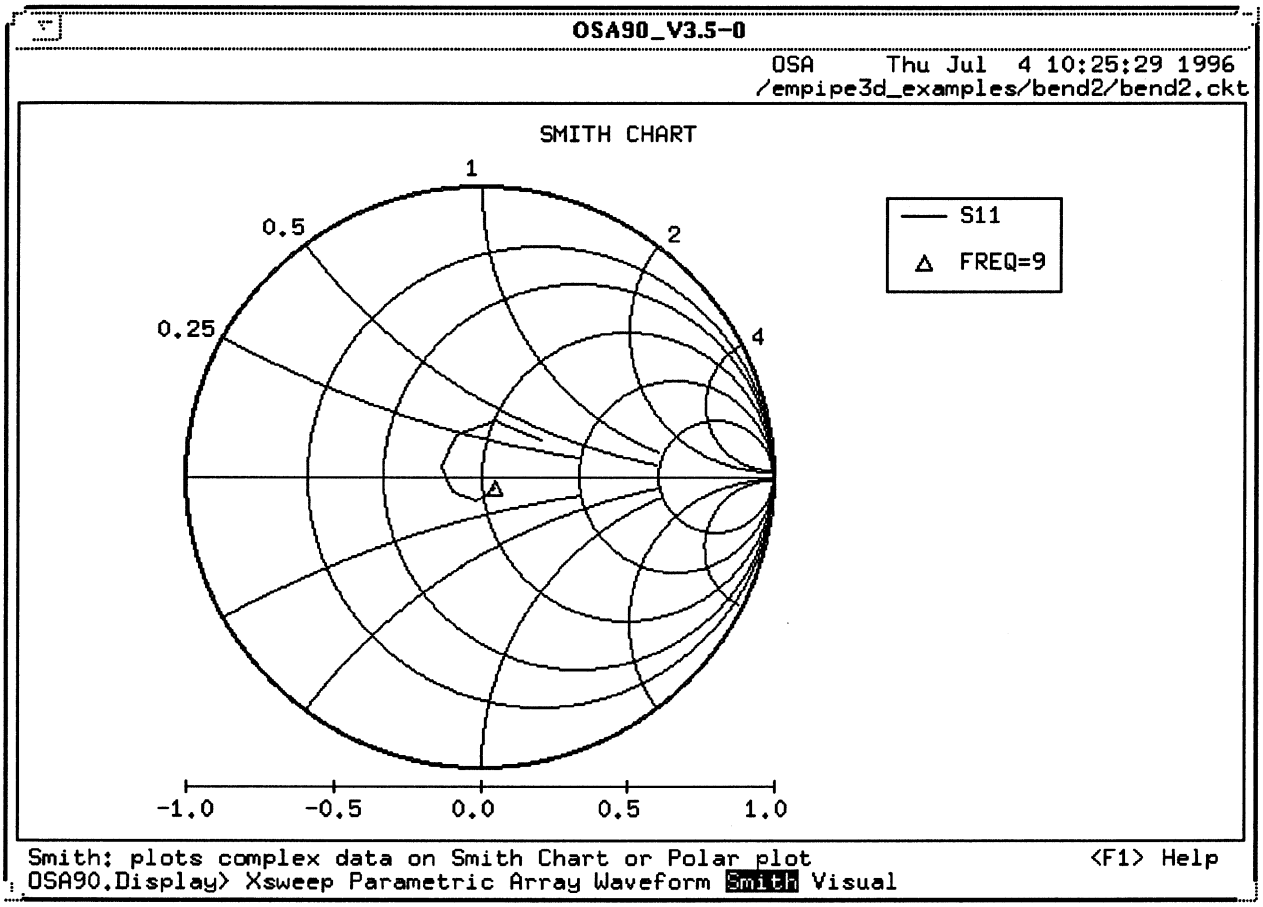
this netlist is automatically generated from the data entered in Empipe3D form editor windows

Waveguide Bend Response Before Optimization



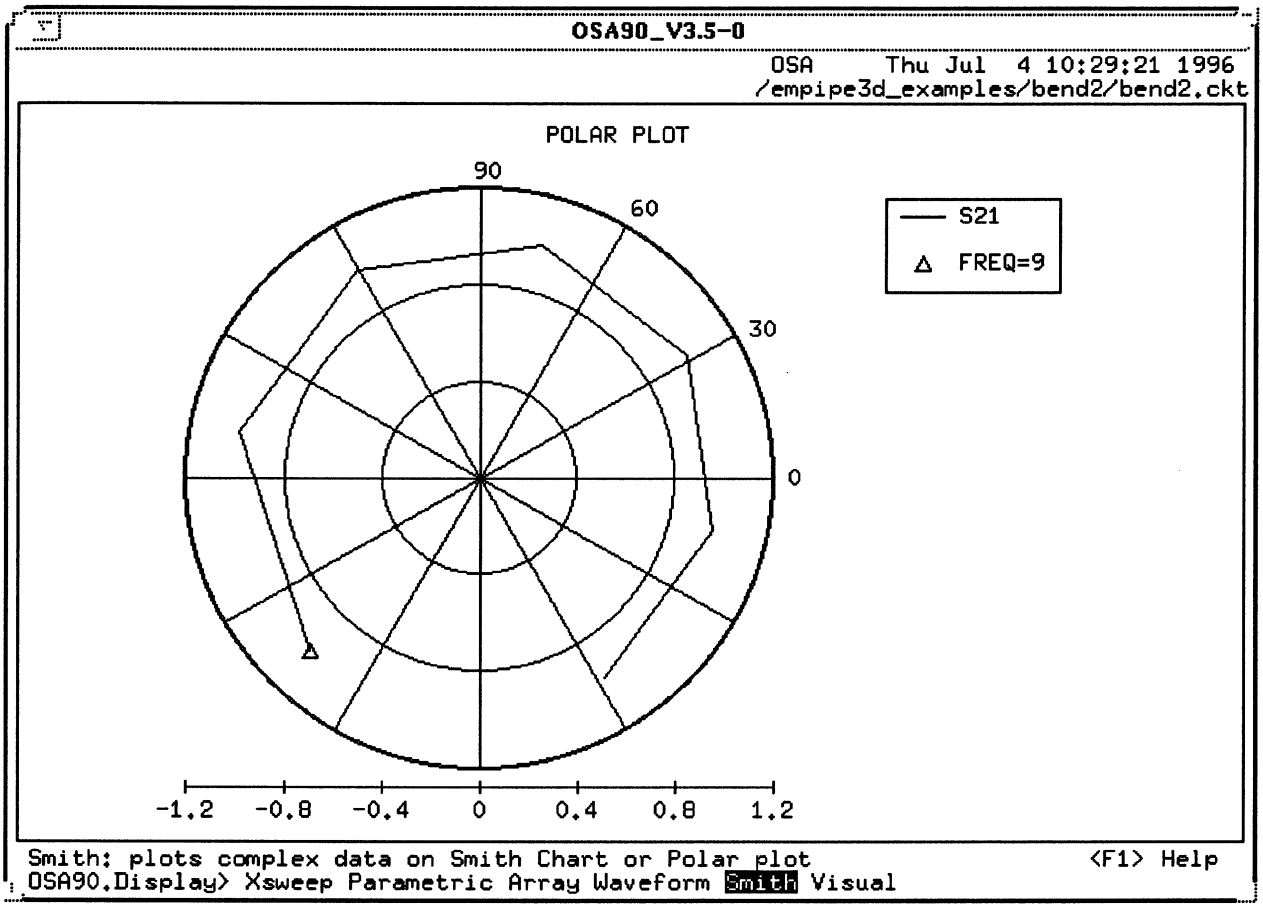
the specification of -40 dB on MS11_DB (magnitude of S_{11} in dB) is clearly not satisfied

Viewing the Smith Chart



S_{11} of the waveguide mitered bend before optimization displayed on the Smith Chart

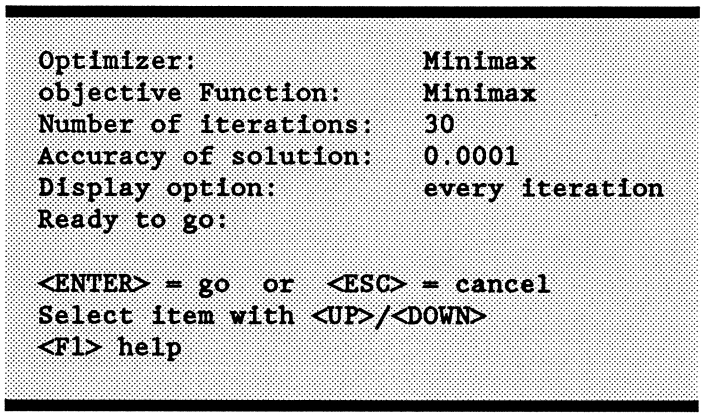
Viewing the Polar Plot



S_{21} of the waveguide mitered bend before optimization displayed on the Polar Plot

