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# Filter Design Using Ansoft HFSS

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# Outline

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- Introduction
- Finite Element Method (FEM) Employed by HFSS
- Features of HFSS
- General Design Procedure
- Design Examples:
  - ◆ Eigen Mode: Dielectric Resonator
  - ◆ Driven Mode: Dielectric Resonator Filter  
Microstrip Line Structure

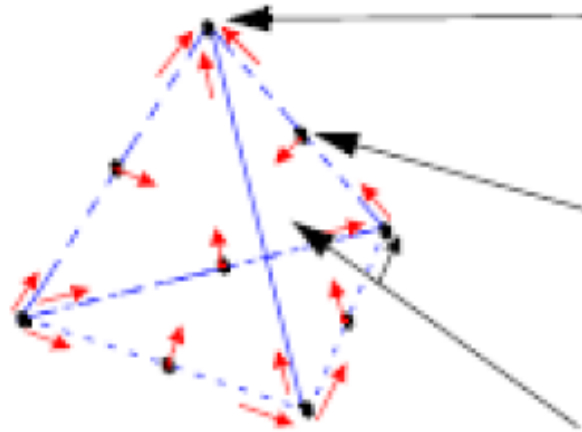
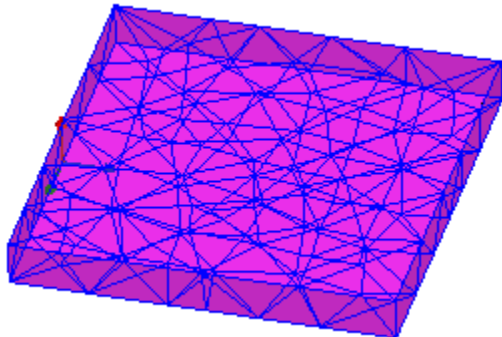
# Introduction

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- The Ansoft High Frequency Structure Simulator (HFSS) is a full-wave electromagnetic (EM) software package for calculating the electromagnetic behavior of a 3-D structure.
- Using HFSS, you can compute:
  - ♦ Basic electromagnetic field quantities and, for open boundary problems, radiated near and far fields;
  - ♦ The eigenmodes, or resonances, of a structure;
  - ♦ Port characteristic impedances and propagation constants;
  - ♦ Generalized S-parameters and S-parameters renormalized to specific port impedance;

# FEM

- FEM is a numerical method for solving Maxwell Equations.
- Meshing Scheme:
  - 2D-triangles
  - 3D-tetrahedra



The components of a field that are tangential to the edges of an element are explicitly stored at the vertices.

The component of a field that is tangential to the face of an element and normal to an edge is explicitly stored at the midpoint of selected edges.

The value of a vector field at an interior point is interpolated from the nodal values.

# Features of HFSS

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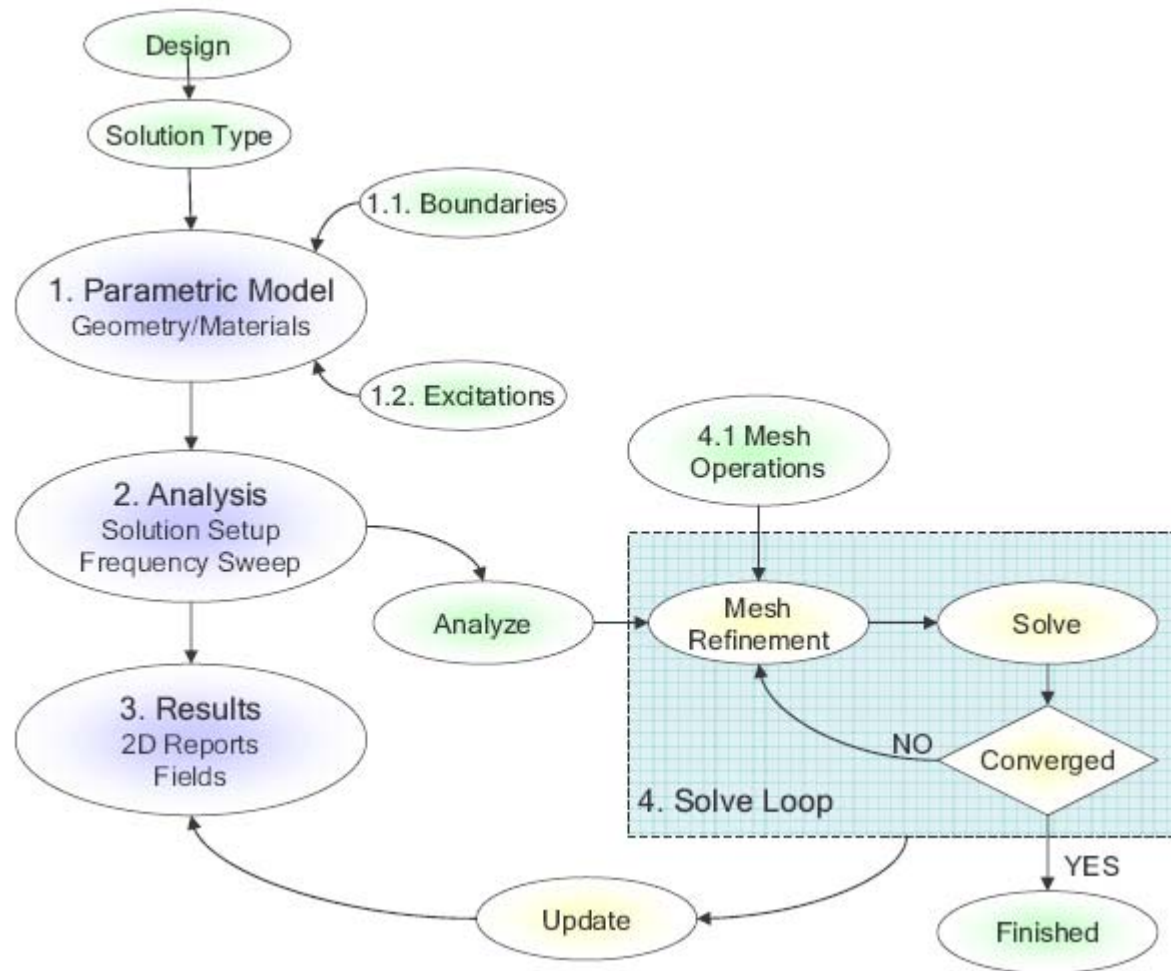
- Capabilities:
  - ◆ Accurate full-wave EM simulation
  - ◆ Import/export of 3D structures
  - ◆ Automatic adaptive mesh generation and refinement
  - ◆ Adaptive Lanczos-Padé Sweep for fast frequency sweeps
  - ◆ Inclusion of skin effect, losses
  - ◆ Direct and iterative matrix solvers
  - ◆ Eigen mode matrix solver

## Features of HFSS (cont.)

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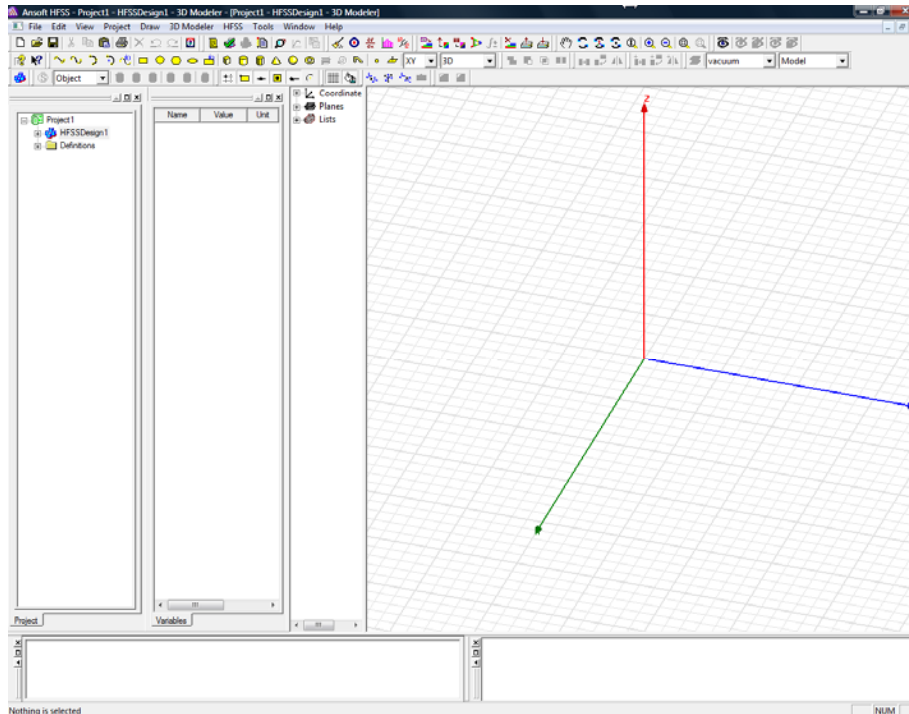
- Solution Data (Visualization):
  - ◆ S-, Y-, Z-parameter matrix (2D plot, Smith Chart)
  - ◆ Port characteristic impedance
  - ◆ Current, E-field, H-field (3D static and animated field plot in vector display or magnitude display)
  - ◆ Far-field calculation (2D, 3D, gain, radiation pattern)
  - ◆ Material losses, radiation losses

# General Design Procedure

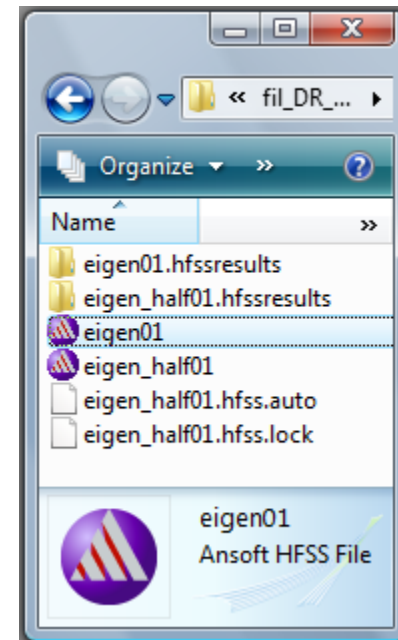


# Design Examples (Eigen mode: DR)

- Opening a HFSS Project
  - ♦ To open a new project in a HFSS window:  
*Select File > New, select Project > Insert HFSS Design*



- ♦ To open an existing project:

