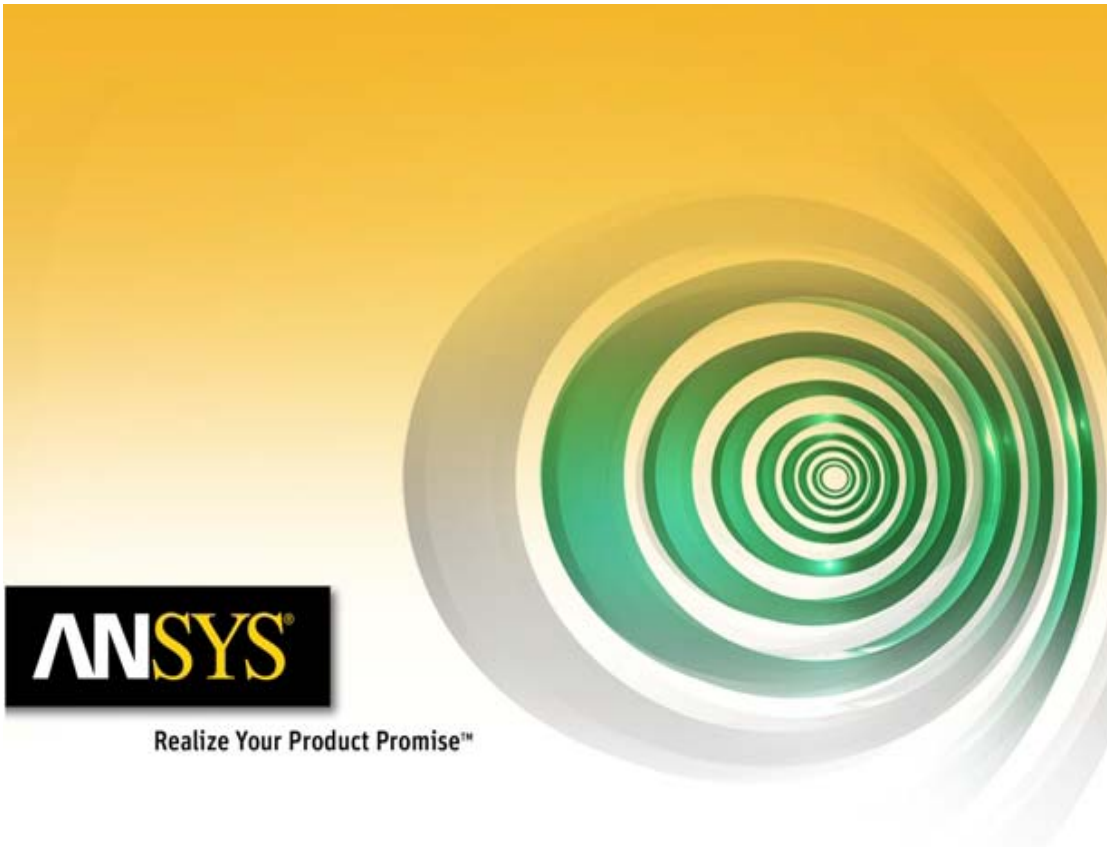

Getting Started with HFSS™

Silicon Spiral Inductor

ANSYS, Inc.
275 Technology Drive
Canonsburg, PA 15317
USA
Tel: (+1) 724-746-3304
Fax: (+1) 724-514-9494
General Information: AnsoftInfo@ansys.com
Technical Support: AnsoftTechSupport@ansys.com

November 2012

The information contained in this document is subject to change without notice. ANSYS makes no warranty of any kind with regard to this material, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. ANSYS shall not be liable for errors contained herein or for incidental or consequential damages in connection with the furnishing, performance, or use of this material.

New editions of this manual incorporate all material updated since the previous edition. The manual printing date, which indicates the manual's current edition, changes when a new edition is printed. Minor corrections and updates that are incorporated at reprint do not cause the date to change.

Update packages may be issued between editions and contain additional and/or replacement pages to be merged into the manual by the user. Pages that are rearranged due to changes on a previous page are not considered to be revised.

Edition	Date	Software Version
1	May 2003	9
2	June 2005	10
3	June 2007	11
4	Sept 2009	12
5	October 2010	13.0
6	August 2011	14.0

Conventions Used in this Guide

Please take a moment to review how instructions and other useful information are presented in this guide.

- Procedures are presented as numbered lists. A single bullet indicates that the procedure has only one step.
- Bold type is used for the following:
  - Keyboard entries that should be typed in their entirety exactly as shown. For example, "**copy file1**" means to type the word **copy**, to type a space, and then to type **file1**.
  - On-screen prompts and messages, names of options and text boxes, and menu commands. Menu commands are often separated by carats. For example, click **HFSS>Excitations>Assign>Wave Port**.
  - Labeled keys on the computer keyboard. For example, "Press **Enter**" means to press the key labeled **Enter**.
- Italic type is used for the following:
  - Emphasis.
  - The titles of publications.
  - Keyboard entries when a name or a variable must be typed in place of the words in italics. For example, "**copy** *file name*" means to type the word **copy**, to type a space, and then to type a file name.
- The plus sign (+) is used between keyboard keys to indicate that you should press the keys at the same time. For example, "Press **Shift+F1**" means to press the **Shift** key and the **F1** key at the same time.
- Toolbar buttons serve as shortcuts for executing commands. Toolbar buttons are displayed after the command they execute. For example,

  "On the **Draw** menu, click **Line**  " means that you can click the Draw Line toolbar button to execute the **Line** command.

Getting Help

ANSYS Technical Support

To contact ANSYS technical support staff in your geographical area, please log on to the ANSYS corporate website, https://www1.ansys.com. You can also contact your ANSYS account manager in order to obtain this information.

All ANSYS software files are ASCII text and can be sent conveniently by e-mail. When reporting difficulties, it is extremely helpful to include very specific information about what steps were taken or what stages the simulation reached, including software files as applicable. This allows more rapid and effective debugging.

Help Menu

To access online help from the HFSS menu bar, click **Help** and select from the menu:

- **Contents** - click here to open the contents of the online help.
- **Seach** - click here to open the search function of the online help.
- **Index** - click here to open the index of the online help.

Context-Sensitive Help

To access online help from the HFSS user interface, do one of the following:

- To open a help topic about a specific HFSS menu command, press **Shift**+**F1**, and then click the command or toolbar icon.
- To open a help topic about a specific HFSS dialog box, open the dialog box, and then press **F1**.

Table of Contents

1. Introduction

Sample Project - Silicon Spiral Inductor 1-2

2. Set Up The Project

Launch HFSS 2-2
Set Tool Options 2-2
Insert HFSS design 2-3
- Set Model Units 2-3
- Set Solution Type 2-4

3. Setup Si Spiral Inductor

Create 3D Model for Dielectrics 3-2
- Create Substrate 3-2

Create Oxide 3-3
- Create Passivation 3-5
- Create Air Body 3-6
- Assign Radiation Boundary 3-7
- Create Ground 3-8

Assign Perfect E Boundary to the Ground 3-9
- Hide Dielectrics 3-10

Create Spiral Inductor Geometry 3-10
- Create Offset Coordinate System 3-10
- Create Spiral Path 3-11
- Assign Thickness to the Spiral 3-12

Create Underpass 3-14
- Create Via1 3-14

Create Via2 3-15
Create Feed 3-16
Unite Spiral Objects 3-17
Solve Inside Conductors 3-18
Seed Mesh Conductors Set for Solve Inside . 3-19
Create Ground Ring 3-19
Create Inner Ring 3-21
Complete the Ring 3-22
Create Extension 1 3-23
Create Extension 2 3-24
Create Source 1 3-25
Create Source 2 3-25
Group the Conductors 3-26
Assign Excitation for Source1 3-26
Assign Excitation for Source2 3-27
Show All 3-28
Boundary Display (Optional) 3-28

4. Analyze Spiral Conductor

Create Analysis Setup 4-2
Add a Frequency Sweep 4-3
Model Validation 4-3
Analyze the Model 4-4
Review Solution Data 4-4
Review the Profile Panel 4-4
Review the Convergence Panel 4-5
Review the Matrix Data Panel 4-6
Review the Mesh Statistics Panel 4-6
Generate Reports 4-7
Create S-parameter vs. Frequency Plot 4-7
Custom Equations – Output Variables 4-8
Use Output Variables for Next Report 4-11

1 Introduction

This document is intended as supplementary material to HFSS for beginners and advanced users. It includes instructions to create, simulate, and analyze a silicon spiral inductor model.

