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HP HFSS OPTIMIZATION EXAMPLES

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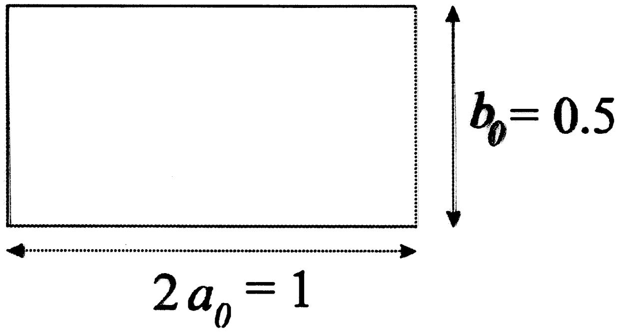
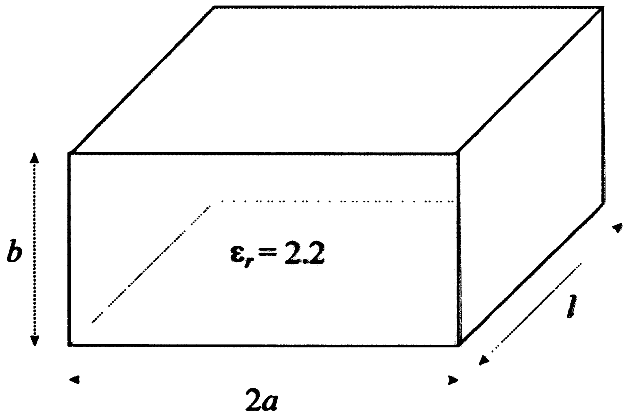
Optimization of a Dielectric-Filled Waveguide Section

optimization of a simple dielectric-filled waveguide section for resonant match to identical input/output air-filled waveguide ports at $f_0 = 9$ GHz

dimensions of the cross-section of the ports in inches



dielectric-filled waveguide section



the width $2a$, the height b, and the length l are optimized

the dielectric constant is fixed at ε_r=2.2

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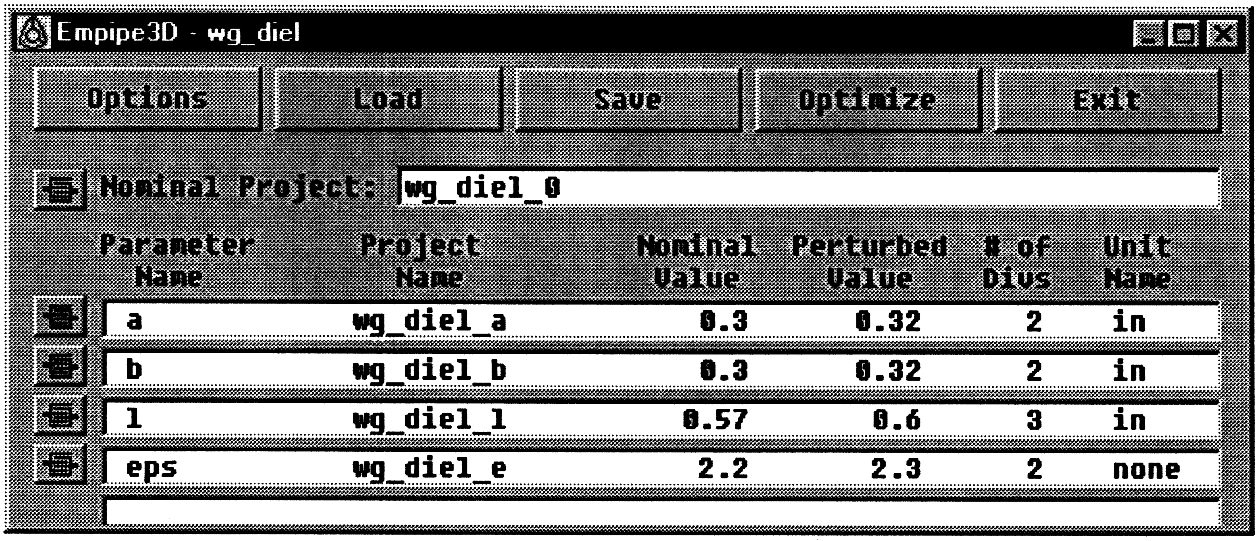
Setting Up the Optimization Project

Empipe3D Geometry Capture form editor requires a set of HP HFSS geometry projects – a nominal and perturbed project

the interpolation data base grid is controlled through the # of Divs parameter



Nominal Project: wg_diel_0

Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
a	wg_diel_a	0.3	0.32	2	in
b	wg_diel_b	0.3	0.32	2	in
l	wg_diel_l	0.57	0.6	3	in
eps	wg_diel_e	2.2	2.3	2	none

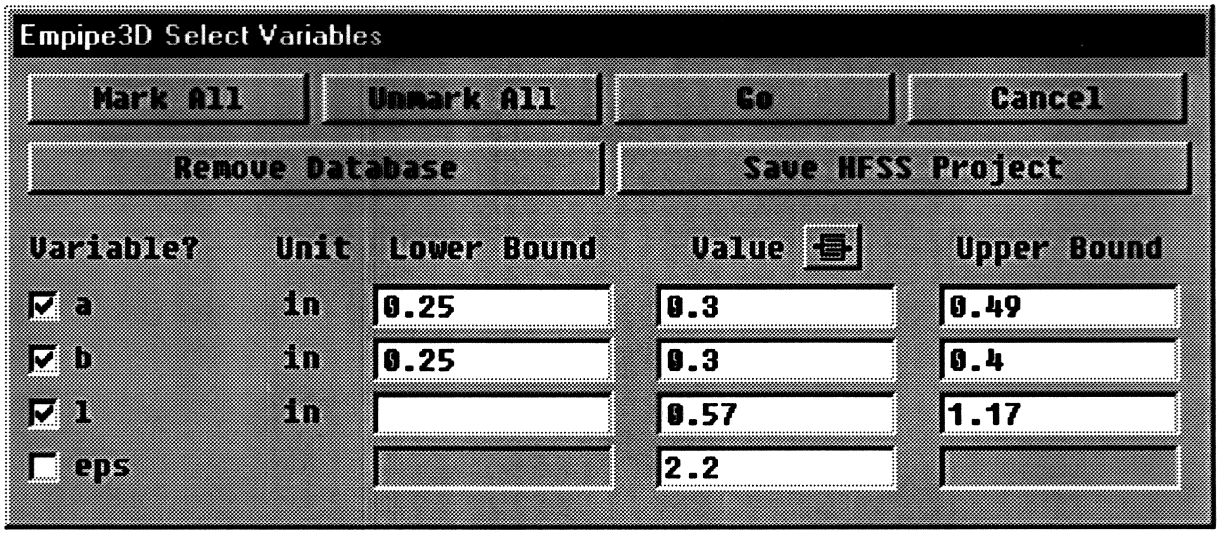
Optimization Variables and Constraints

the nominal values of the optimization variables are chosen to be close to a rough analytical estimate

the structure is analyzed only for the dominant mode and the optimization constraints are chosen so that higher-order modes are cut off at 10 GHz and the dominant mode cutoff is less than 8 GHz

the upper limit of the section length *l* is set roughly equal to the estimated wavelength at 9 GHz

dielectric constant ε_r is considered fixed

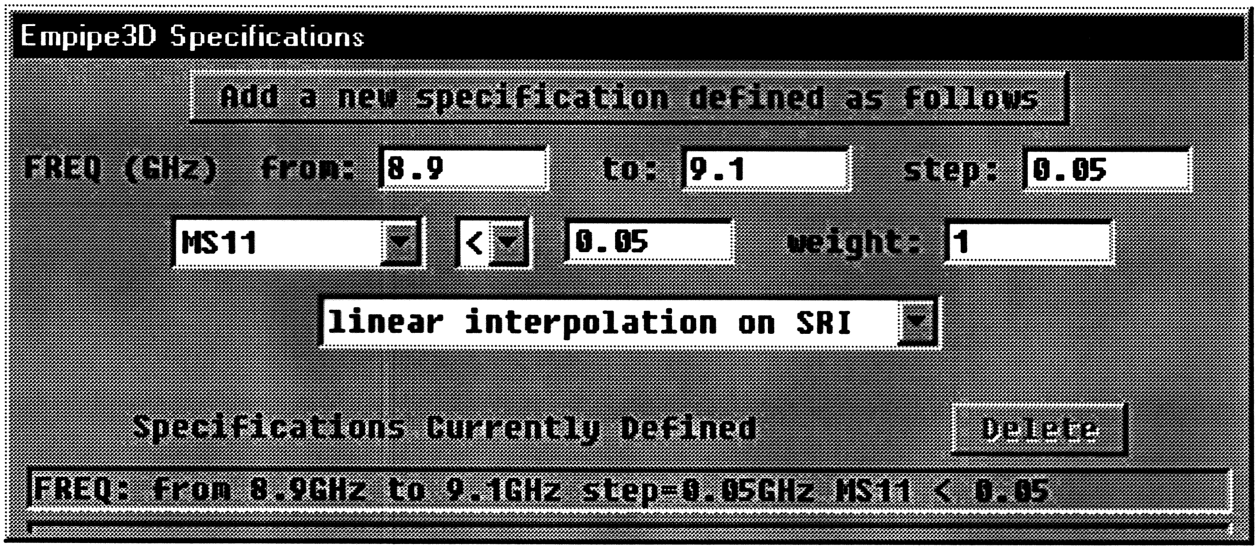


Variable?	Unit	Lower Bound	Value	Upper Bound
☑ a	in	0.25	0.3	0.49
☑ b	in	0.25	0.3	0.4
☑ l	in		0.57	1.17
☐ eps			2.2	

Optimization Specifications

a minimum reflection coefficient $|S_{11}|$ over a narrow frequency band ensures the necessary resonance of the structure at 9 GHz

linear interpolation is used to reduce the number of HP HFSS calls



FREQ (GHz) from: 8.9 to: 9.1 step: 0.05

MS11 < 0.05 weight: 1

linear interpolation on SRI

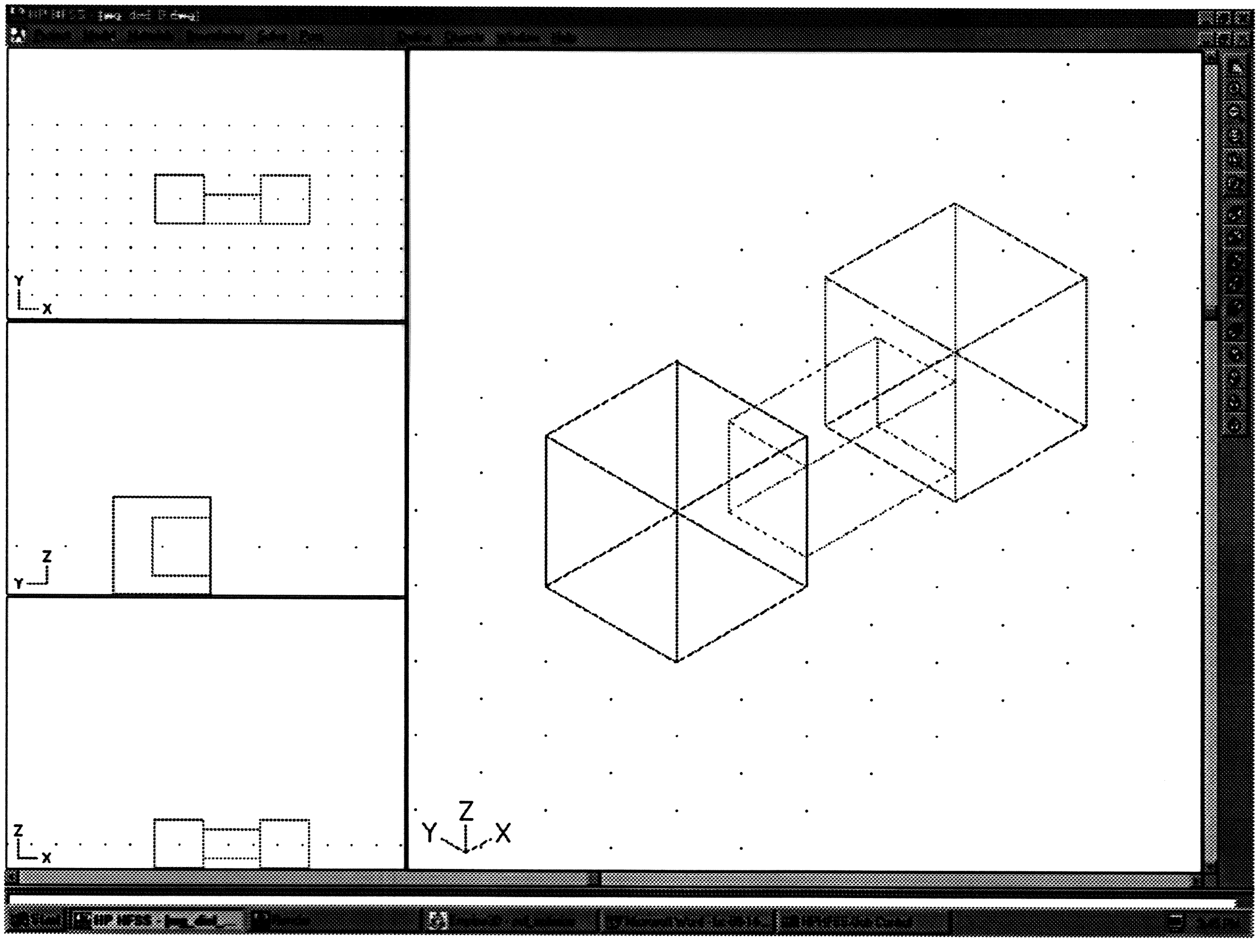
Specifications Currently Defined

FREQ: from 8.9GHz to 9.1GHz step=0.05GHz MS11 < 0.05

The Nominal Project

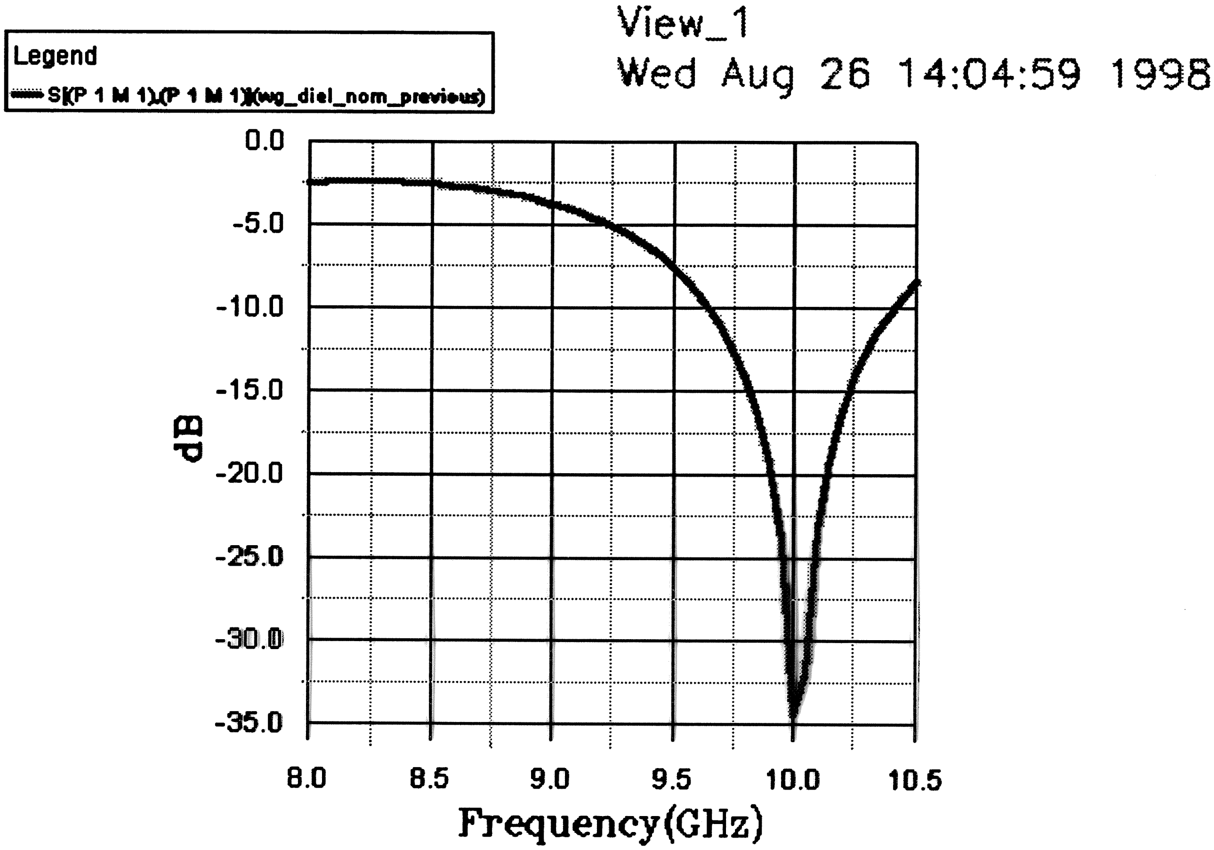
a *Perfect H Boundary* is imposed at the plane of symmetry of the dominant mode field distribution

the solid model of the nominal project consists of three waveguide sections **(boxes)**



The Nominal Project Response

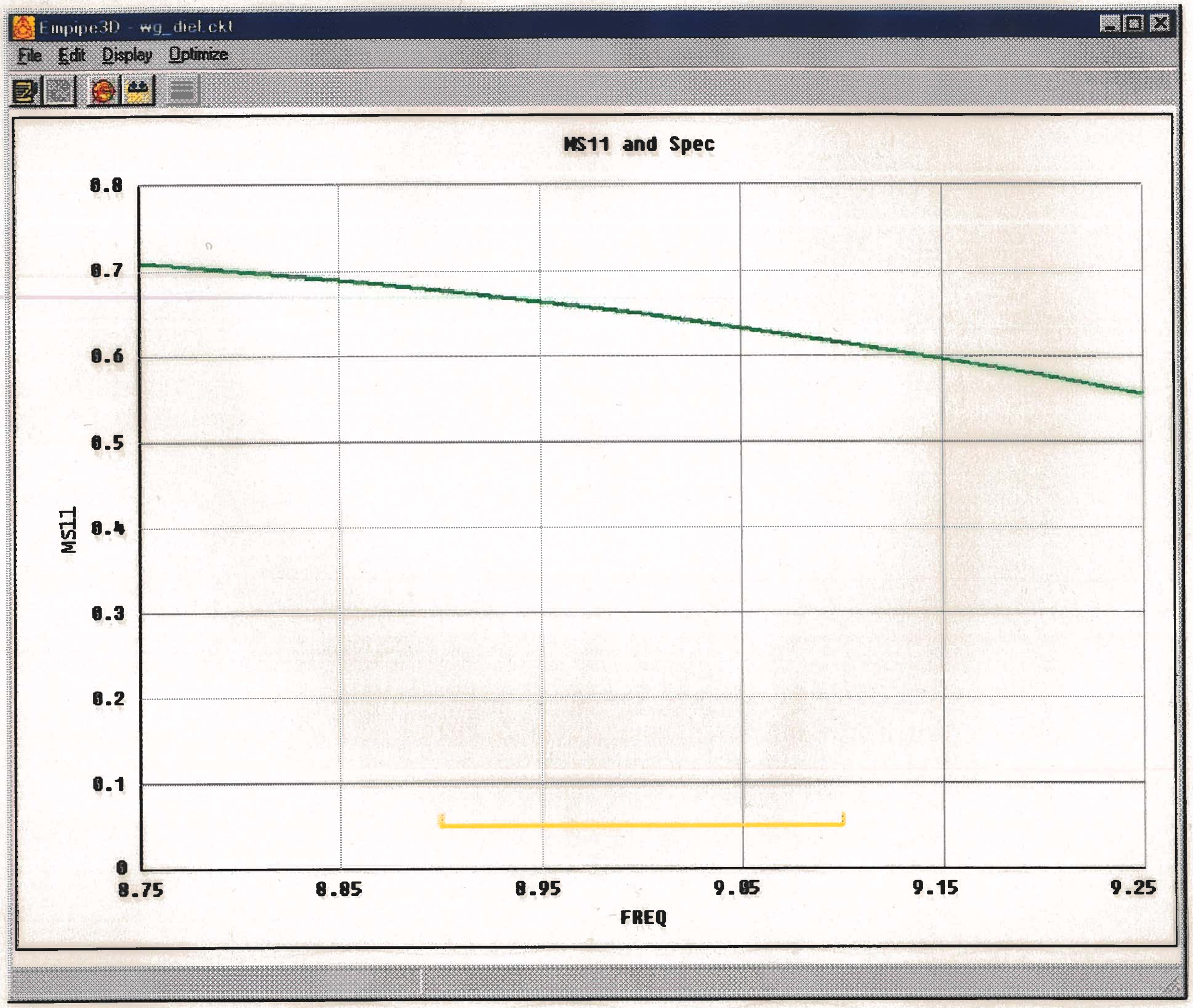
HP HFSS broadband output for $|S_{11}|$ in dB before optimization