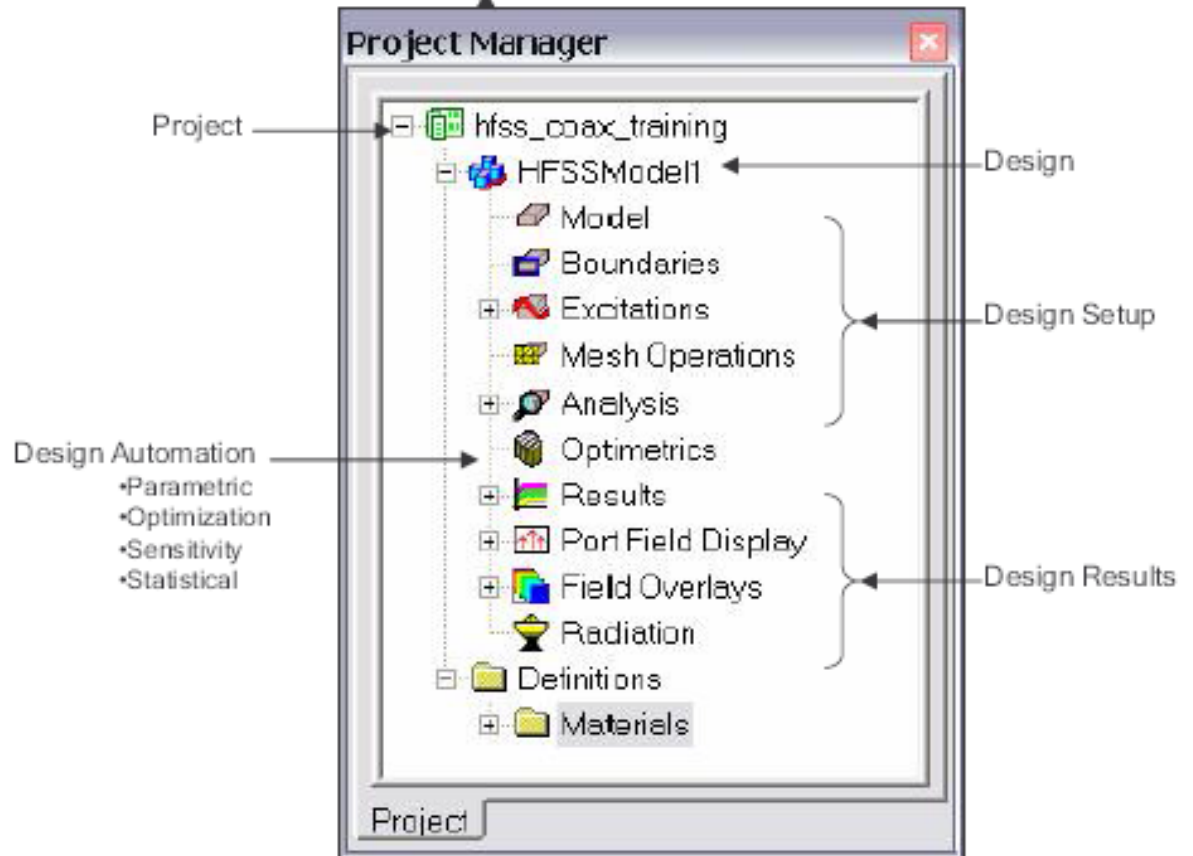




# Design Examples (Eigen mode: DR) cont.

- Project Manager

Project Manager Window

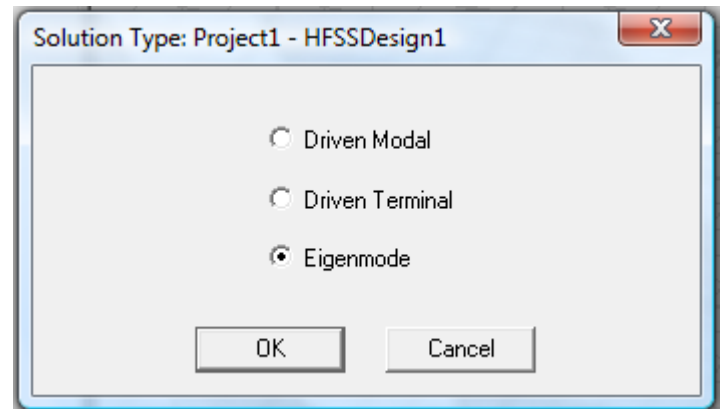


## Design Examples (Eigen mode: DR) cont.

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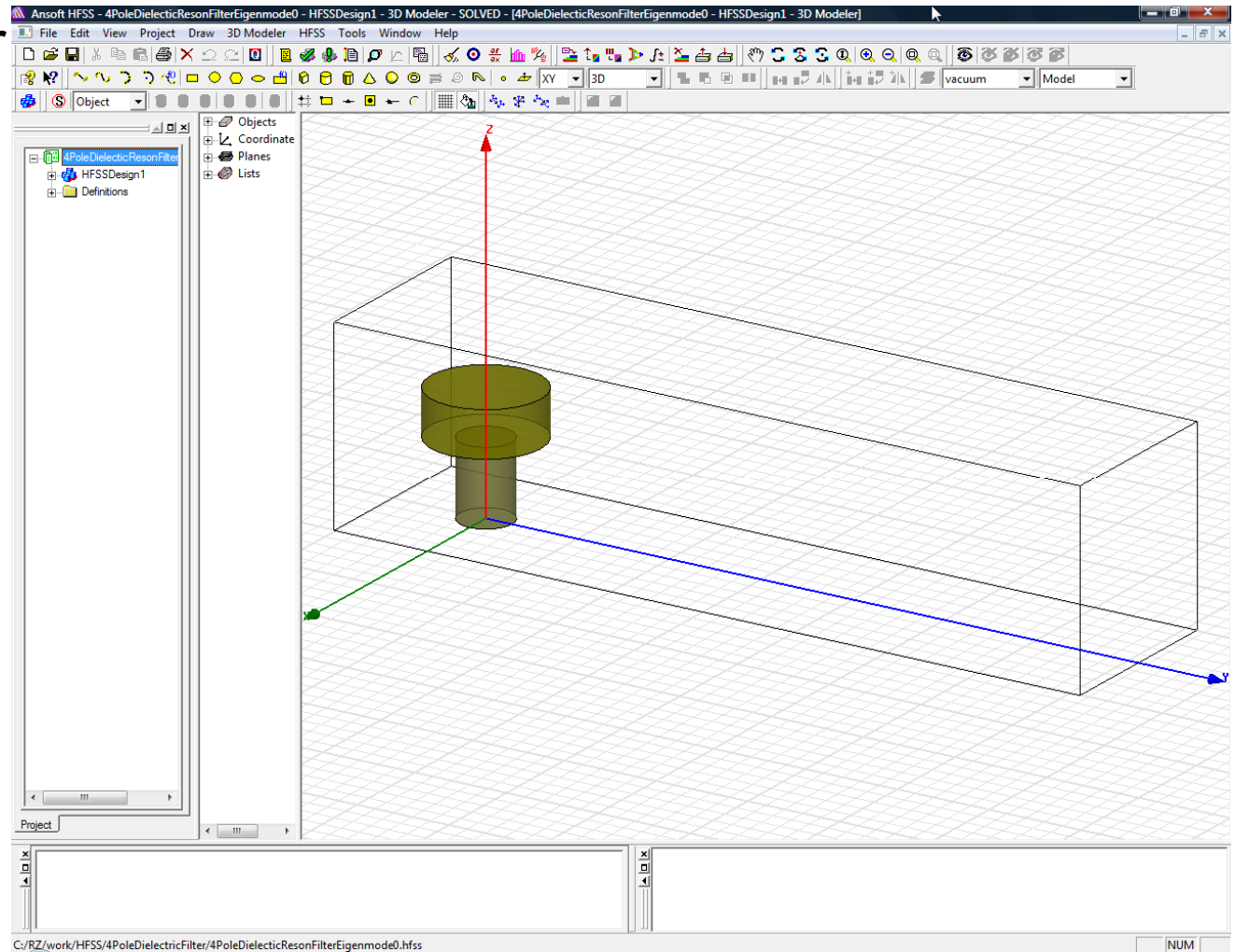
- Solution Type
  - ♦ **Driven Modal:** S-matrix solutions will be expressed in terms of the incident and reflected powers of waveguide modes.
  - ♦ **Driven Terminal:** S-matrix solutions of multi-conductor transmission line ports will be expressed in terms of terminal voltages and currents.
  - ♦ **Eigen Mode:** finding the resonant frequencies of the structure and the fields at those resonant frequencies.

- To Set the Solution Type  
Select *HFSS > Solution Type*



# Design Examples (Eigen mode: DR) cont.

- 3D Modeler



# Design Examples (Eigen mode: DR) cont.

- Parametric Model Creation

The screenshot shows the Ansoft HFSS 3D Modeler interface. The main window displays a 3D workspace with a grid and a coordinate system (X, Y, Z axes). A cylinder is being created, and its properties are shown in the 'Properties: Project1 - HFSSDesign1 - 3D Modeler' dialog box.

The 'Properties' dialog box contains the following table:

Name	Value	Unit	Evaluated Value
Command	CreateCylinder		
Coordinate System	Global		
Center Position	0, 0, 20.32	mm	0mm, 0mm, 20.32mm
Axis	Z		
Radius	14.935	mm	14.935mm
Height	12.21	mm	12.21mm

The dialog box also includes a 'Show Hidden' checkbox and 'OK' and 'Cancel' buttons.

# Design Examples (Eigen mode: DR) cont.

- Defining Variables

The screenshot displays a 3D modeling environment with a purple cylinder on a grid. A red vertical line passes through the center of the cylinder. Two windows are overlaid on the scene:

- Properties: Project1 - HFSSDesign1 - 3D Modeler**: A table showing the cylinder's parameters.
- Add Variable**: A dialog box for defining a new variable.

Name	Value	Unit	Evaluated Value
Command	CreateCylinder		
Coordinate System	Global		
Center Position	0,0,20.32	mm	0mm, 0mm, 20.32mm
Axis	Z		
Radius	D1/2	mm	14.935mm
Height	12.21	mm	12.21mm

**Add Variable** dialog details:

- Name: D1
- Value: 29.87mm
- Define variable value with units: "1 mm"
- Local Variable
- Buttons: OK, Cancel

# Design Examples (Eigen mode: DR) cont.

- Variable Settings

Properties: 4PoleDielectricResonFilterEigenmode0 - HFSSDesign1

Local Variables

Value  Optimization  Tuning  Sensitivity  Statistics

Name	Value	Unit	Evaluated Value	Description	Read-only	Hidden
D1	29.87	mm	29.87mm		<input type="checkbox"/>	<input type="checkbox"/>
Ds	14.22	mm	14.22mm		<input type="checkbox"/>	<input type="checkbox"/>
Ls	20.32	mm	20.32mm		<input type="checkbox"/>	<input type="checkbox"/>
Ld	12.21	mm	12.21mm		<input type="checkbox"/>	<input type="checkbox"/>
C	50.8	mm	50.8mm		<input type="checkbox"/>	<input type="checkbox"/>
S	51.5	mm	51.5mm		<input type="checkbox"/>	<input type="checkbox"/>
D2	29.87	mm	29.87mm		<input type="checkbox"/>	<input type="checkbox"/>
T	3.81	mm	3.81mm		<input type="checkbox"/>	<input type="checkbox"/>