Optimization

a pop-up window shows the options related to optimization

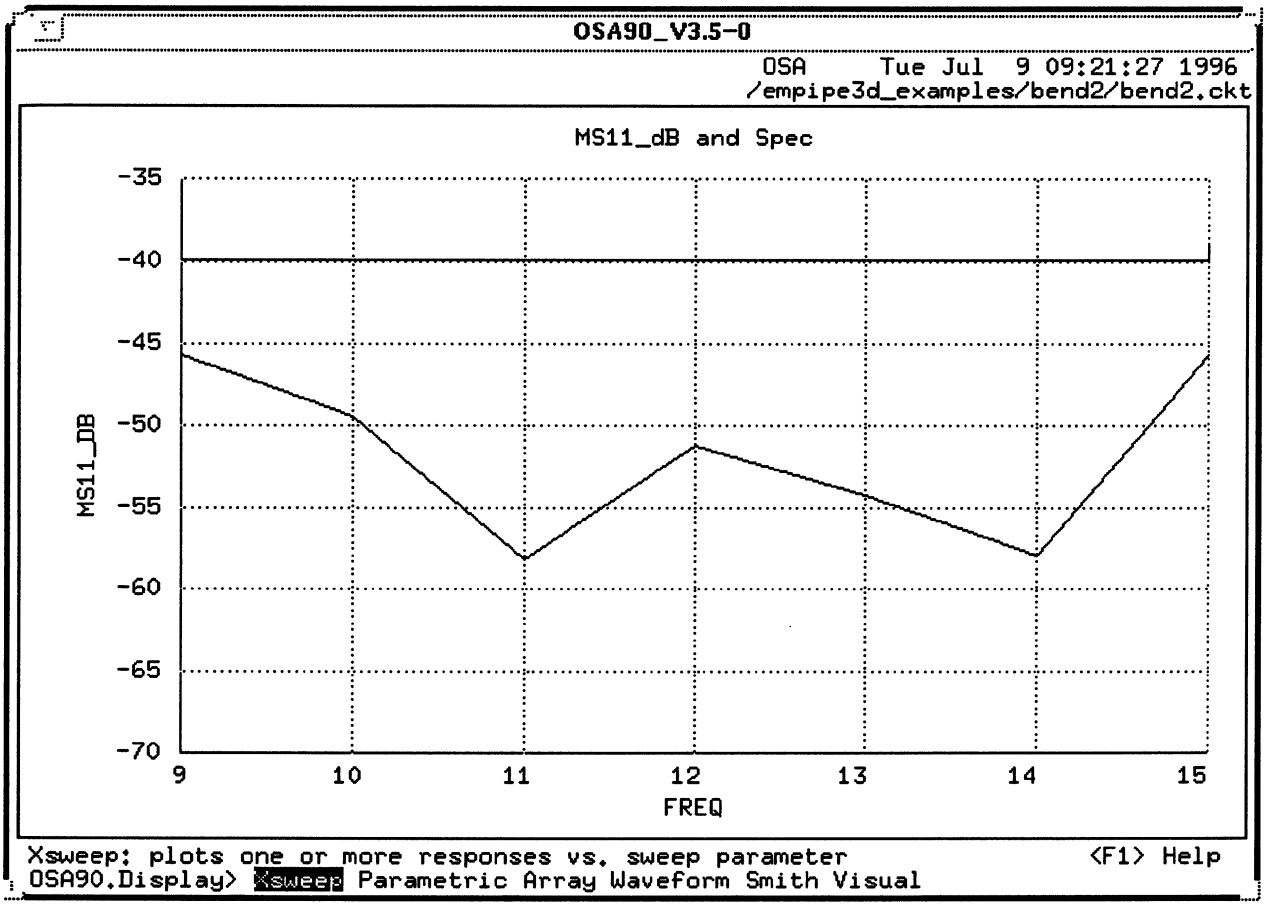


the progress of optimization is reported on the screen

```
Iteration  1/30 Max Error=27.6123
Iteration  2/30 Max Error=24.2567
Iteration  3/30 Max Error=5.62896
Iteration  4/30 Max Error=27.7546
Iteration  5/30 Max Error=14.416
Iteration  6/30 Max Error=-4.11578
Iteration  7/30 Max Error=-1.44774
Iteration  8/30 Max Error=-4.82617
Iteration  9/30 Max Error=-5.59967
Iteration 10/30 Max Error=-5.86199
Iteration 11/30 Max Error=-5.87395
Solution  Max Error=-5.87395
```

the optimization of the two-section mitered bend required 7 simulations by the 3D Solver

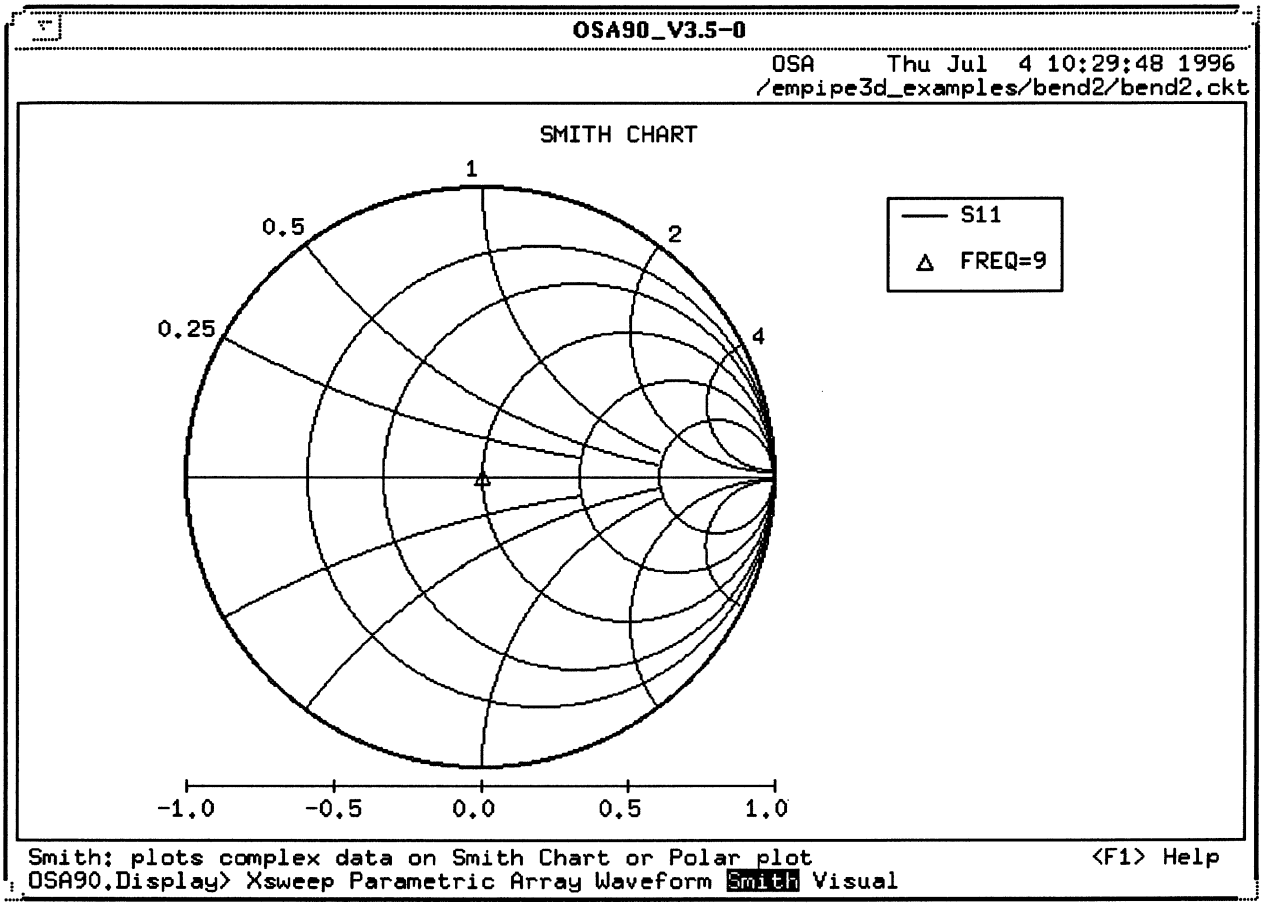
Waveguide Bend Response After Optimization



the specification of -40 dB on MS11_DB is now clearly satisfied

the responses of the optimized waveguide bend can be viewed instantly: they are retrieved from the database

The Optimized Response on the Smith Chart



since the optimized S_{11} is nearly zero, the curve on the Smith Chart appears to be reduced to a single point

Verifying the Optimized Response

can we trust the optimized response calculated by Empipe3D, since it is likely the result of interpolation?

the optimized response can be verified by forcing Empipe3D to invoke directly the 3D Solver (no interpolation)