the nominal structure resonance is significantly shifted

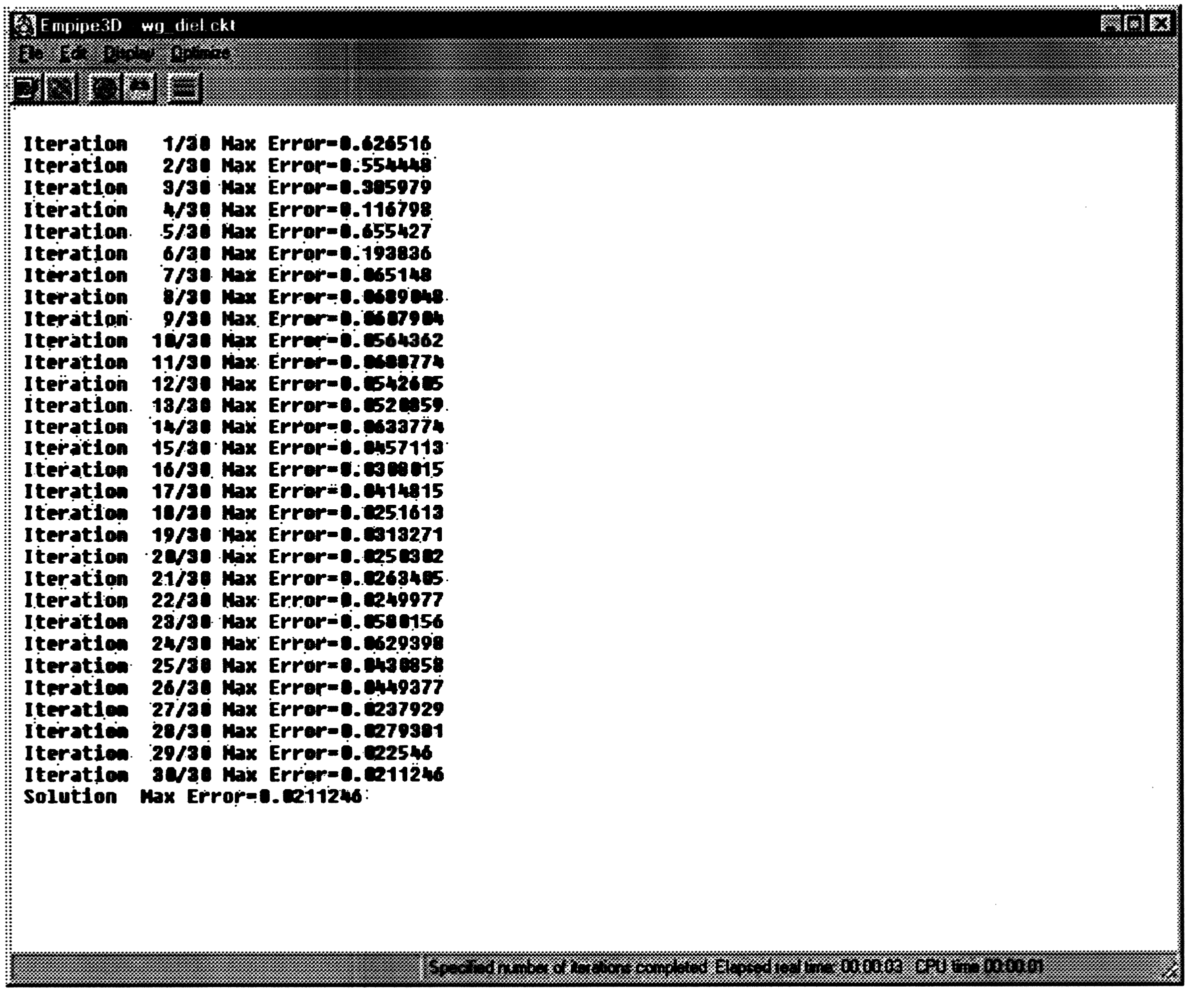
The Starting Point

the nominal structure is the default starting point of the optimization process



Minimax Optimization

the progress of the objective function is reported by Empipe3D



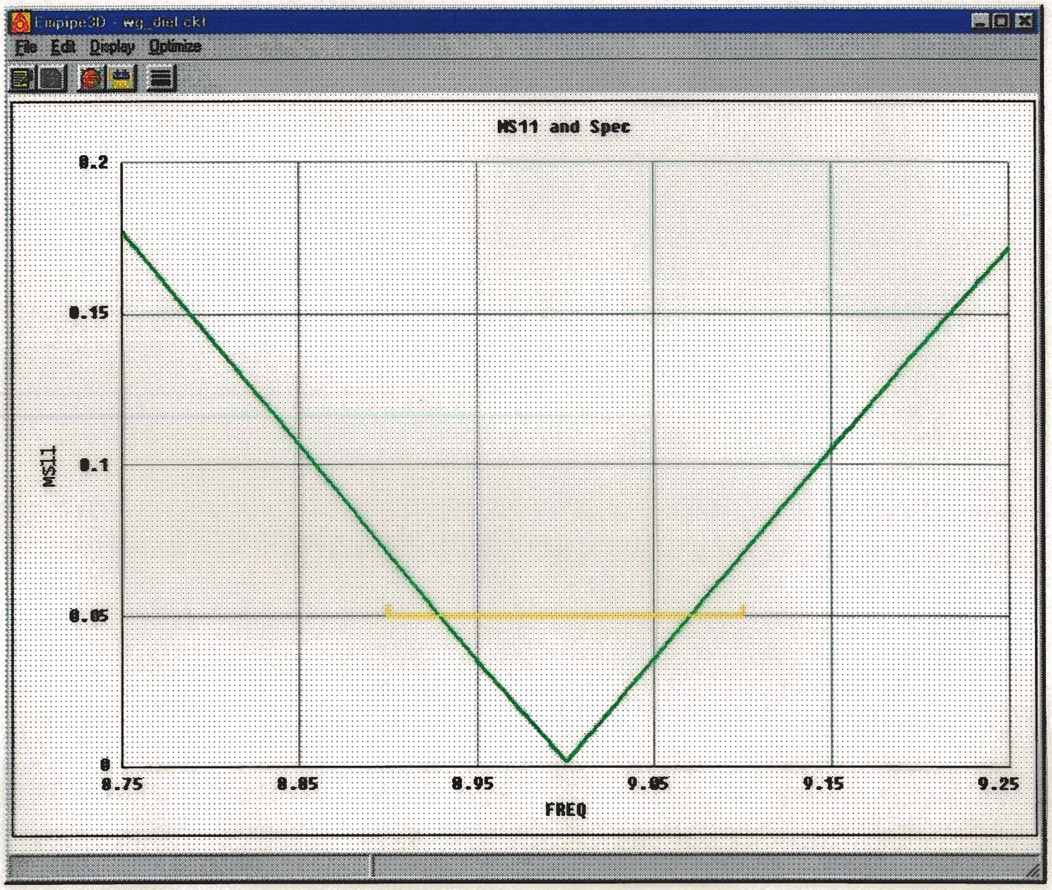
```
Iteration   1/30 Max Error=0.626516
Iteration   2/30 Max Error=0.554448
Iteration   3/30 Max Error=0.385979
Iteration   4/30 Max Error=0.116798
Iteration   5/30 Max Error=0.655427
Iteration   6/30 Max Error=0.193836
Iteration   7/30 Max Error=0.065148
Iteration   8/30 Max Error=0.0689048
Iteration   9/30 Max Error=0.0607904
Iteration  10/30 Max Error=0.0564362
Iteration  11/30 Max Error=0.0600774
Iteration  12/30 Max Error=0.0542605
Iteration  13/30 Max Error=0.0520859
Iteration  14/30 Max Error=0.0633774
Iteration  15/30 Max Error=0.0457113
Iteration  16/30 Max Error=0.0300015
Iteration  17/30 Max Error=0.0414815
Iteration  18/30 Max Error=0.0251613
Iteration  19/30 Max Error=0.0313271
Iteration  20/30 Max Error=0.0250302
Iteration  21/30 Max Error=0.0263405
Iteration  22/30 Max Error=0.0249977
Iteration  23/30 Max Error=0.0580156
Iteration  24/30 Max Error=0.0629398
Iteration  25/30 Max Error=0.0430858
Iteration  26/30 Max Error=0.0449377
Iteration  27/30 Max Error=0.0237929
Iteration  28/30 Max Error=0.0279301
Iteration  29/30 Max Error=0.022546
Iteration  30/30 Max Error=0.0211246
Solution  Max Error=0.0211246
```

Specified number of iterations completed Elapsed real time: 00:00:03 CPU time 00:00:01

a second minimax optimization is carried out because the first optimization process terminates at 30 iterations

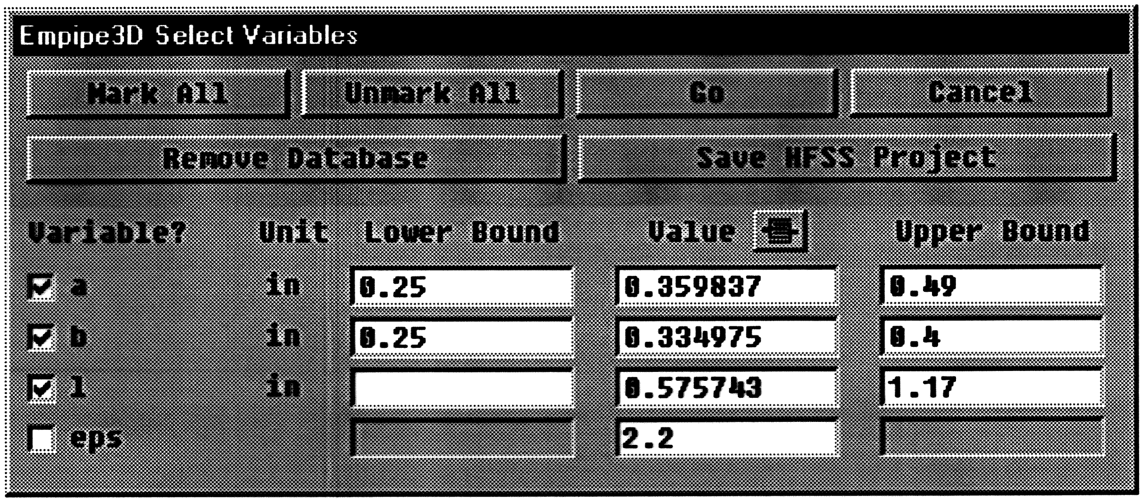
Final Optimized Minimax Response

$|S_{11}|$ response and specifications after optimization



Optimized Parameter Values

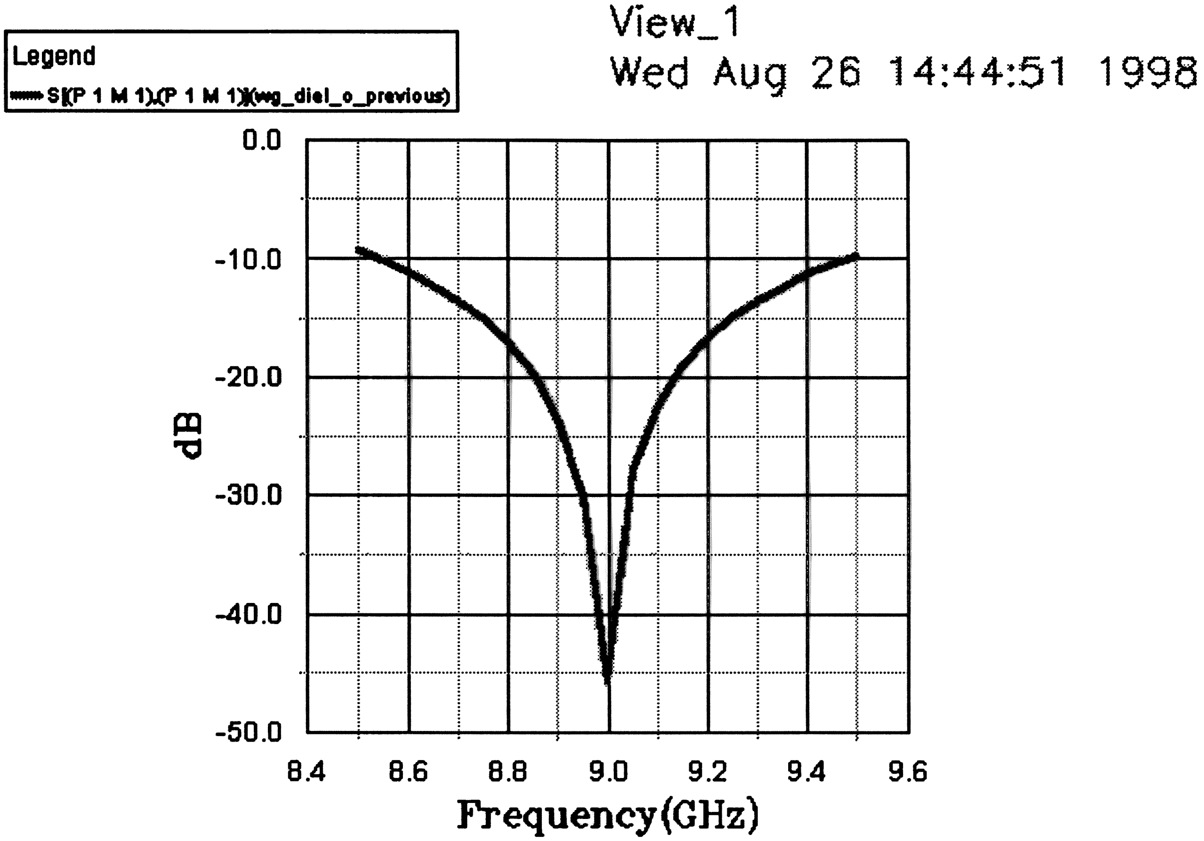
the optimized parameter values are reported in the Empipe3D Select Variables window



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ a	in	0.25	0.359837	0.49
☑ b	in	0.25	0.334975	0.4
☑ l	in		0.575743	1.17
☐ eps			2.2	

HP HFSS Frequency Sweep at the Optimum

frequency sweep over a wider frequency band



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Practical Aspects of Direct Optimization

the smaller the number of optimization parameters the fewer the number of calls to HP HFSS

the CPU time required by the optimizers is negligible in comparison with the CPU time spent in finite element simulations

gradient optimization algorithms are designed to terminate naturally at a local minimum of the objective function

a careful choice of starting values facilitates the convergence of the optimization process

if the existence of multiple minima is expected, the designer should investigate as many solutions as possible, starting from different initial sets of values of the optimization parameters

the designer could also reduce the complexity of the problem by fixing some parameters

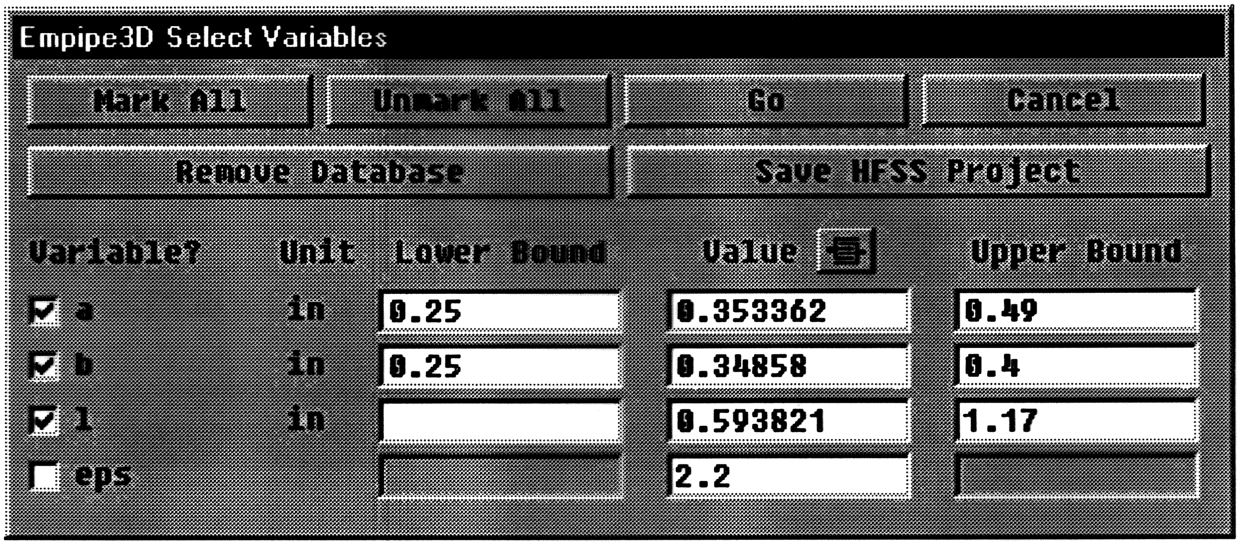
results are never lost because Empipe3D stores every single simulation output in a database

Examples of Dealing with Nonuniqueness of the Solution

searching for multiple solutions

the example is a typical under-determined design problem: the parameters a and l are uniquely related through the guide wavelength λ_g and through the requirement for resonant match

another solution (local minimum of the objective function) is readily obtained after starting a new optimization process from a different set of initial values

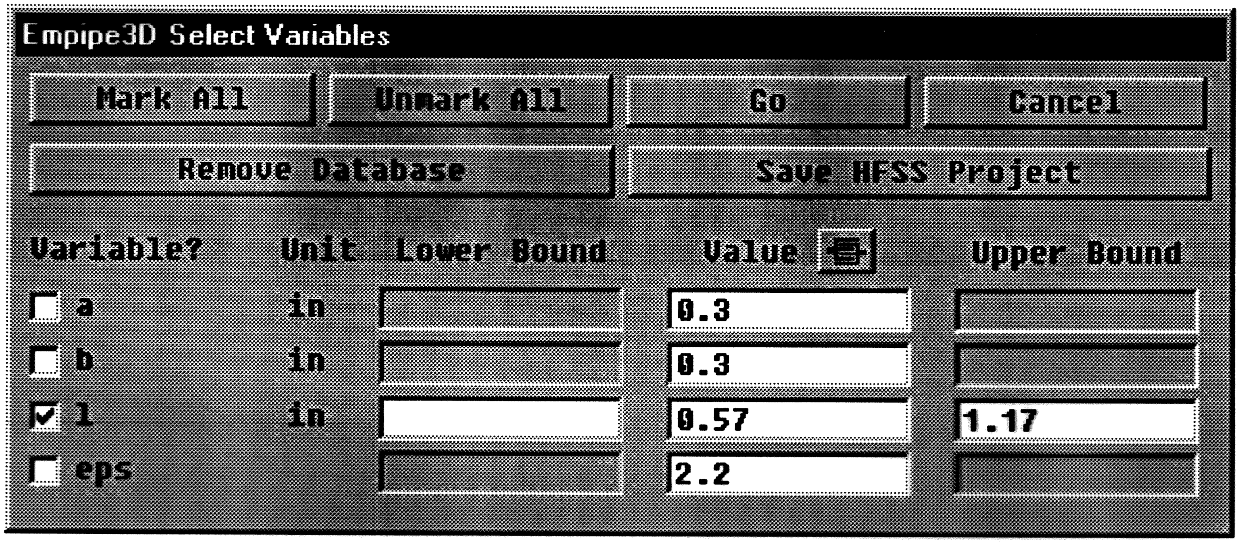


Variable?	Unit	Lower Bound	Value	Upper Bound
☑ a	in	0.25	0.353362	0.49
☑ b	in	0.25	0.34858	0.4
☑ l	in		0.593821	1.17
☐ eps			2.2	

the response of this new optimal structure is practically identical to the response of the previous optimal geometry

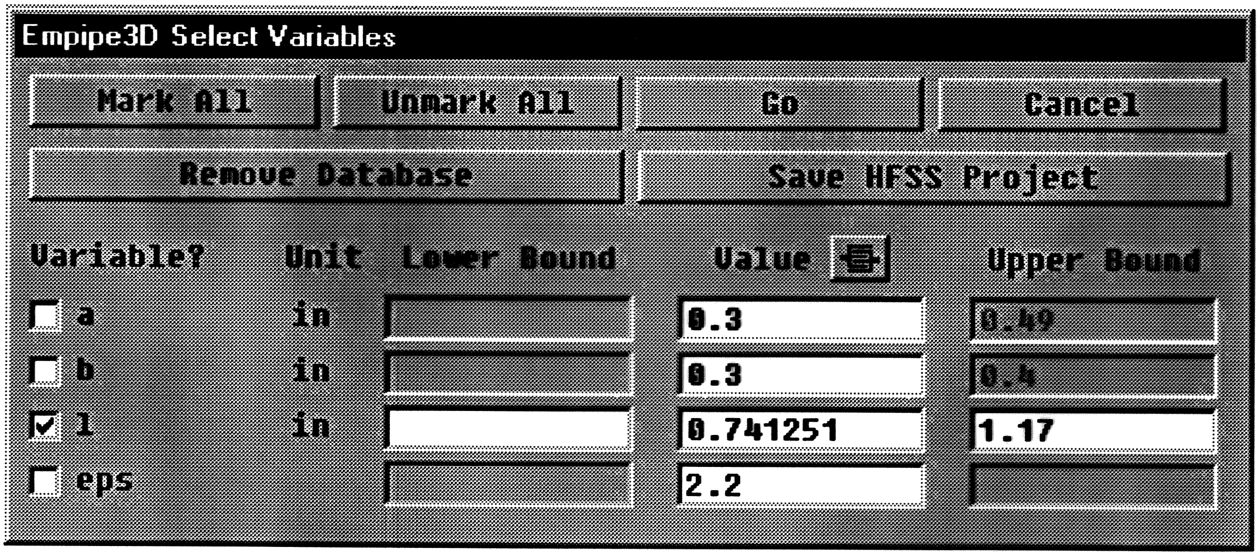
Simplifying the Project

fix some parameters before starting the optimization process



Variable?	Unit	Lower Bound	Value	Upper Bound
☐ a	in		0.3	
☐ b	in		0.3	
☑ l	in		0.57	1.17
☐ eps			2.2	

after optimization



Variable?	Unit	Lower Bound	Value	Upper Bound
☐ a	in		0.3	0.49
☐ b	in		0.3	0.4
☑ l	in		0.741251	1.17
☐ eps			2.2	

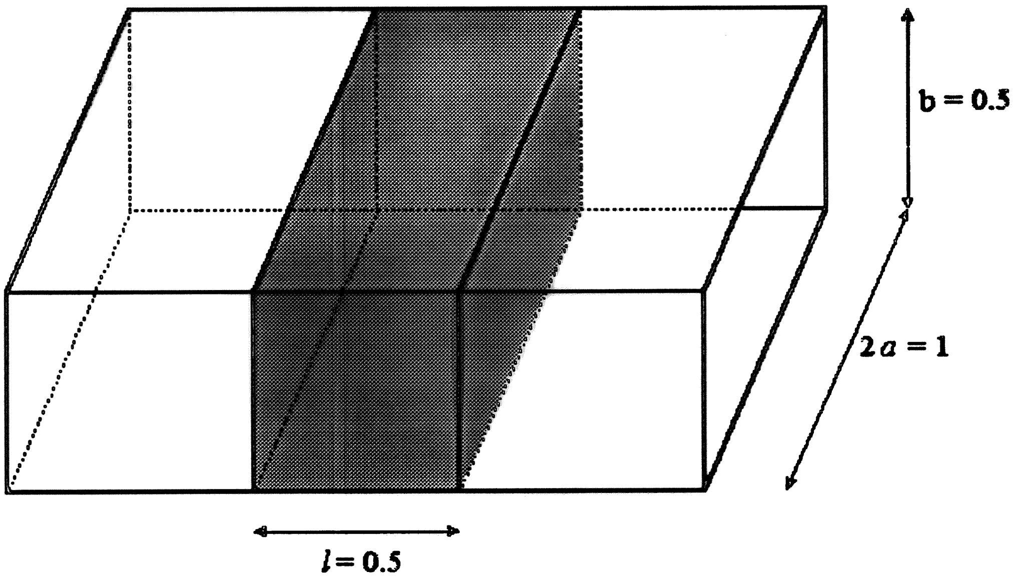
the solution is valid and it is unique w.r.t. *l* covering roughly half a wavelength

Parameter Extraction of Dielectric Constant

parameter extraction is the problem of finding a set of parameter values for a device model such that its response matches a set of measurements on a corresponding DUT