This chapter contains the following topic:

- Sample Project - Silicon Spiral Inductor

Sample Project - Silicon Spiral Inductor

In this project, we will use HFSS to create, simulate, and analyze a 2.5 turn spiral inductor.

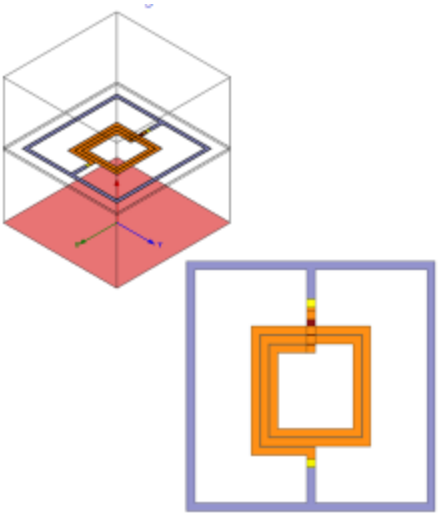

Figure 1. Spiral Inductor

This nominal design consists of the following components with their corresponding dimensions:

- **Spiral:** 2.5T, W=15um, S=1.5um, Rad=60um
  M6, 2um, σ= 2.8e7 S/m
- **Underpass:** M5, 0.5um, σ= 2.8e7 S/m
- **Stackup**:Passivation**:** 0.7um, εr = 7.9,
- **Oxide:** 9.8um, εr = 4.0
- **Substrate:** 300um
  εr = 11.9, σ= 10 S/m

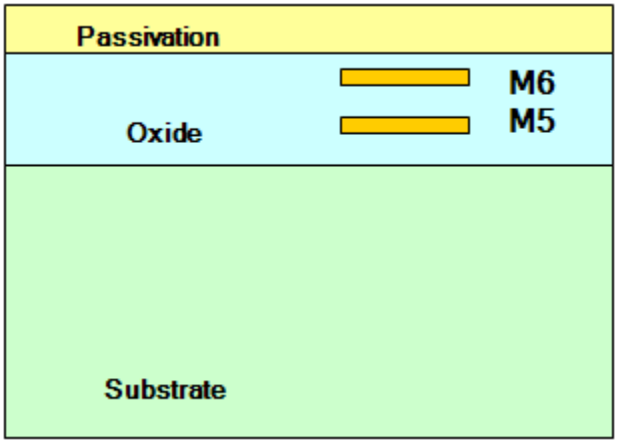

Figure 2. Passivation, Oxide and Substrate

2 Set Up The Project

This chapter contains the following topic:

- Launch HFSS
- Set Tool Options
- Insert HFSS design
- Set Model Units(cm)
- Set Solution Type(Terminal)

Launch HFSS

Store a shortcut of the HFSS application on your desktop.

1 Double-click the **HFSS** icon to launch the application.

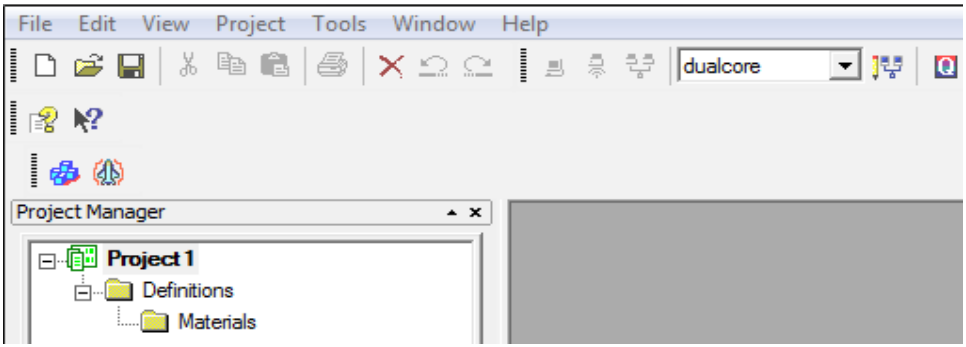

Figure 1. HFSS opens

Note If the application does not list the folder, go to **File** and click **New**. If the **Project Manager** window does not appear, go to **View** and enable it.

Set Tool Options

Verify the options under the **Tools** menu as follows:

1 Click **Tools>Options>HFSS Options.**

The **HFSS Options** dialog box appears.

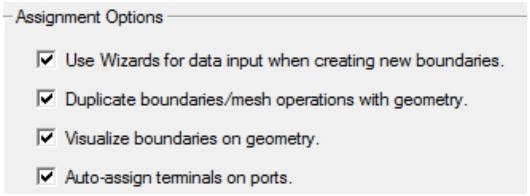

Figure 2. Assignment Options

2 On the **General** tab ensure all **Assignment Options** are checked and click **OK** to close the dialog box.

3 Click **Tools>Options>Modeler Options.**

The **Modeler Options** dialog box appears.

4 On the **Operation** tab check **Automatically cover closed polylines.**

5 On the **Drawing** tab check **Edit properties of new primitives** and click **OK.**

Note This option causes a **Properties** dialog box to appear whenever you create a new object.

Insert HFSS design

The icon below represents the **Insert HFSS design** (**IHd**) option.

Figure 3. IHd

1 Expand the project tree.

2 If **IHd** is present, proceed to rename and save the project and if it is absent click the **IHd** icon to include it.

Note Inclusion of **IHd** modifies the project and hence the asterisk appears on **Project1**.

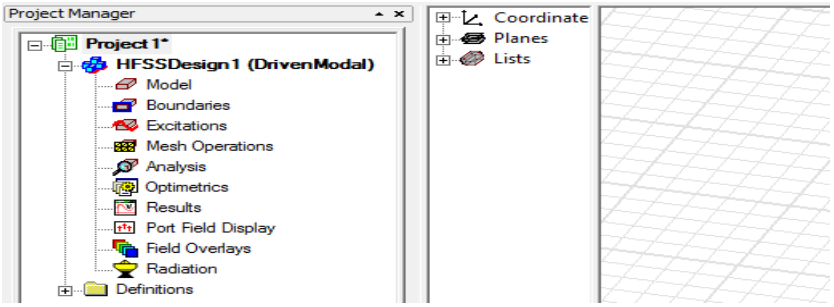

Figure 4. IHd included

3 Click **Project1***, hit **F2**, rename the project and save it.

Set Model Units

Set the units for the geometric model as follows:

1 On the HFSS toolbar, click **Modeler>Units**.

The **Set Model Units** dialog box appears.

2 Select the unit as **um** and click **OK.**

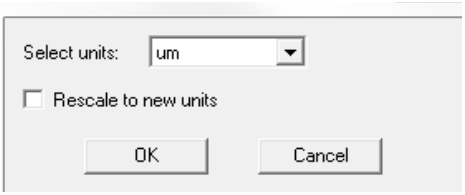

Figure 5. Set Model Units dialog

Set Solution Type

To set the solution type:

1. On the toolbar, click **HFSS>Solution Type**

   The **Solution Type** dialog box appears.