turning off the interpolation option is possible in the OSA90 file editor

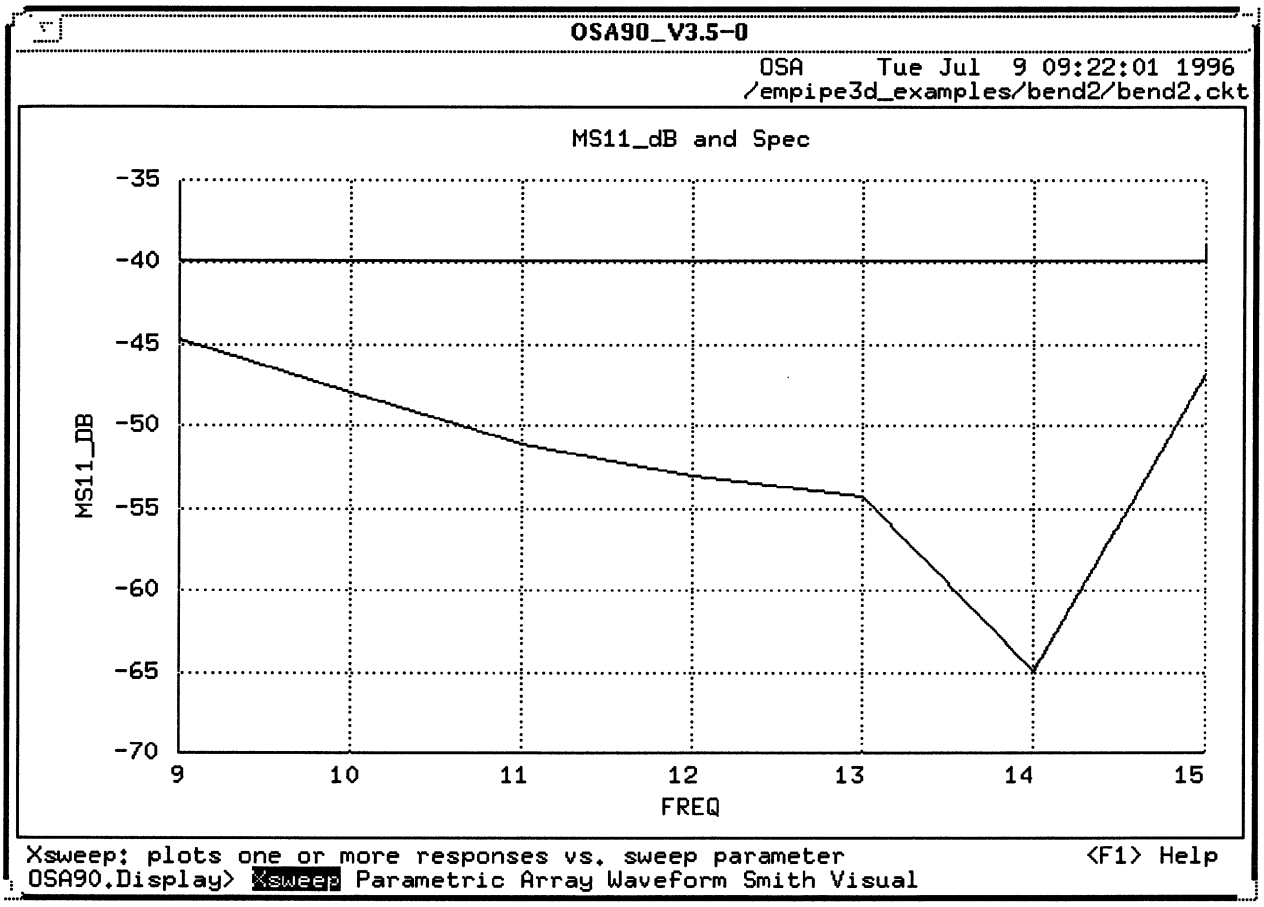
the following text appears near the top of the input file (netlist)

```
BEND2_d: ?0.025 0.133166 0.35?;

BEND2  1 2 0  model=7
  d=(BEND2_d * 1in);
```

to turn off the interpolation feature, change the "model" option

```
BEND2  1 2 0  model=0
```

The Optimized Response Calculated Without Interpolation



comparison with the interpolated response confirms that interpolation actually worked very well

the differences between the responses calculated with and without interpolation occur mostly below -50 dB

Generating Projects Using Empipe3D

tweaking a design in its final stage by experienced hands often involves changing one or two parameters for a number of trials until a satisfactory result emerges

use of the 3D Solver without Empipe3D

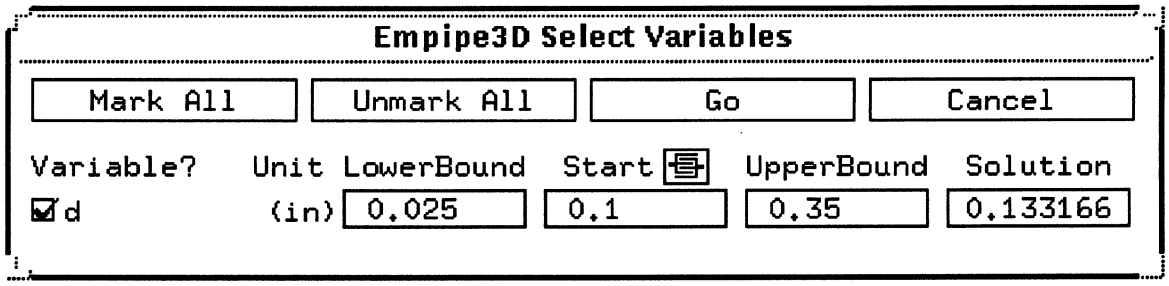
> besides having to wait for the EM field analysis, another tedious task is to redraw the solid model for each trial structure

with Empipe3D

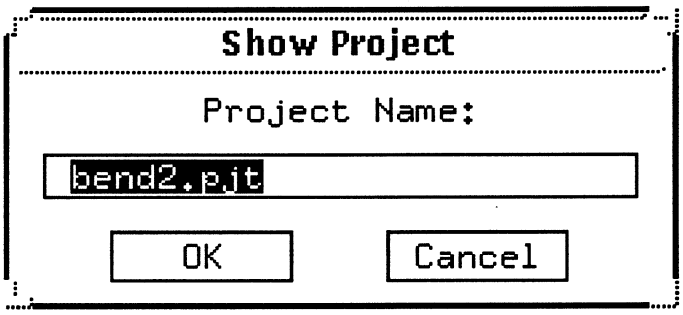
> once the structure has been parameterized, one click of a button generates a new 3D Solver project (all files) for arbitrarily changed parameter values

Generating a Project for the Optimized Bend

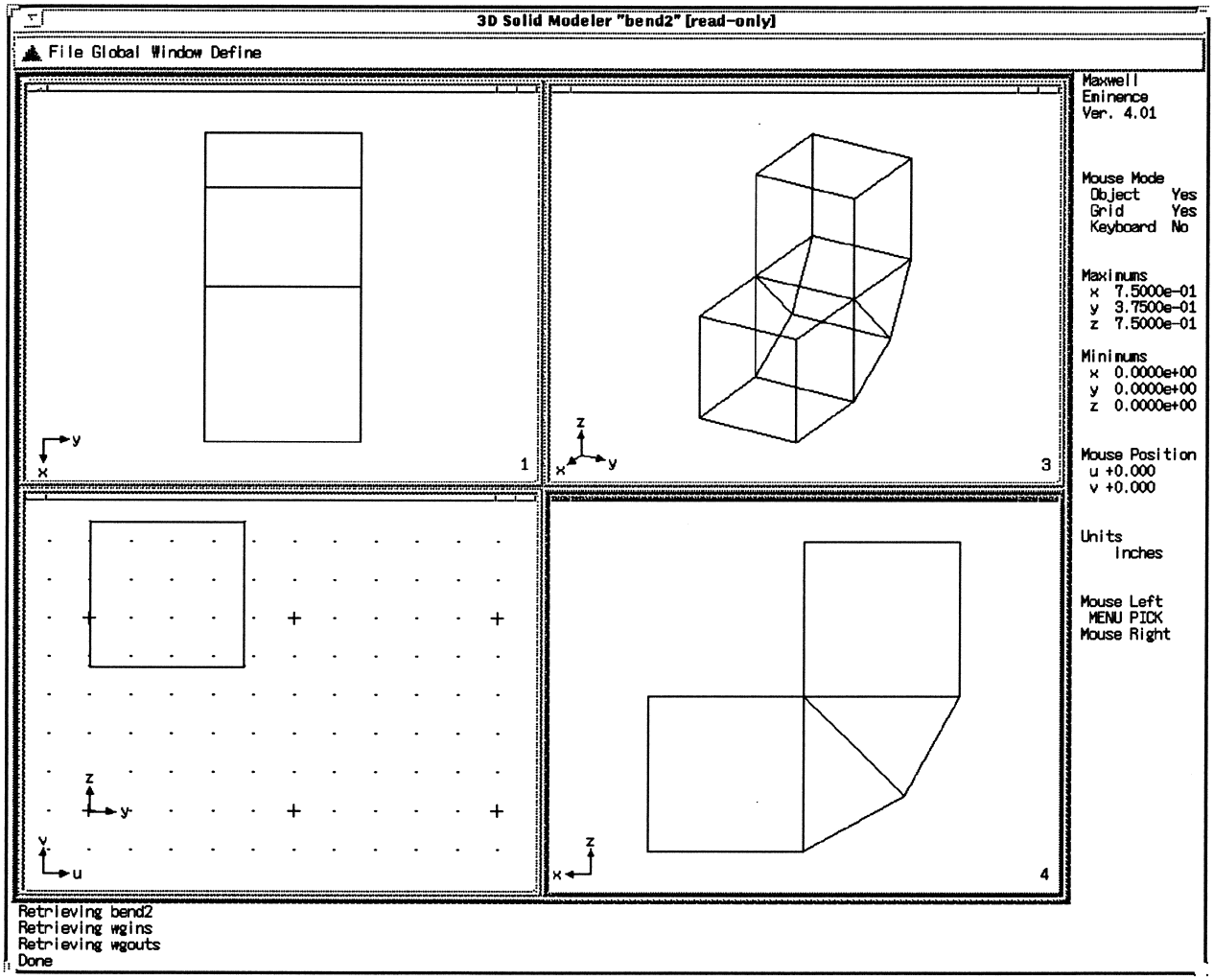
upon exiting from the OSA90 environment, the "Empipe3D Select Variables" window reappears on the screen



change the entry box under the heading "Start" to the optimized parameter value "0.133166" and click on