Empipe3D can be used for solving parameter extraction problems

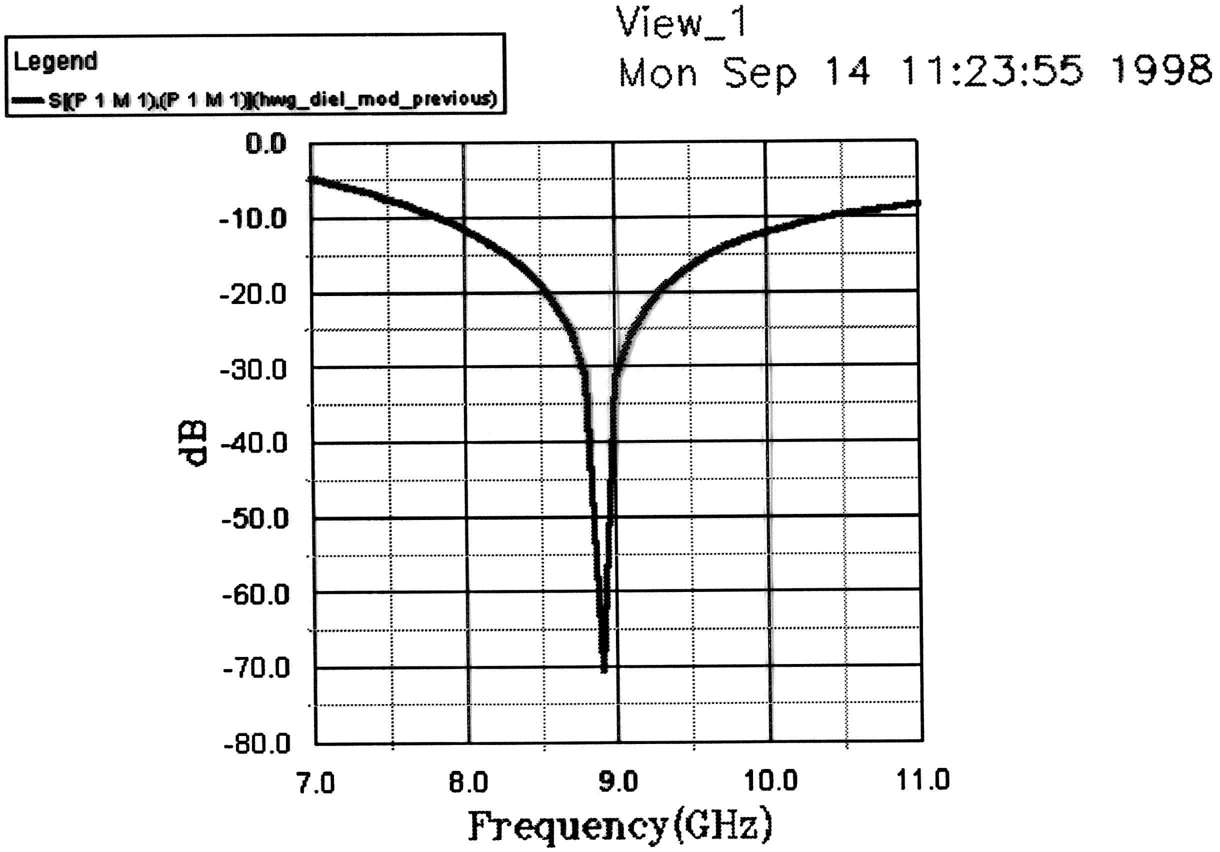
the DUT is a dielectric-filled waveguide section with $\varepsilon_r = 2.2$



Measurements on the DUT

“measurement” data (the S_{11} response) for the DUT is prepared by running an HP HFSS discrete frequency sweep from 7 GHz to 11 GHz with a step of 0.1 GHz

the $|S_{11}|$ response in dB as viewed in the HP HFSS postprocessor window

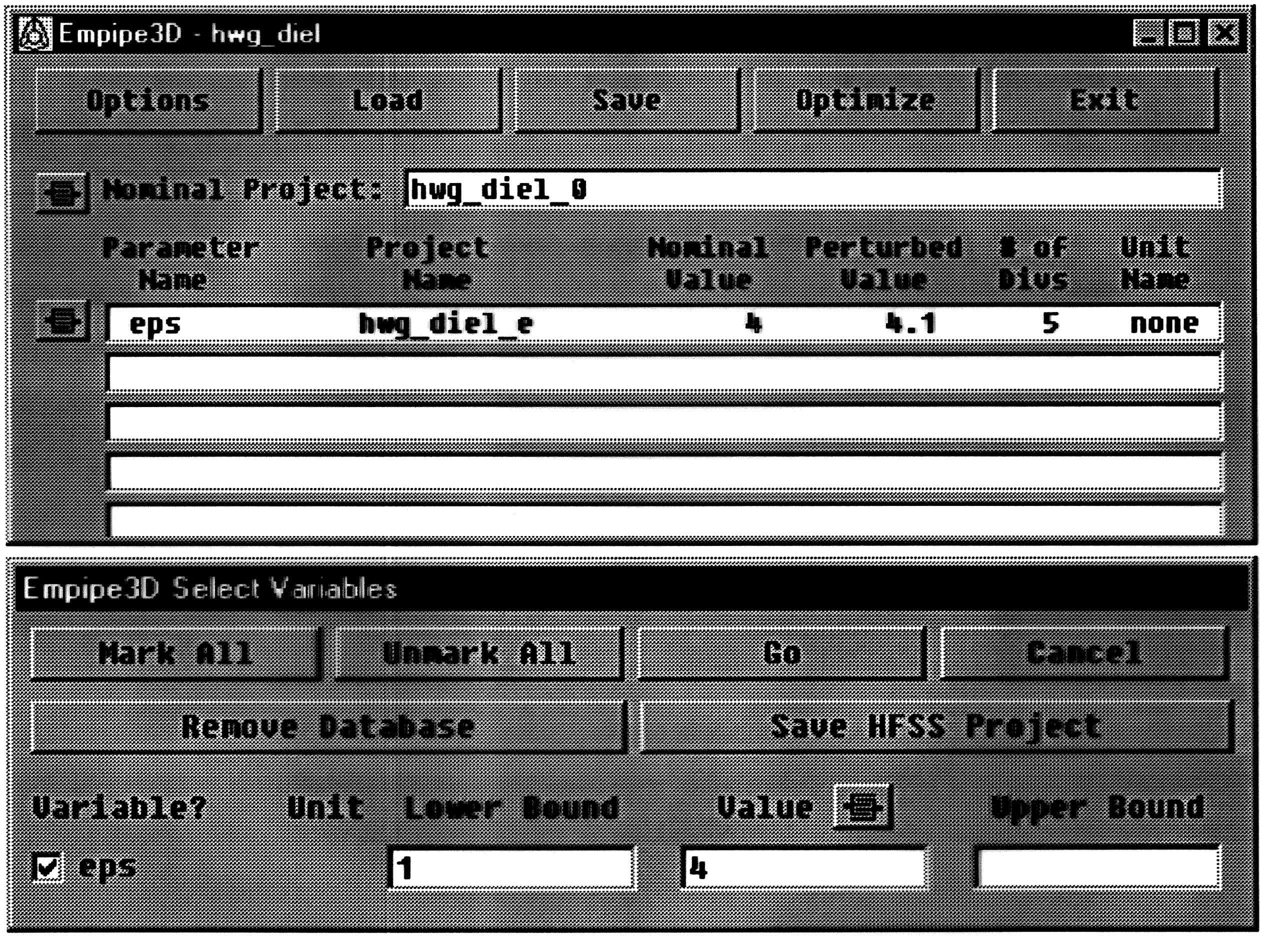


the S_{11} response versus frequency is exported as a Touchstone file format

Parameter Extraction Using Empipe3D

it is assumed that the geometry is known, i.e., it is identical to the "measured" structure

the dielectric constant is assumed unknown, i.e., it is the optimization parameter



Nominal Project: hwg_diel_0

Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
eps	hwg_diel_e	4	4.1	5	none

Variable?	Unit	Lower Bound	Value	Upper Bound
☑ eps		1	4	

Parameter Extraction Using Empipe3D (cont'd)

the "measurement" data S_{11}^{m} is inserted explicitly into the netlist file

the optimization goal is to find the value of ε_r, which minimizes the difference between the response of the structure and the set of measurements at every point of the frequency band

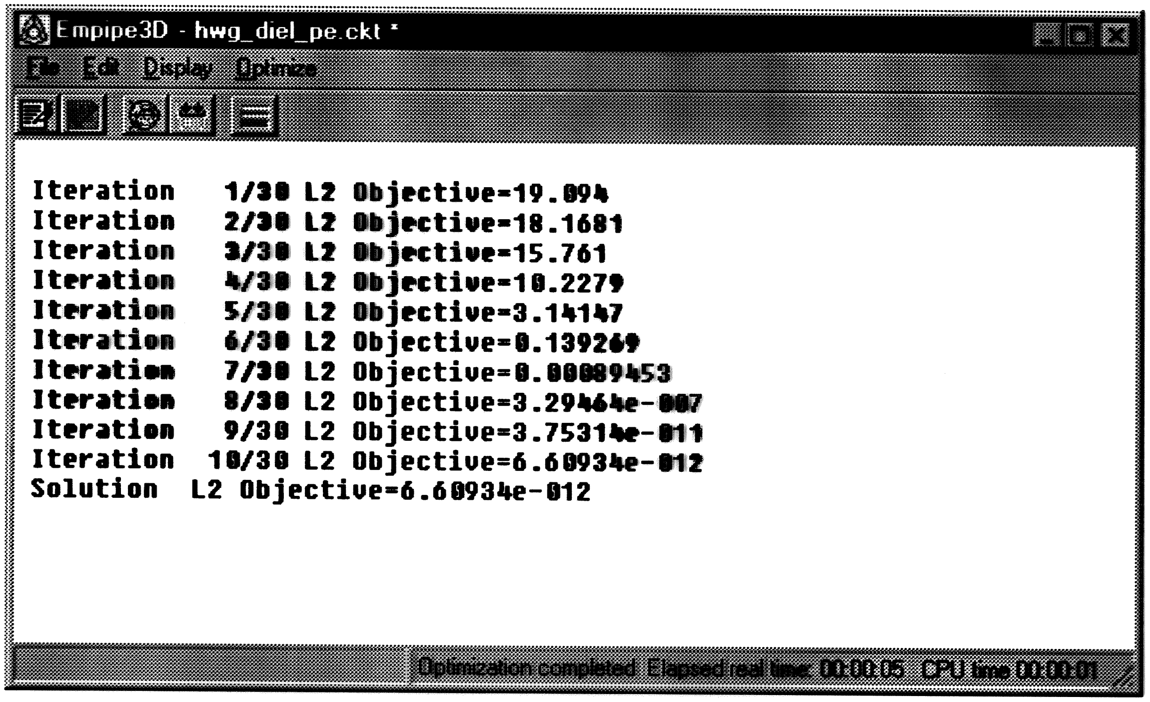
$$\text{minimize} \parallel S_{11}(\varepsilon_r) - S_{11}^{\mathrm{m}} \parallel$$

implementation in Empipe3D

```
Spec
   AC: FREQ: from 7GHz to 11GHz step=0.1GHz
   RS11=S11_m[J,1]   ! real part
   IS11=S11_m[J,2]   ! imaginary part
end
```

L2 Optimization

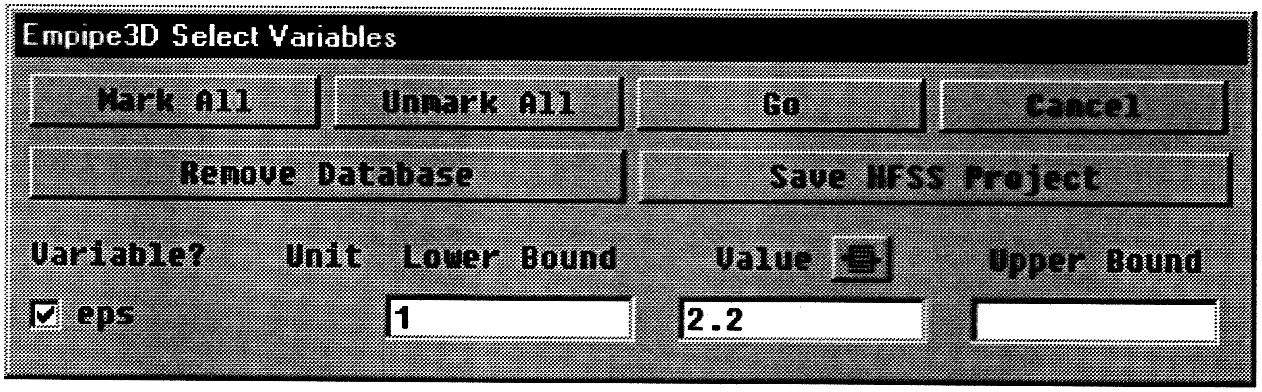
the optimization iterations report shows the final value of the objective function



```
Iteration   1/30 L2 Objective=19.094
Iteration   2/30 L2 Objective=18.1681
Iteration   3/30 L2 Objective=15.761
Iteration   4/30 L2 Objective=10.2279
Iteration   5/30 L2 Objective=3.14147
Iteration   6/30 L2 Objective=0.139269
Iteration   7/30 L2 Objective=0.00089453
Iteration   8/30 L2 Objective=3.29464e-007
Iteration   9/30 L2 Objective=3.75314e-011
Iteration  10/30 L2 Objective=6.60934e-012
Solution  L2 Objective=6.60934e-012
```

Optimization completed Elapsed real time: 00:00:05 CPU time 00:00:01

after the optimization is completed the extracted parameter ε_r is obtained

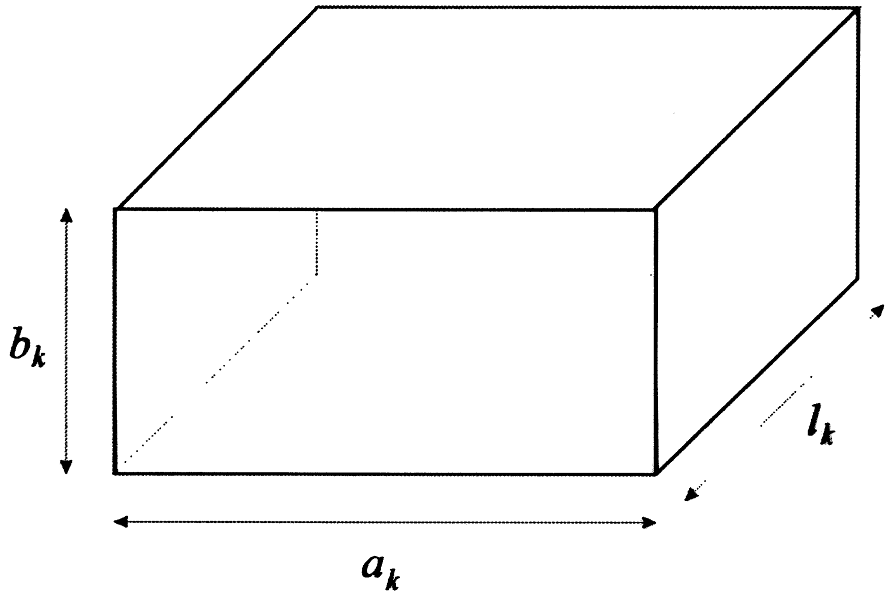


Variable?	Unit	Lower Bound	Value	Upper Bound
☑ eps		1	2.2	

Optimization of an Inhomogeneous Two-Section Waveguide Transformer

two-section waveguide transformer between waveguides with identical heights but different widths (*Young 1960, Bandler 1969*)

band of interest 8.16 GHz to 9.26 GHz



the widths of the two sections are fixed

their heights and lengths are optimized

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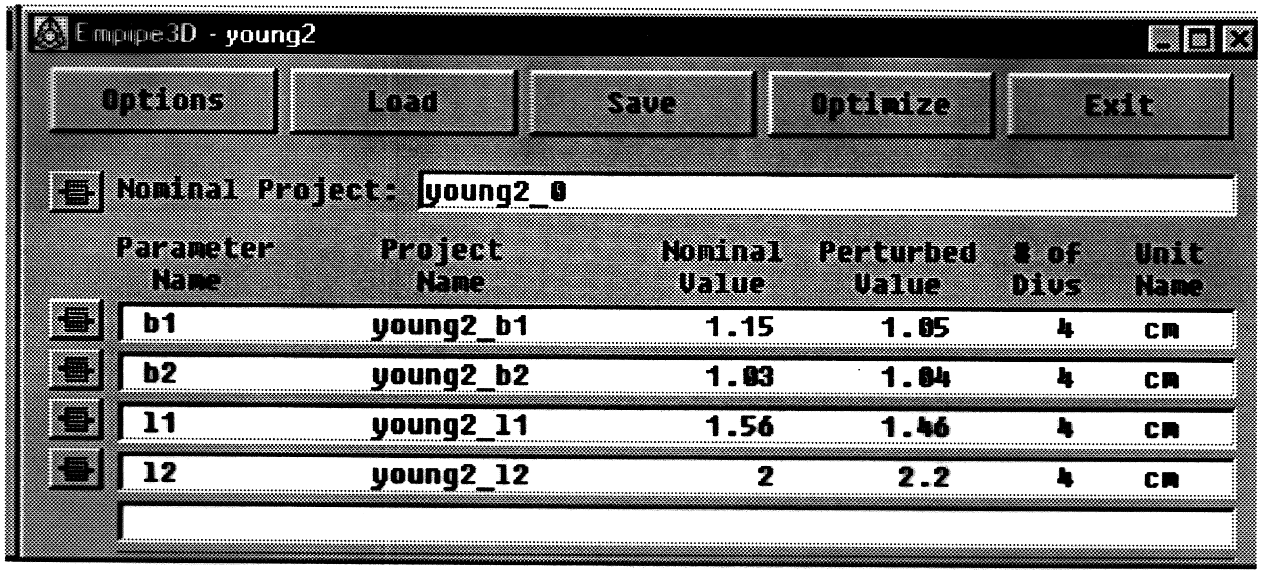
Setting Up the Optimization Project

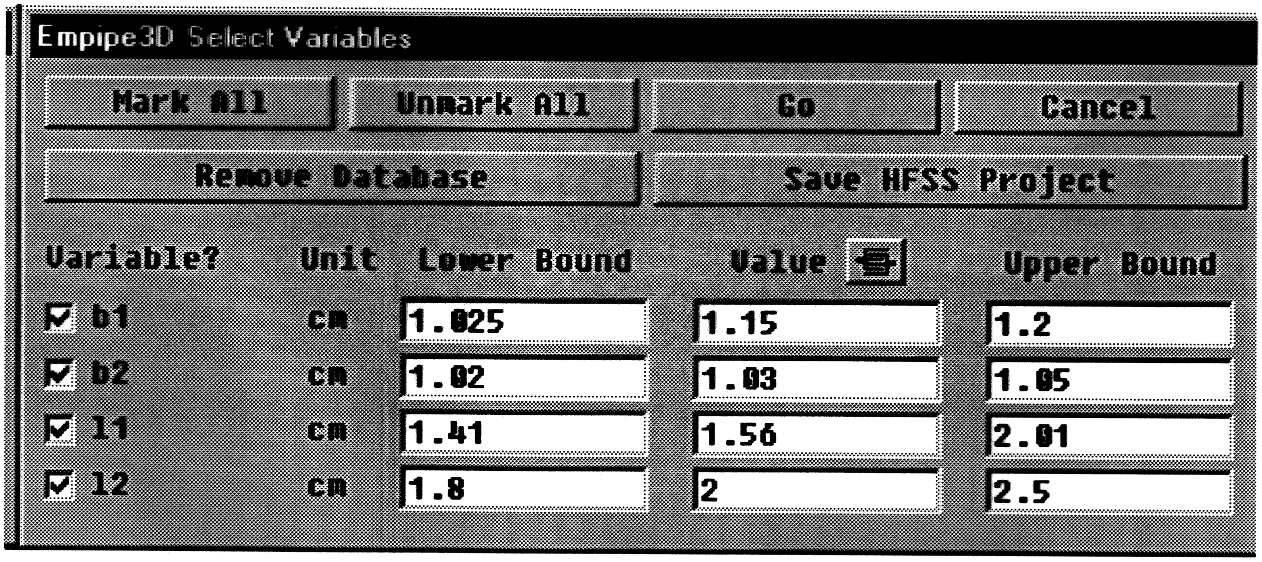
nominal values are close to a design using analytical approximations



Nominal Project: young2_0

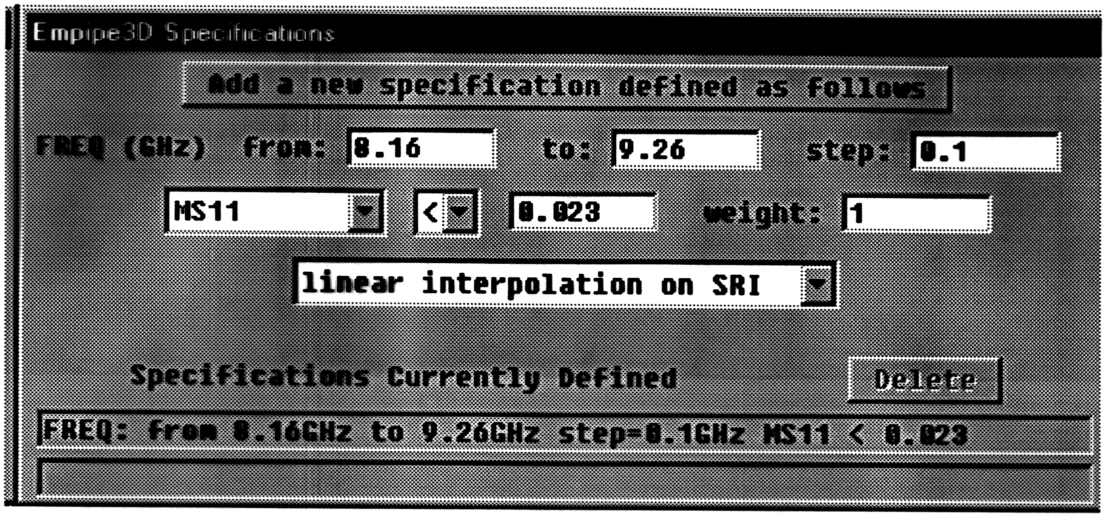
Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
b1	young2_b1	1.15	1.05	4	cm
b2	young2_b2	1.03	1.04	4	cm
l1	young2_l1	1.56	1.46	4	cm
l2	young2_l2	2	2.2	4	cm

optimization variables and their bounds



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ b1	cm	1.025	1.15	1.2
☑ b2	cm	1.02	1.03	1.05
☑ l1	cm	1.41	1.56	2.01
☑ l2	cm	1.8	2	2.5

Optimization Specifications (VSWR < 1.047)