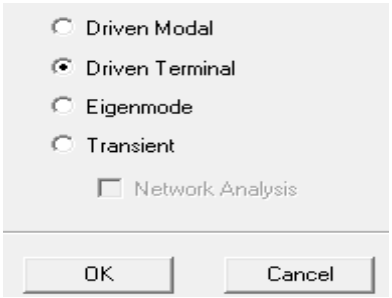

Figure 5: Solution Type dialog

2. Select **Driven Terminal** and click **OK.**

   Note Driven Terminal calculates the terminal-based S-parameters of multi-conductor transmission line ports. The S-matrix solutions will be expressed in terms of terminal voltages and currents.

3 Setup Si Spiral Inductor

This chapter describes how to build the 3D spiral inductor model in HFSS.

This chapter contains the following topics:

- Create 3D Model for Dielectrics
- Create Substrate
- Create Oxide
- Create Passivation
- Create Air Body
- Assign Radiation Boundary
- Create Ground
- Assign Perfect E Boundary to the Ground
- Create Spiral Inductor Geometry
- Assign Thickness to the Spiral
- Create Underpass
- Create Via1
- Create Via2
- Create Feed
- Unite Spiral Objects
- Solve Inside Conductors
- Seed Mesh Conductors Set for Solve Inside
- Create Ground Ring
- Create Inner Ring
- Complete The Ring
- Create Extension1
- Create Extension2
- Create Source1
- Create Source2
- Group the Conductors
- Assign Excitation for Source1
- Assign Excitation for Source2

Create 3D Model for Dielectrics

The creation of the 3D model requires you to draw a number of geometrical pieces. The following sections describe the procedures to do the same.

Create Substrate

To create a substrate, you will draw a box freehand as follows:

1. Click **Draw>Box.**

   The cursor is accompanied by a black square box.
2. Click inside the Modeler window to establish the x,y axes and drag the mouse to draw the rectangle.
3. Click the mouse to establish the z axis and drag the mouse along the z-axis to draw the height.
4. Click the mouse to complete the box.

   The **Properties** dialog box appears.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-270 ,-270 ,0	um	-270um , -270um , ...
	XSize	540	um	540um
	YSize	540	um	540um
	ZSize	300	um	300um

Figure 1. Properties dialog

5. Edit the fields in the **Command** dialog box as in Figure 1.
6. On the **Attribute**, enter *Sub* in the **Name** field and from the **Materials** drop-down menu, select **Edit.**

   The **Select Definition** dialog box appears.
7. Click **Add Material** and edit the fields in the dialog box as in Figure 2.

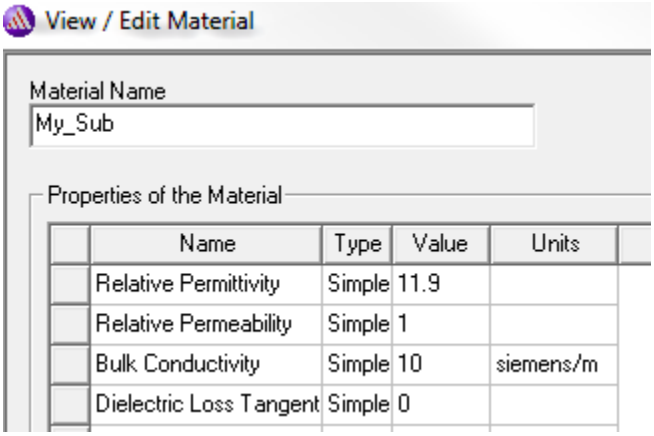

Figure 2. View/Edit Material dialog

8 Click **OK** to close the **View/Edit Materia**l dialog box and repeat the same on the other dialog boxes to exit.

9 Do **Ctrl+D** to fit the view.

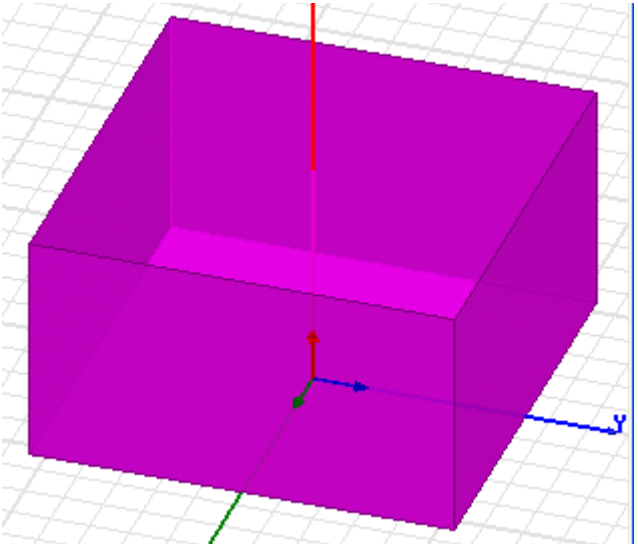

Figure 3. Substrate created

Create Oxide

1 Draw the box freehand.

The **Properties** dialog box appears.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-270 ,-270 ,300	um	-270um , -270um , 300um
	XSize	540	um	540um
	YSize	540	um	540um
	ZSize	9.8	um	9.8um

Figure 4. Command dialog for Oxide

2 On the **Command** tab, edit the fields as in Figure 4 and click **Attribute** and rename box to: *Oxide*

3 From the **Materials** drop-down menu, select **Edit.**
The **Select Definition** dialog box appears.

4 Click **Add Material** and edit the fields as in Figure 5.
The **View/Edit Material** dialog box appears.

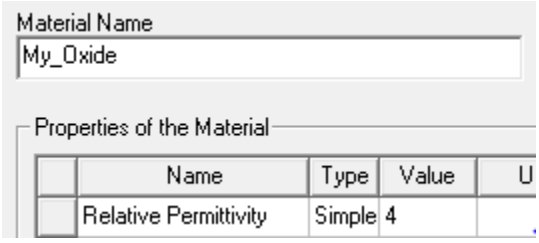

Figure 5. View/Edit Material dialog

5 Click **OK** to close the **View/Edit Materia**l dialog box and repeat the same on the other dialog boxes to exit.

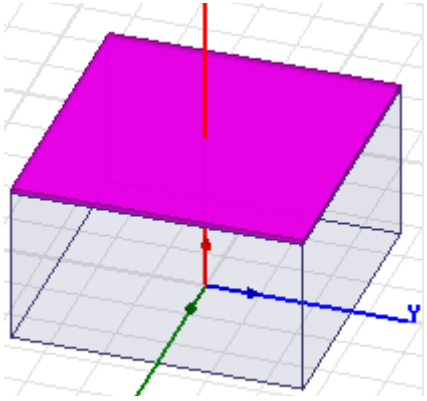

Figure 6. for the oxide substrate

Create Passivation

1 Draw the box freehand.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-270 ,-270 ,309.8	um	-270um , -270um , 309.8...
	XSize	540	um	540um
	YSize	540	um	540um
	ZSize	0.7	um	0.7um

Figure 7. Command tab for passivation

2 On the **Command** tab edit the fields as shown in Figure 7 and on the **Attribute** tab rewrite the **Name** field to *Pass*.

3 Select **Edit** from the **Materials** drop down menu.

4 Click **Add Material** and edit the fields as in Figure 8.

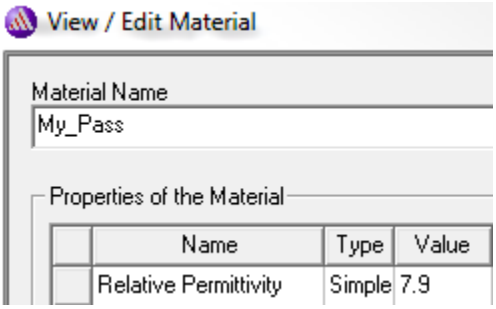

Figure 8. View/Edit Material dialog

5 Click **OK** to close the **View/Edit Materia**l dialog box and repeat the same on the other dialog boxes to exit.

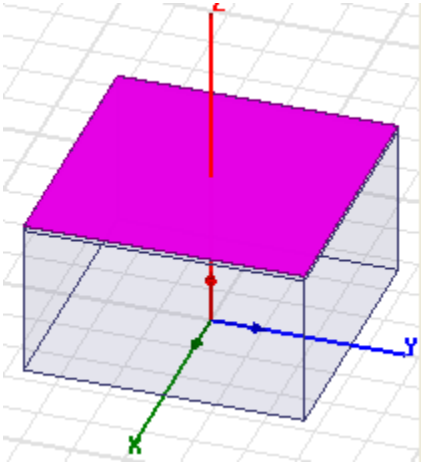

Figure 9. Passivation applied.