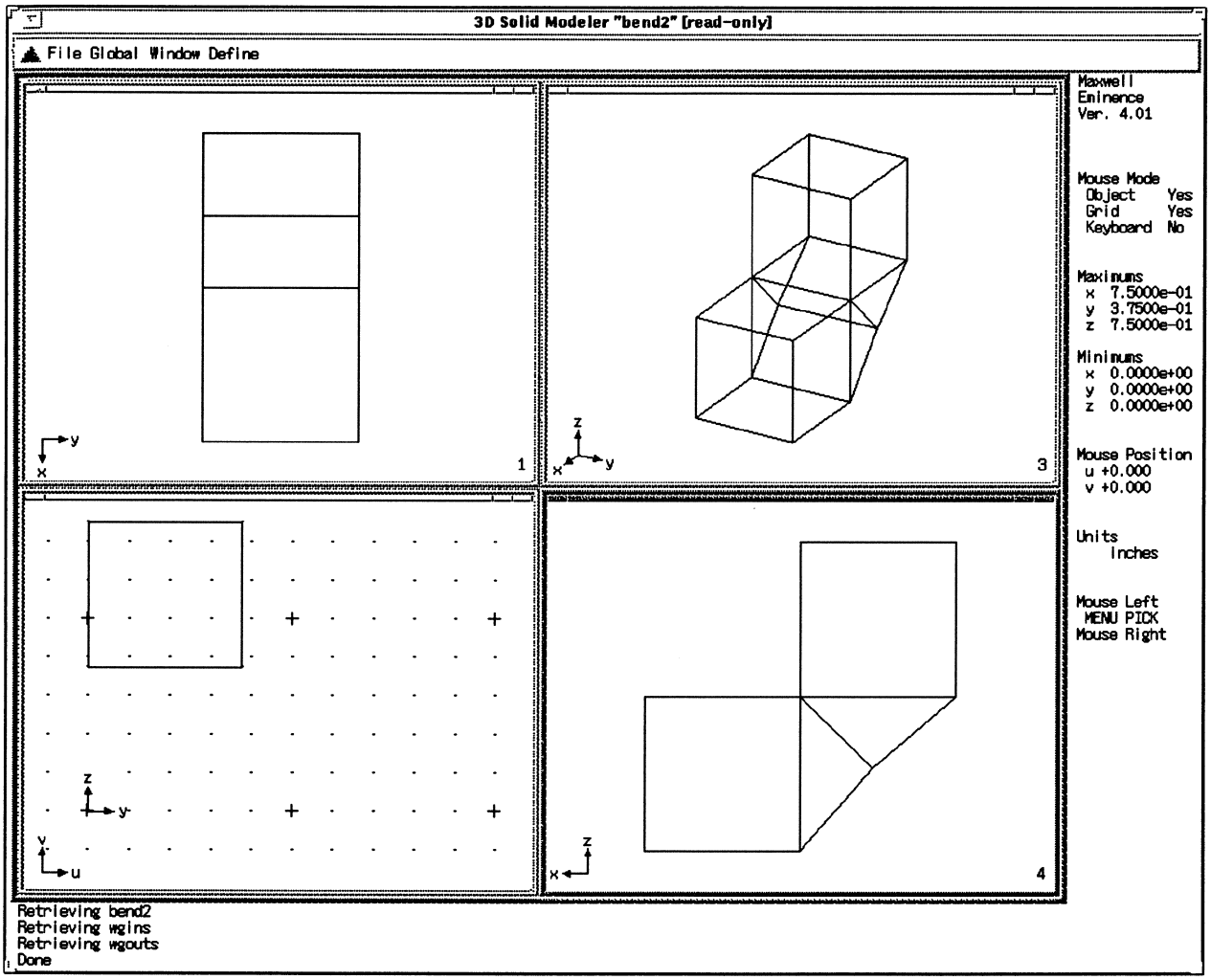
The Solid Model of the Optimized Bend



the optimized structure is saved in the project directory "bend2.pjt"

Projects with Arbitrary Parameter Values

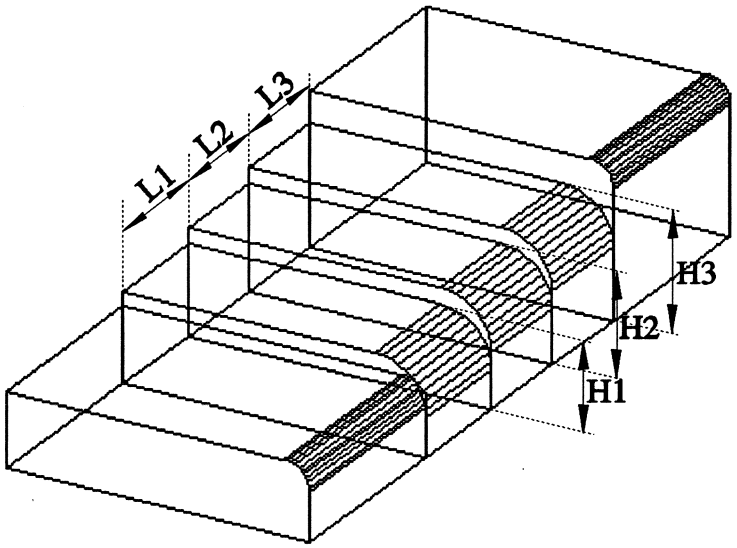
can be generated using the same procedure



the solid model for $d = 0.2$ inch

generating new projects for arbitrary parameter values can also be used as a means of validating the result of Geometry Capture

Three-Section Waveguide Impedance Transformer



including the corner radius in the model makes it unsuitable for MM simulators and necessitates the use of a FEM solver

designed for impedance matching between a WR-75 half height and a WR-75 full height waveguides - the heights and lengths of the three sections are optimizable variables

design specification

$$20\,log_{10}(|S_{11}|) < -30$$

for frequencies from 9.5 to 15 GHz (with a 0.5 GHz step)

Outline

projects for Geometry Capture of a 3D structure with multiple parameters

defining variables and specifications

verifying the parameterization result by visual inspection

simulation and optimization

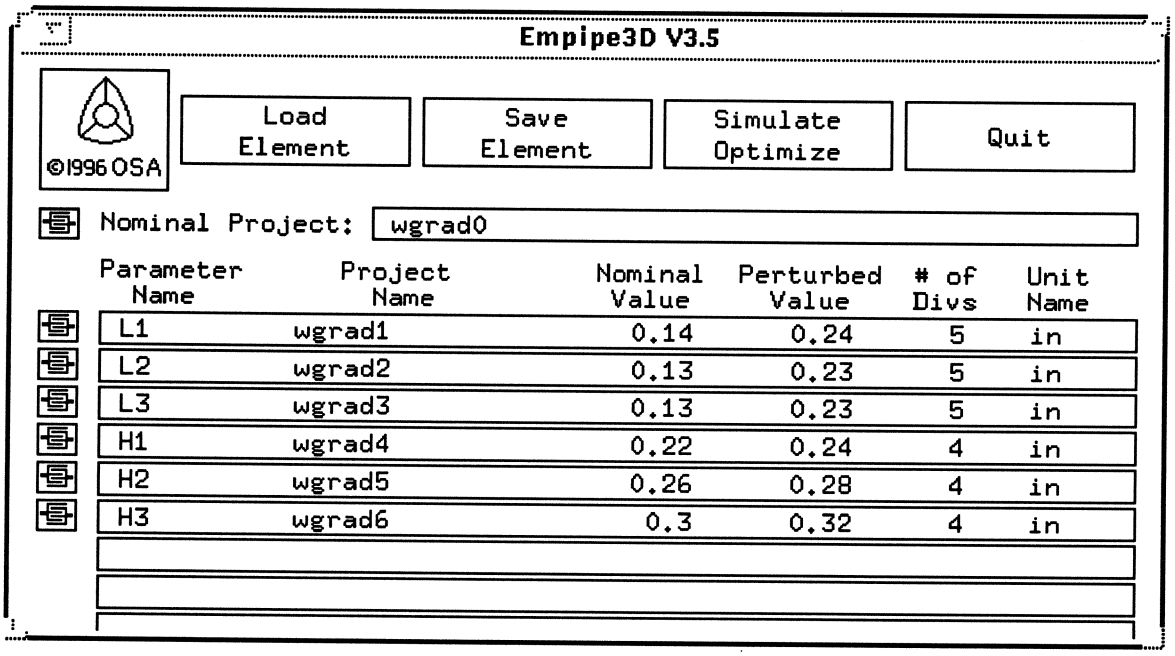
how to manipulate the various display options