FREQ (GHz) From: 8.16 to: 9.26 step: 0.1

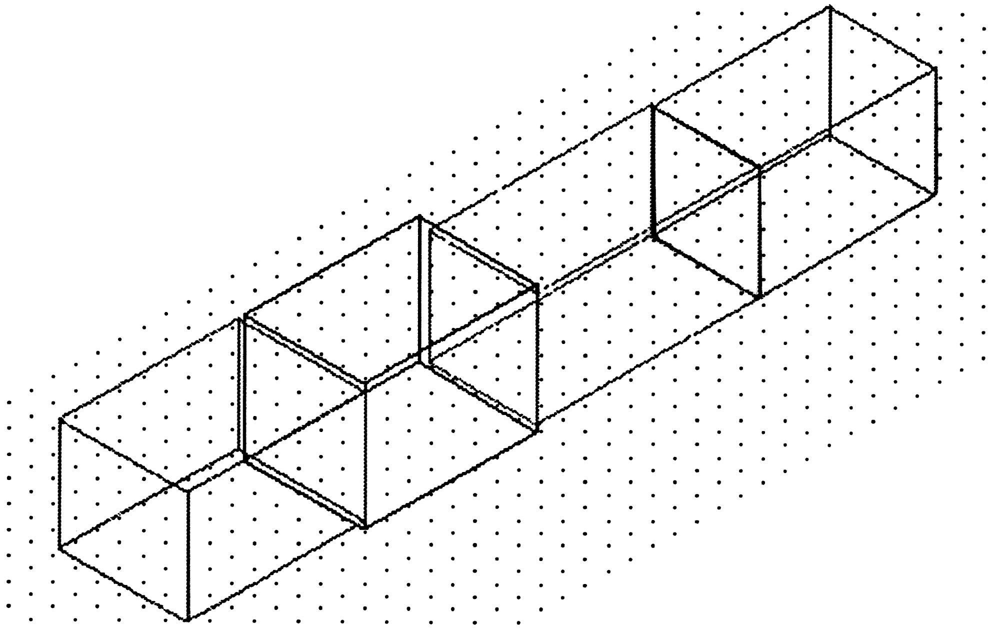
MS11 < 0.023 weight: 1

linear interpolation on SRI

Specifications Currently Defined

FREQ: from 8.16GHz to 9.26GHz step=0.1GHz MS11 < 0.023

The Nominal Structure Geometry

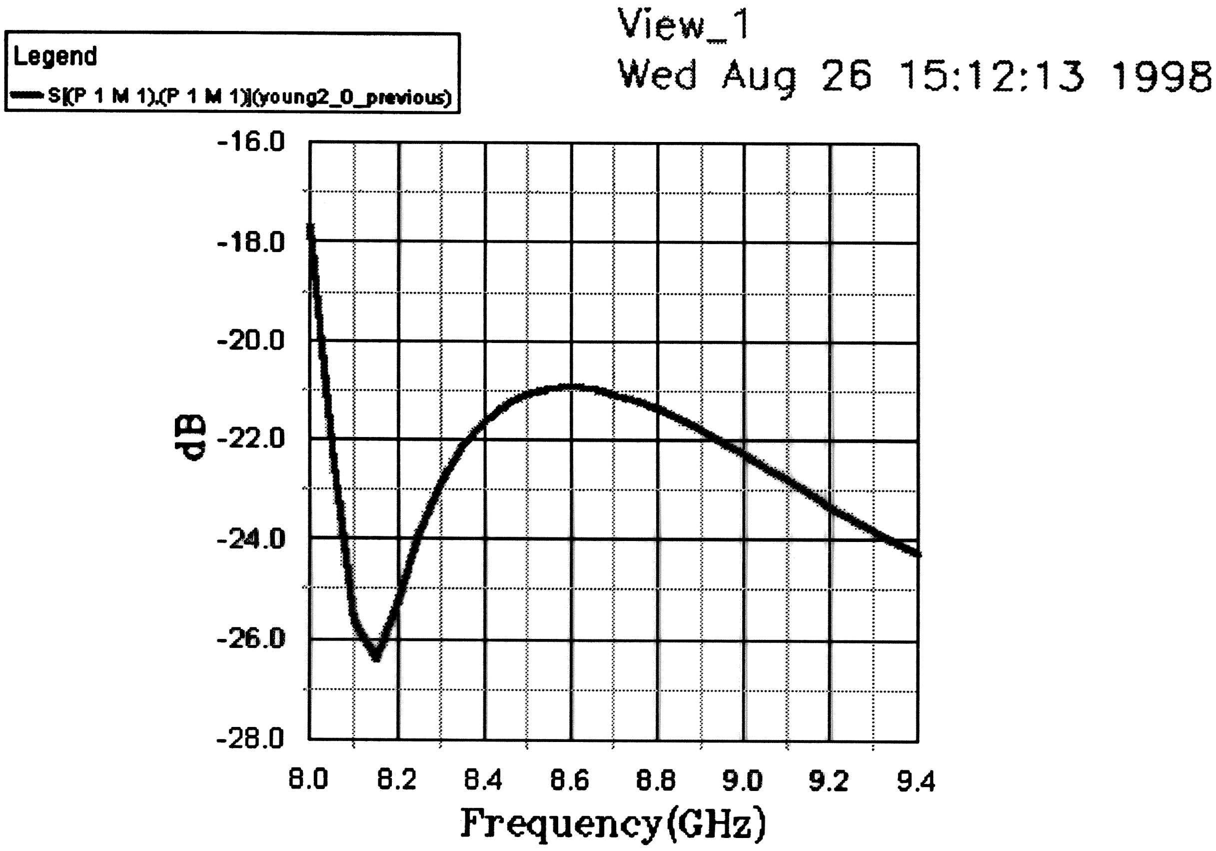


only half of the structure is seen because a *Perfect H Boundary* is applied along the plane of symmetry of the dominant mode

The Nominal Structure Response

preliminary frequency sweep using HP HFSS directly over a broader frequency band from 8 GHz to 9.4 GHz

results for $|S_{11}|$ in dB



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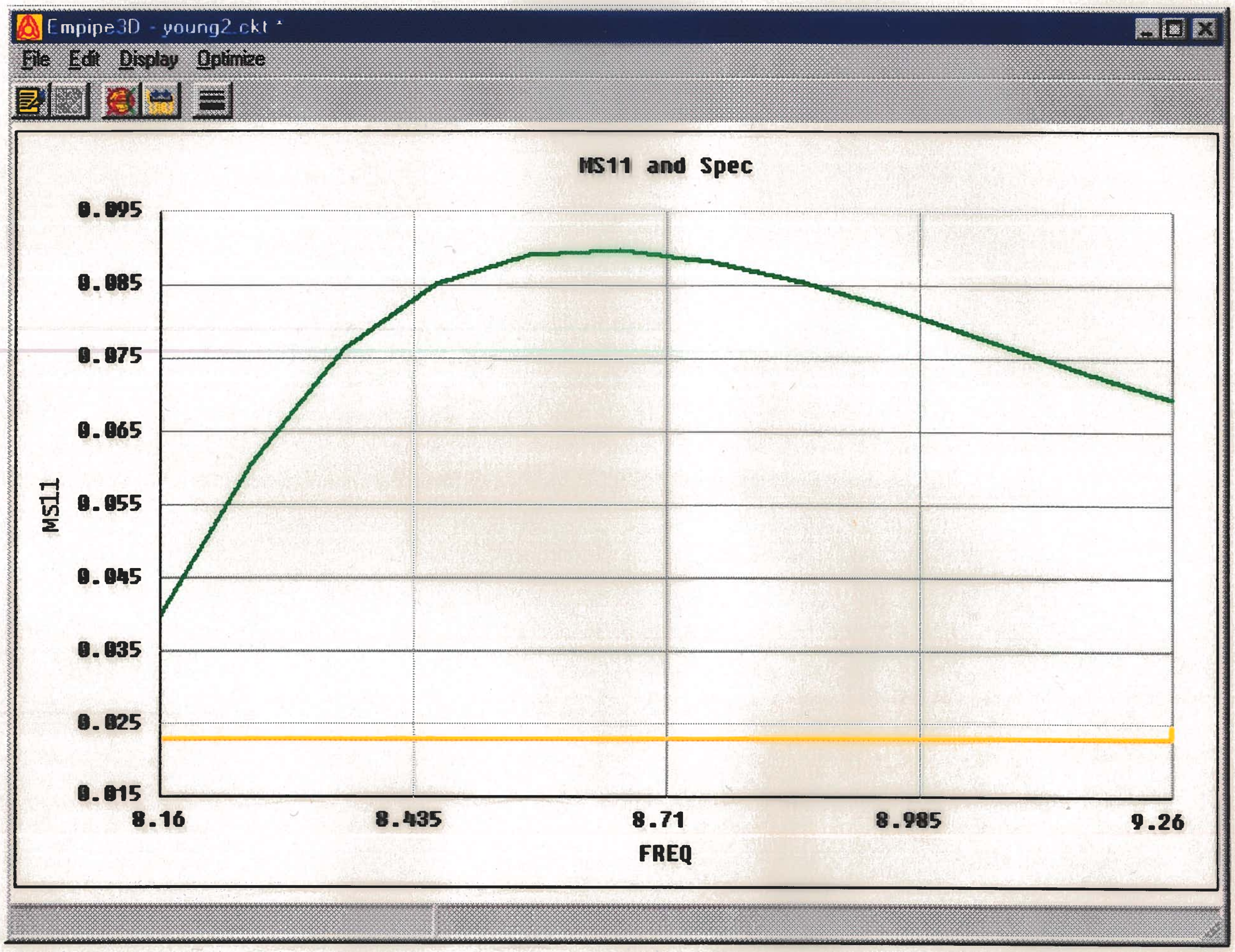
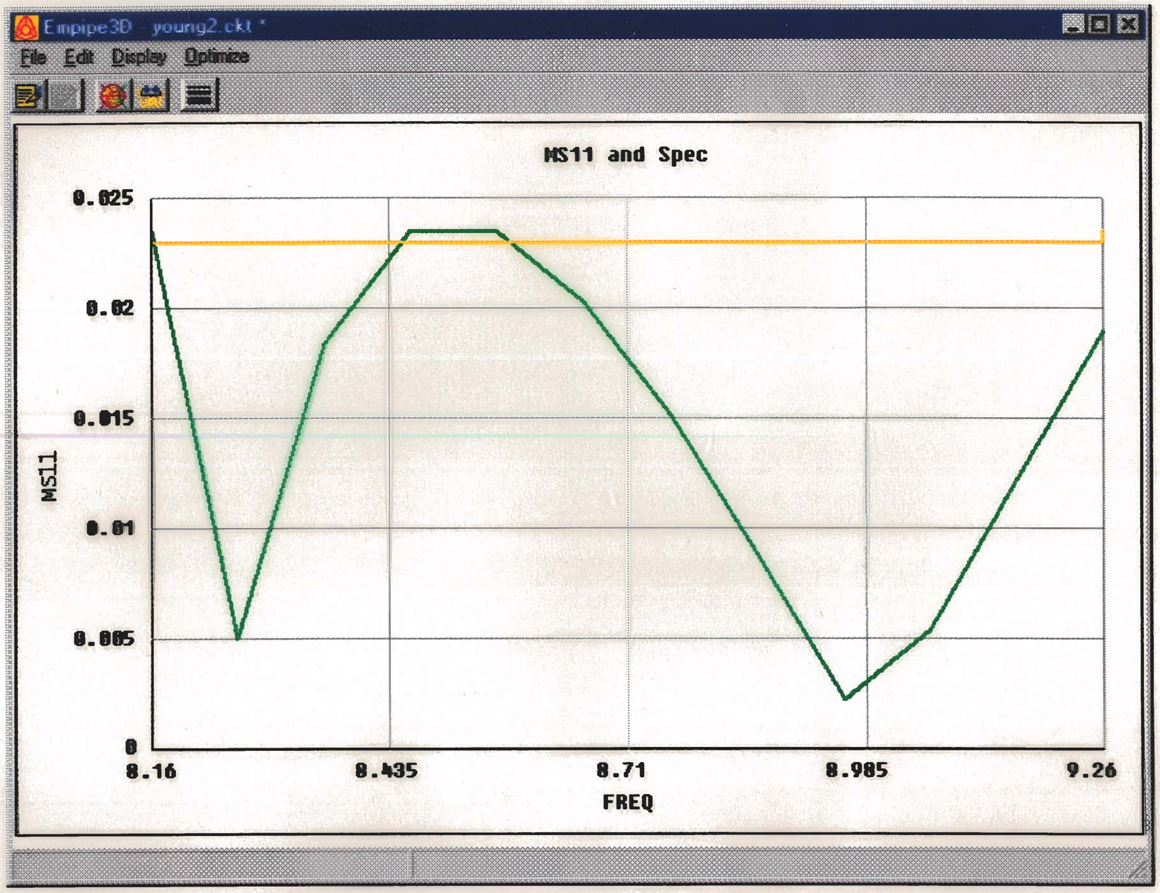
Optimization Results

the display frequency sweep of the nominal structure shows the response and the specifications at the starting point



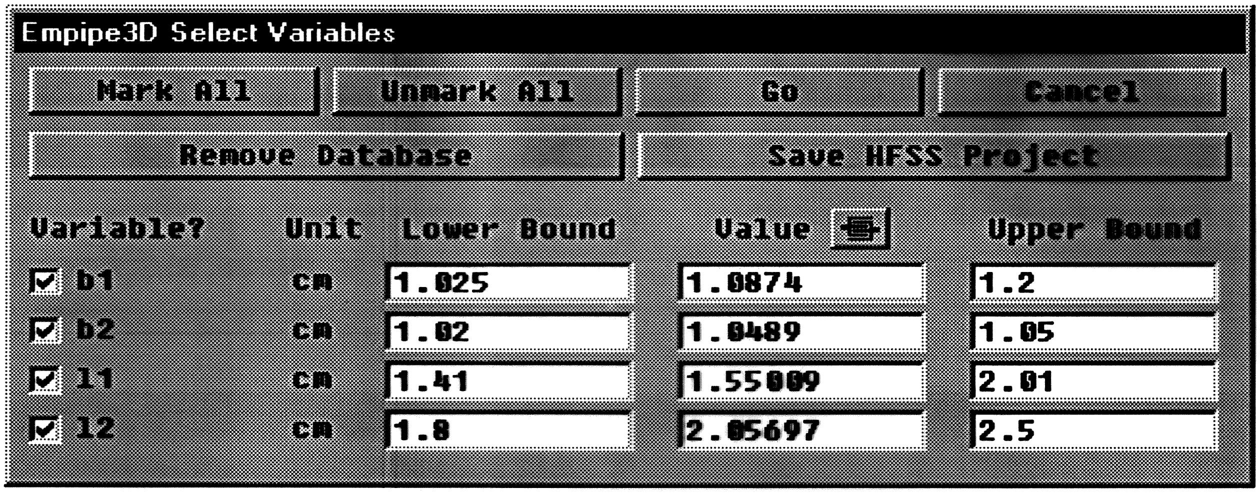
Optimization Results (cont'd)

$|S_{11}|$ response and specifications after minimax optimization



Optimized Parameter Values

the optimized parameter values are reported in the Empipe3D Select Variables window



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ b1	cm	1.025	1.0874	1.2
☑ b2	cm	1.02	1.0489	1.05
☑ l1	cm	1.41	1.55009	2.01
☑ l2	cm	1.8	2.05697	2.5

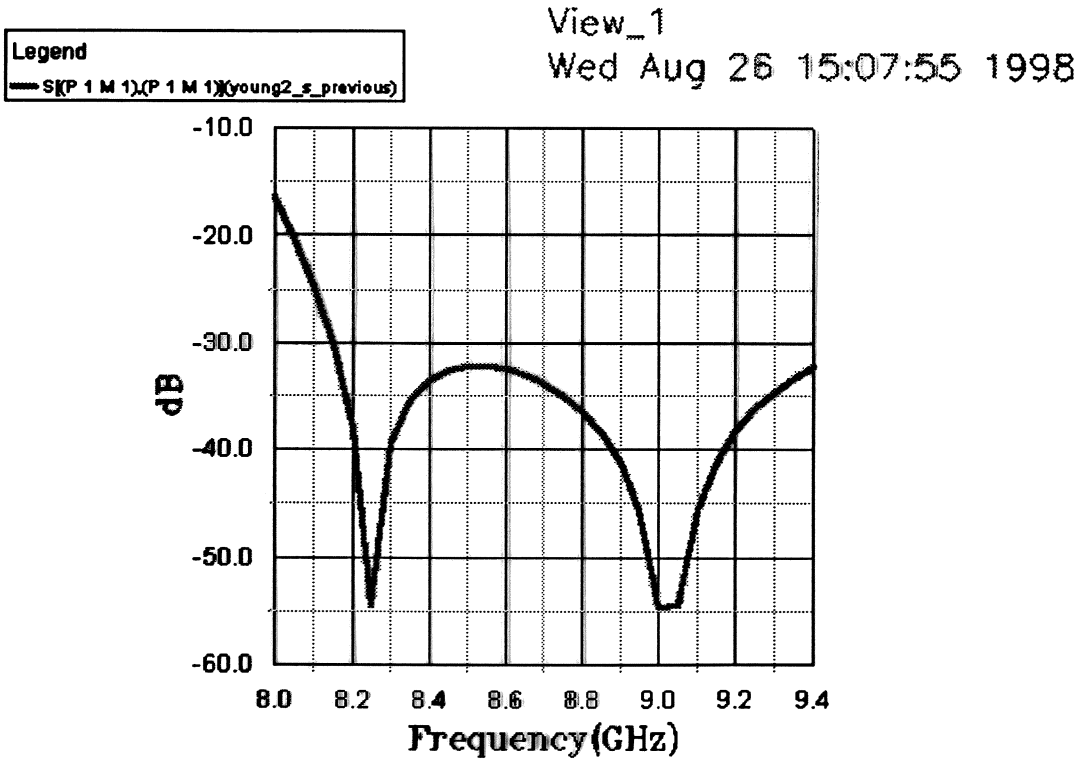
Final Validation

Empipe3D utilizes interpolation of responses to reduce the number of HP HFSS calls

to avoid errors due to interpolation a final validation of the optimal design using HP HFSS directly is advisable

the optimal structure can be generated automatically through the Empipe3D Geometry Capture feature

HP HFSS output for $|S_{11}|$ in dB for the optimized two-section transformer structure

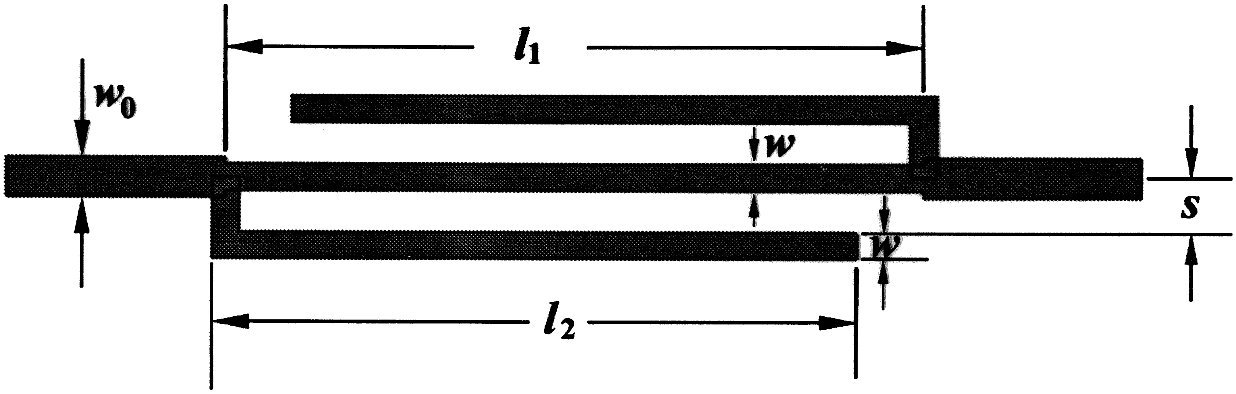


Optimization of a Microstrip Double Folded Stub Bandstop Filter (*Bandler et al. 1994*)

substrate parameters: height h=5 mil, dielectric constant ε_r=9.9

input/output microstrip-line width w_0=4.8 mil ($Z_0 \approx 50\ \Omega$)

the set of optimization parameters includes l_1, l_2, s and w



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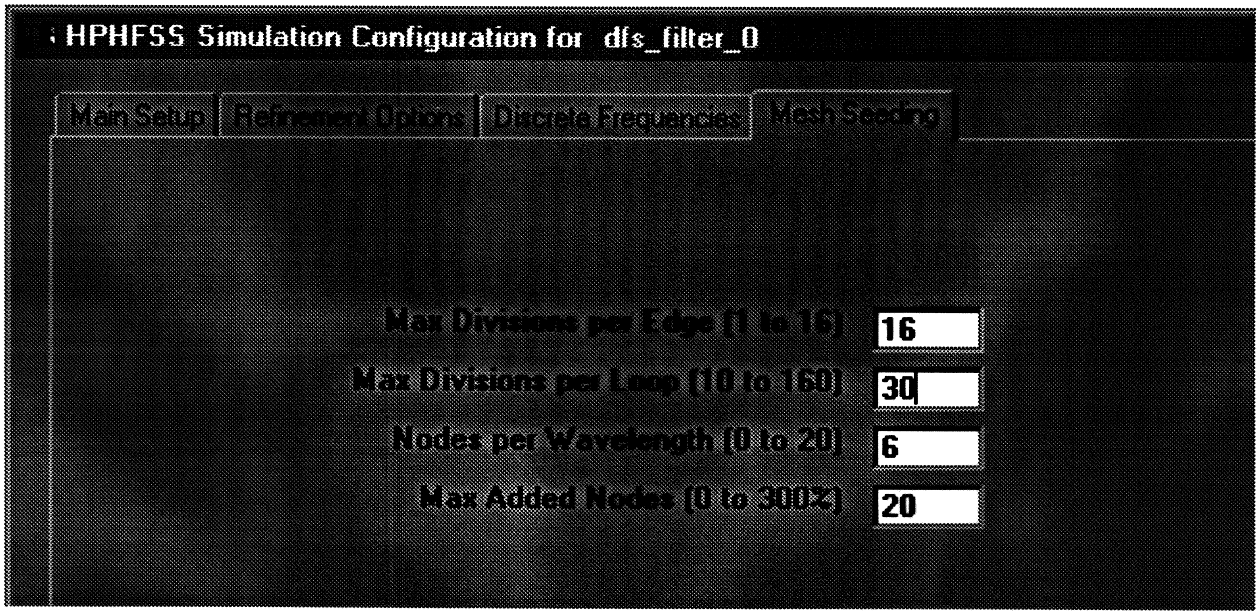
Setting Up the HP HFSS Solution

special care is taken of the HP HFSS solution setup when microstrip structures are solved because default settings are no longer appropriate

adaptive refinement of the HP HFSS solution

Global Delta S-Parameter = 0.05
mesh refinement frequency *Mesh Freq.* = 15 GHz
(the center frequency of the stopband)

mesh seeding limits



Max Divisions per Edge (1 to 16) 16
Max Divisions per Loop (10 to 160) 30
Nodes per Wavelength (0 to 20) 6
Max Added Nodes (0 to 300%) 20