Add... Remove  Show Hidden OK Cancel

Add new variables

# Design Examples (Eigen mode: DR) cont.

- Checking and Modifying Dimensions in 3D Modeler Tree

Properties: 4PoleDielectricResonFilterEigenmode0 - HFSSDesign1 - 3D Modeler

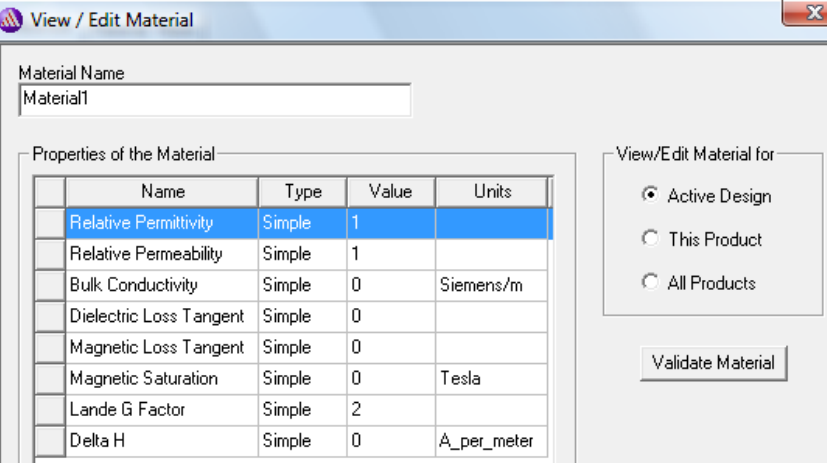
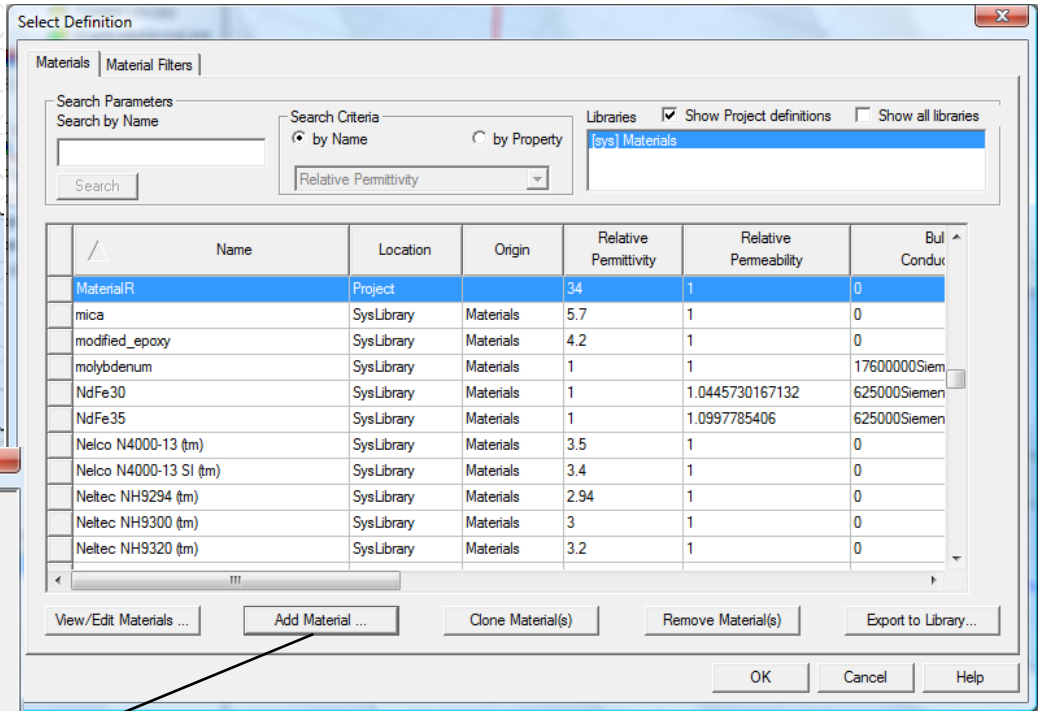
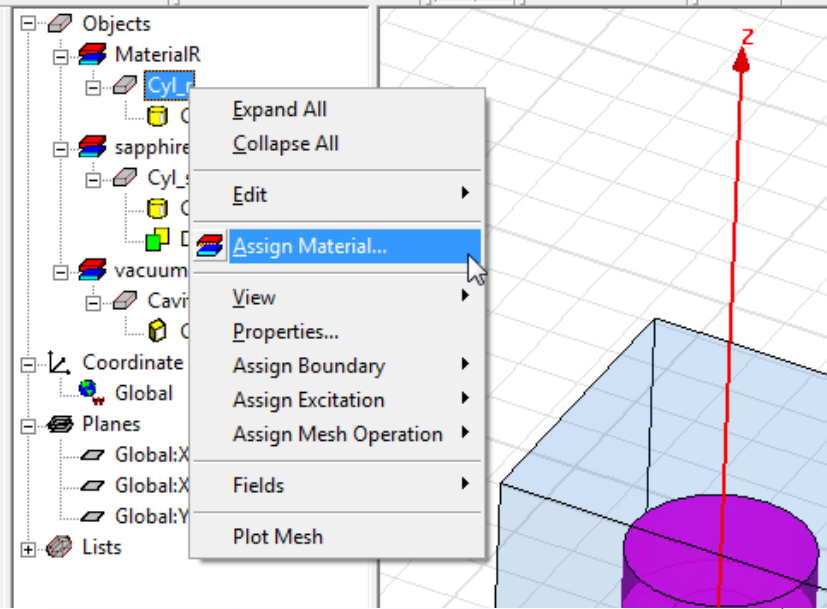
Name	Value	Unit	Evaluated Value
Command	CreateCylinder		
Coordinate System	Global		
Center Position	0mm , 0mm , Ls		0mm , 0mm , 20.32mm
Axis	Z		
Radius	D1/2		14.935mm
Height	Ld		12.21mm

Expand All  
Collapse All  
Properties...

3D Modeler Tree

# Design Examples (Eigen mode: DR) cont.

## Assigning Materials





# Design Examples (Eigen mode: DR) cont.

- Properties of the Objects

The screenshot shows the HFSS software interface. On the left, the 'Objects' tree is visible, with a context menu open over a cylindrical object named 'Cyl\_r'. The 'Properties...' option is selected. The main 3D view shows a purple cylindrical resonator with a red vertical line through its center, representing the excitation axis. The 'Properties: 4PoleDielectricResonFilterEigenmode0 - HFSSDesign1 - 3D Modeler' dialog box is open, displaying the following table:

Attribute	Name	Value	Unit	Evaluated Value	Descri
	Name	Cyl_r			
	Material	MaterialR			
	Solve Inside	<input checked="" type="checkbox"/>			
	Orientation	Global			
	Model	<input checked="" type="checkbox"/>			
	Display Wireframe	<input type="checkbox"/>			
	Color	Edit			
	Transparent	0.3			

At the bottom right of the dialog box, there is a 'Show Hidden' checkbox and 'OK' and 'Cancel' buttons.

## Design Examples (Eigen mode: DR) cont.

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- Common Boundary Conditions
  - ♦ Material properties
    - Boundary between two dielectrics
    - Finite conductivity of a conductor
  - ♦ Surface approximations
    - Perfect electric or magnetic surfaces
    - Radiation surfaces
    - Symmetry planes
    - Background or outer surfaces
  - ♦ Excitations (Driven mode)
    - Wave ports (External)
    - Lumped ports (Internal)

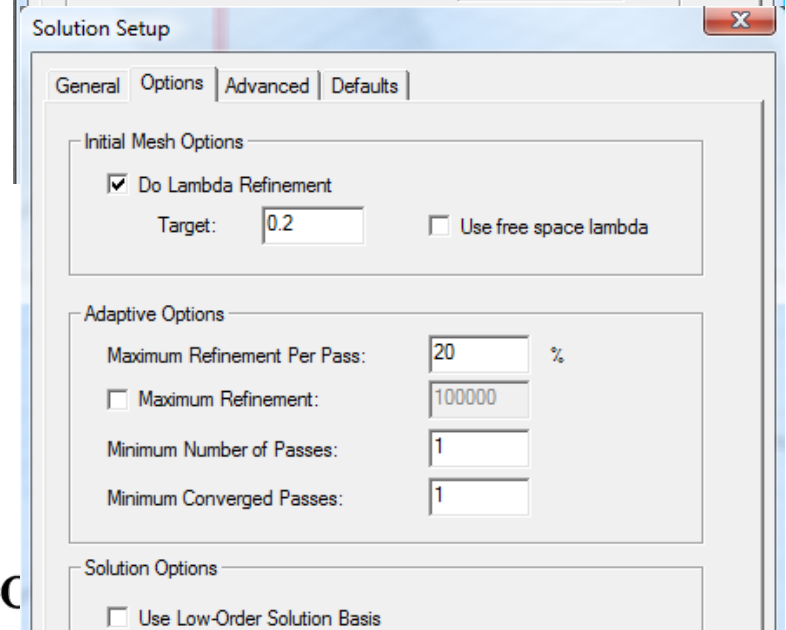
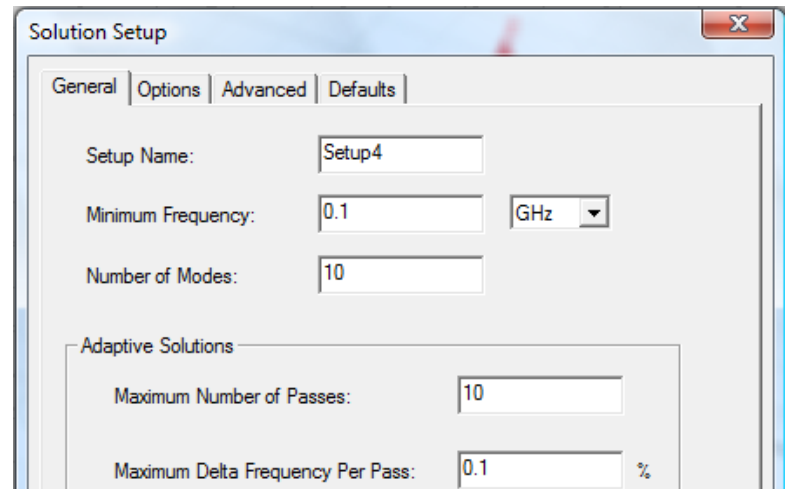
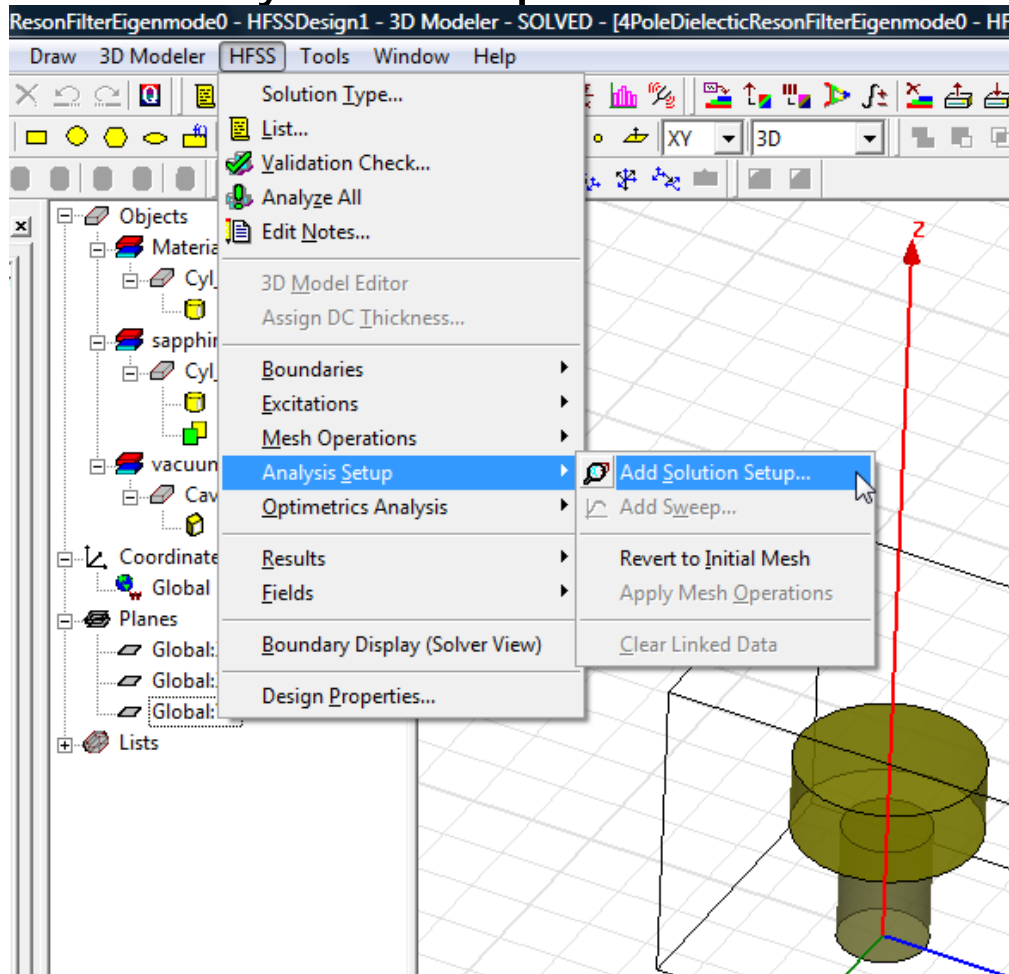
# Design Examples (Eigen mode: DR) cont.