Setting up the Projects

start Empipe3D using the command

```
empipe3d  wgrad
```

"wgrad" represents the Empipe3D element name

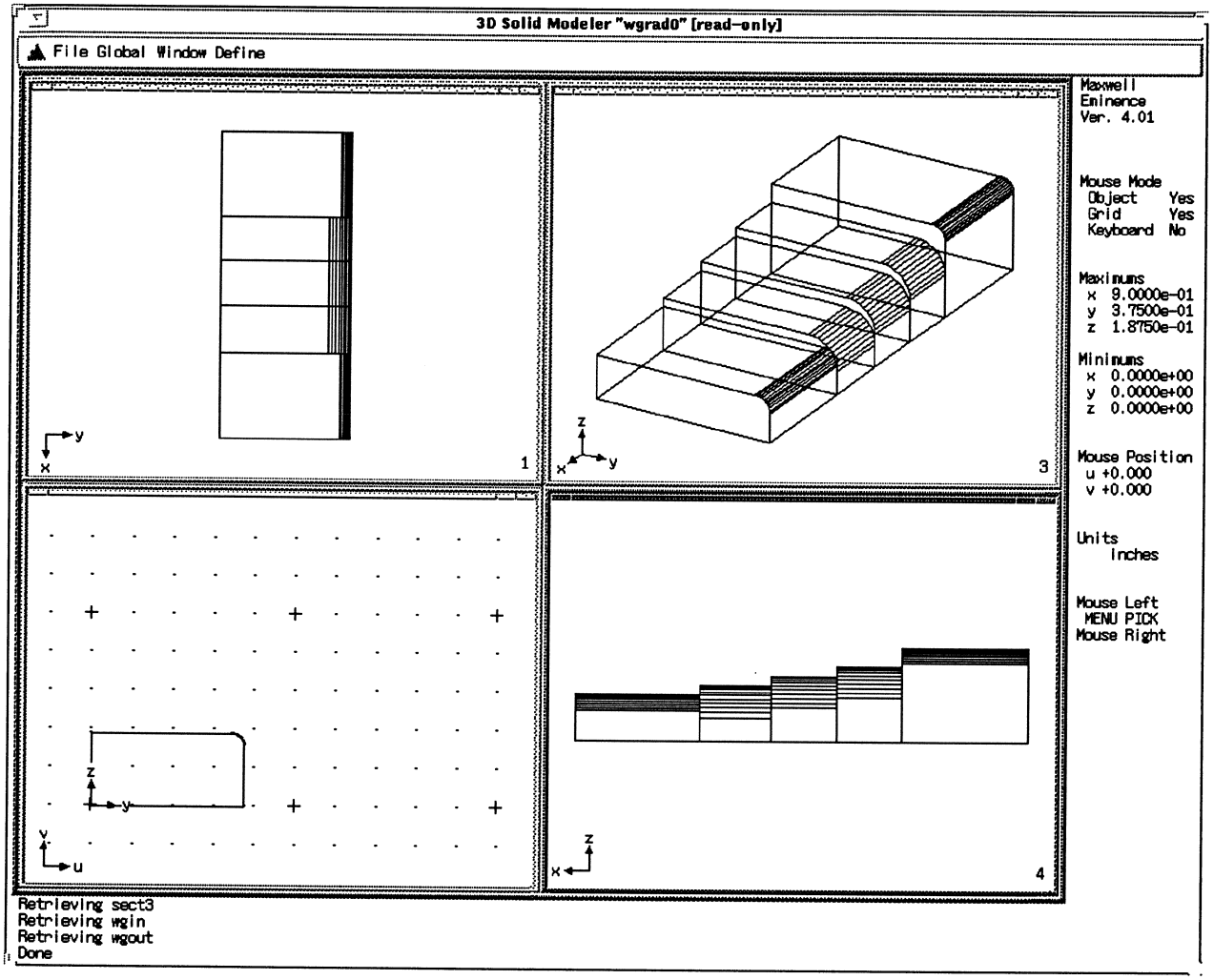


Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
L1	wgrad1	0.14	0.24	5	in
L2	wgrad2	0.13	0.23	5	in
L3	wgrad3	0.13	0.23	5	in
H1	wgrad4	0.22	0.24	4	in
H2	wgrad5	0.26	0.28	4	in
H3	wgrad6	0.3	0.32	4	in

"wgrad0" is the nominal project name

six additional projects: "wgrad1", "wgrad2", "wgrad3", "wgrad4", "wgrad5" and "wgrad6"

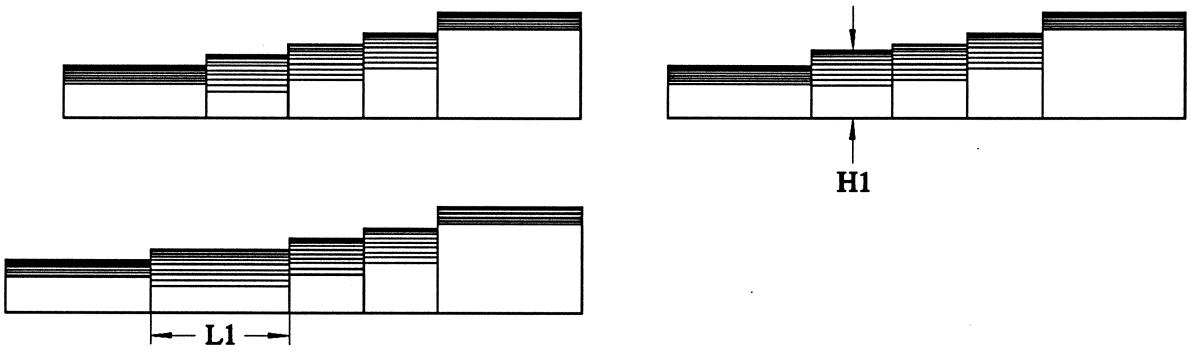
Solid Model for the Nominal Project



three-section waveguide impedance transformer

only a quarter of the structure is drawn

Representing an Incremental Change



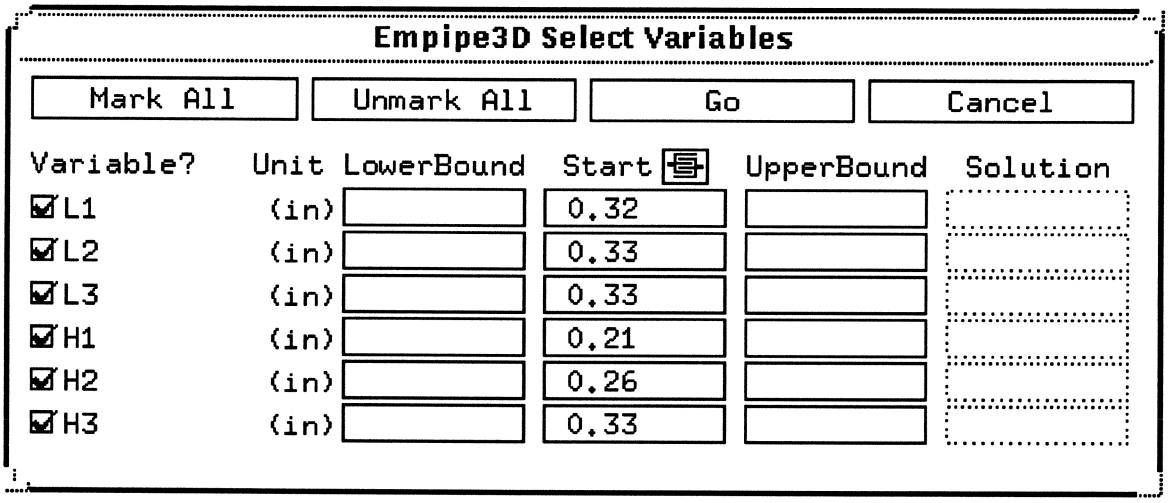
six additional projects are needed to parameterize the structure for optimization

by comparing the new project with the nominal project Empipe3D captures the information necessary for translating parameter values to a corresponding solid model

six parameters

L1, L2, L3, H1, H2 and H3

Selecting Optimization Variables



the starting values can be different from the nominal values

the nominal parameter values were chosen for convenience of drawing using the 3D Solid Modeler

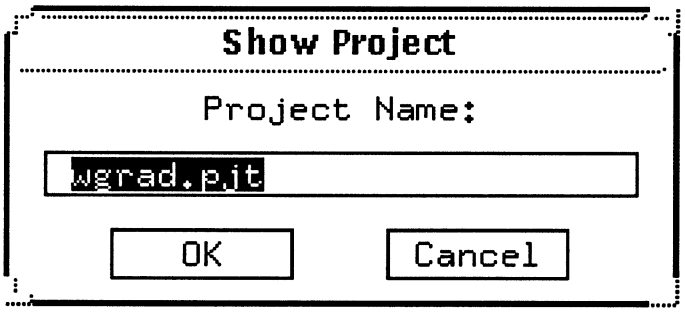
the starting values come from the optimized solution of the same structure using an empirical model which ignores the corner radius

Verifying the Result of Geometry Capture

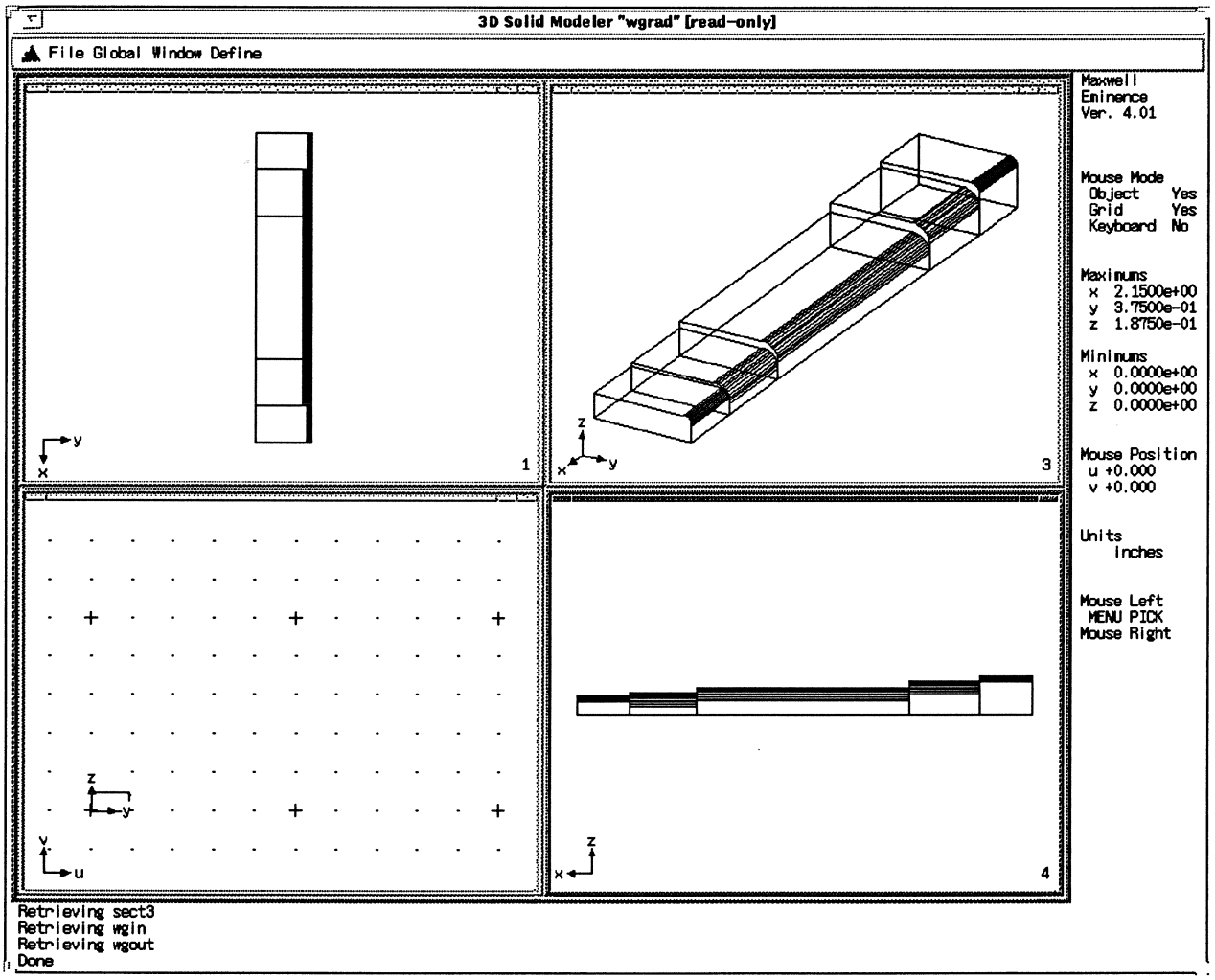
to make sure that the incremental change projects have been implemented and processed properly

a simple test: ask Empipe3D to derive a new project from the parameterization data

for example, change the entry box under the heading "Start" for the parameter "L2", enter a new value "1", click on the button, and select the project name