Create Air Body

1. Draw a box freehand.
2. Set the **Command** dialog box as in Figure 10.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-270 ,-270 ,0	um	-270um , -270um , 0um
	XSize	540	um	540um
	YSize	540	um	540um
	ZSize	600	um	600um

Figure 10. Properties dialog for Air

3. On the **Attribute** tab, rename object to *Air.*
4. Ensure that the **Material** selected is *vacuum* and click **OK**.

   The box gets updated with the new dimensions and properties that you set.

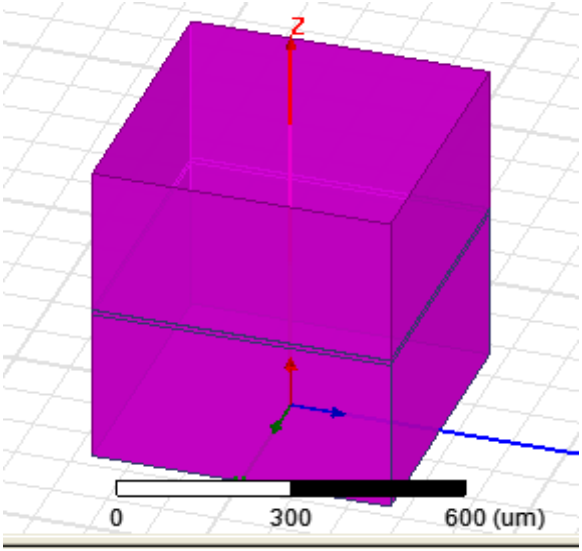

Figure 11. Air Enlcosure drawn

Assign Radiation Boundary

You will now assign the radiation boundary to the air body.

1. Select **Air** from the **History Tree** dialog box.

   The air body gets highlighted.

2. Right click **Air** and select **Assign Boundary>Radiation** from the short-cut menu.

   The **Radiation Boundary** dialog box appears.

3. Edit the fields as shown in Figure 12 and click **OK**.

Figure 12. Radiation Boundary

Create Ground

1. Draw a rectangle freehand.

   The **Properties** dialog box appears.
2. Click **OK** to accept the values in the **Properties** dialog box.
3. Double-click **CreateRectangle** from the history tree.

   The **Command** dialog box appears.

	Name	Value	Unit	Evaluated Value
	Command	CreateRectangle		
	Coordinate System	Global		
	Position	-270 ,-270 ,0	um	-270um , -270um , 0um
	Axis	Z		
	XSize	540	um	540um
	YSize	540	um	540um

Figure 13. Properties for Rectangle

4. Edit the fields as shown in Figure 13.

   The rectangle updates itself with the new settings.
5. Double-click **Rectangle1** in the history tree and on the **Attribute** dialog box enter *Ground* in the **Name** field and click **OK**.

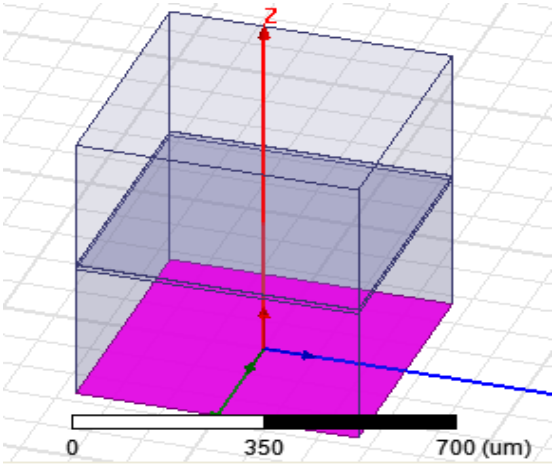

Figure 14. The structure with rectangle drawn

Assign Perfect E Boundary to the Ground

1. Click outside the structure to de-select all 2D and 3D objects.
2. Select **Ground** from the history tree to highlight it.
3. Right-click **Ground** and select **Assign Boundary**>**Perfect E** from the short-cut menu.

   The **Perfect E Boundary** dialog box appears.
4. Enter *PerfE_Ground* in the **Name** field.

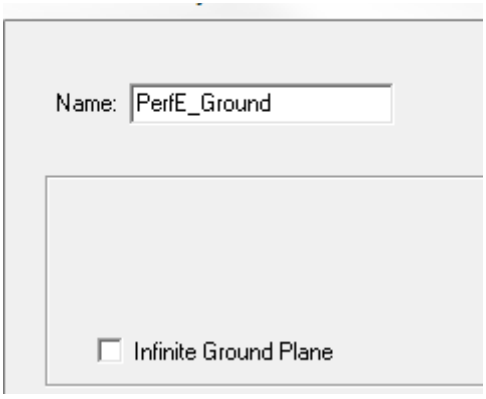

Figure 15. Perfect E boundary dialog

5. Leave the **Infinite Ground Plane** unchecked and click **OK**.

   The Perfect E boundary is applied and the Message Manager gives the following warning:

   - *Boundary Rad1 and Boundary PerfE_Ground overlap*.

   This is because you applied the PerfE boundary on a face that already has the Radiation boundary. However, PerfE_Ground overrides the Radiation boundary on that face owing to a higher priority.

   Note By default priority is assigned according to the order in which the boundaries are applied. Since PerfE_Ground was assigned after Rad1, it has a higher priority. HFSS lets you reprioritize the boundaries, but it is not needed for this project.

Hide Dielectrics

1. Click **Edit>Select All Visible**
2. Click **View>Visibility>Hide Selection>All Views**

   All the objects are now hidden.

Create Spiral Inductor Geometry

Before you create the spiral inductor, you can set the default material.

1. From the **Modeler Materials** toolbar, choose **Select.**

   The **Select Definition** dialog box appears.
2. Click **Add Material.**

   The **View/Edit Material** dialog box appears.

   Edit the fields as shown in Figure 23.

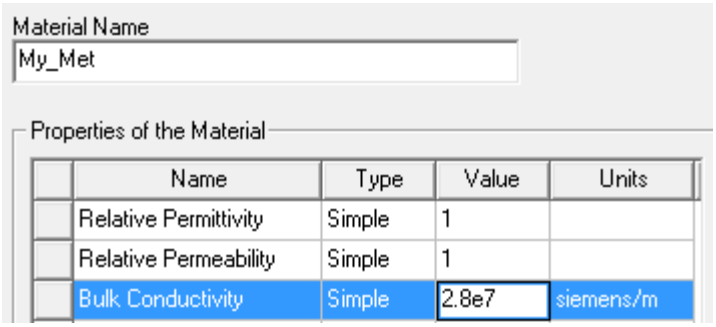

Figure 16. View/Edit Material dialog

3. Click **OK** to close the **View/Edit Materia**l dialog box and repeat the same on the other dialog box to exit.

Create Offset Coordinate System

1. Click **Modeler>Coordinate System>Create>Relative CS>Offset**
2. In the coordinate fields, enter the origin as follows:

   X: *0.0*, **Y:** *0.0*, **Z:** *304.8*.