## • Assigning Boundaries

The screenshot displays the Ansoft HFSS software interface for a project named "4PoleDielectricR". The main 3D view shows a purple, wedge-shaped object on a grid. A red arrow labeled "Z" points upwards from the top surface. A context menu is open over the top surface, with "Assign Boundary" selected, and a sub-menu showing "Perfect E..." as the chosen option. On the left, the "Object" dropdown menu is open, showing "Face" selected. Below it, a selection menu is visible with "Select Faces" checked and "F" as the key. The "Objects" tree on the left lists "MaterialR", "sapphire", "vacuum", and "Cavit". The "Coordinate System" and "Planes" are also visible. On the right, the "HFSSDesign" tree shows "Model", "Bound...", "Excitat...", "Mesh O...", "Analysis...", "Optime...", "Results", and "Field O...". A second context menu is open over the "HFSSDesign" tree, with "Boundary Display (Solver View)" selected. The bottom of the image features the University of Waterloo logo.

# Design Examples (Eigen mode: DR) cont.

## • Analysis Setup



## Design Examples (Eigen mode: DR) cont.

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- Adaptive Meshing
  - ♦ The mesh in HFSS is automatically constructed and tuned to give the most accurate and efficient mesh possible.
  - ♦ The adaptive meshing algorithm searches for the largest gradients in the E-field or error and sub-divides the mesh in those regions. It also targets singularities, such as the edge of a conductor, as locations to add extra elements.
  - ♦ The mesh growth for each adaptive pass is controlled by the Tetrahedron Refinement in percentage, which ensures that between each pass the mesh is sufficiently perturbed and guarantees the correct convergences.
  - ♦ After the mesh has been refined, a full solution is performed and the process is repeated until convergence.

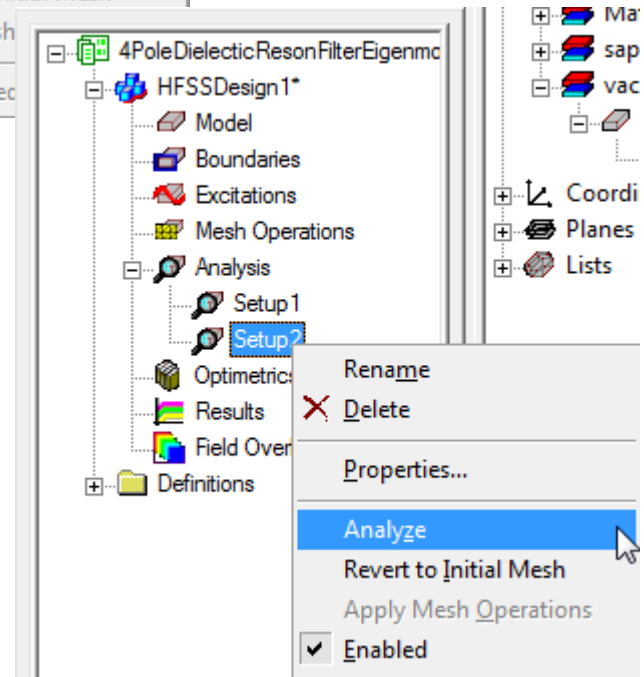
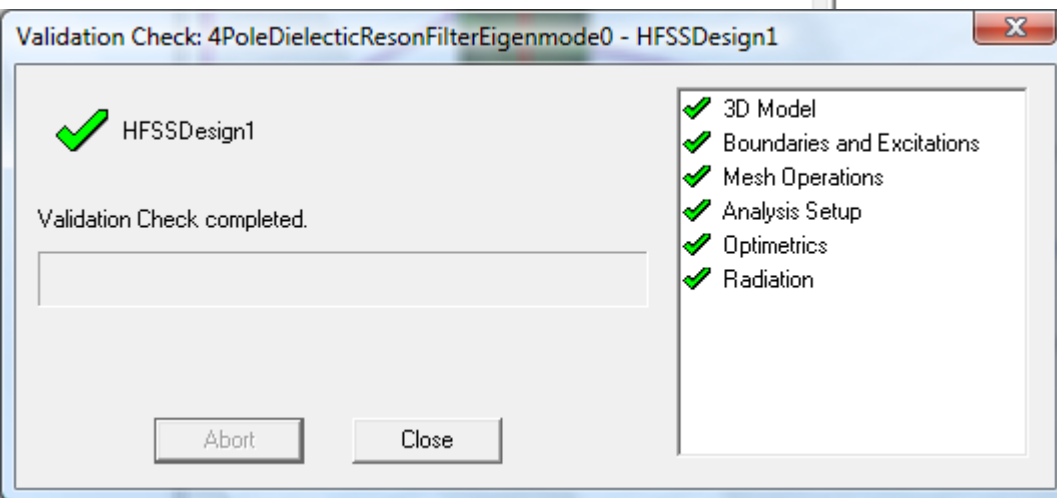
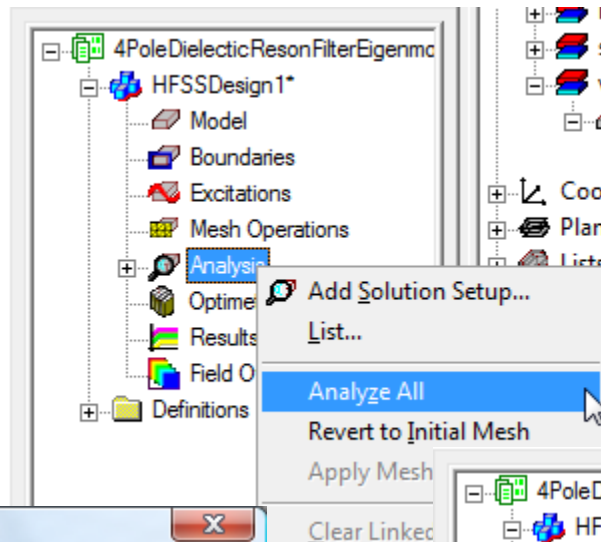
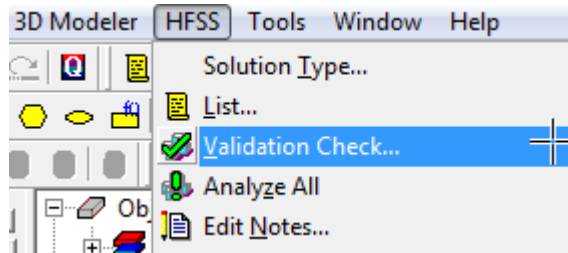
## Design Examples (Eigen mode: DR) cont.

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- Convergence
  - ♦ After each adaptive pass, HFSS compares the results (Frequencies for eigen mode, S-Parameters for driven mode) from the current mesh to the results of the previous mesh. If the answers have not changed by the user defined value or Delta Freq (for eigen mode)/Delta S (for driven mode), then the solution has converged and the current or previous mesh can be used to perform a frequency sweep (for driven mode).
  - ♦ If the solution has converged, then technically, the previous mesh is as good as the current mesh. In this case, HFSS will use the previous mesh (less than current mesh) to perform frequency sweeps (for driven mode) if they have been requested.

# Design Examples (Eigen mode: DR) cont.

- Validation Check and Starting Analysis



# Design Examples (Eigen mode: DR) cont.

## Monitoring the Solution Process and Checking Solution Data

The screenshot shows the HFSS software interface. The project tree on the left includes '4PoleDielectricResonFilter', 'HFSSDesign1', 'Model', 'Boundaries', 'Excitations', 'Mesh Operations', 'Analysis', 'Optimetrics', 'Results', 'Field Calculator', and 'Definitions'. The 'Solutions' panel shows 'Design Variation: D1='29.87mm' D2='...' and 'Simulation: Setup1'. A 'Task Log' window is open, displaying the following table:

Task	Real Time	CPU Time	Memory	Information
Adaptive Pass 17				Eigenmode Solution
mesh3d_adapt_FT	00:00:02	00:00:01	43.3 M	11206 tetrahedra
adapt_part1_eigen	00:00:03	00:00:02	69.7 M	11206 tetrahedra
Solver MRS	00:00:27	00:00:22	242 M	69948 matrix, 153MB disk
eigen	00:02:04	00:01:54	69 M	69948 matrix
adapt_part2_eigen	00:00:05	00:00:04	49.5 M	11206 tetrahedra
Adaptive Pass 18				Eigenmode Solution
mesh3d_adapt_FT	00:00:02	00:00:01	44.2 M	13286 tetrahedra
adapt_part1_eigen	00:00:04	00:00:03	81.4 M	13286 tetrahedra
Total	00:12:09	00:10:20		

The 'Eigenmode Data' panel shows convergence statistics. The 'Number of Passes' section indicates 17 completed passes, with a maximum of 20 and a minimum of 1. The 'Max Delta Freq. %' section shows a target of 0.1 and a current value of 2.0172. The 'View' is set to 'Table'. Below this, it states 'NOT CONVERGED' with 'Consecutive Passes' set to 1 and 'Current' set to 0. The table below shows the following data:

Pass Number	# Tetrahedra	Max Delta Freq. %
3	574	13.369
4	700	9.0673
5	889	3.4876
6	1128	2.6449
7	1443	5.3468
8	1805	0.91353
9	2242	1.9531
10	2750	1.3034
11	3321	0.27601
12	4004	0.10826
13	5023	0.13239
14	6243	2.0875
15	7616	1.9376
16	9278	2.1122
17	11206	2.0172

The 'Solved Modes' panel shows the following table:

Eigenmode	Frequency (GHz)
Mode 1	1.9017
Mode 2	2.2162
Mode 3	2.3982
Mode 4	2.4415
Mode 5	2.4714
Mode 6	2.4792
Mode 7	2.7758
Mode 8	2.9639
Mode 9	2.9853
Mode 10	3.0033

Below the table is a plot of 'Max Delta Freq. %' versus 'Pass Number'. The y-axis ranges from 0.00E+000 to 4.00E+001. The x-axis ranges from 0 to 18. The plot shows a sharp decrease in the maximum delta frequency percentage from approximately 13% at pass 3 to below 1% by pass 10, with some minor fluctuations between passes 14 and 17.