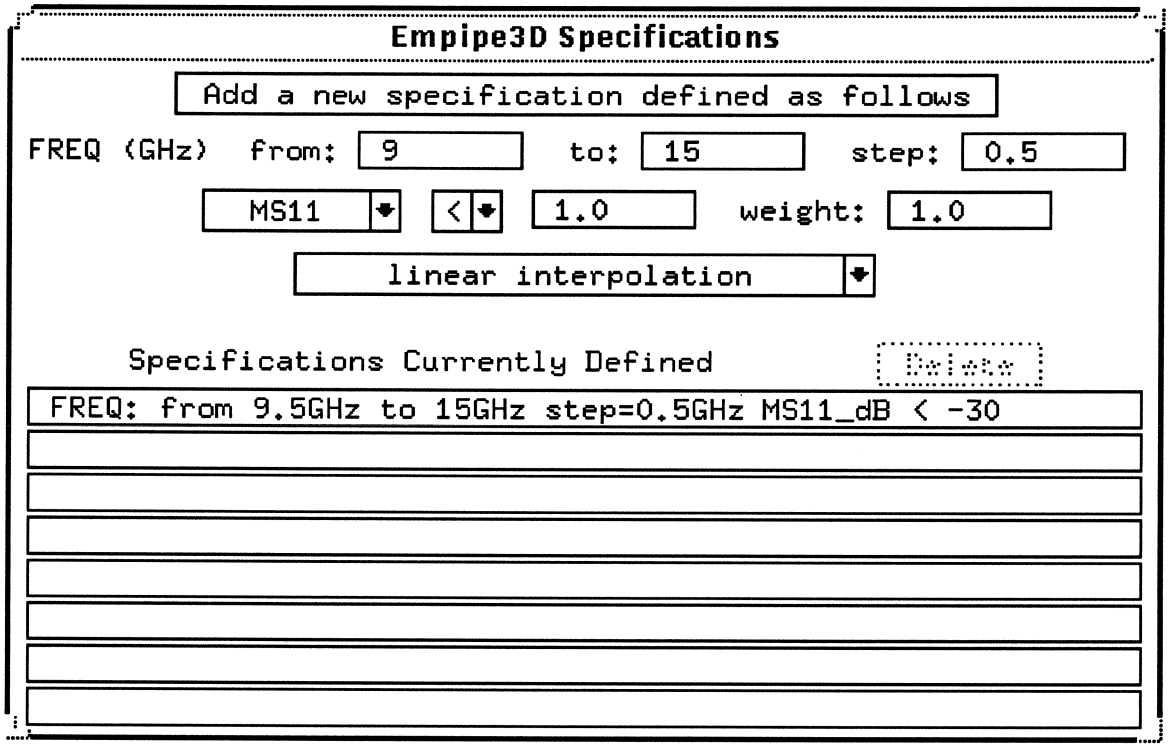
Generating a New Project



"L2" is changed from 0.33 inch to 1 inch

the new project files are automatically and instantly generated

Specifications for Optimization



select

frequency range (9.5 GHz to 15 GHz)
S-parameter response (e.g., $|S_{11}|$ in dB)
specification type (upper, lower or equality)
interpolation type (optional)

enter

numerical value as the goal (-30 dB)
weighting factor (optional)

OSA90 Simulation

OSA90_V3.5-0

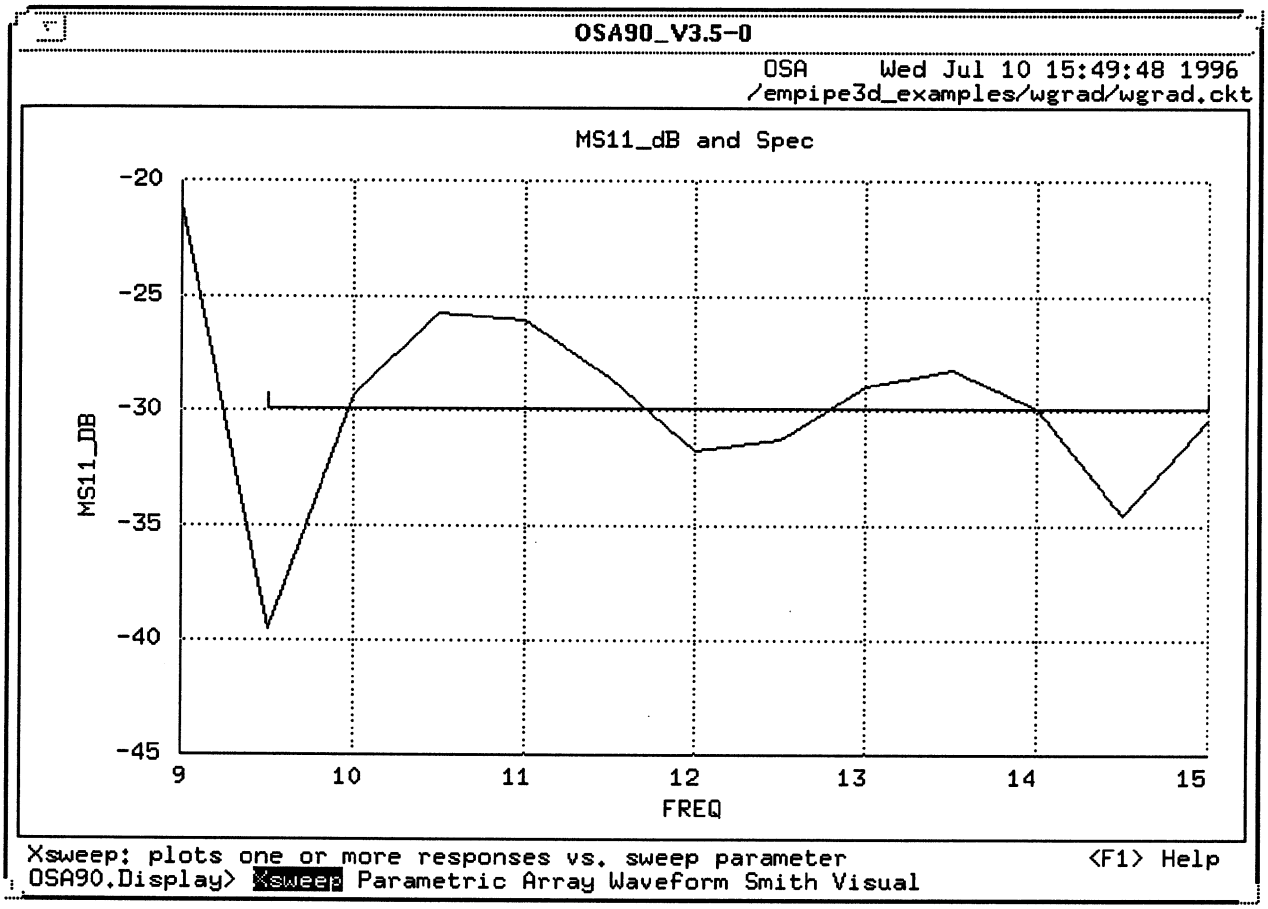
File Parsing Completed | OSA Thu Jul 4 09:56:50 1996 /empipe3d_examples/wgrad/wgrad.ckt

```
! Empipe3D user-defined structure WGRAD

Model
#include "wgrad_osa/wgrad.inc";

   WGRAD_L1: 0.14;
   WGRAD_L2: 0.13;
   WGRAD_L3: 0.13;
   WGRAD_H1: 0.22;
   WGRAD_H2: 0.26;
   WGRAD_H3: 0.3;

   WGRAD  1 2 0  model=1
      L1=(WGRAD_L1 * 1in)  L2=(WGRAD_L2 * 1in)
      L3=(WGRAD_L3 * 1in)  H1=(WGRAD_H1 * 1in)
      H2=(WGRAD_H2 * 1in)  H3=(WGRAD_H3 * 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];
end

Sweep
   AC: FREQ: from 9GHz to 15GHz step=0.5GHz MS11_dB
      {XSWEEP title="MS11_dB and Spec" X=FREQ Y=MS11_dB
       SPEC=(from 9.5GHz to 15GHz, < -30)};

   AC: FREQ: from 9GHz to 15GHz step=0.5GHz MS MS_DB PS
      {Smith MP=(MS11,PS11).S11}
      {Polar MP=(MS21,PS21).S21};
end

Spec
   AC: FREQ: from 9.5GHz to 15GHz step=0.5GHz MS11_dB < -30;
end
```

File: reads, edits, parses and saves files <F1> Help
OSA90> File Display Optimize Macro Sensitivity monteCarlo Learn