   Note The co-ordinate fields appear on the status bar at the bottom and are titled **Select the origin**.
3. Hit **Enter.**

Create Spiral Path

To create the path:

1. Click **Draw>Line**

   Using the coordinate entry fields, enter the vertex point: X: **-67.5** , Y: **7.5**, Z: **1.0** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **-67.5** , Y: **-67.5** , Z: **1.0** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **84.0**, Y: **- 67.5**, Z: **1.0** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **84.0**, Y: **84.0**, Z: **1.0** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: - **84.0**, Y: **84.0**, Z: **1.0** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: - **84.0**, Y: **-84.0,** Z: **1.0**, Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **100.5** , Y: **-84.0**, Z: **1.0,** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **100.5** , Y: **100.5**, Z: **1.0**, Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: - **100.5** , Y: **100.5**, Z: **1.0,** Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: - **100.5** , Y: **- 100.5**, Z: **1.0**, Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **117.0**, Y: -**100.5**, Z: **1.0**, Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **117.0**, Y: **0.0**, Z: **1.0**, Press the **Enter** key
   Using the coordinate entry fields, enter the vertex point: X: **131.0**, Y: **0.0**, Z: **1.0**, Press the **Enter** key
2. Using the mouse, right-click and select **Done.**
3. Select **Attribute** and enter *Spiral* in the **Name** field and click **OK.**

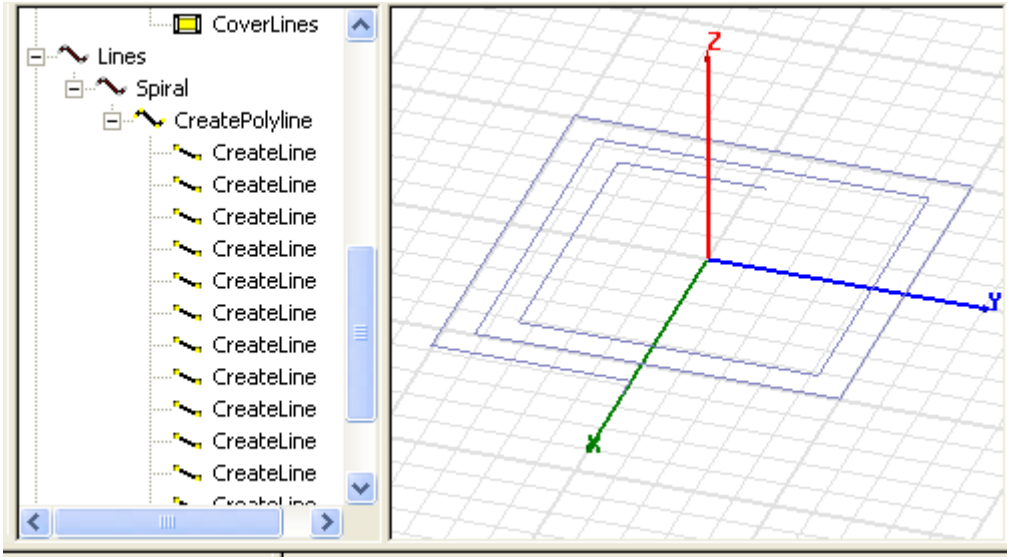

Figure 17. Spiral drawn.

Assign Thickness to the Spiral

To assign trace width and thickness perform the following:

1. Right-click **Create Polyline** under **Spiral** from the **History Tree**.
2. Select **Properties** from the short-cut menu.
   The **Properties** dialog box appears.

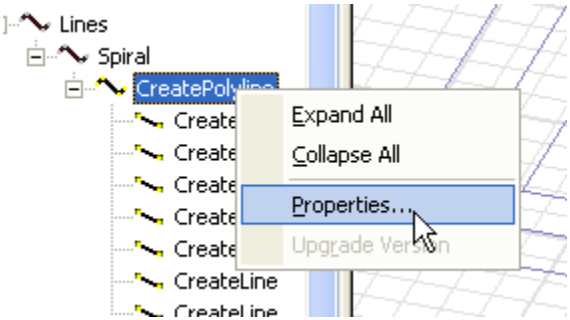

Figure 18. History Tree

	Name	Value	Unit	Evaluated V...
	Command	CreatePolyline		
	Coordinate System	Global		
	Number of points	13		
	Number of curves	12		
	--Cross Section			
	Type	Rectangle		
	Orientation	Auto		
	Width/Diameter	15	um	15um
	Top Width	0	um	0um
	Height	2	um	0um
	Number of Segments	0		0

Figure 19. Command dialog box

3 Edit the fields as shown in Figure 19 and click **OK** to close the **Properties** dialog box.

The spiral is assigned the thickness that you set.

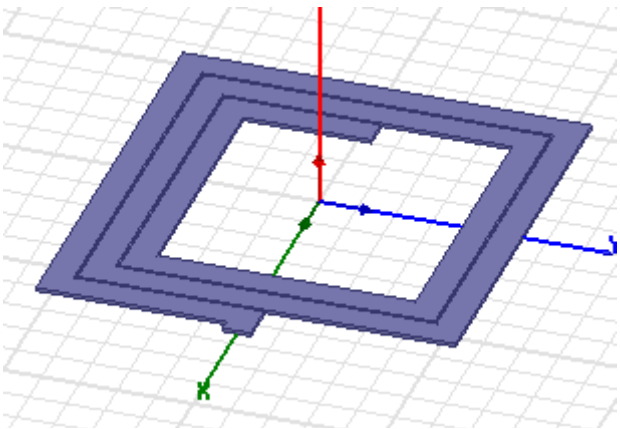

Figure 20. The updated spiral

Create Underpass

Before creating the underpass ensure the grid plane is *XY*.

1. Click **Modeler>Grid Plane>XY**
2. Draw a box freehand edit the fields on the **Command** tab

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-60 ,7.5 ,-0.8	um	-60um , 7.5um , -0.8um
	XSize	-75	um	-75um
	YSize	-15	um	-15um
	ZSize	-0.5	um	-0.5um

Figure 21. Properties dialog

as shown in Figure 21.

3. On the **Attribute** tab rename object as *Underpass* and click **OK** to close the **Properties** dialog box.

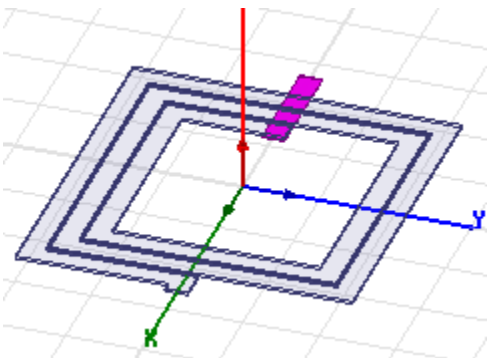

Figure 22. The Underpass

Create Via1

1. Draw a freehand and on the Command tab edit the fields as shown inFigure 23.
2. On the **Attribute** tab enter *Via1* in the **Name** field and click **OK**.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-60 ,7.5 ,0	um	-60um , 7.5um , 0um
	XSize	-15	um	-15um
	YSize	-15	um	-15um
	ZSize	-0.8	um	-0.8um

Figure 23. Properties dialog

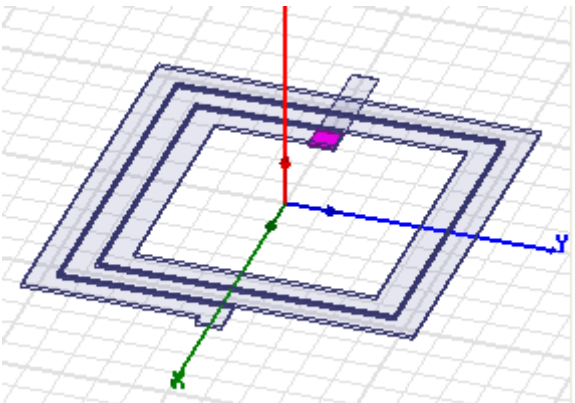

Figure 24. Via1 applied

Create Via2

1 **Draw** a box freehand and edit the fields on the Connad tab as shown in Figure 25**.**

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-120 ,7.5 ,0	um	-120um , 7.5um , 0um
	XSize	-15	um	-15um
	YSize	-15	um	-15um
	ZSize	-0.8	um	-0.8um

Figure 25. Via2 Properties

2 On the **Attribute** tab enter *Via2* in the **Name** field and click **OK**.

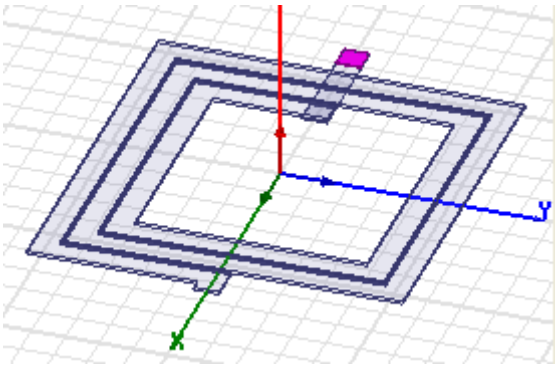

Figure 26. Via2 applied.