Q will be provided for lossy cases →



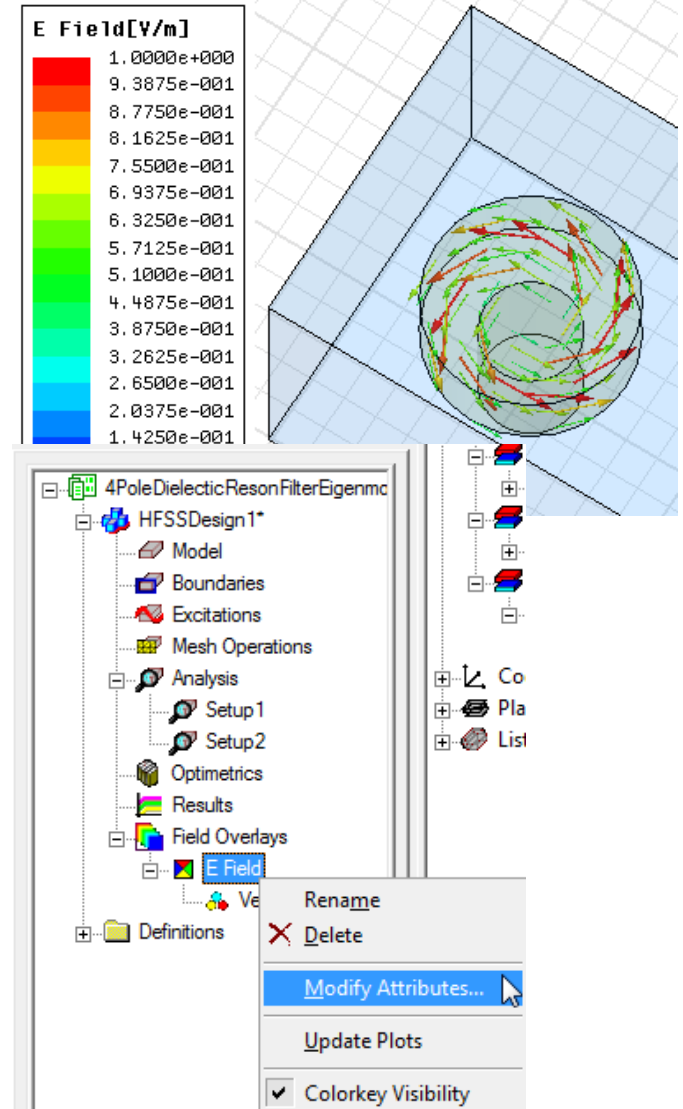
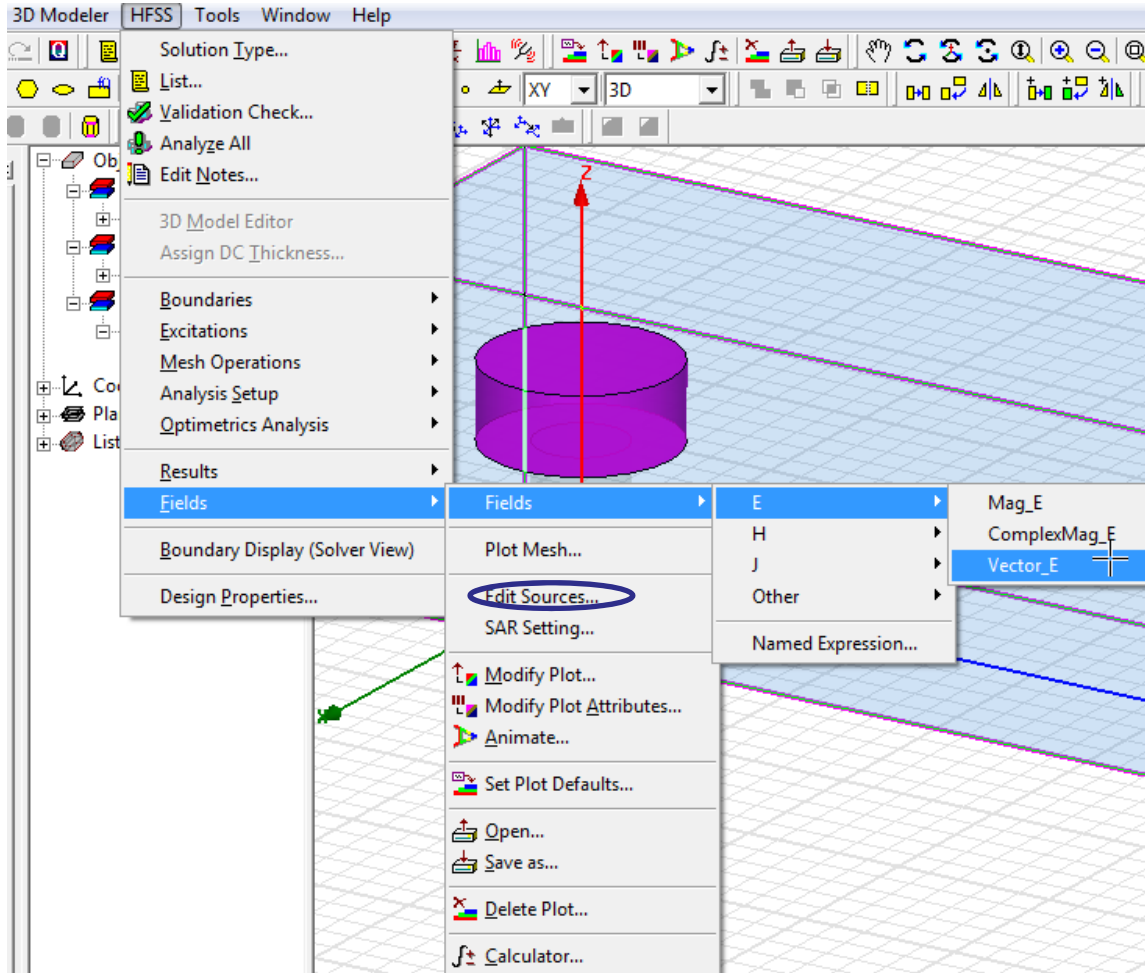
# Design Examples (Eigen mode: DR) cont.

## Plotting Mesh

The image illustrates the process of plotting a mesh in HFSS. The main window shows a 3D model of a cylindrical structure. A context menu is open, and the 'Plot Mesh...' option is selected. This opens the 'Select Plot Folder' dialog, which shows the 'MeshPlots' folder and the 'E Field' plot. The 'Plot Mesh' dialog is then shown, allowing the user to configure the plot settings. The 'Plot' is set to 'Mesh1', the 'Scale factor' is 100%, and the 'Transparency' is 0%. The 'Mesh type' is set to 'Shaded' with 'Add grid' checked. The 'Mesh color' is set to 'Line' (blue) and 'Filled' (white). The 'Surface only' and 'Real time mode' options are checked. The 'Save as default' button is also visible.

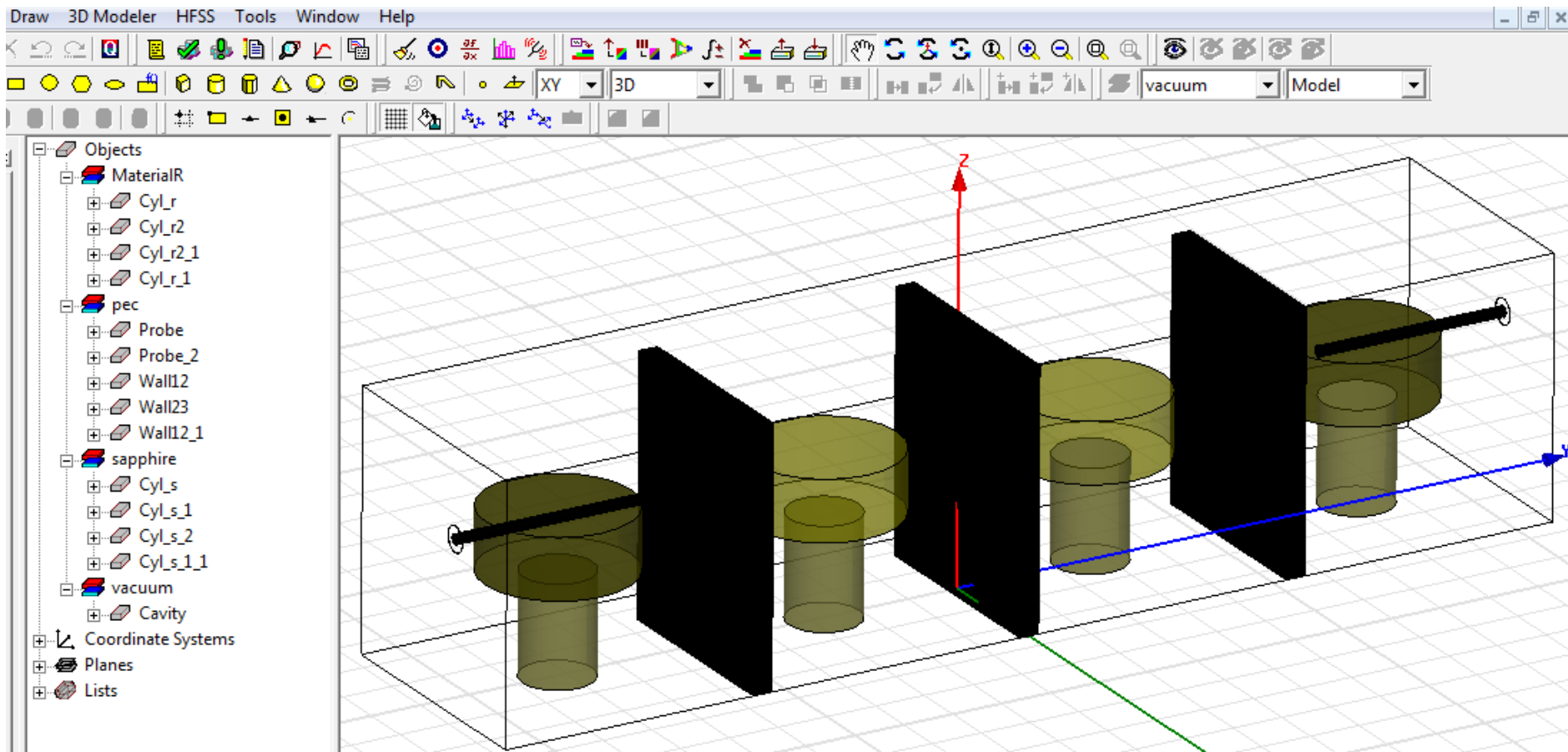
# Design Examples (Eigen mode: DR) cont.

## Field Distributions



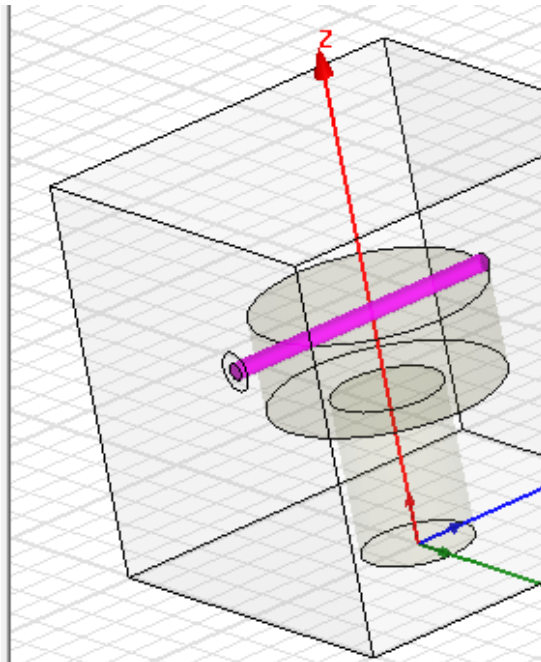
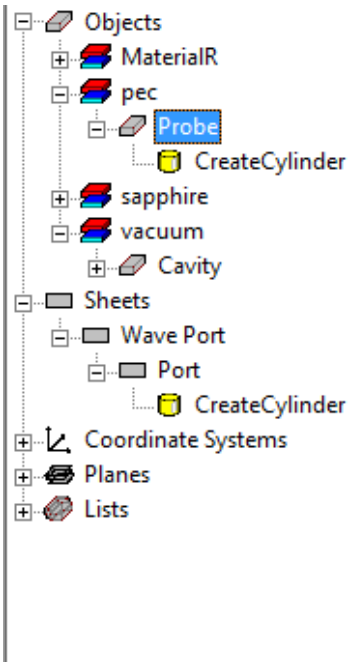
# Design Examples (Driven mode: DR Filter)

- 3D Model of the DR Filter

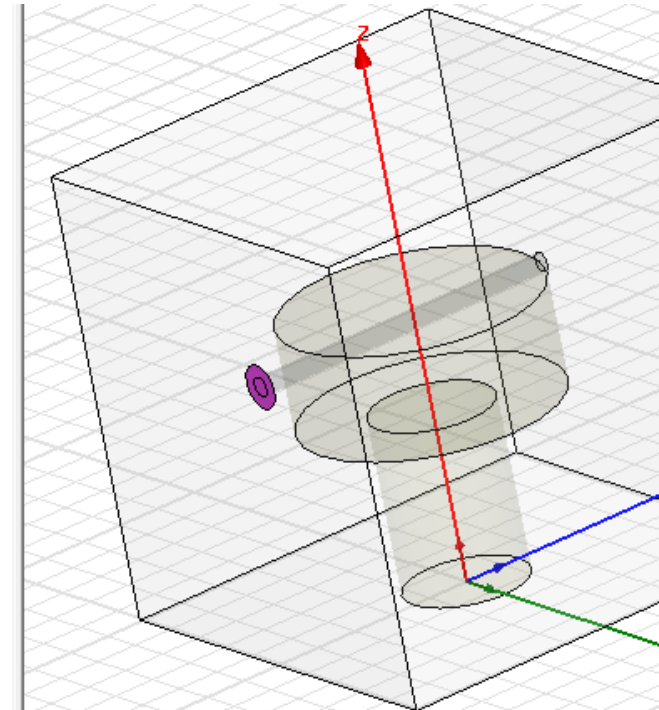
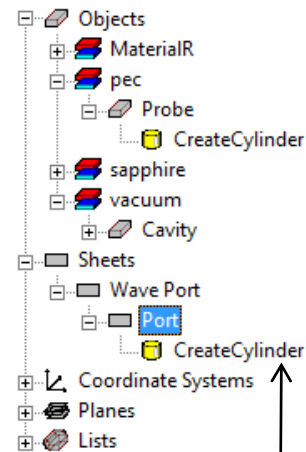