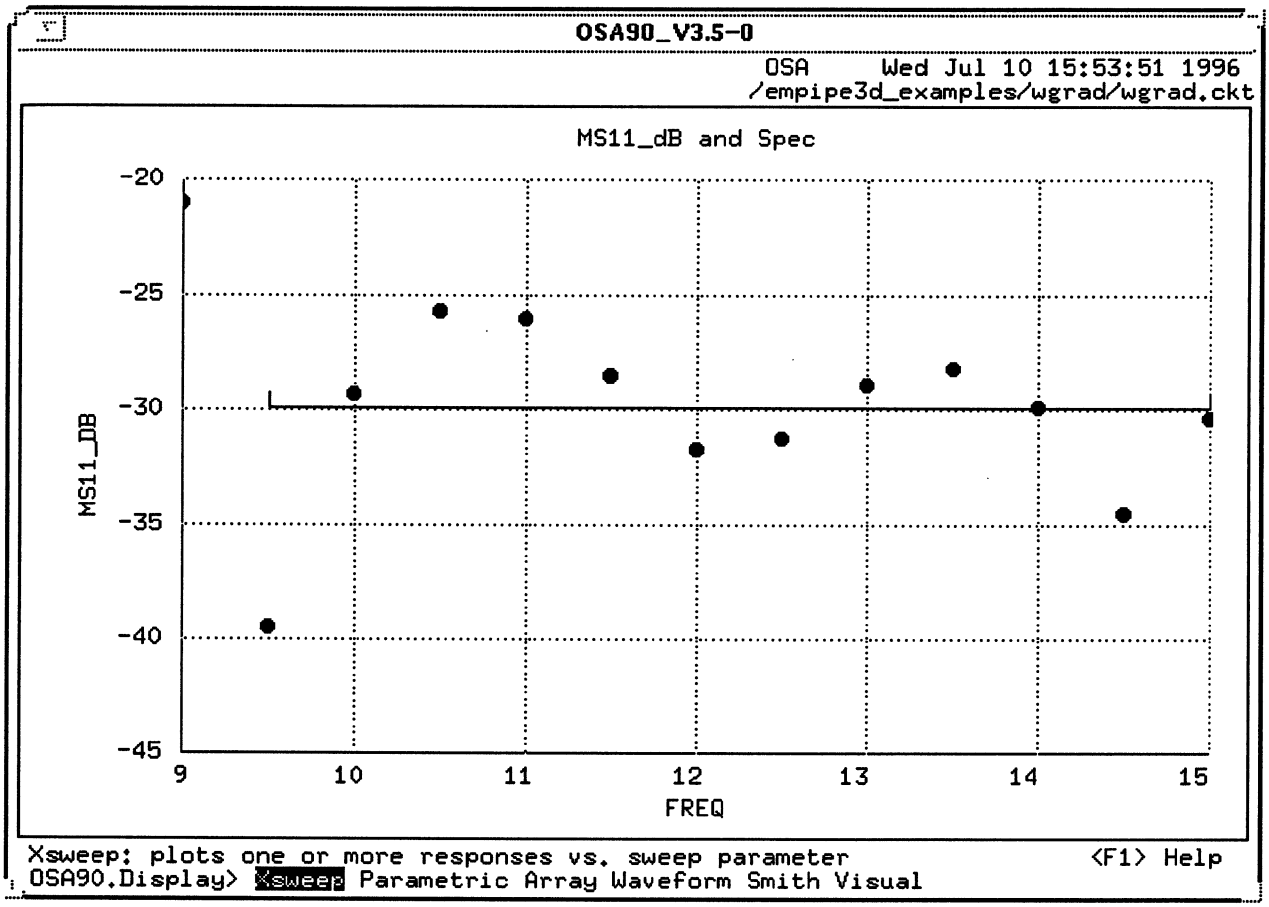
the netlist is automatically generated from the data entered in Empipe3D form editor windows

EM Simulation at the Starting Point



the impedance transformer S_{11} response in dB before optimization

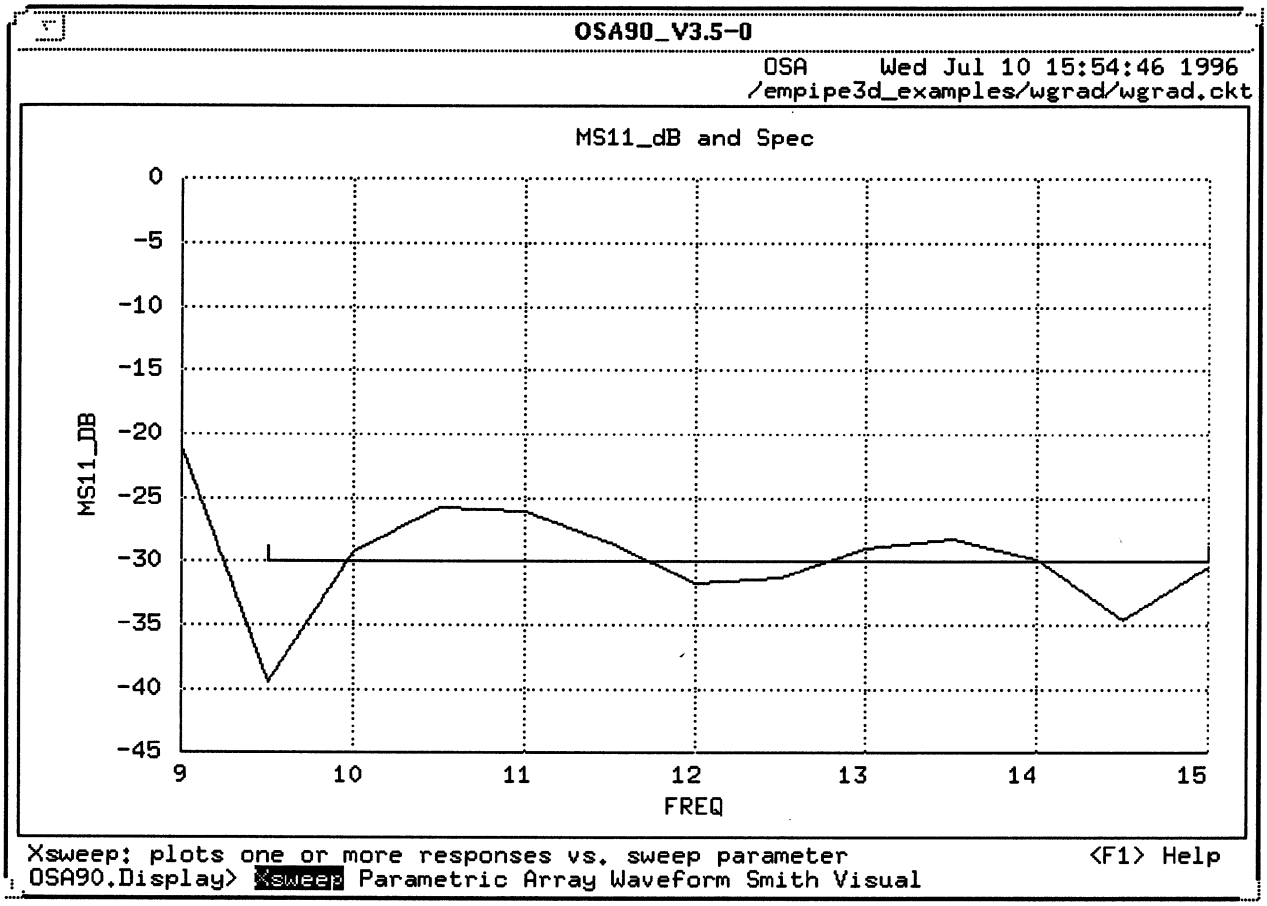
Changing the Type of Drawing



by selecting "Draw type" in display menu option "Xsweep" we can change the style of plotting the response

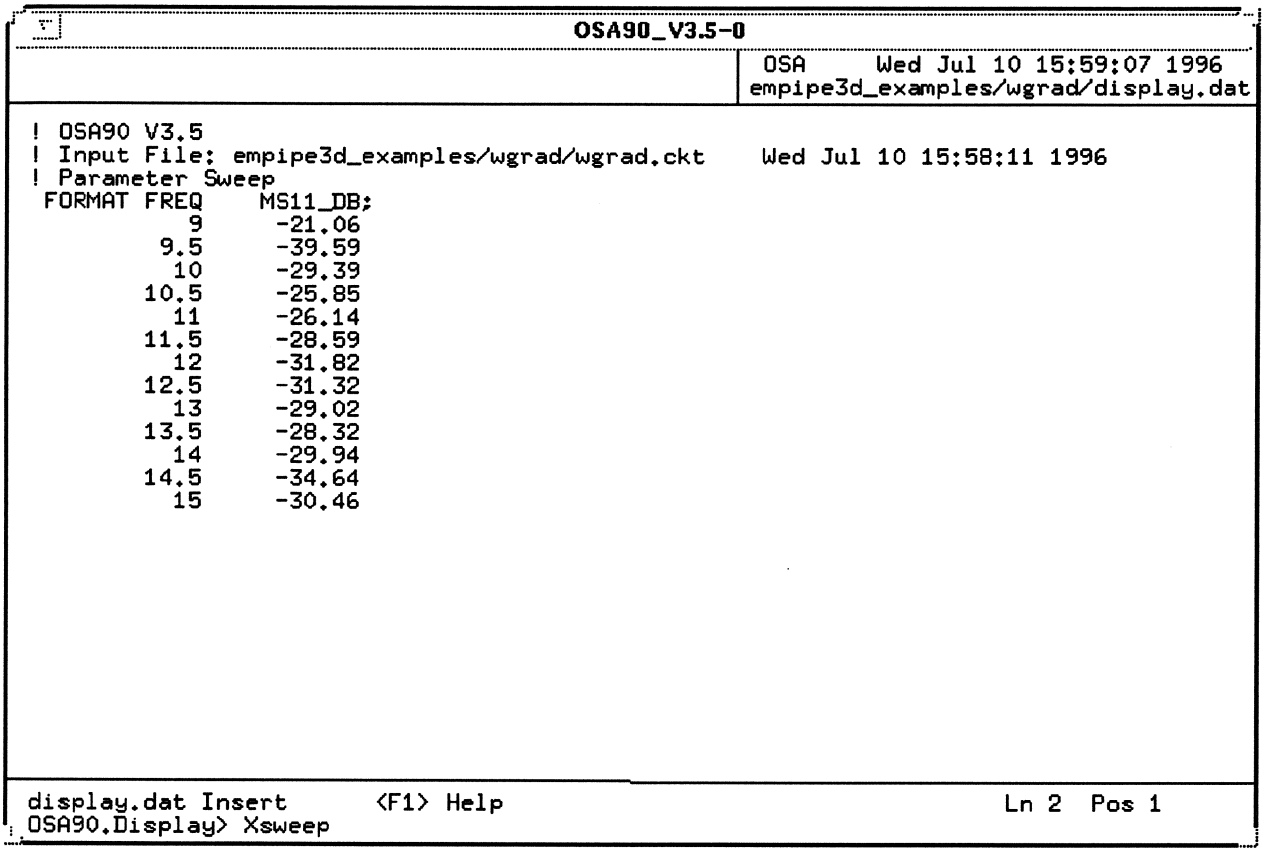
continuous curve
series of dots
series of triangles, squares, etc.