Create Feed

1 Draw a box freehand.

The **Properties** dialog box appears.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-120 ,7.5 ,0	um	-120um , 7.5um , 0um
	XSize	-22	um	-22um
	YSize	-15	um	-15um
	ZSize	2	um	2um

Figure 27. Feed Properties

2 Edit the fields as shown in Figure 27 and on the **Attribute** tab enter *Feed* in the **Name** field and click **OK** to close the **Properties** dialog box.

3 Do **Ctrl+D** to fit the view.

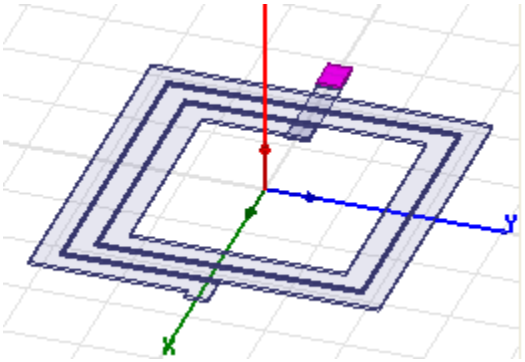

Figure 28. Feed applied.

Unite Spiral Objects

You will now unite the spiral objects.

1 Click **Spiral,** press the Ctrl key and select **Via1, Via2, Feed,** and **Underpass.**

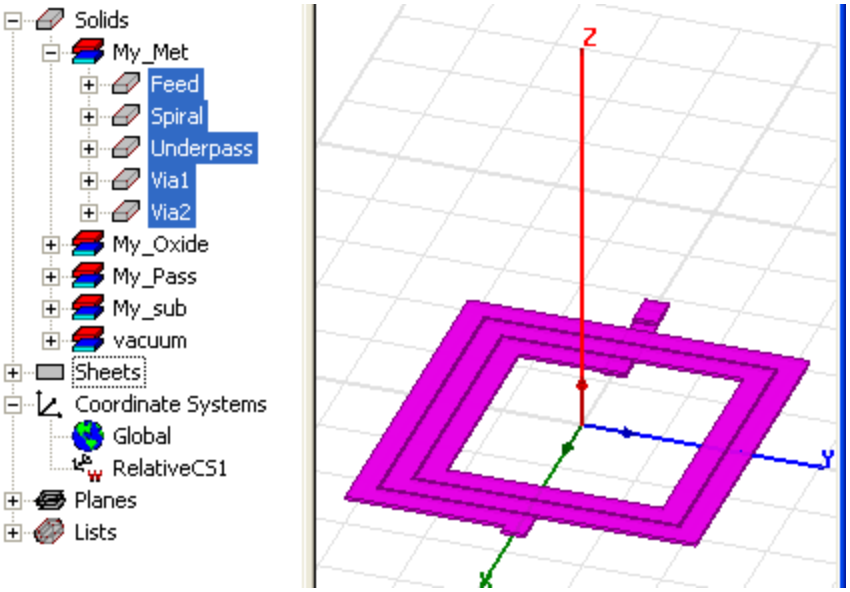

Figure 29. The pieces united

Note The order in which you click the objects determines the name of the united structure. If you click **spiral** first followed by the rest, the united structure will be named spiral. If you selected **Feed** first, then, the united

structure will be named as **Feed**.

2 Click **Modeler>Boolean>Unite**

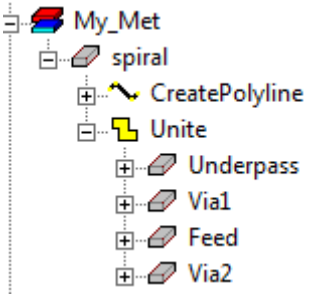

Figure 30. The united object names itself as spiral

3 Do **Ctrl+D** to fit the view.

Solve Inside Conductors

In this section, we will select **Solve Inside** for spiral.

By default **Solve Inside** gets unchecked for metals or highly conductive materials. In such cases, the conductive material is represented by a boundary condition that removes the need to solve inside the metal. For most projects, we recommend that you use the default settings for **Solve Inside**.

When **Solve Inside** is selected it includes tetrahedra inside a conductor for simulation which could require a large mesh. Solve Inside can be useful for low frequency analysis of electrically small projects for enhanced accuracy of especially sensitivity design parameters such as the Q factor.

1 Double-click **spiral** from the history tree.

The **Attributes** dialog box appears.

2 Select **Solve Inside** and click **OK**.

The **Message Manager** displays the following message: *Solving inside a solid with high conductivity may require a large mesh*.

Note For this project, ignore this message.

Seed Mesh Conductors Set for Solve Inside

In this section you will set HFSS to refine the length of the tetrahedral elements untill they are below the specified value.

1. Click **Edit>Select All Visible**
2. Click **HFSS>Mesh Operations>Assign>Inside Selection>Length Based**

   The **Element Length Based Refinement** dialog box appears.
3. Edit the fields as shown in the figure below and click **OK**.

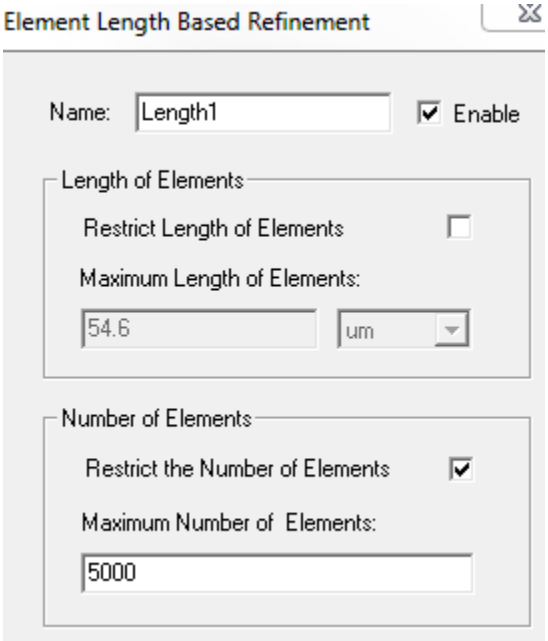

Figure 31. Element Length Based Refinement settings

Create Ground Ring

1. Draw a box freehand.

   The **Properties** dialog box appears.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-225 ,-225 ,0	um	-225um , -225um , 0um
	XSize	450	um	450um
	YSize	450	um	450um
	ZSize	2	um	2um

Figure 32. Ring Properties

2 On the **Command** tab edit the fields as shown in Figure 32.

3 On the **Attribute** tab enter *Ring* in the **Name** field and select **Edit** from the **Materials** drop-down menu.

The **Select Definition** window appears.

4 Type *pec* in the **Search by Name** field.

5 Click **OK** to close the **View/Edit Material** dialog box and repeat the same on the other dialog boxes to exit.

The **Message Manager** window displays the following message: *Solve inside for object 'Ring' is unset, due to material asssignment change*.

Note No action is required to deal with this message. The electric field inside a perfect conductor is zero. So, HFSS deselects this option.