# Design Examples (Driven mode: DR Filter) cont.

- Excitation
  - ◆ Probe

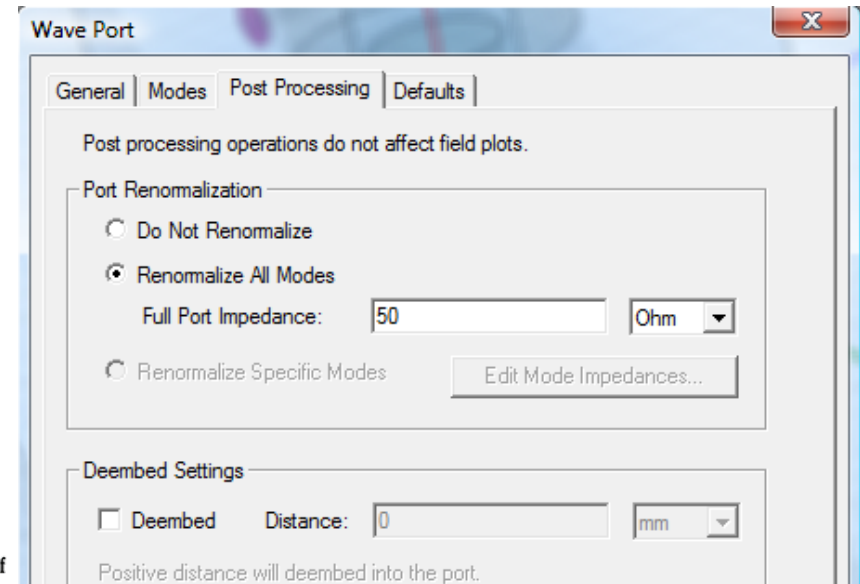
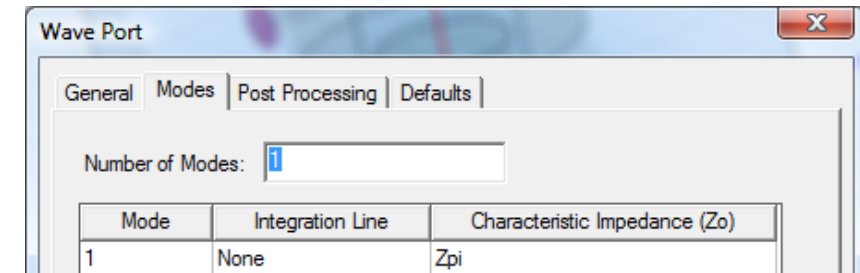
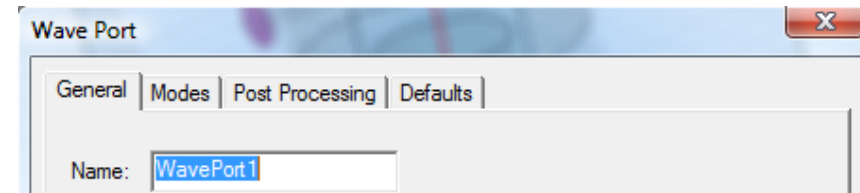
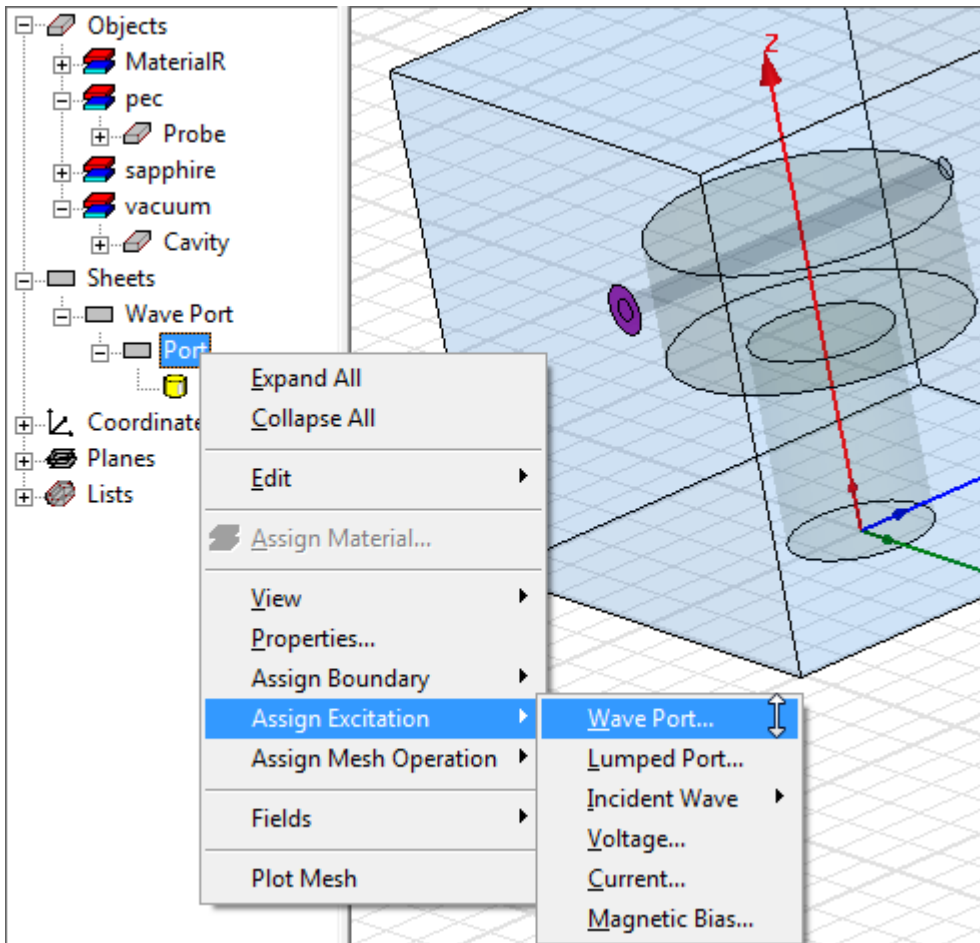


- ◆ Port



# Design Examples (Driven mode: DR Filter) cont.

## Defining Port



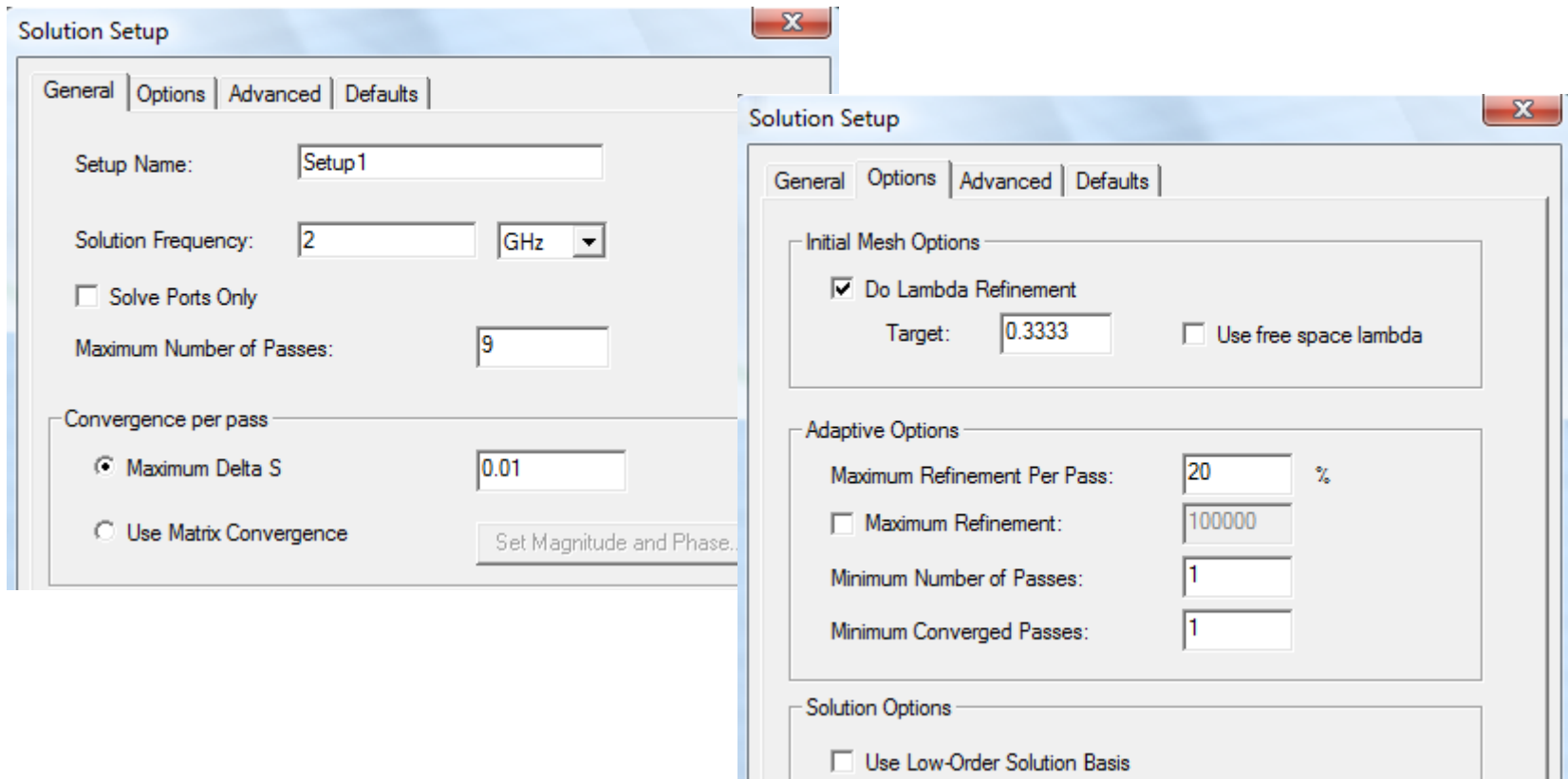
## Design Examples (Driven mode: DR Filter) cont.

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- Wave Port
  - HFSS assumes that the Wave Port is connected to a semi-infinite long waveguide that has the same cross-section and material properties as the port.
  - Wave ports calculate characteristic impedance, complex propagation constant, and generalized S-Parameters.
- Lumped Port
  - Lumped ports are similar to traditional wave ports, but can be located internally and have a complex user-defined impedance.