Changing the Zoom Scale



the display with a modified scale

Numerical Display

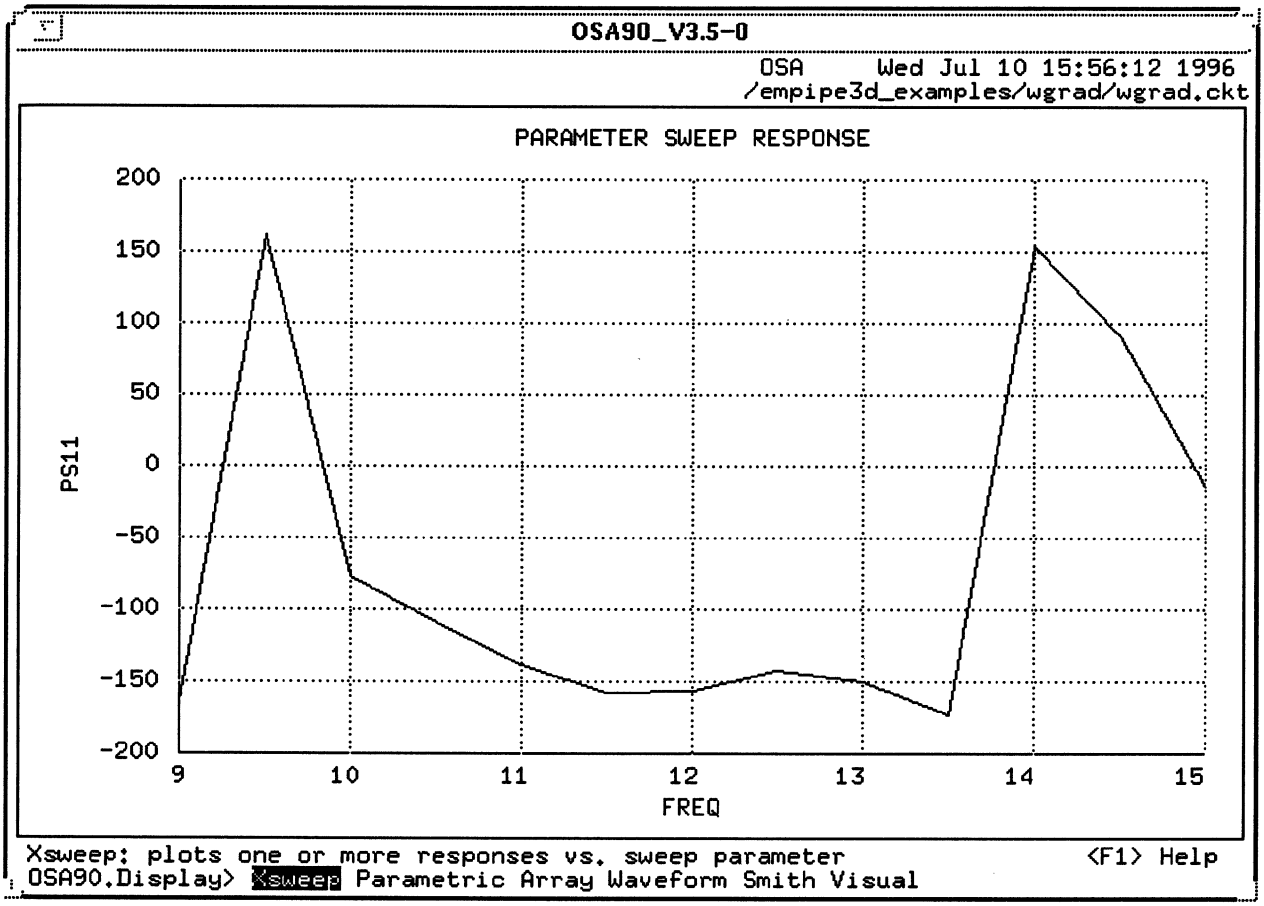


available options

- Graphical
- Numerical
- Numerical append

the numerical data is displayed within the OSA90 file editor, so the user can edit the data and save it to a disk file

Displaying Different Responses



display of PS11 (the phase of S_{11})

Optimization

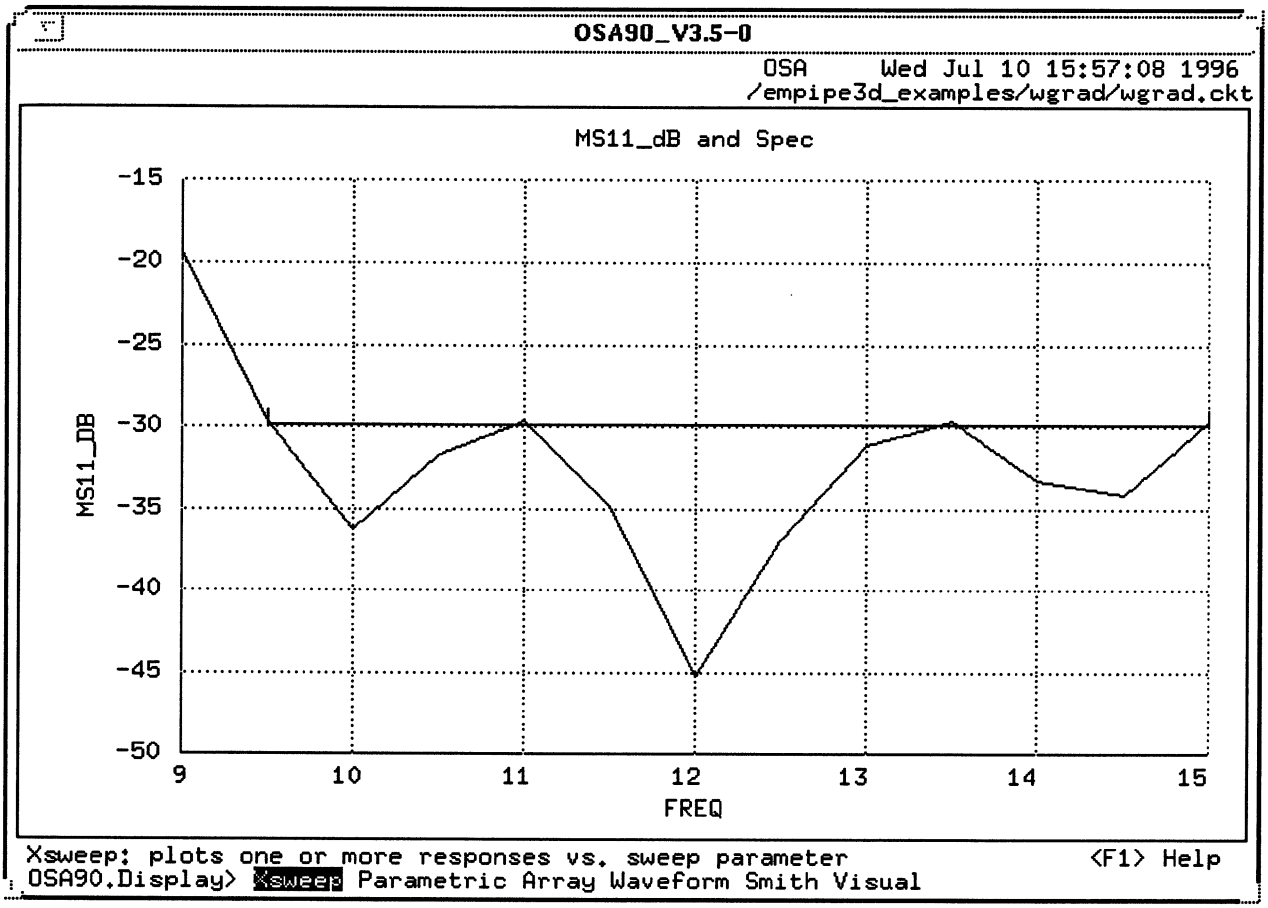
click on the menu option "Optimize"

the progress of optimization is reported on the screen

```
Iteration  1/30 Max Error=4.15486
Iteration  2/30 Max Error=2.75391
Iteration  3/30 Max Error=1.29814
Iteration  4/30 Max Error=2.1607
Iteration  5/30 Max Error=0.491133
Iteration  6/30 Max Error=0.482656
Iteration  7/30 Max Error=0.328469
Iteration  8/30 Max Error=0.292162
Iteration  9/30 Max Error=0.248581
Iteration 10/30 Max Error=1.93186
Iteration 11/30 Max Error=0.228823
Iteration 12/30 Max Error=0.225896
Iteration 13/30 Max Error=0.209504
Solution  Max Error=0.209504
```

the 3D Solver simulation results are saved in a database

Impedance Transformer Response After Optimization



the MS11_DB response (magnitude of S_{11} in dB) is greatly improved from that of the starting point

The Optimized Parameter Values

after optimization is finished, the Empipe3D window reappears on the screen