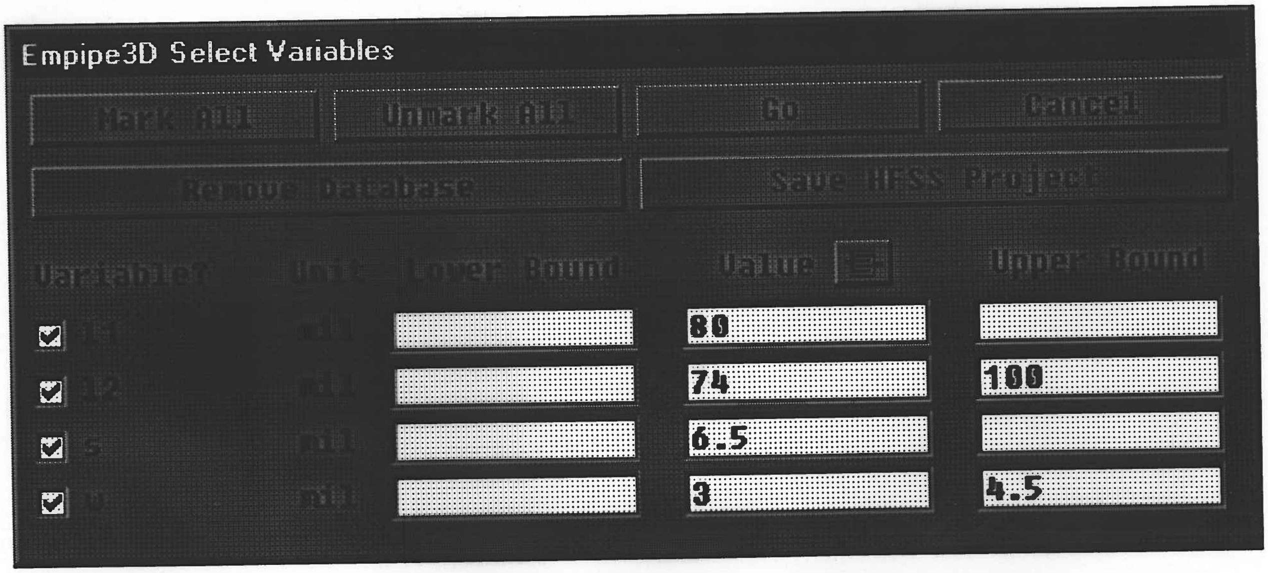
Setting Up the Optimization Problem

the Empipe3D Geometry Capture form editor

Nominal Project: dfs_filter_0

Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
l1	dfs_filter_l1	80	90	10	mil
l2	dfs_filter_l2	74	75	1	mil
s	dfs_filter_s	6.5	6	1	mil
w	dfs_filter_w	3	2	2	mil

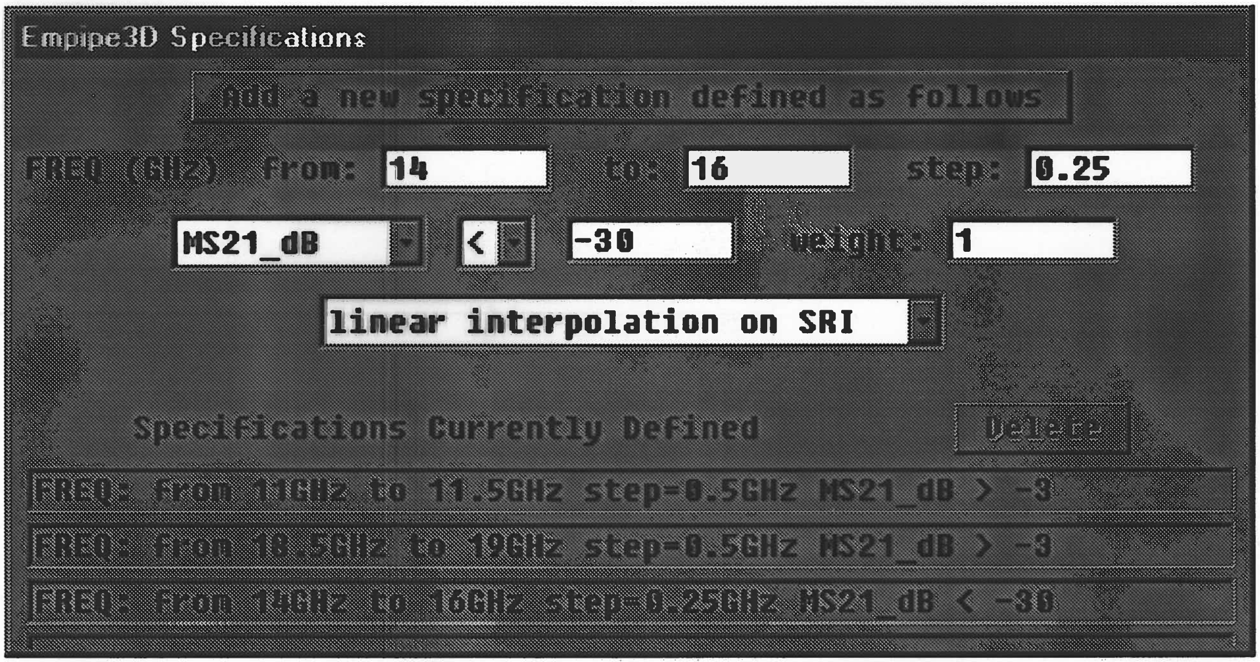
selecting the optimization variables and setting their constraints



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ l1	mil		80	
☑ l2	mil		74	100
☑ s	mil		6.5	
☑ w	mil		3	4.5

Setting Up the Optimization Problem (cont'd)

optimization specifications are defined in terms of the transmission coefficient $|S_{21}|$ in dB



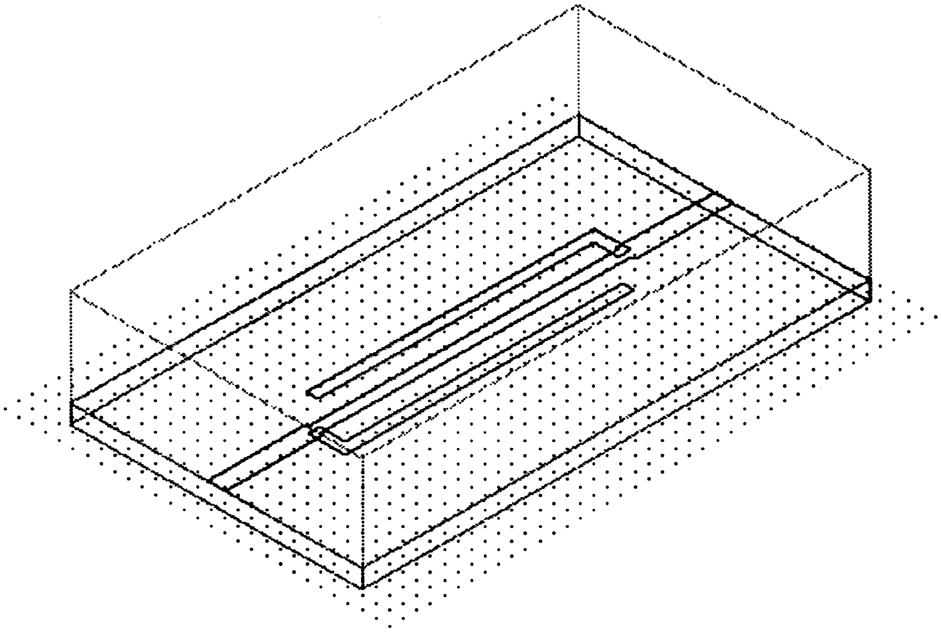
FREQ (GHz) from: 14 to: 16 step: 0.25

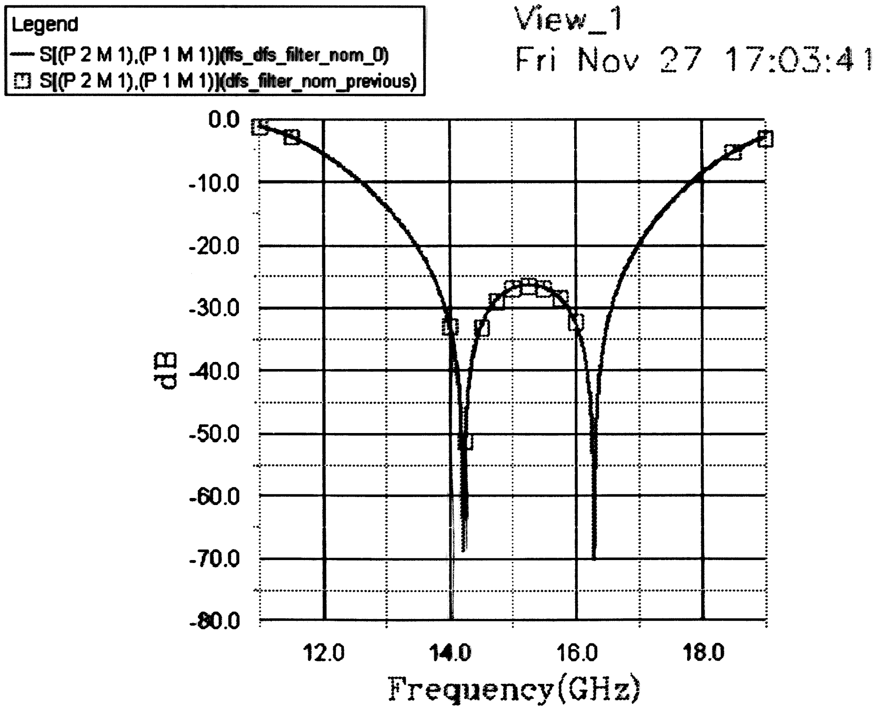
MS21_dB < -30 weight: 1

linear interpolation on SRI

FREQ: from 11GHz to 11.5GHz step=0.5GHz MS21_dB > -3
FREQ: from 18.5GHz to 19GHz step=0.5GHz MS21_dB > -3
FREQ: from 14GHz to 16GHz step=0.25GHz MS21_dB < -30

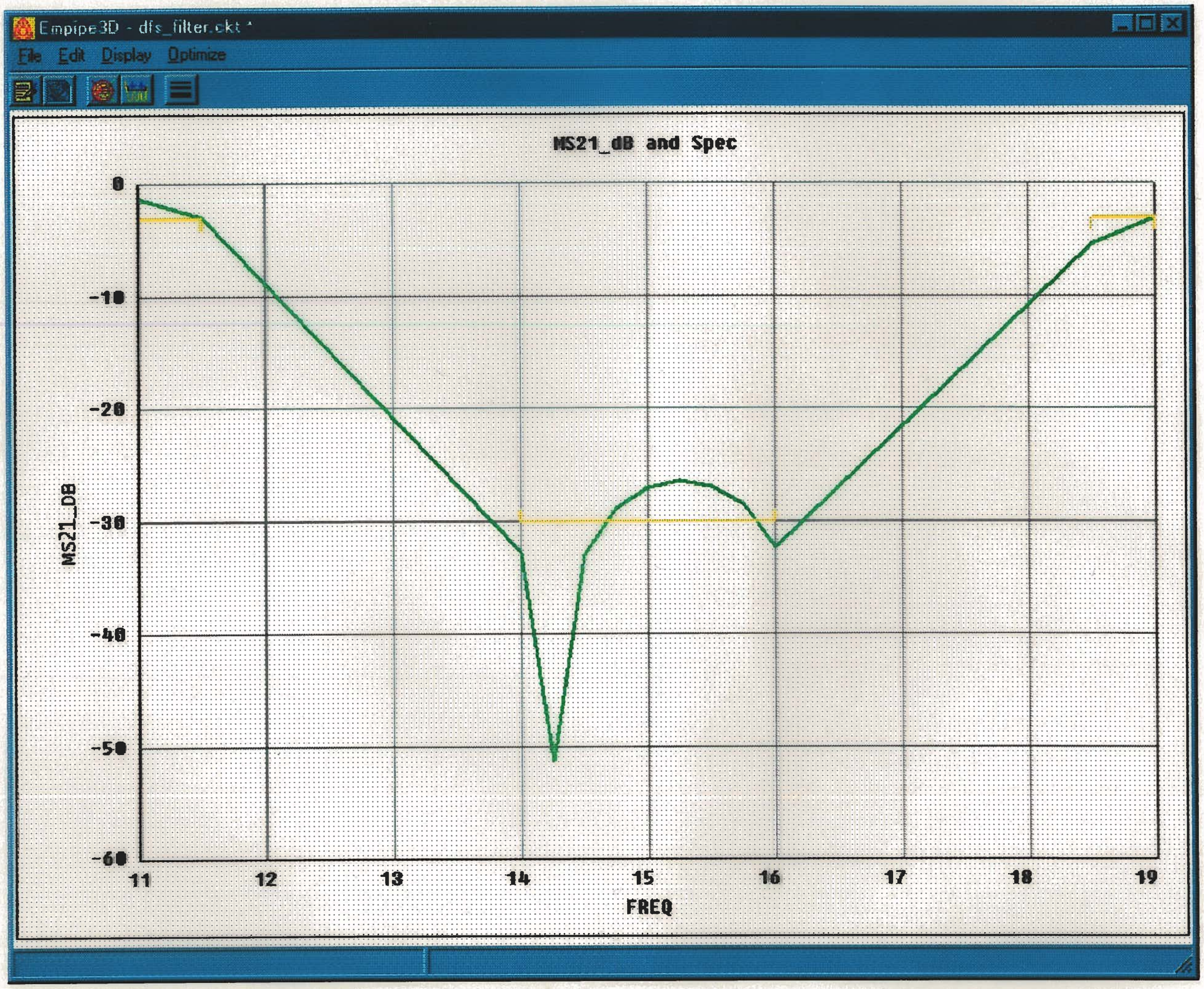
The Nominal Structure and its $|S_{21}|$ Response





Optimization Results

$|S_{21}|$ and specifications before optimization (display sweep with *model* = 0, no interpolation)



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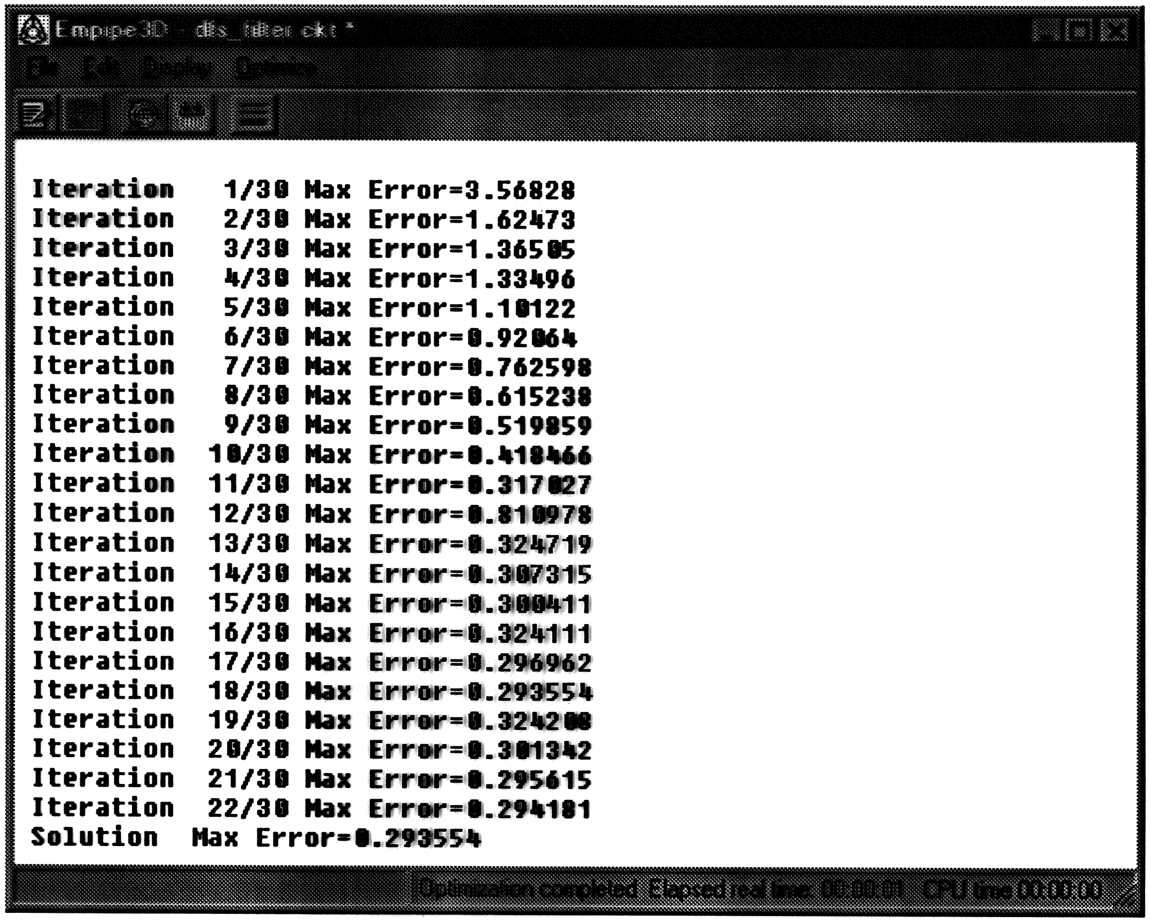
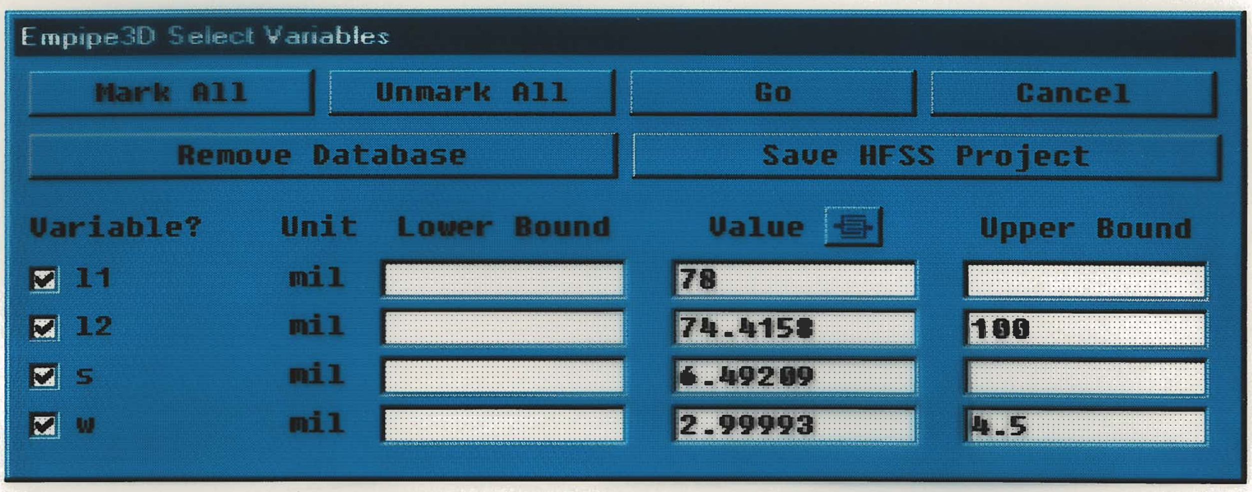
Minimax Solution



```
Iteration   1/30 Max Error=3.56828
Iteration   2/30 Max Error=1.62473
Iteration   3/30 Max Error=1.36505
Iteration   4/30 Max Error=1.33496
Iteration   5/30 Max Error=1.10122
Iteration   6/30 Max Error=0.92064
Iteration   7/30 Max Error=0.762598
Iteration   8/30 Max Error=0.615238
Iteration   9/30 Max Error=0.519859
Iteration  10/30 Max Error=0.418466
Iteration  11/30 Max Error=0.317027
Iteration  12/30 Max Error=0.810978
Iteration  13/30 Max Error=0.324719
Iteration  14/30 Max Error=0.307315
Iteration  15/30 Max Error=0.300411
Iteration  16/30 Max Error=0.324111
Iteration  17/30 Max Error=0.296962
Iteration  18/30 Max Error=0.293554
Iteration  19/30 Max Error=0.324200
Iteration  20/30 Max Error=0.301342
Iteration  21/30 Max Error=0.295615
Iteration  22/30 Max Error=0.294181
Solution  Max Error=0.293554
```

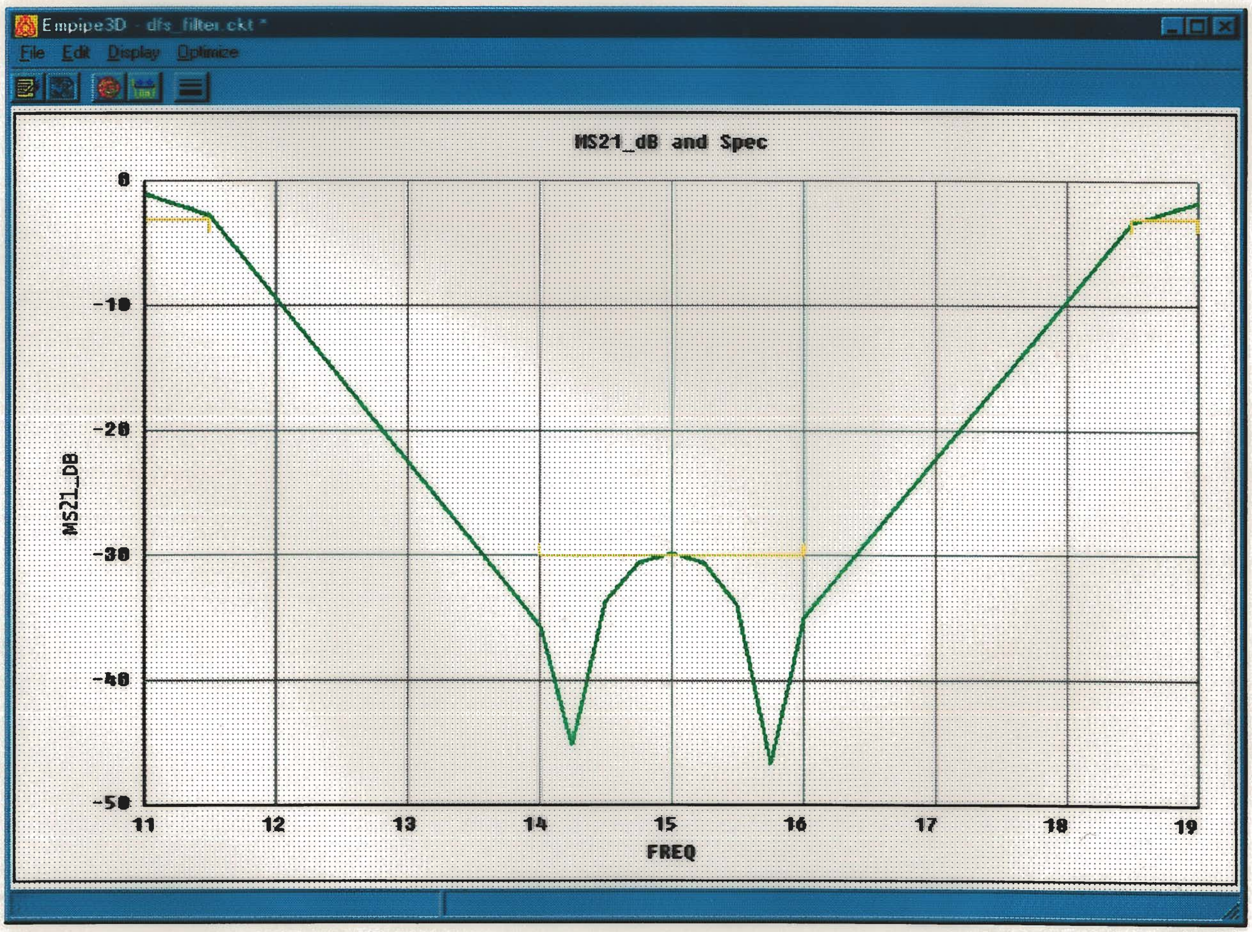
Optimization completed Elapsed real time: 00:00:01 CPU time 00:00:00