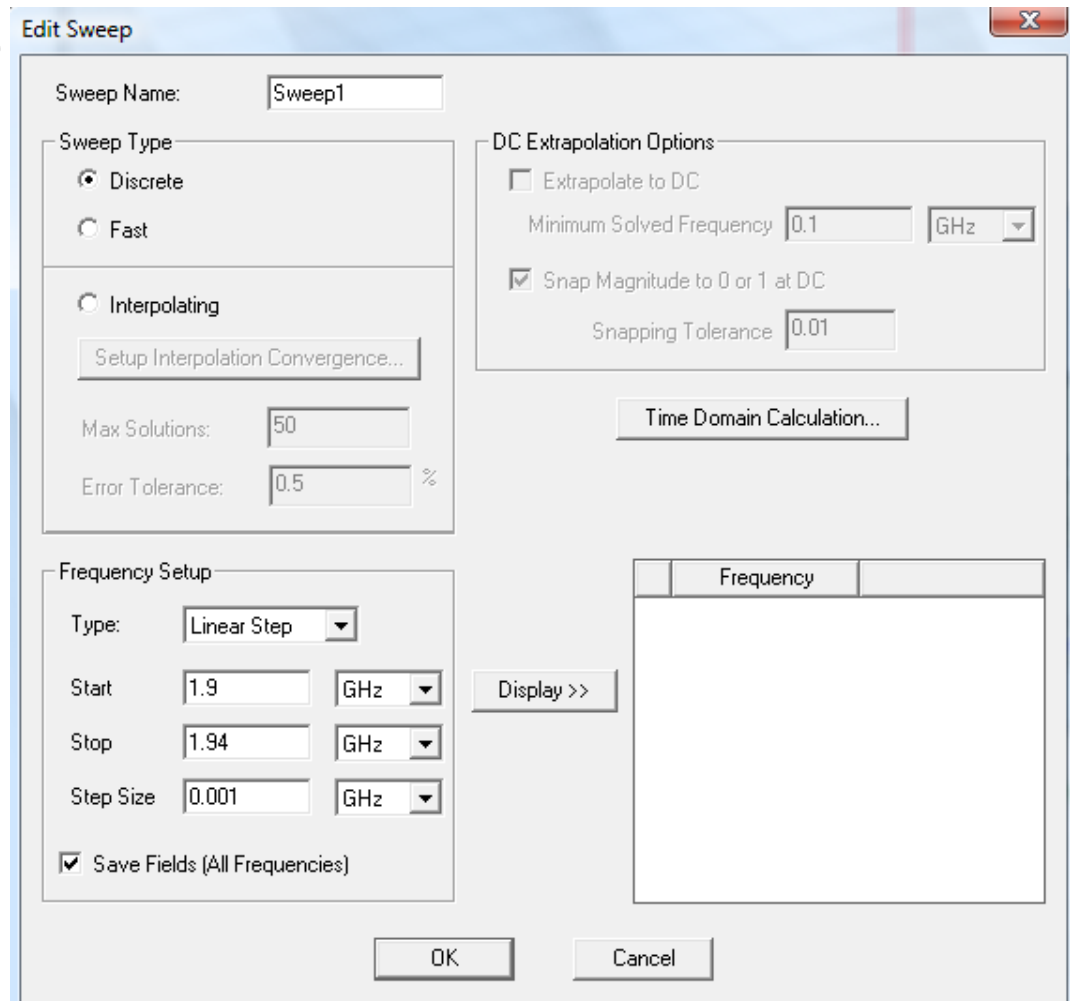
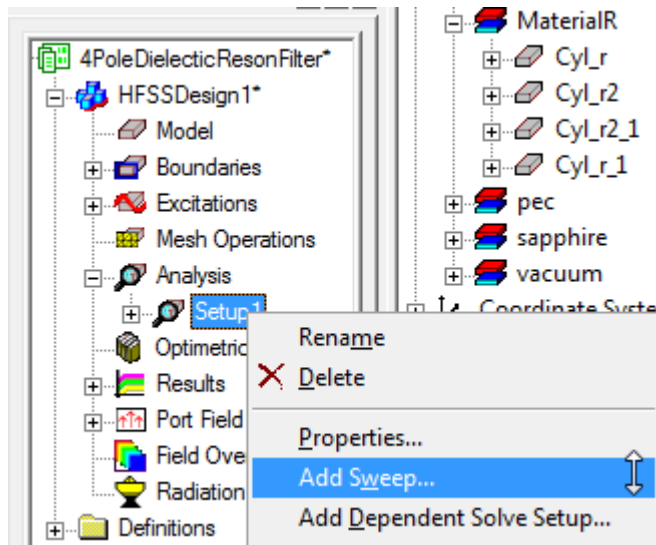
# Design Examples (Driven mode: DR Filter) cont.

- Analysis Setup
  - ◆ Single Frequency



# Design Examples (Driven mode: DR Filter) cont.

- Analysis Setup (cont.)
  - Frequency Sweep





# Design Examples (Driven mode: DR Filter) cont.

- Solution Data

Solutions: 4PoleDielectricResonFilter2\_3 - HFSSDesign1

Design Variation: '12.21mm' Ls='20.32mm' S='51.5mm' T='3.81mm' TP='0.1mm' W12='10.058mm'

Simulation: Setup1

Profile | Convergence | Matrix Data

Number of Passes

Completed 15  
Maximum 15  
Minimum 1

Max Mag. Delta S

Target 0.01  
Current 0.021342

View:  Table  Plot

NOT CONVERGED

Consecutive Passes

Target 1  
Current 0

Pass Number	# Tetrahedra	Max Mag. Delta S
1	4925	N/A
2	5739	1.0365
3	6684	1.3885
4	7814	0.7
5	9164	0.23503
6	10781	0.2556
7	12725	0.066175
8	15054	0.13555
9	17631	0.085955
10	20905	0.15014
11	24388	0.10422
12	29028	1.4731
13	34572	0.11683
14	39563	0.0769
15	45270	0.021342

Solutions: 4PoleDielectricResonFilter2\_3 - HFSSDesign1

Design Variation: '12.21mm' Ls='20.32mm' S='51.5mm' T='3.81mm' TP='0.1mm' W12='10.058mm' W2='10.058mm'

Simulation: Setup1 Sweep1

Profile | Convergence | Matrix Data

S Matrix  Gamma  Y Matrix  Zo  Z Matrix

1.9 (GHz) Export Matrix Data...  
All Freqs. Edit Freqs... Equivalent Circuit Export...

Magnitude/Phase(deg)

Freq	S:WavePort1:1	S:WavePort2:1
1.9 (GHz)	WavePort1:1 ( 0.99997, -18.3)	WavePort2:1 ( 0.0073384, -109)
	WavePort2:1 ( 0.0073384, -109)	WavePort1:1 ( 0.99997, -18.7)

Export Network Data Solution

File name: 4PoleDielectricResonFilter2\_3

Save as type: Touchstone (\*.sNp)

Browse Folders

- Touchstone (\*.sNp)
- Data Table (spreadsheet) (\*.tab)
- Planar EM/HFSS v6+ (\*.szg)
- Neutral Model Format (\*.nmf)
- MATLAB (\*.m)
- Citfile (\*.cit)

# Design Examples (Driven mode: DR Filter) cont.

## Plotting Solution Data

**Create Report**

Target Design: HFSSDesign1

Report Type: Modal Solution Data

Display Type: Rectangular Plot

OK

X	Y	Y-axis
1 Freq	dB(S(WavePort1,WavePort1))	Y1
2 Freq	dB(S(WavePort2,WavePort1))	Y1

Context

Design: HFSSDesign1

Solution: Setup1 : Sweep1

Domain: Sweep

TDR Options ...

Sweeps X Y

Category:	Quantity:	Function:
Variables	S(WavePort1,WavePort1)	ang_deg
Output Variables	S(WavePort1,WavePort2)	ang_rad
S Parameter	S(WavePort2,WavePort1)	cang_deg
Y Parameter	S(WavePort2,WavePort2)	cang_rad
Z Parameter		dB
VSWR		im
Gamma		mag
Port Zo		re
Group Delay		
Active S Parameter		
Active Y Parameter		
Active Z Parameter		
Active VSWR		

Add Trace

Remove Trace

Remove All Traces

Add Trace

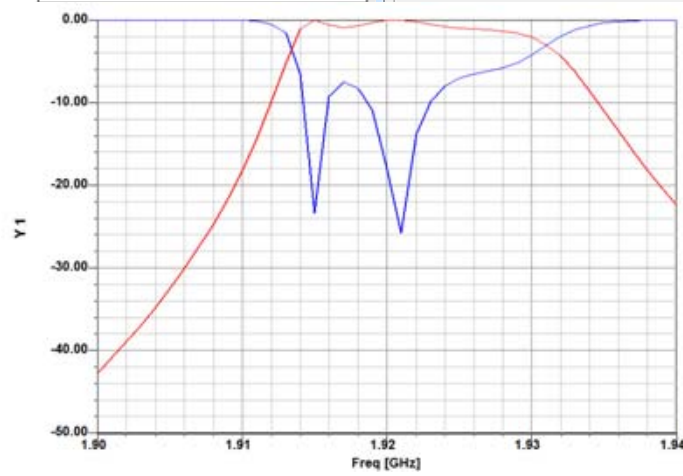
Replace Trace

Done

Cancel

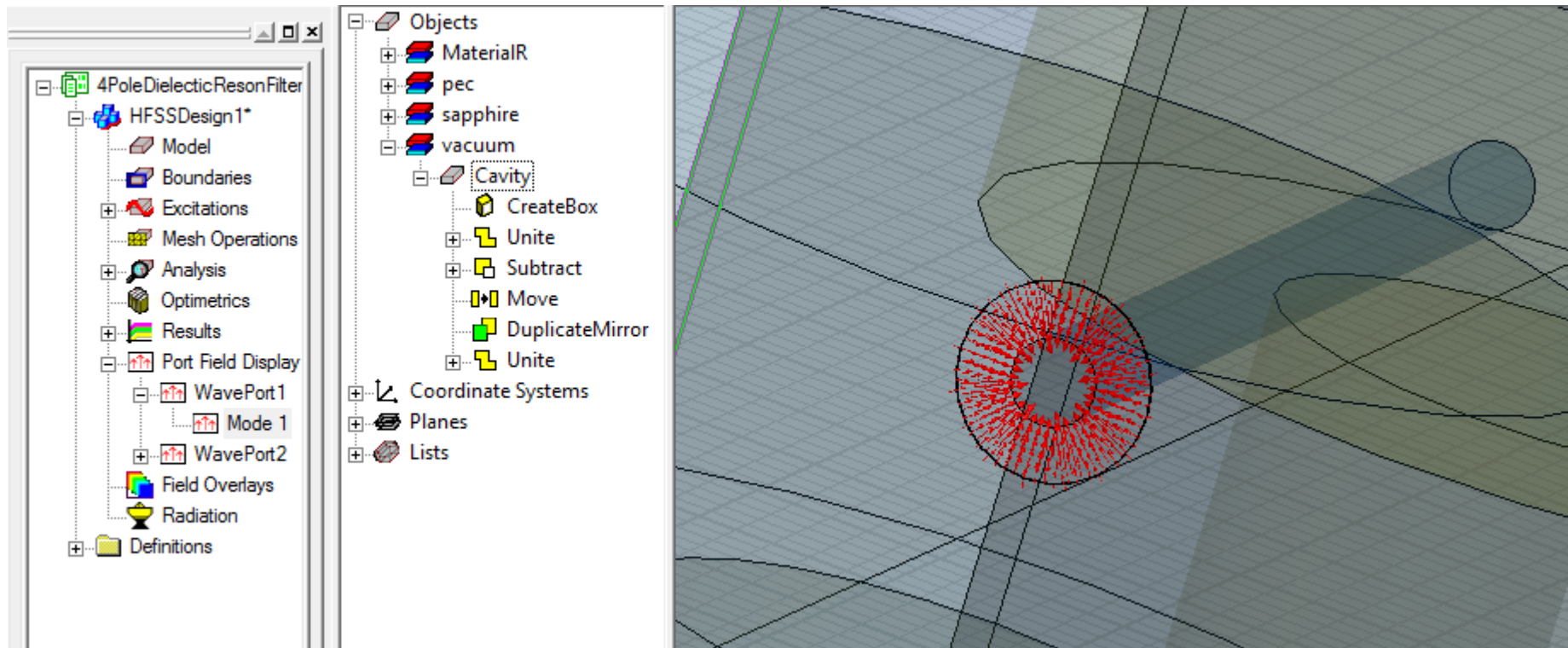
4PoleDielectricResonFilter

- HFSSDesign1
  - Model
  - Boundaries
  - Excitations
  - Mesh Operations
  - Analysis
  - Optimetrics
  - Results
    - Create Report...
    - Solution Data...
    - Output Variables...
  - Update Reports
  - Open All Reports
  - Delete All Reports
  - Browse Solutions...
  - Clean Up Solutions...
  - Import Solutions...