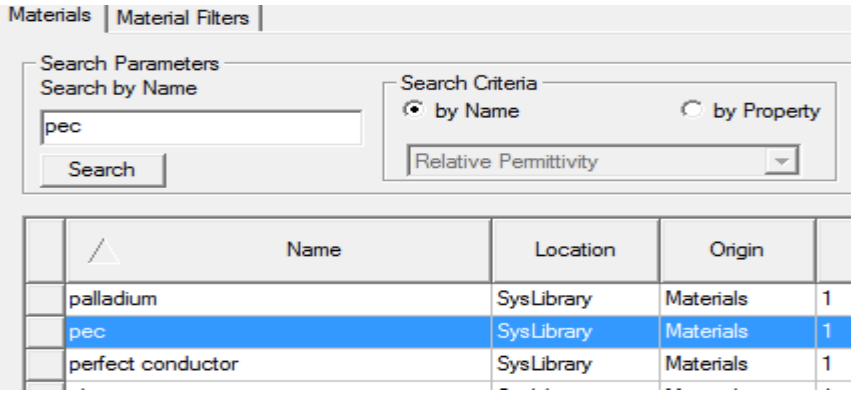

Figure 33. Select Definition window

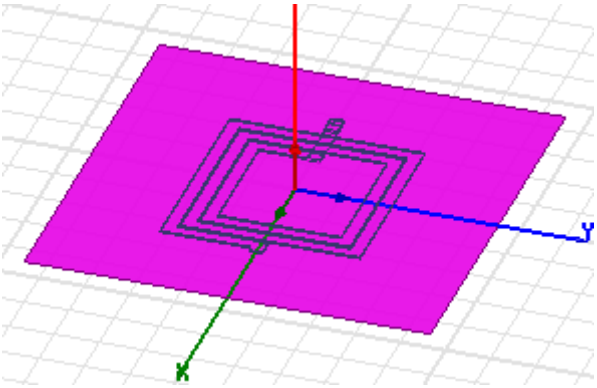

Figure 34. Ring applied

Create Inner Ring

1. Draw a box freehand.

   The **Properties** dialog box appears.

2. On the **Command** tab, edit the fields as shown in Figure 35.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	-210 ,-210 ,0	um	-210um , -210um , 0um
	XSize	420	um	420um
	YSize	420	um	420um
	ZSize	2	um	2um

Figure 35. The Properties dialog box for Inner Ring

3. On the **Attribute** tab enter *Inner* in the **Name** field and ensure that the **Material** assigned is *pec* and click **OK**.

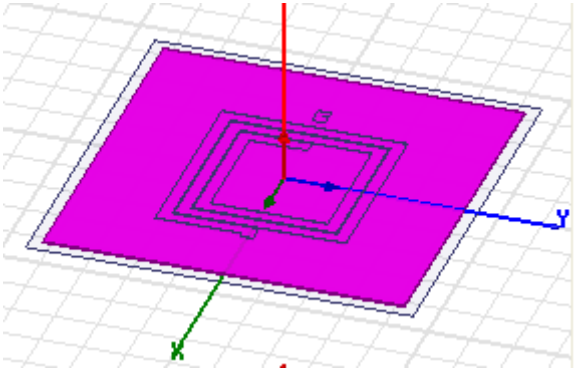

Figure 36. Inner ring drawn

Complete the Ring

1. Click **Edit>Select>By Name**

   The **Select Object** dialog box appears.

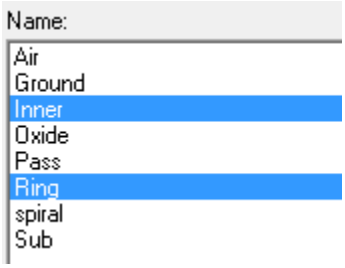

Figure 37. Select Object dialog box

2. Select **Ring,** press the **Ctrl** key and click **Inner** and click **OK.**
3. Click **Modeler>Boolean>Subtract**

   The **Subtract** dialog box appears.
4. Verify *Ring* is in the **Blank Parts** and *Inner* in the **Tool Parts** and click **OK**.

   Post subtraction, the structure should resemble the one in Figure 39.

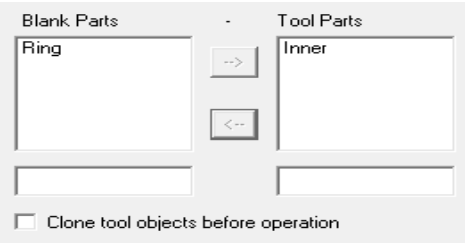

Figure 38. Subtract dialog box

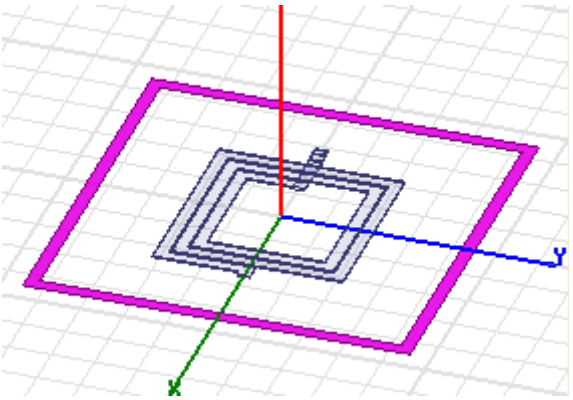

Figure 39. The subtracted ring

Create Extension 1

1. Draw a box freehand.

   The **Properties** dialog box appears.
2. On the **Command** tab edit the fields as shown in Figure 47.
3. On the **Attribute** tab enter the **Name** as *Ring_Ext1*, ensure that *pec* is selected from the **Material** drop-down and click **OK.**

	Command	CreateBox		
	Coordinate System	Global		
	Position	-157 ,7.5 ,0	um	-157um , 7.5um , 0um
	XSize	-53	um	-53um
	YSize	-15	um	-15um
	ZSize	2	um	2um

Figure 40. Extension1 properties

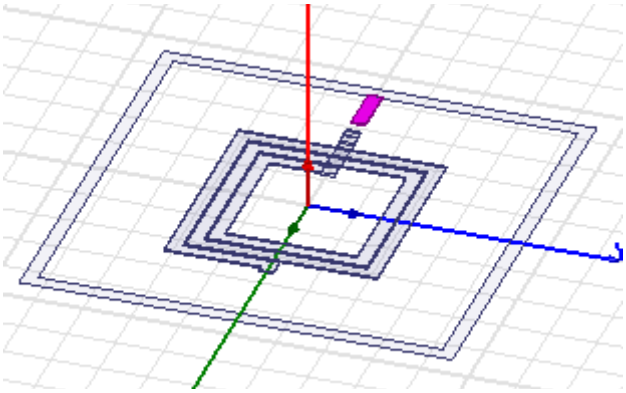

Figure 41. The Ring_Ext1 applied

Create Extension 2

1. Draw a box freehand.

   The **Properties** dialog box appears.

2. Edit the fields as shown in the Figure 42.

	Name	Value	Unit	Evaluated Value
	Command	CreateBox		
	Coordinate System	Global		
	Position	146 ,7.5 ,0	um	146um , 7.5um , 0um
	XSize	64	um	64um
	YSize	-15	um	-15um
	ZSize	2	um	2um

Figure 42. Properties dialog box for Ring_Ext2

3. On the **Attribute** tab enter the **Name** as *Ring_Ext2* and click **OK**.

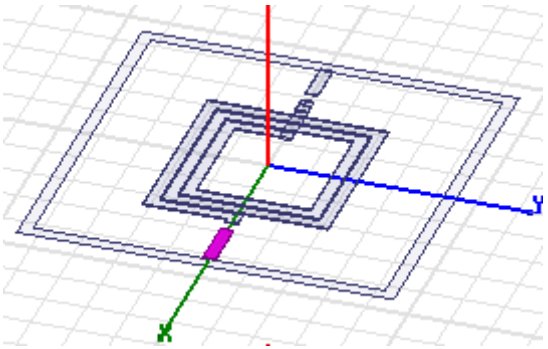

Figure 43. Ring_Ext2 applied

Create Source 1

1. Draw the rectangle freehand.

   The **Properties** dialog box appears.
2. Click **OK** to accept the current settings.
3. Double click **CreateRectangle** from the history tree.
4. Edit the fields in the **Command** dialog box as in Figure 44.