Optimized Parameter Values



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ l1	mil		78	
☑ l2	mil		74.4158	100
☑ s	mil		6.49209	
☑ w	mil		2.99993	4.5

$|S_{21}|$ and specifications after optimization



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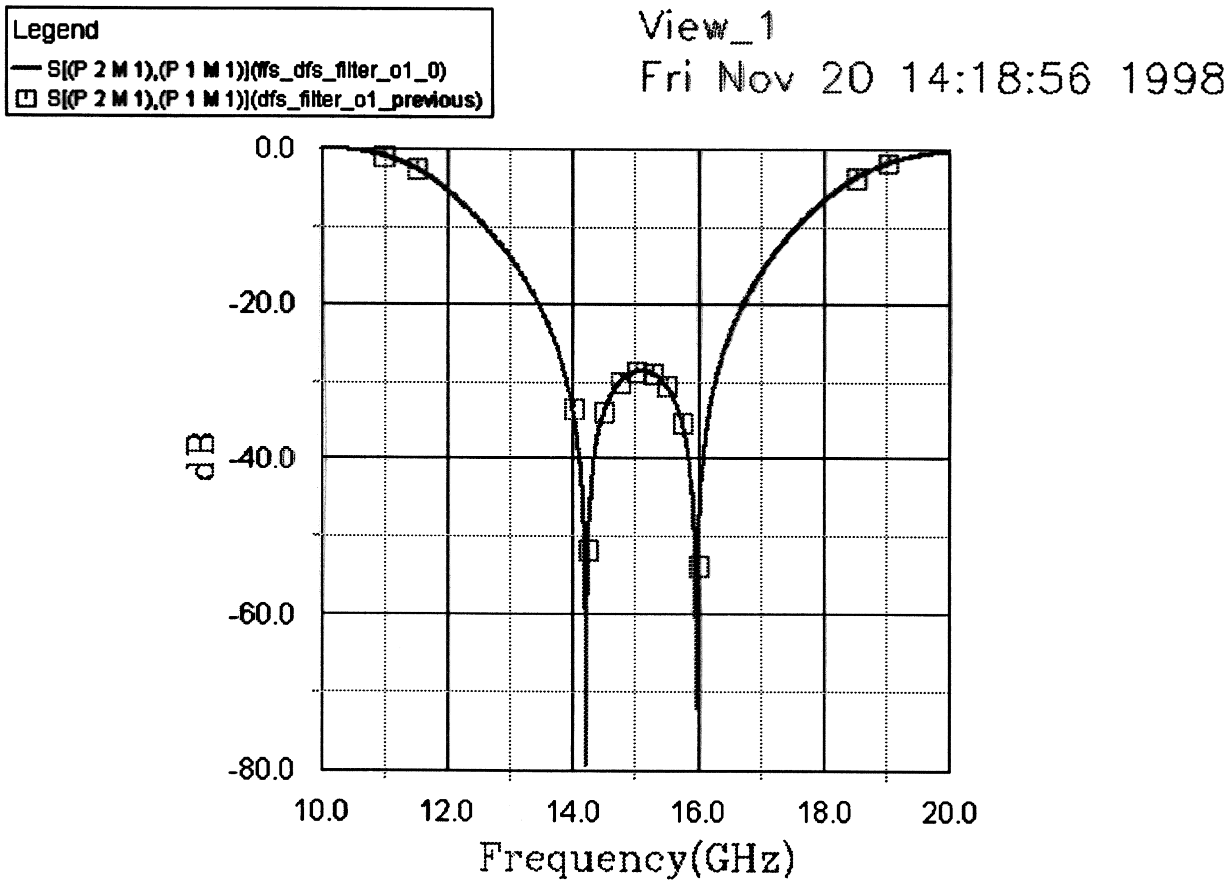
Final Validation of the Optimal Solution

fast frequency sweep from 10 GHz to 20 GHz expanding from 15 GHz, discrete frequency sweep at frequency points at which optimization specifications are defined

the $|S_{21}|$ response in dB generated by HP HFSS

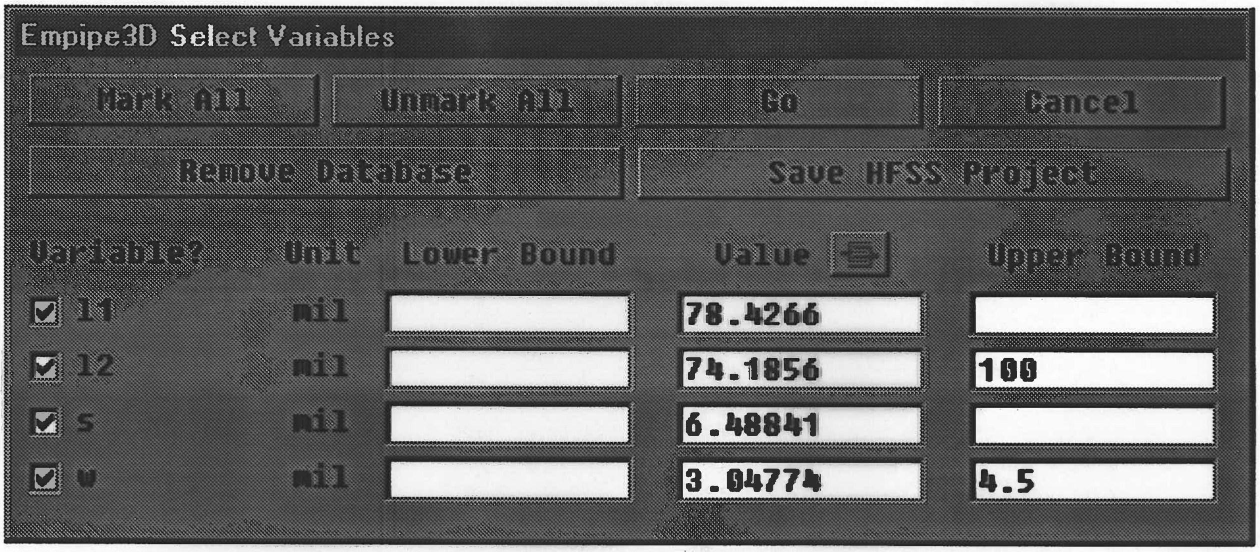


Exploring Other Possible Solutions

a number of starting points close to the above optimal solution are explored

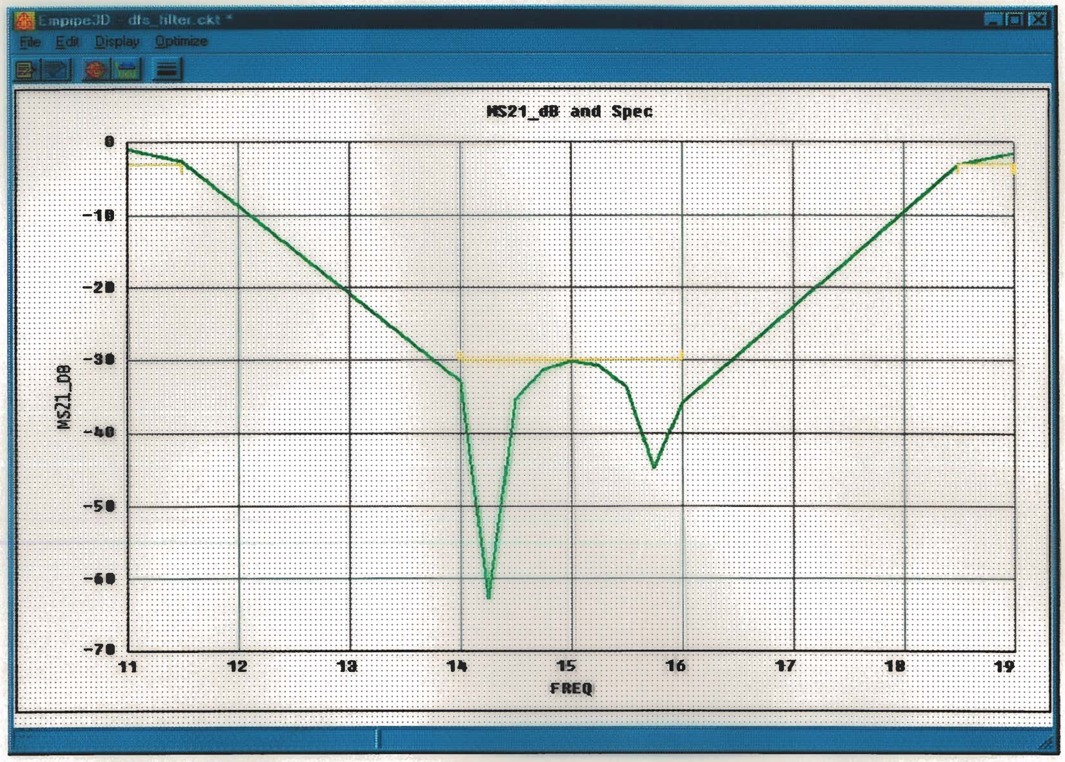
to finally refine the solution response, interpolation can be switched off by setting *model*=0

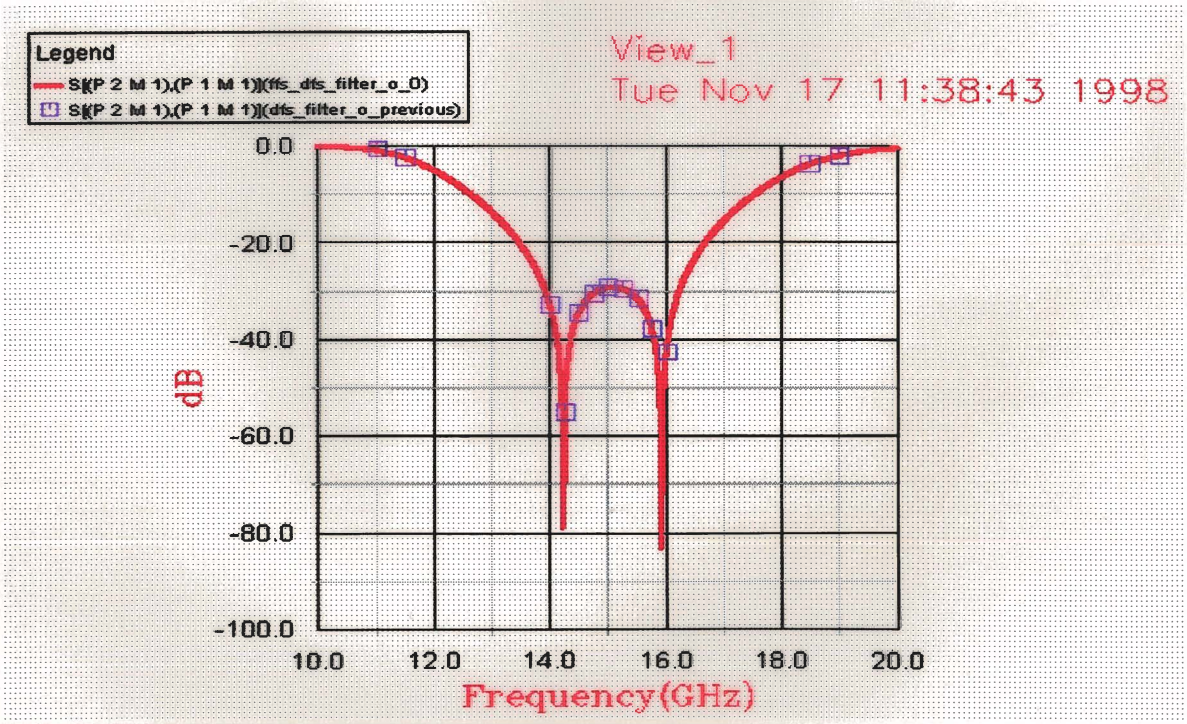
a better solution is found with a Solution Max Error of 0.11 dB



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ l1	mil		78.4266	
☑ l2	mil		74.1856	100
☑ s	mil		6.48841	
☑ w	mil		3.04774	4.5

Exploring Other Possible Solutions (cont'd)





Optimization of a High-Temperature Superconducting Microwave Filter

narrow bandwidth: 1.24 %; passband: 4.008 - 4.058 GHz

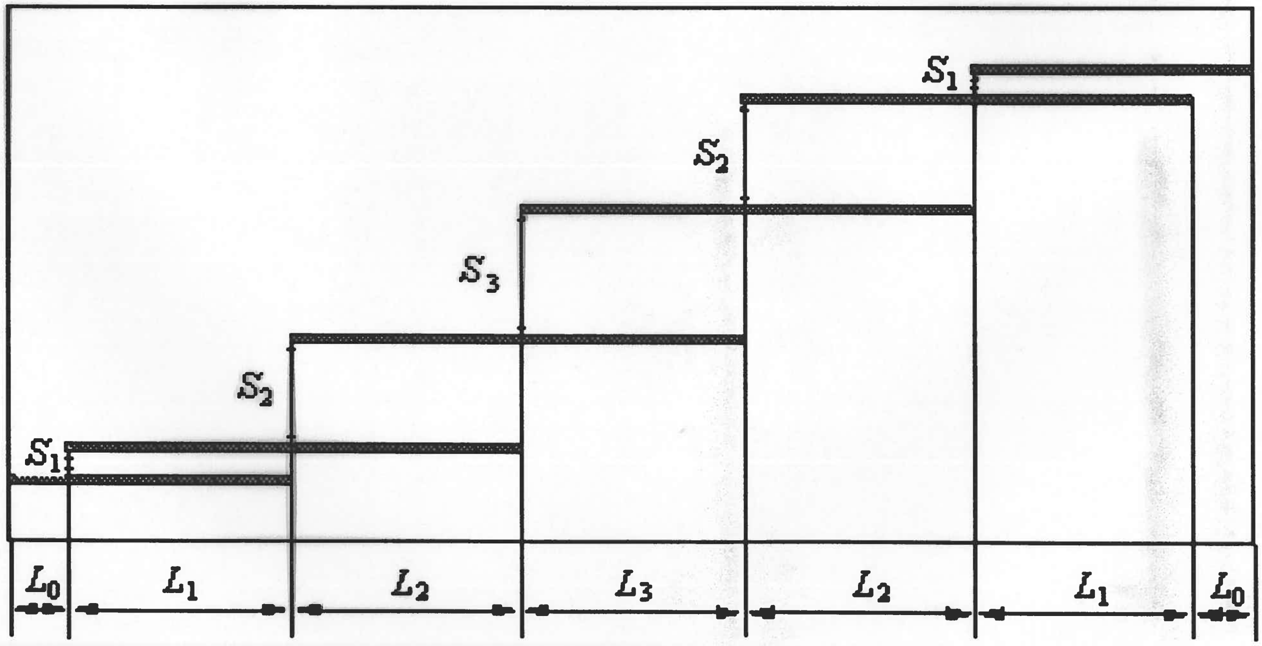
substrate: $\varepsilon_r = 23.425$; $h = 20$ mil

parallel coupled-line design, strip width $w = 7$ mil

traditional microwave circuit design techniques are not reliable because built-in microstrip-element models are not accurate for such dielectric constants

radiation losses, surface-wave coupling and higher-order modes are also unaccounted for by the microwave-circuit CAD tools

(*Talisa et al. 1991, Lyons et al. 1991, Bandler et al. 1995*)



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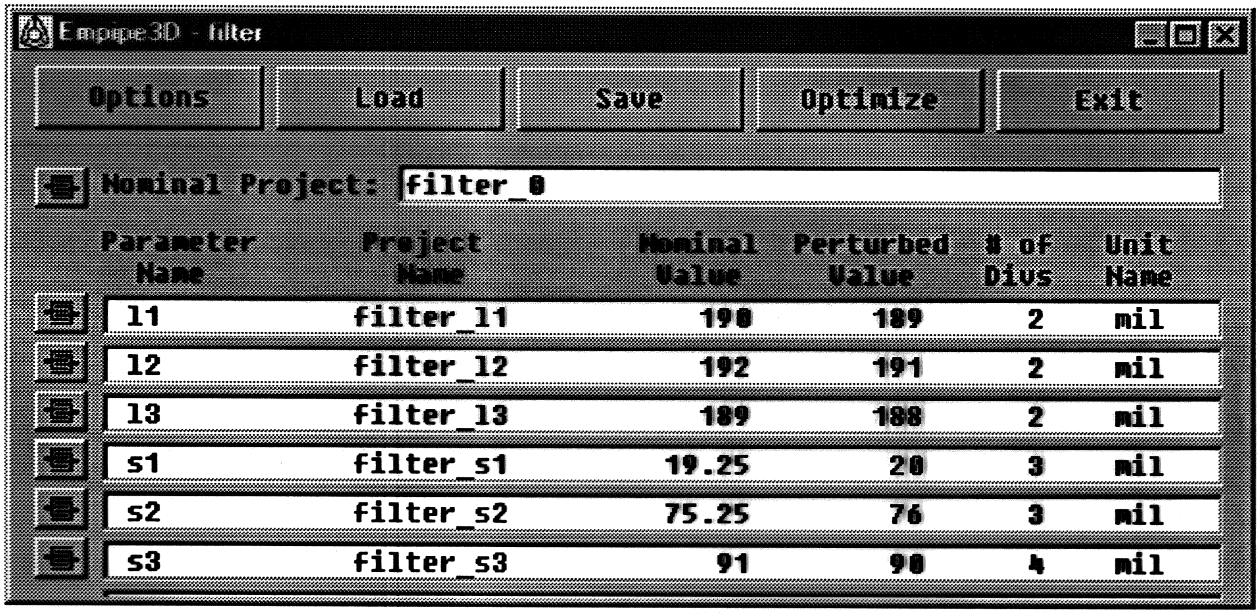
The Nominal and Perturbed Parameter Values

the nominal (starting) values of the optimization variables are chosen to be close to those obtained by Bandler *et al.* 1995

the nominal and perturbed values of the optimization parameters and the corresponding projects can be viewed in the Empipe3D form editor window



Nominal Project: filter_0

Parameter Name	Project Name	Nominal Value	Perturbed Value	# of Divs	Unit Name
l1	filter_l1	190	189	2	mil
l2	filter_l2	192	191	2	mil
l3	filter_l3	189	188	2	mil
s1	filter_s1	19.25	20	3	mil
s2	filter_s2	75.25	76	3	mil
s3	filter_s3	91	90	4	mil

The Solution Setup and the Nominal Project Response

a preliminary fast frequency sweep of the nominal project is absolutely necessary when narrow-band filter structures are designed

the nominal (starting) design might produce a response which is shifted more than two bandwidths away from the expected center frequency, thus making the optimizer see nothing but full rejection in the specifications' frequency band for any parameter perturbation

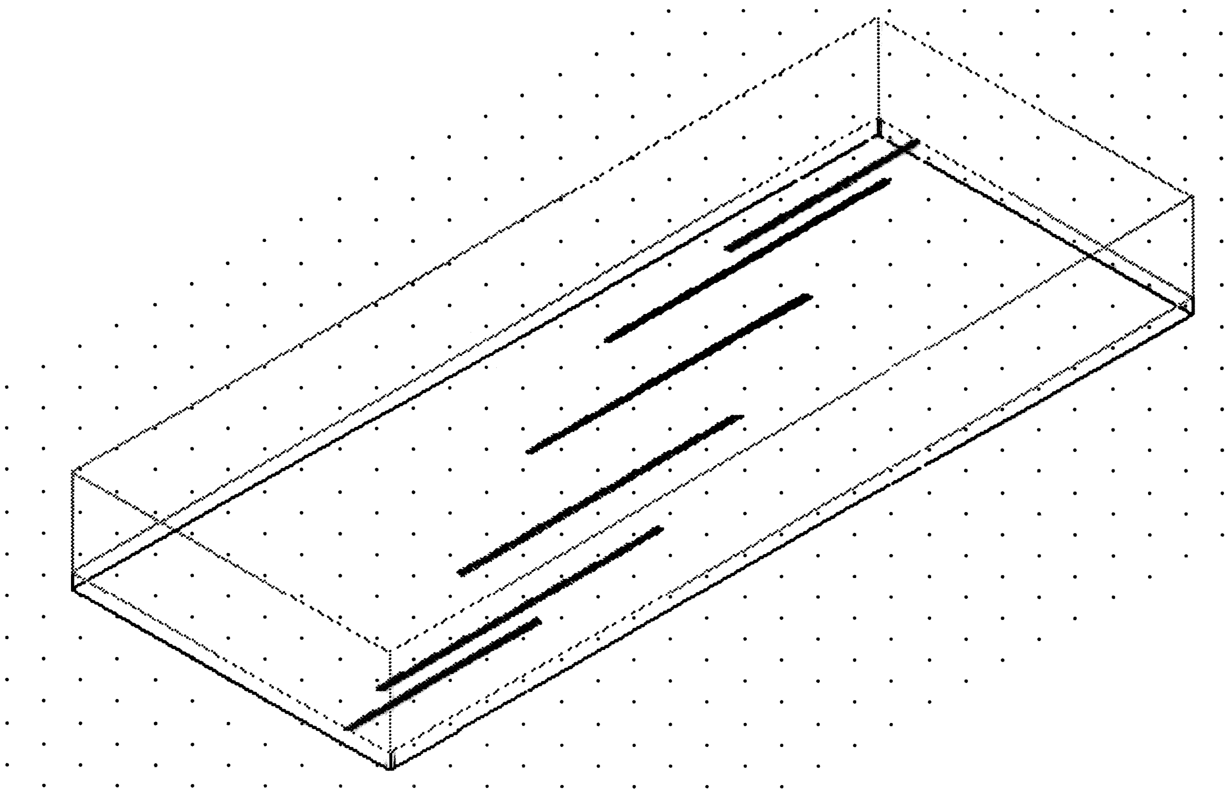
direct optimization in such cases may be very difficult or even impossible

a preliminary sweep would also give the designer a good sense of the expected CPU time and memory requirements of the current solution setup

the computational load of a single HP HFSS simulation is largely dependent on the refinement options of the adaptive solutions as well as on mesh-seeding

when narrow-band filters are designed, it appears to be advisable to refine the mesh not at the highest frequency of interest but at a frequency in the passband, where the S-parameters are most sensitive to numerical (meshing) errors

The Original Nominal Project Solid Model



default Refinement Options and Mesh Seeding limits are not suitable

large aspect ratios (the maximum possible *Max Divisions per Edge* limit is specified)

very high dielectric constant (a larger number of *Nodes per Wavelength* is necessary, the default number of 2 nodes per wavelength in air is unacceptable)