# Design Examples (Driven mode: DR Filter) cont.

- Port Field Display



# Design Examples (Driven mode: DR Filter) cont.

- Parametric Analysis

The screenshot displays the HFSS software interface with the 'Add/Edit Sweep' dialog box open. The dialog shows the following settings:

- Variable: D1
- Step type: Linear step (selected)
- Start: 29.8 mm
- Stop: 30 mm
- Step: 0.01 mm

The 'Optimetrics Analysis' menu is open, showing the following options:

- Add Parametric... (highlighted)
- Add Optimization (highlighted)
- Setup Sweep Analysis
- Ad...
- Ad...
- Tur...
- Op...

The 'Setup Sweep Analysis' dialog box is also visible, showing the following table:

Sync #	Variable	Description
	D1	Linear Step from 29.8mm to 30mm, step=0.01mm

# Design Examples (Driven mode: DR Filter) cont.

- Optimization

Properties: 4PoleDielectricResonFilter2\_3 - HFSSDesign1

Local Variables

Value  Optimization  Tuning

	Name	Include	Nominal Value
	H	<input type="checkbox"/>	37.84mm
	G	<input type="checkbox"/>	0.254mm
	a	<input type="checkbox"/>	1.117mm
	b	<input type="checkbox"/>	2.54mm
	D1	<input checked="" type="checkbox"/>	29.87mm
	D2	<input checked="" type="checkbox"/>	29.66mm
	d	<input type="checkbox"/>	7.47mm
	Ds	<input type="checkbox"/>	14.22mm
	Ls	<input type="checkbox"/>	20.32mm

Setup Optimization

Goals | Variables | General | Options

Optimizer: Quasi Newton

Max. No. of Iterations: 1000

Cost Function:

Solution	Calculation	Calc. Range	Condition	Goal	Weight
Setup 1 : Sweep1	S11_opt	Freq(From 1.91GHz to 1.93GHz)	<=	[-20]	[1]
Setup 1 : Sweep1	S21_opt	Freq(Single value at 1.905GHz)	<=	[-40]	[1]
Setup 1 : Sweep1	S21_opt	Freq(Single value at 1.935GHz)	<=	[-40]	[1]
Setup 1 : LastAdaptive			=		

Add Delete Edit Calculation... Edit Cal. Range... Edit Goal/Weight...

Acceptable Cost: 0 Noise: 0.0001  Show Advanced Option

OK Cancel

# Design Examples (Driven mode: DR Filter) cont.

- Optimization (cont.)

**Output Variables**

	Name	Expression
1	S11_opt	dB(S(WavePort1,WavePort1))
2	S21_opt	dB(S(WavePort1,WavePort1))

Name:  Add Update Delete

Expression:

Calculation

Design: HFSSDesign1 Report Type: Modal Solution Data Solution: Setup1 : LastAdaptive

Insert Quantity Into Expression

Category:	Quantity:	Function:
Variables	S(WavePort1,WavePort1)	conig
Output Variables	S(WavePort1,WavePort2)	cos
S Parameter	S(WavePort2,WavePort1)	cosh
Y Parameter	S(WavePort2,WavePort2)	dB
Z Parameter		deriv
VSWR		exp
Gamma		im
Port Zo		integ
Active S Parameter		In
Active Y Parameter		log10
Active Z Parameter		mag
Active VSWR		...

**Edit Calculation Range**

Edit Range

Variable: Freq

Range  Single Value

Start: 1.91GHz Stop: 1.93GHz

Valid	Variable	Range
<input checked="" type="checkbox"/>	Freq	From 1.91GHz to 1.93GHz

Add Update Delete

**Edit Goal Value/Weight**

Goal Value | Weight

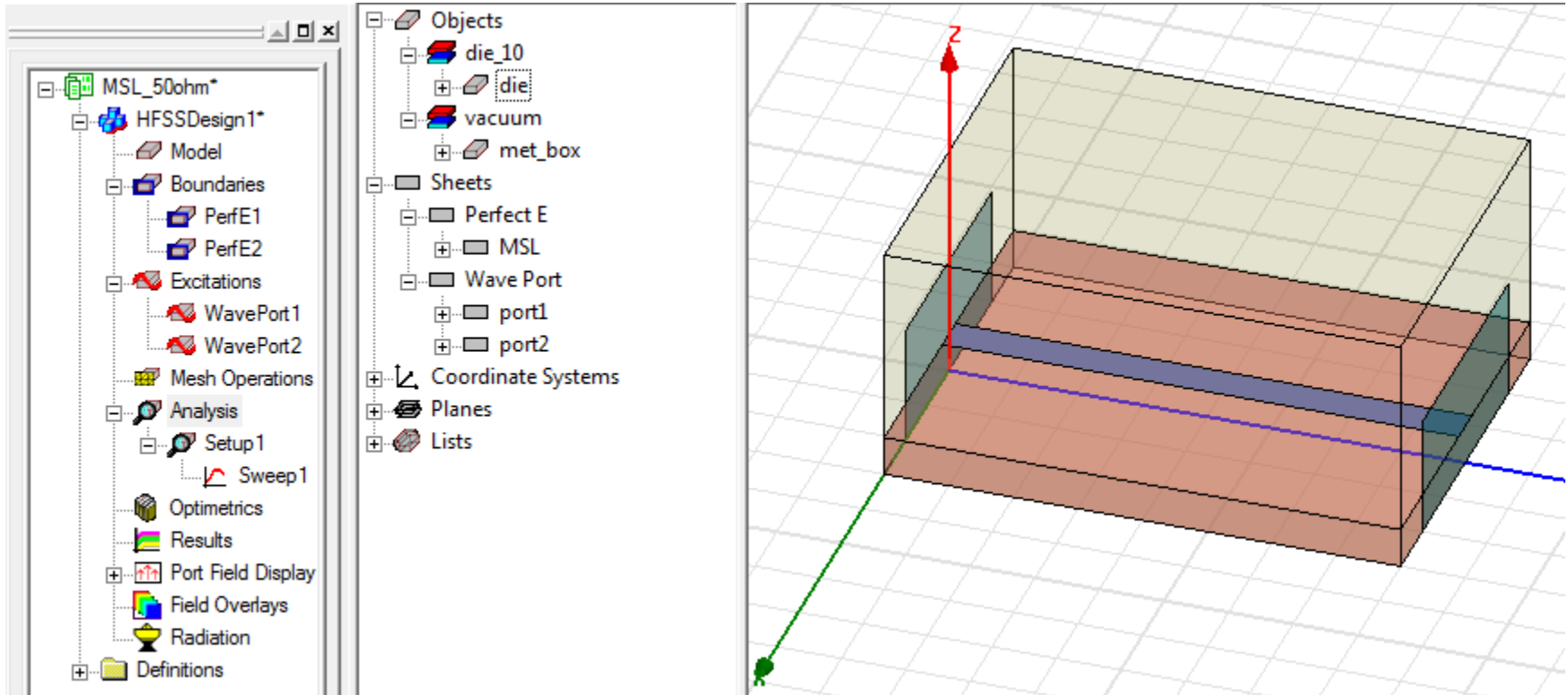
Type: Simple Numeric Value

Goal Value	Weight
-20	

OK Cancel Help

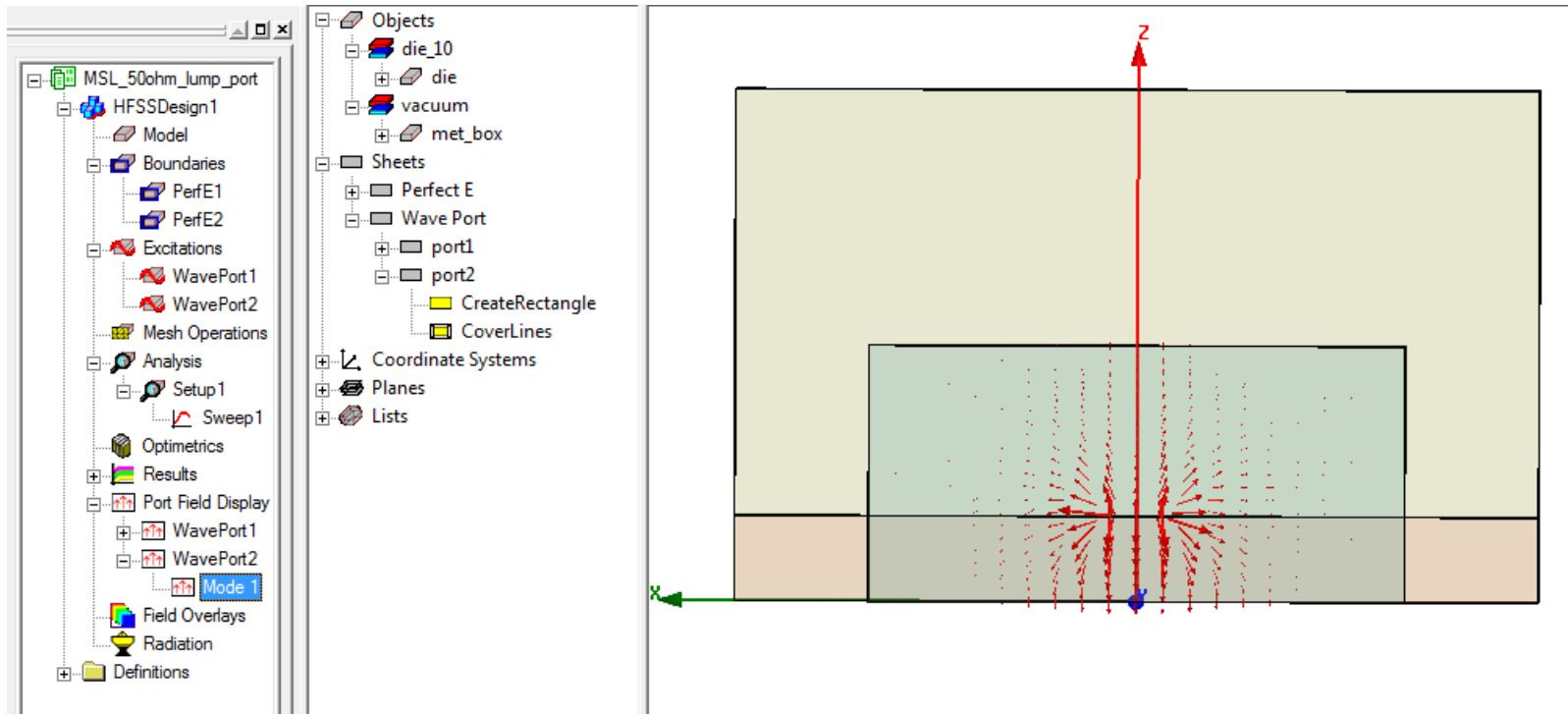
# Design Examples (Driven mode: MSL)

- 3D Model of the MSL



# Design Examples (Driven mode: MSL)

- Port Field Display





# Design Examples (Driven mode: MSL)

- Solution Data

Solutions: MSL\_50ohm - HFSSDesign1

Design Variation: H='0.635mm' L='8mm' w='6mm' w\_50='0.6mm' w\_P=

Simulation: Setup1 Sweep1

Profile Convergence Matrix Data

S Matrix  Gamma  Y Matrix  Zo  All Freqs.  Z Matrix

Magnitude/Phase(deg)

Freq	Port Zo
3.9 (GHz)	WavePort1:1 ( 48.386, 0.00271)
	WavePort2:1 ( 48.4, 0.00271)
4 (GHz)	WavePort1:1 ( 48.372, 0.00271)
	WavePort2:1 ( 48.386, 0.00271)
4.1 (GHz)	WavePort1:1 ( 48.358, 0.00271)
	WavePort2:1 ( 48.371, 0.00271)