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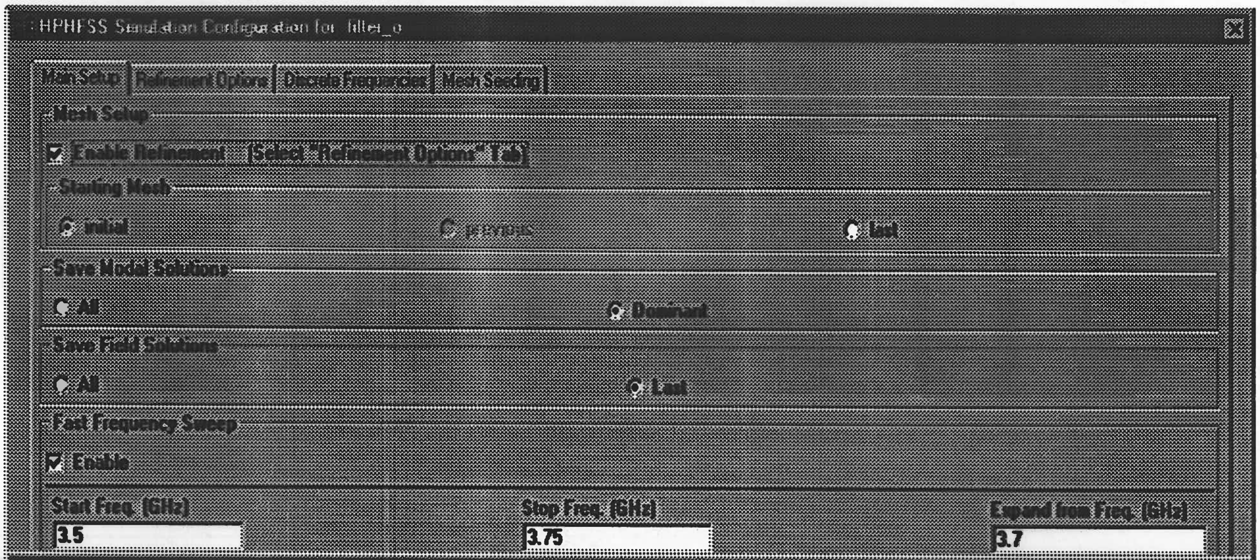
The Original Nominal Project Solution Setup



Mesh Setup

☑ Enable Refinement (Select "Refinement Options" Tab)

Starting Mesh

○ initial ○ previous ● last

Save Modal Solutions

○ All ● Dominant

Save Field Solutions

○ All ● Last

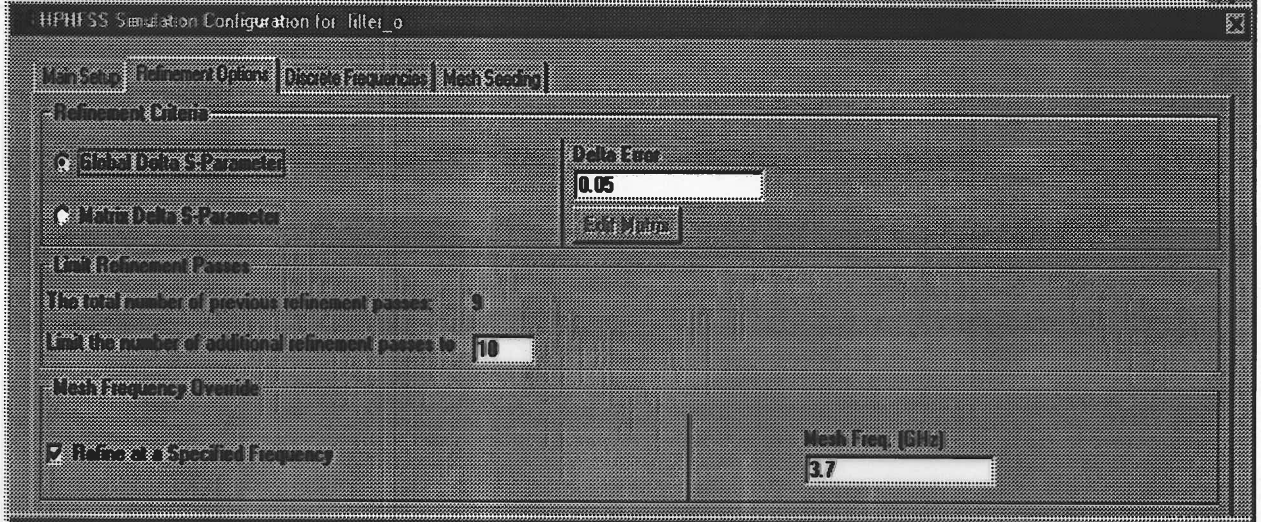
Fast Frequency Sweep

☑ Enable

Start Freq. (GHz): 3.5

Stop Freq. (GHz): 3.75

Expand from Freq. (GHz): 3.7



Refinement Criteria

● Global Delta S-Parameter

○ Matrix Delta S-Parameter

Delta Error: 0.05

Limit Refinement Passes

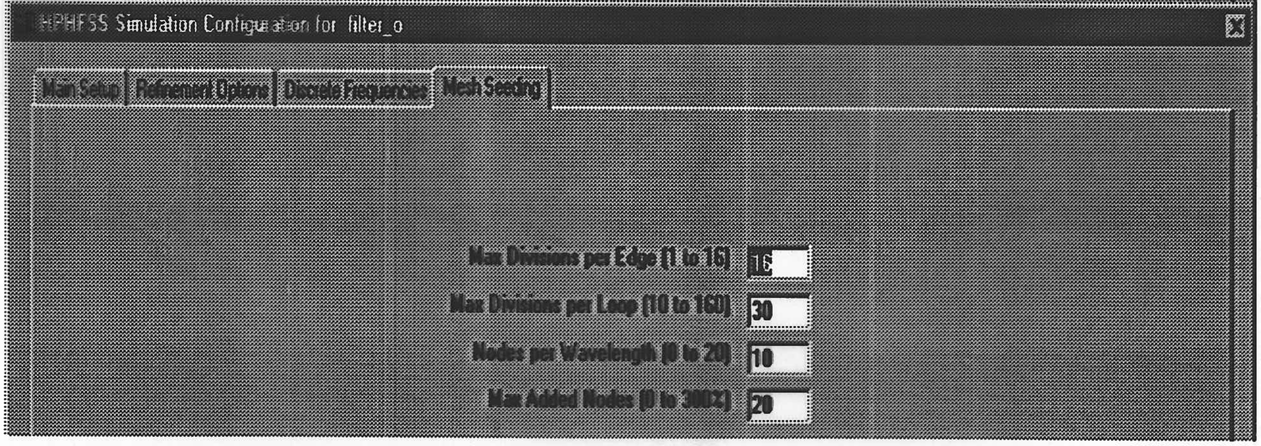
The total number of previous refinement passes: 9

Limit the number of additional refinement passes to 10

Mesh Frequency Override

☑ Refine at a Specified Frequency

Mesh Freq. (GHz): 3.7



Max Divisions per Edge (1 to 16): 16

Max Divisions per Loop (10 to 160): 30

Nodes per Wavelength (0 to 20): 10

Max Added Nodes (0 to 300%): 20

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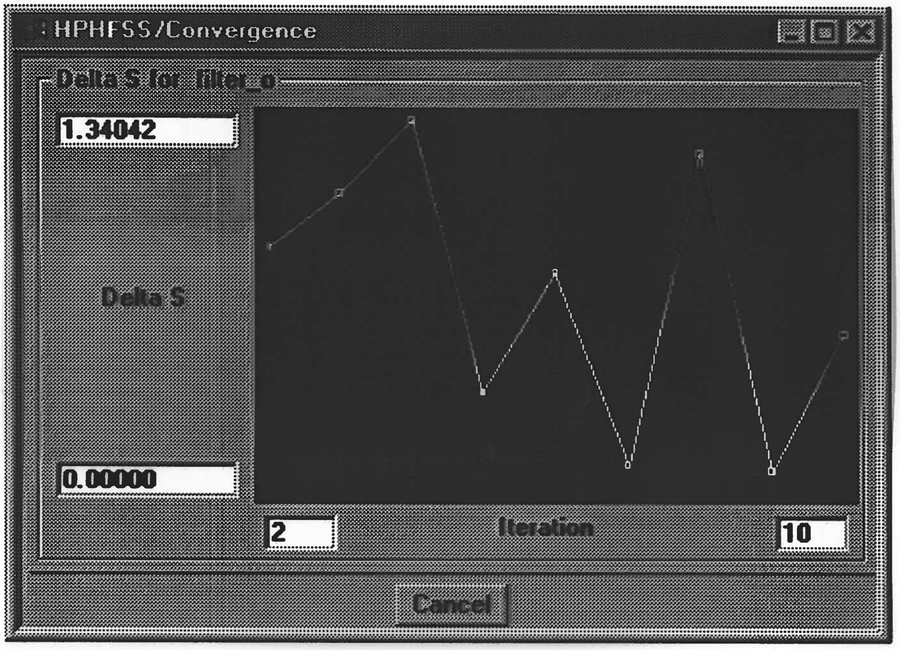
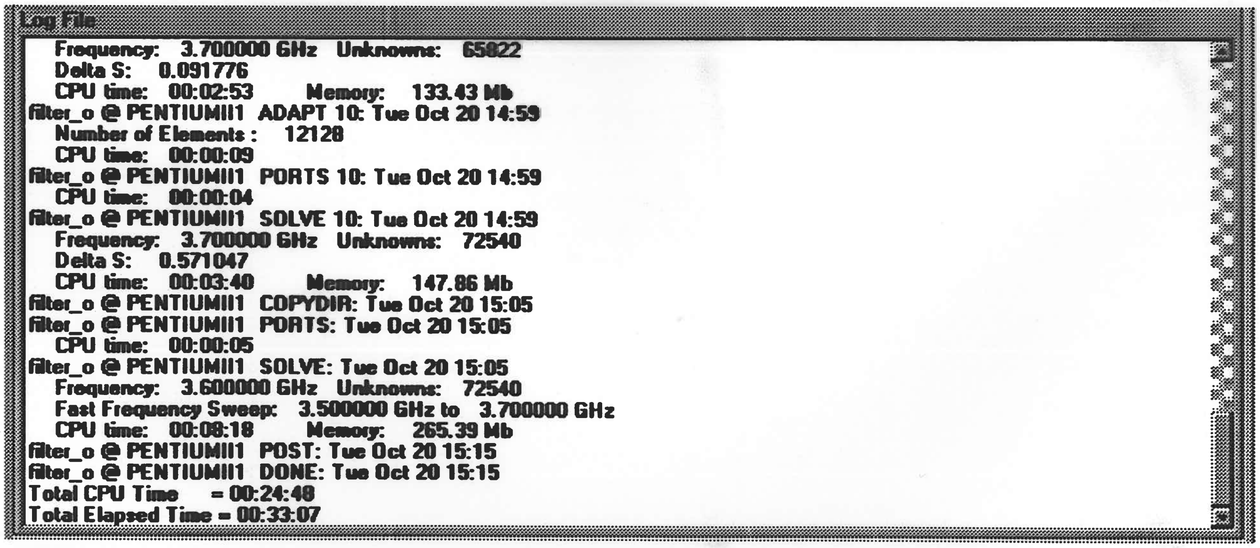
The Original Nominal Project Solution

the adaptive solutions produce unusually large ΔS and exhibit very poor convergence

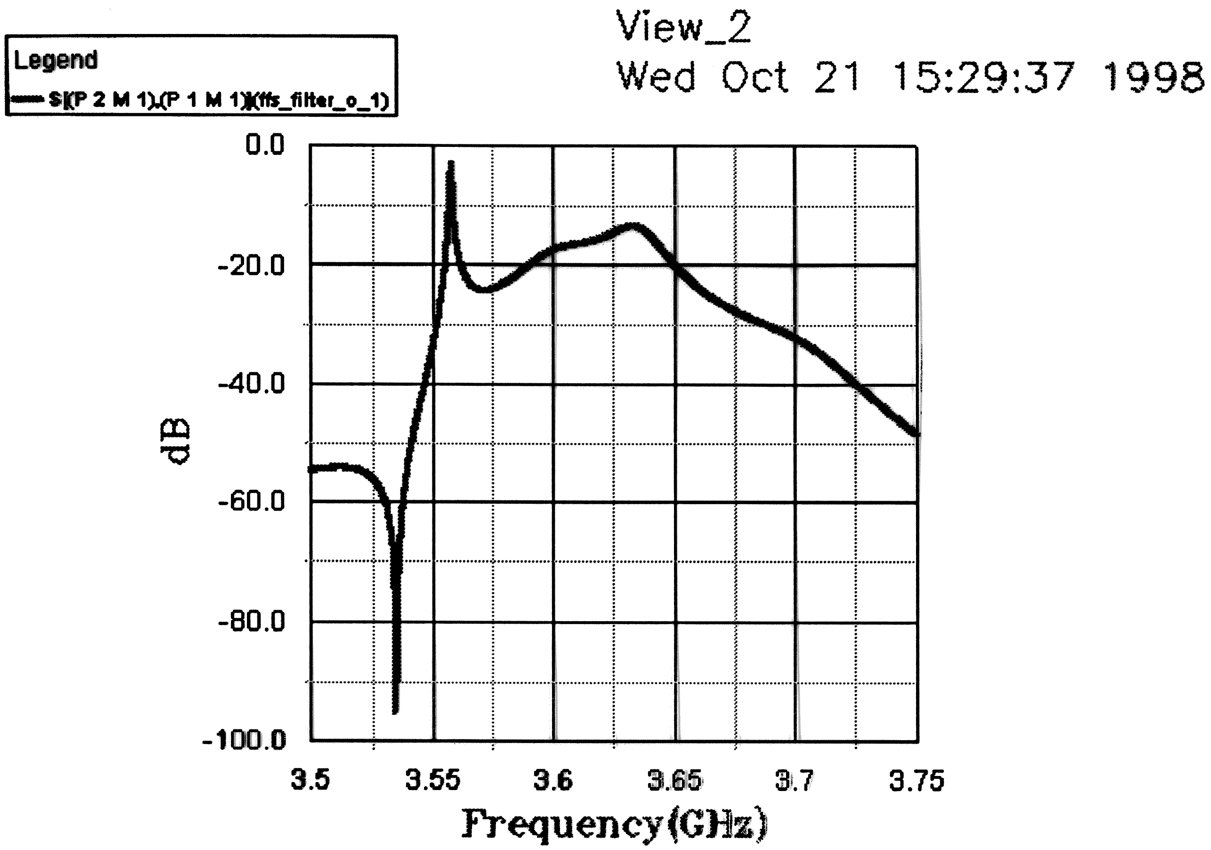


the CPU time and memory requirements for a single simulation become too large



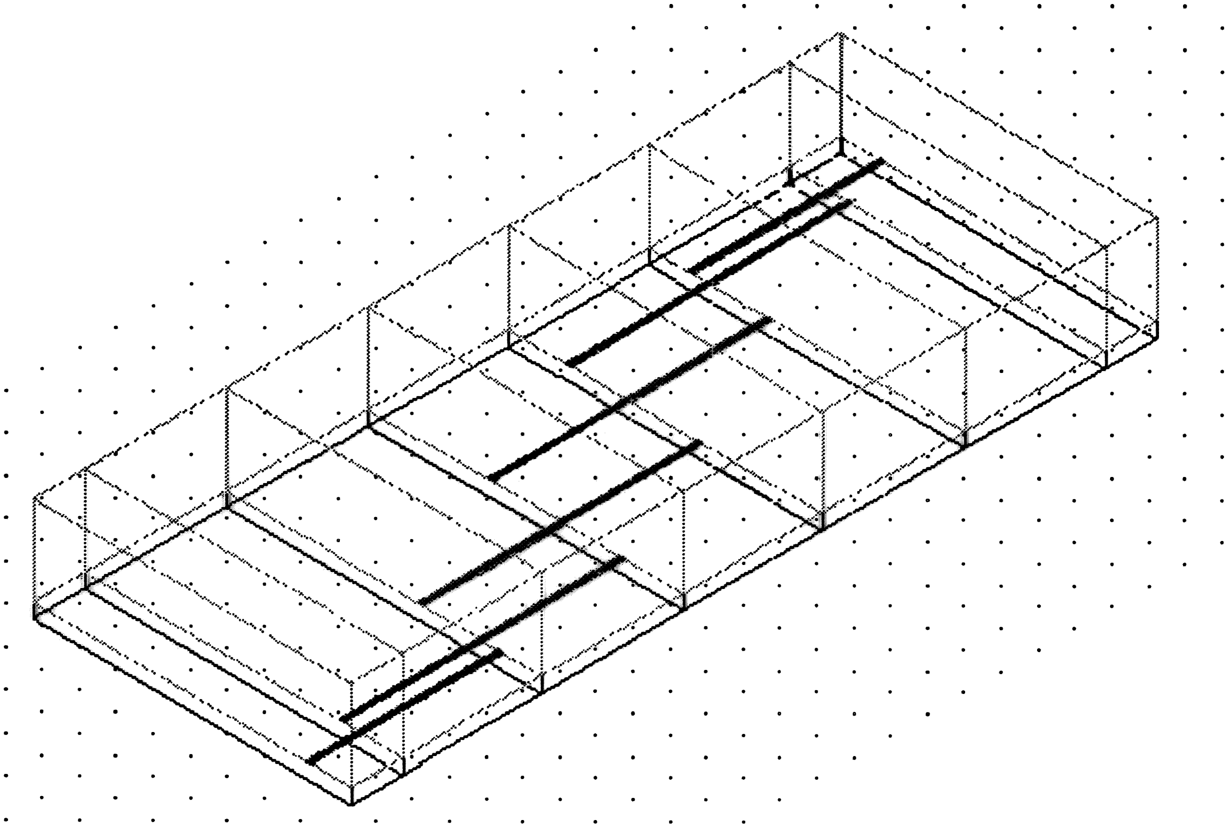
```
    Frequency:   3.700000 GHz   Unknowns:   65822
    Delta S:    0.091776
    CPU time:   00:02:53        Memory:    133.43 Mb
filter_o @ PENTIUMII1  ADAPT 10: Tue Oct 20 14:59
    Number of Elements :    12128
    CPU time:   00:00:09
filter_o @ PENTIUMII1  PORTS 10: Tue Oct 20 14:59
    CPU time:   00:00:04
filter_o @ PENTIUMII1  SOLVE 10: Tue Oct 20 14:59
    Frequency:   3.700000 GHz   Unknowns:   72540
    Delta S:    0.571047
    CPU time:   00:03:40        Memory:    147.86 Mb
filter_o @ PENTIUMII1  COPYDIR: Tue Oct 20 15:05
filter_o @ PENTIUMII1  PORTS: Tue Oct 20 15:05
    CPU time:   00:00:05
filter_o @ PENTIUMII1  SOLVE: Tue Oct 20 15:05
    Frequency:   3.600000 GHz   Unknowns:   72540
    Fast Frequency Sweep:   3.500000 GHz to   3.700000 GHz
    CPU time:   00:08:18        Memory:    265.39 Mb
filter_o @ PENTIUMII1  POST: Tue Oct 20 15:15
filter_o @ PENTIUMII1  DONE: Tue Oct 20 15:15
Total CPU Time     = 00:24:48
Total Elapsed Time = 00:33:07
```

The Original Nominal Project $|S_{21}|$ Response



The Nominal Projects with Virtual Boundaries

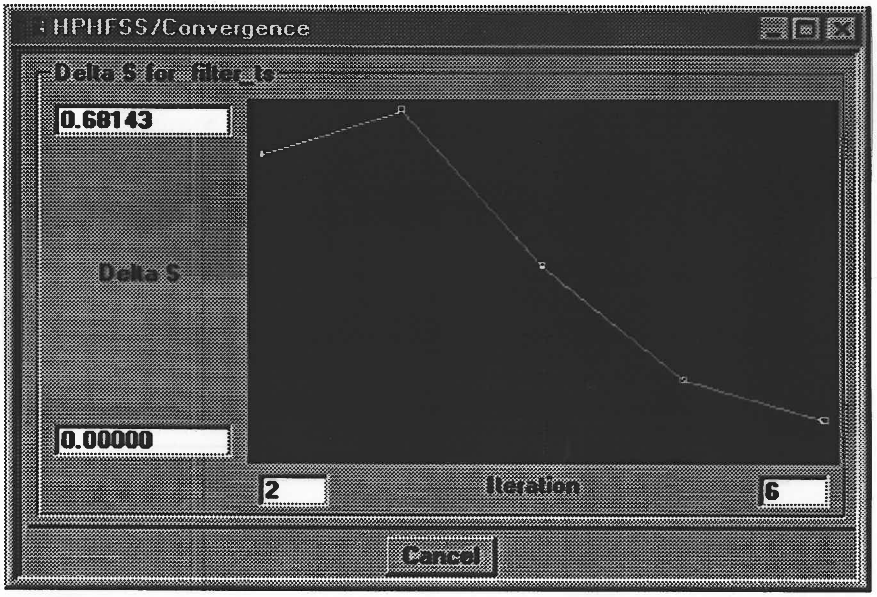
the substrate and the air-box are partitioned into transverse sections, which should improve the aspect ratio between the length and the width of the open-end microstrip lines



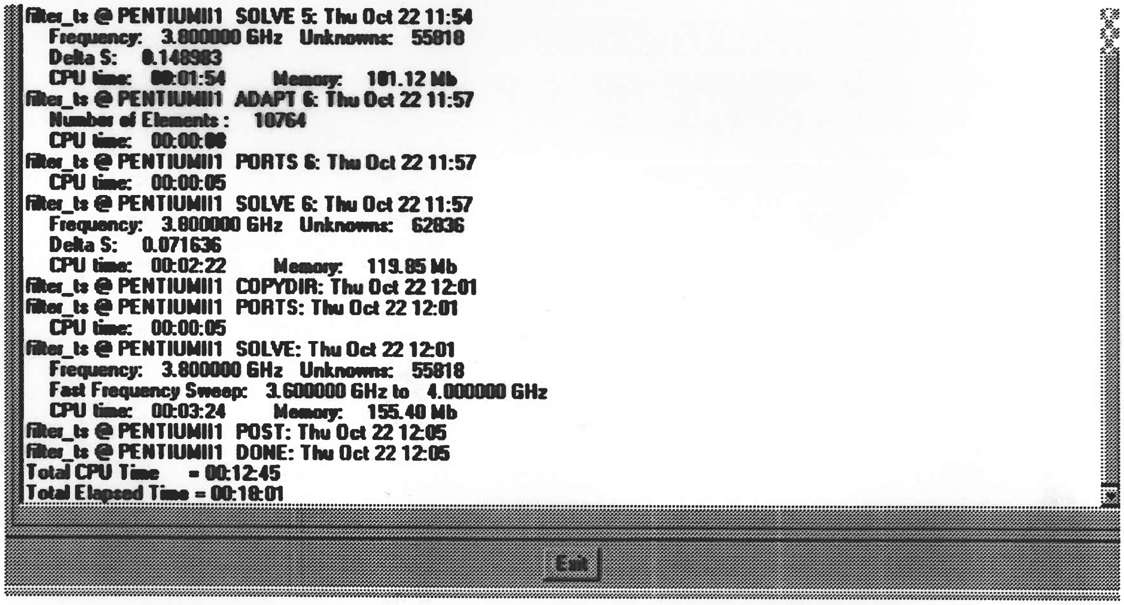
the solution setup and Mesh Seeding limits are kept the same

The New Nominal Project Solution

the solution convergence improves



at the same time the CPU time and memory requirements decrease



```
filter_ts @ PENTIUMII1  SOLVE 5: Thu Oct 22 11:54
   Frequency:  3.800000 GHz  Unknowns:  55818
   Delta S:   0.148983
   CPU time:  00:01:54      Memory:  101.12 Mb
filter_ts @ PENTIUMII1  ADAPT 6: Thu Oct 22 11:57
   Number of Elements :   10764
   CPU time:  00:00:08
filter_ts @ PENTIUMII1  PORTS 6: Thu Oct 22 11:57
   CPU time:  00:00:05
filter_ts @ PENTIUMII1  SOLVE 6: Thu Oct 22 11:57
   Frequency:  3.800000 GHz  Unknowns:  62836
   Delta S:   0.071636
   CPU time:  00:02:22      Memory:  119.85 Mb
filter_ts @ PENTIUMII1  COPYDIR: Thu Oct 22 12:01
filter_ts @ PENTIUMII1  PORTS: Thu Oct 22 12:01
   CPU time:  00:00:05
filter_ts @ PENTIUMII1  SOLVE: Thu Oct 22 12:01
   Frequency:  3.800000 GHz  Unknowns:  55818
   Fast Frequency Sweep:  3.600000 GHz to  4.000000 GHz
   CPU time:  00:03:24      Memory:  155.40 Mb
filter_ts @ PENTIUMII1  POST: Thu Oct 22 12:05
filter_ts @ PENTIUMII1  DONE: Thu Oct 22 12:05
Total CPU Time     = 00:12:45
Total Elapsed Time = 00:18:01
```

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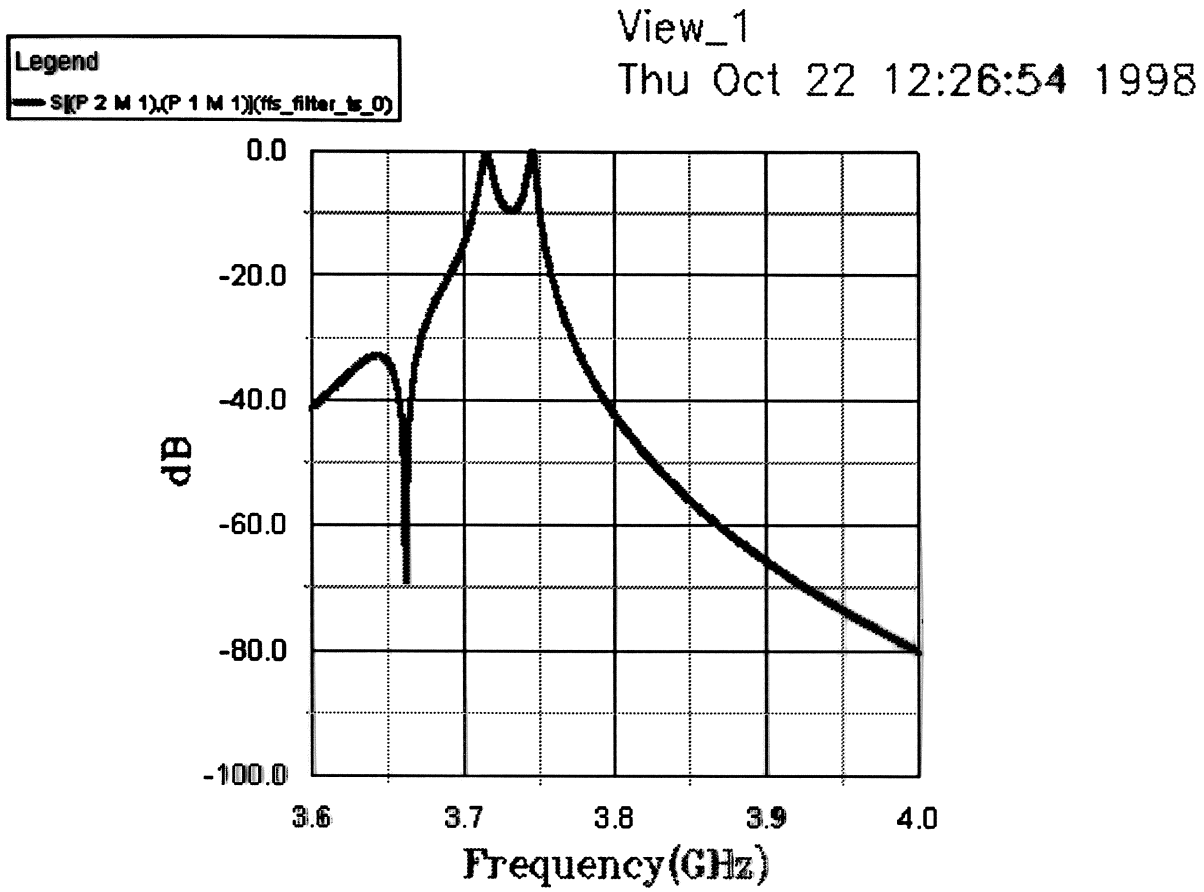
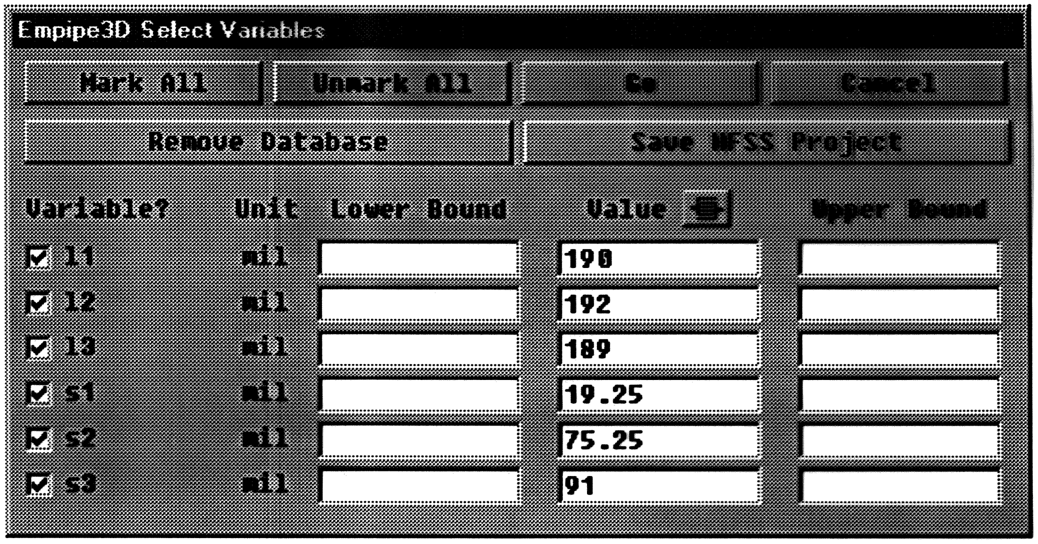
The $|S_{21}|$ Response of the Transversely Segmented Model



Optimization Variables and Specifications

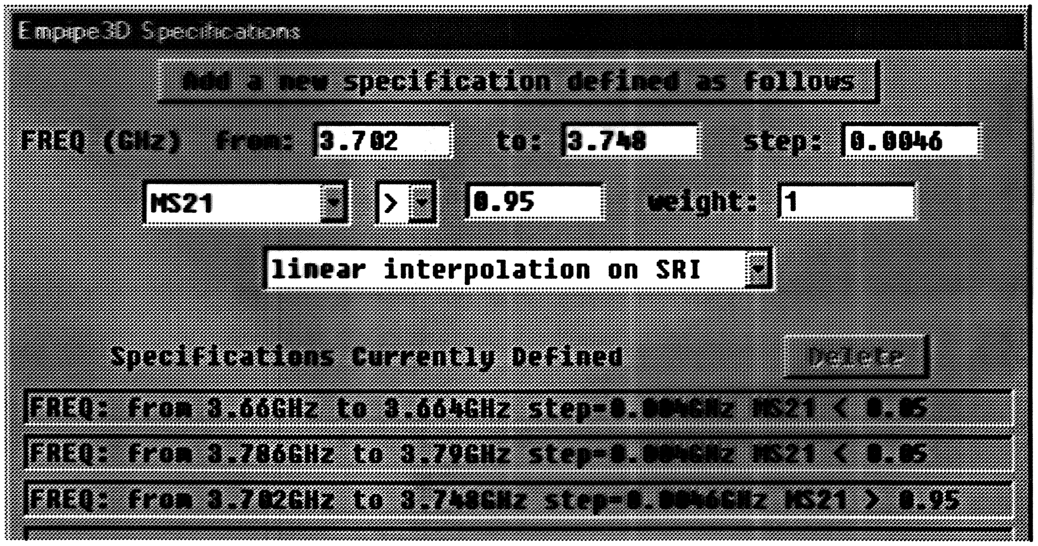
the nominal and incremental projects were created using the project with transverse virtual boundaries

this optimization problem includes six optimization variables



Variable?	Unit	Lower Bound	Value	Upper Bound
☑ l1	mil		190	
☑ l2	mil		192	
☑ l3	mil		189	
☑ s1	mil		19.25	
☑ s2	mil		75.25	
☑ s3	mil		91	

optimization was attempted in the frequency band where the nominal project shows larger $|S_{21}|$ (for a bandwidth of 1.25 %)



FREQ (GHz) from: 3.702 to: 3.748 step: 0.0046

MS21 > 0.95 weight: 1

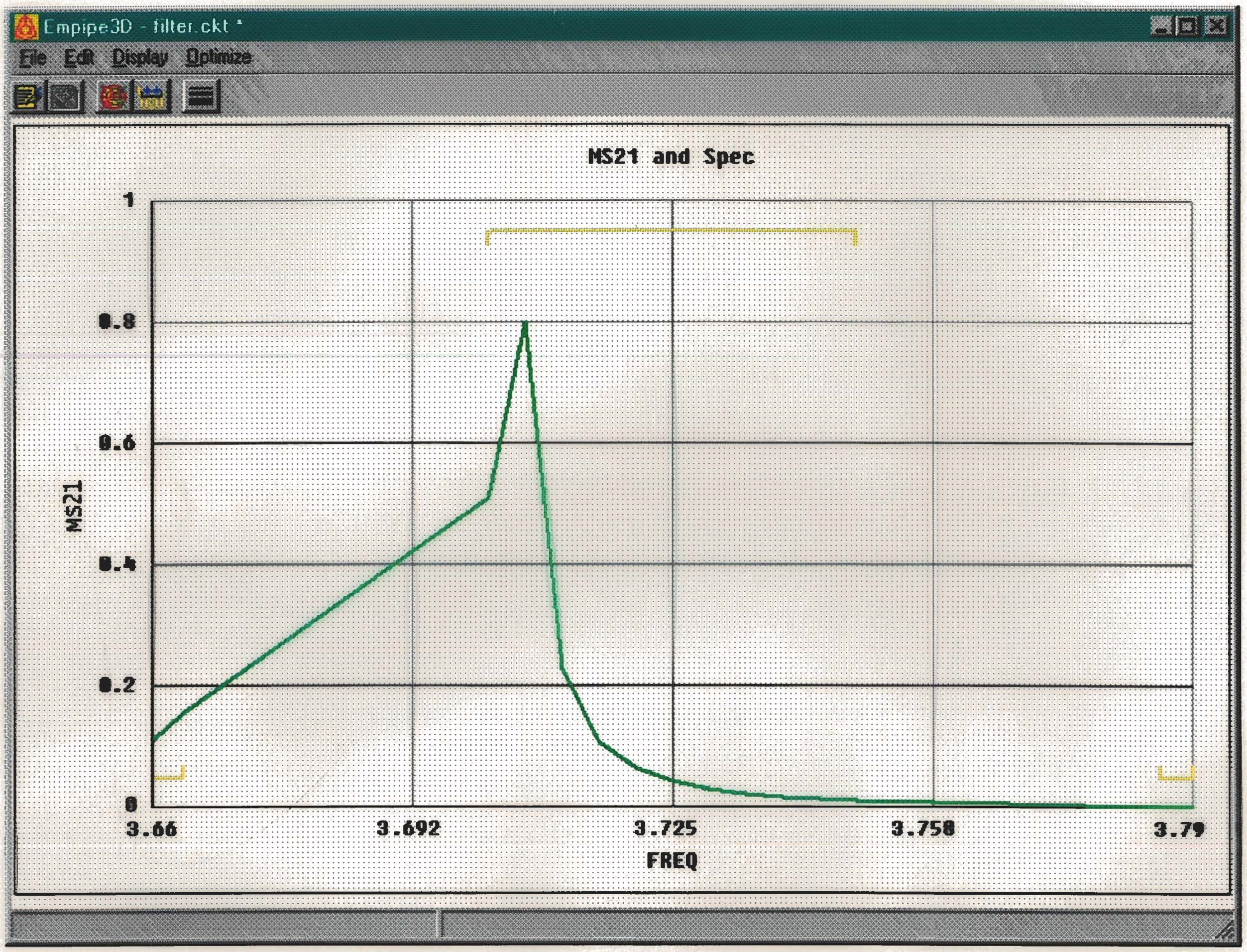
linear interpolation on SRI

Specifications Currently Defined

```
FREQ: from 3.66GHz to 3.664GHz step=0.004GHz MS21 < 0.05
FREQ: from 3.786GHz to 3.79GHz step=0.004GHz MS21 < 0.05
FREQ: from 3.702GHz to 3.748GHz step=0.0046GHz MS21 > 0.95
```

Response Before Optimization

preliminary Display sweep using Empipe3D (*model*=0, no interpolation)



eleven discrete-frequency points in the passband might fail to describe fully the nominal response of the structure

on the other hand introducing too many discrete frequency points makes a single simulation too long and, therefore, optimization becomes almost impossible

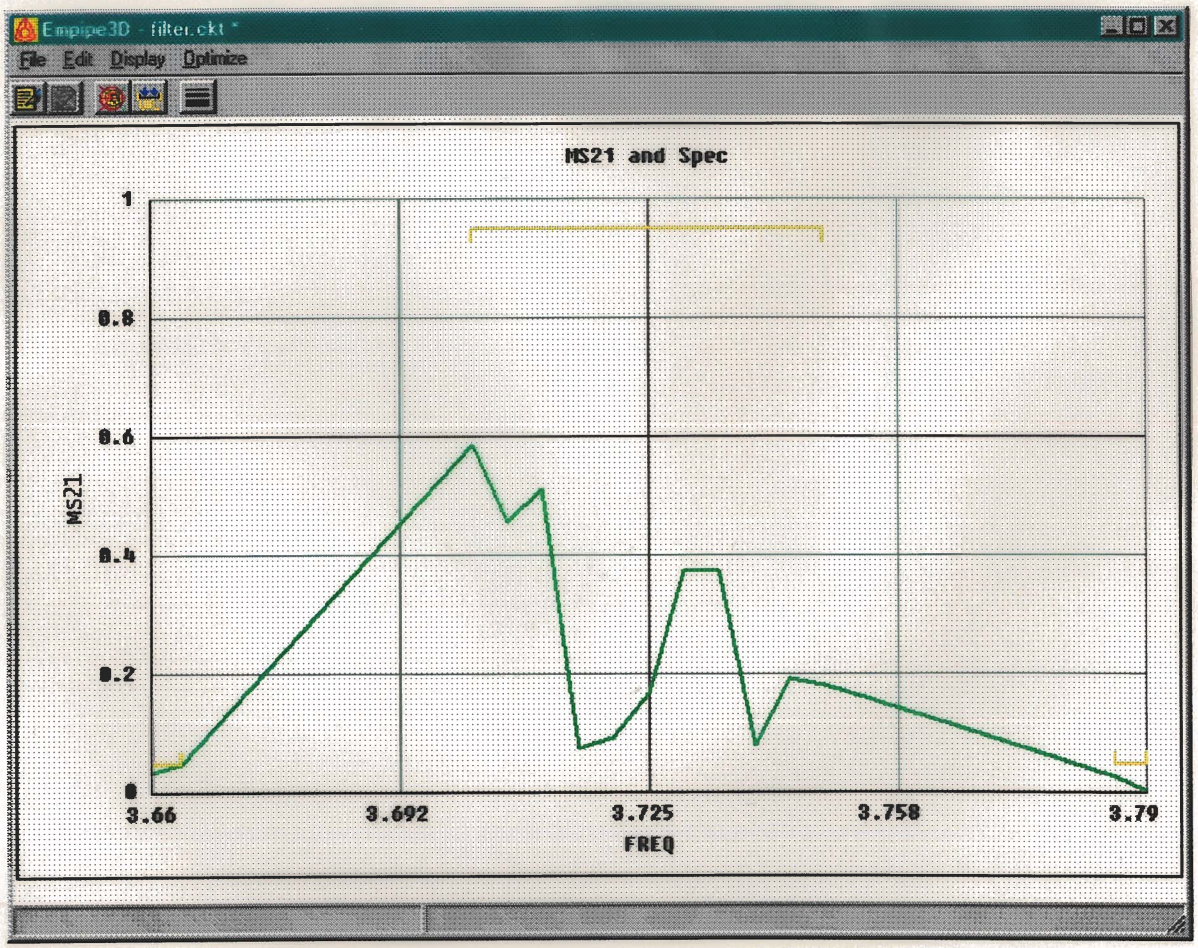
Minimax Optimization

minimax optimization is attempted

since the optimization process does not make much progress, subsequent optimizations using the $L1$ and minimax optimizers are tried

the overall optimization process takes several days of CPU time

the $|S_{21}|$ response and the specifications after optimization

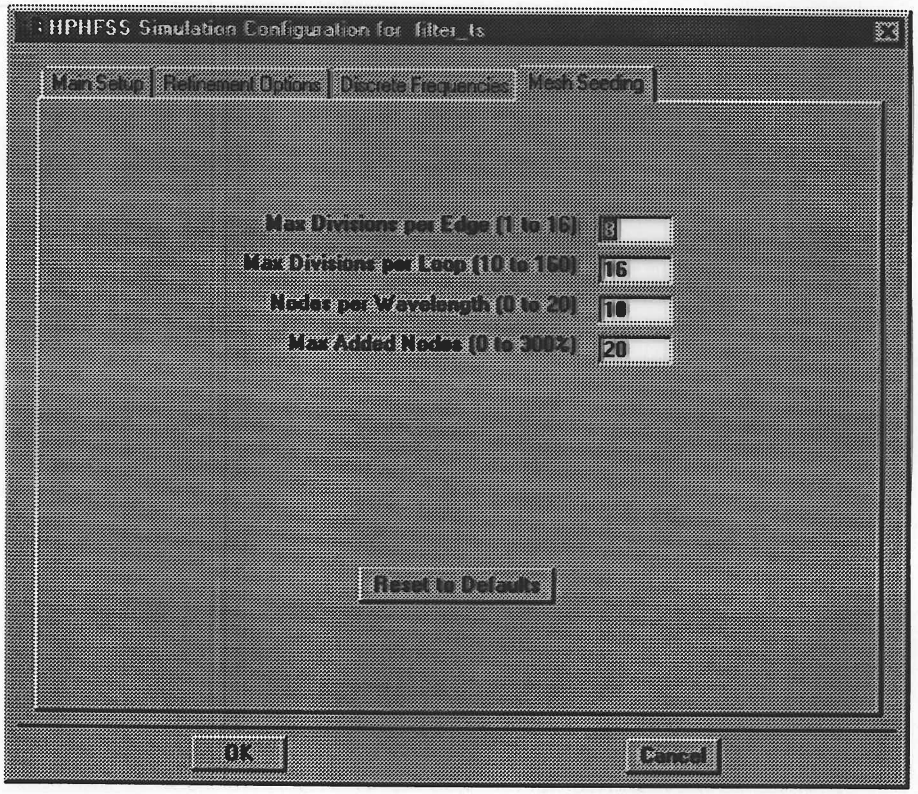


Optimization Results Not Satisfactory

to enhance the optimization process more discrete frequency points should be used in the passband

this would make the optimization impossible because of the CPU time needed for a single discrete sweep

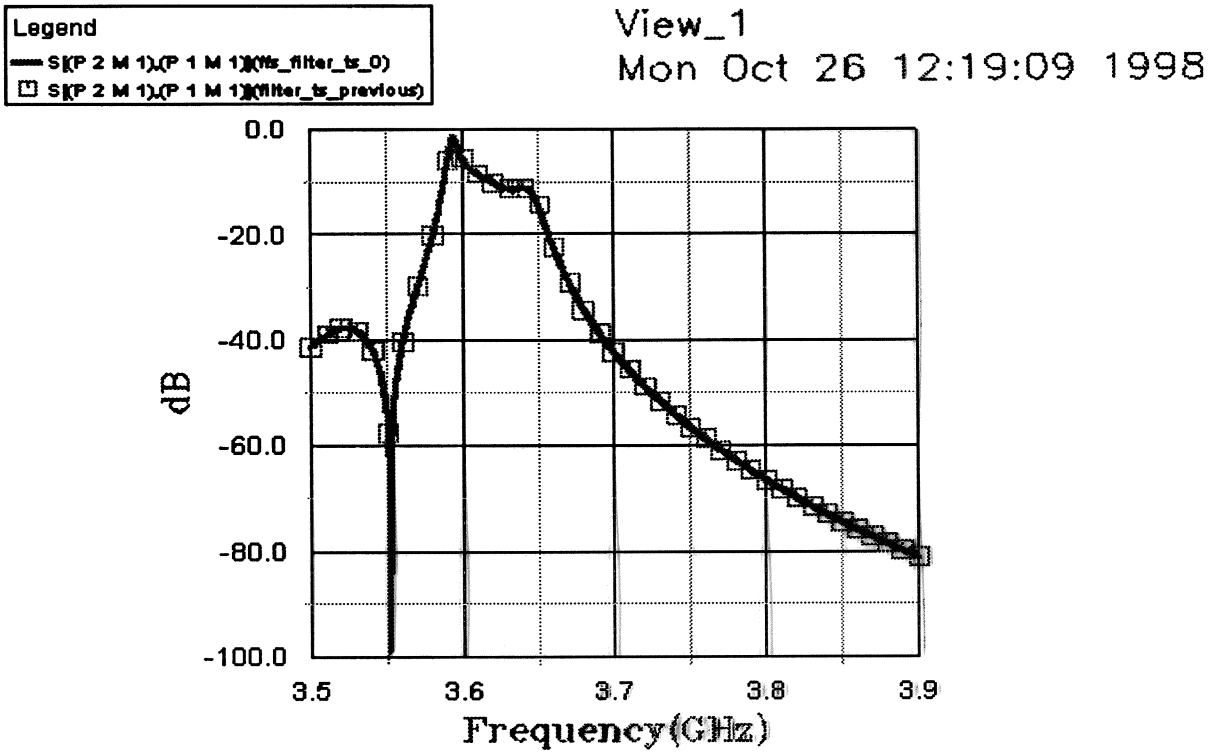
the mesh-seeding limits were somewhat relaxed in order to reduce the number of nodes and , therefore, the CPU time



Max Divisions per Edge (1 to 16) 8
Max Divisions per Loop (10 to 160) 16
Nodes per Wavelength (0 to 20) 10
Max Added Nodes (0 to 300%) 20

New Nominal Sweep

adaptive solution convergence seems good but the *S*-parameter response shifts towards lower frequencies by approximately two bandwidths



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Conclusions to HTS Problem

the *S*-parameter responses exhibit considerable frequency shift depending upon the mesh refinement

this project requires extensive CPU time for a single simulation if an acceptable accuracy of the adaptive solution ($\Delta S \approx 10\ \%$) is to be achieved

aspect ratios greater than 20 and high dielectric constants appear to create problems associated with the automatic mesher

References

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