	Name	Value	Unit	Evaluated Value
	Command	CreateRectangle		
	Coordinate System	Global		
	Position	-142 ,7.5 ,1	um	-142um , 7.5um , 1um
	Axis	Z		
	XSize	-15	um	-15um
	YSize	-15	um	-15um

Figure 44. Command dialog box for Source1

5. Click **Attribute** and enter **Name** type as *Source1* and click **OK**.

Create Source 2

1. Draw the rectangle freehand.

   The **Properties** dialog box appears.
2. Click **OK** to close the dialog box.
3. Under **Rectangle1**, double click **CreateRectangle** from the history tree.

4 Edit the fields as shown in Figure 45.

	Name	Value	Unit	Evaluated Value
	Command	CreateRectangle		
	Coordinate System	Global		
	Position	131 ,7.5 ,1	um	131um , 7.5um , 1um
	Axis	Z		
	XSize	15	um	15um
	YSize	-15	um	-15um

Figure 45. Command dialog box for Source2

5 Double-click **Rectangle1** and enter *Source2* in the **Name** field and click **OK**.

Group the Conductors

1 Click **Edit>Select>By Name**

2 In the **Select Object** dialog box, select the **Ring, Ring_Ext1, Ring_Ext2**

3 Click **OK.**

4 Click **Modeler>Boolean>Unite**

5 Do **Ctrl+D** to fit the view.

Assign Excitation for Source1

We will use wave ports to excite source1:

1 Click **Source1** from the history tree.

Source1 gets highlighted in the structure.

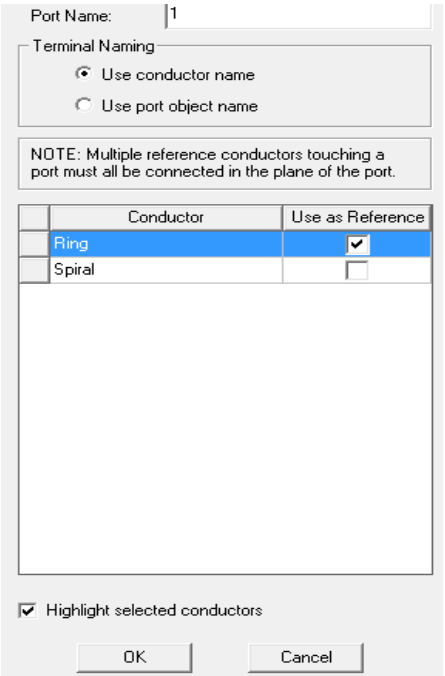

Figure 46. Reference Conductor Terminal dialog box

2 Right click **Source1**, and select **Assign Excitation>Assign>Lumped Port**

Reference Conductor for Terminals dialog box appears.

3 Set the options as shown in Figure 46 and click **OK**.

Assign Excitation for Source2

To select the object Source2:

1 In the **History** tree, expand the **Unassigned** objects tree.

2 Select **Source2.**

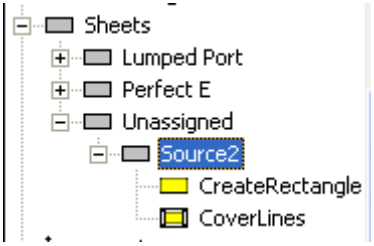

Figure 47. History Tree

To assign lumped port excitation

1. Click **HFSS>Excitations>Assign>Lumped Port**
2. Enter *2* for the Port Name.
3. Set the rest of the options as in Figure 46 and click **OK**.

Show All

To show all objects do the following:

1. Click **View>Visibility>Show All>All Views**
2. Do **Ctrl+D** to fit the view.

Boundary Display (Optional)

Boundary display/solver view provides a snapshot of all boundaries in the model including ports and surface residing on the surrounding background object. It can be very useful for diagnosing problems with design setups.

1. Click **HFSS>Boundary Display (Solver View)**

   The **Solver View of Boundaries** dialog box appears.

   Note HFSS identifies all the unique boundary conditions and ports to display where the boundaries are physically located in the model.
2. Select the boundaries you wish to view from the dialog box as shown in Figure 48.

   The choices made here will show the boundaries in the **Modeler** field. See Figure 49.

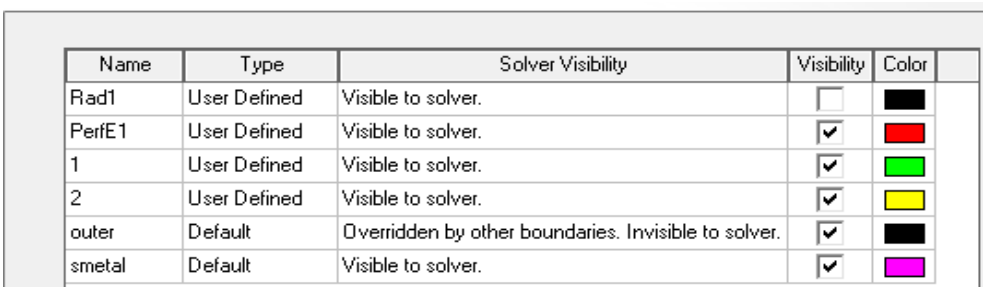

Figure 48. Solver View of Boundaries dialog box

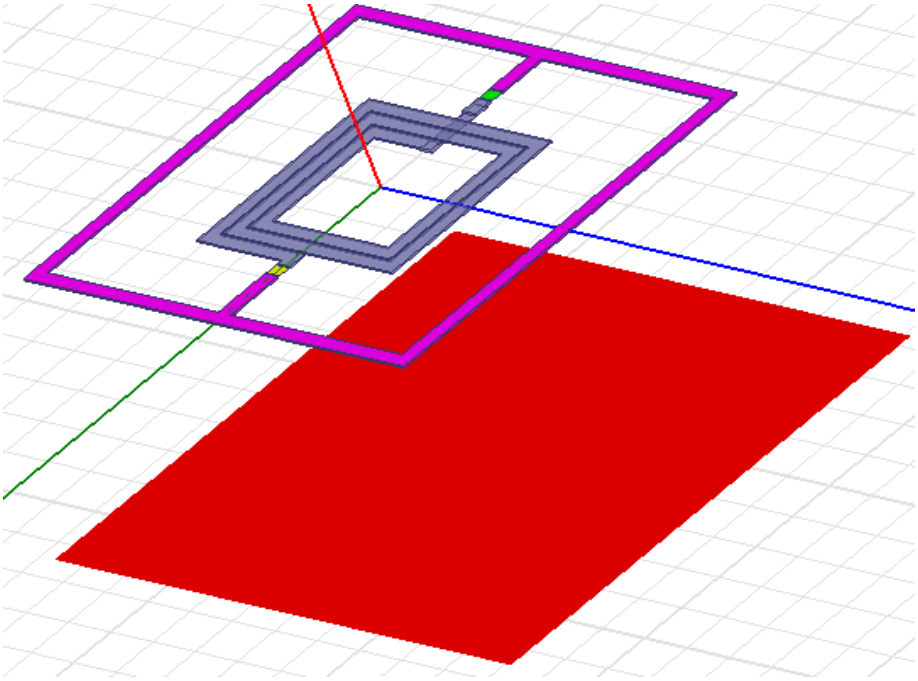

Figure 49. Solver Boundaries selected

Note If you double-click the fields under **Color**, you can change the color as you want from the palette that appears. The background is displayed as the outer boundary and the perfect conductors are displayed as the smetal boundary.

4 Analyze Spiral Inductor

This chapter describes how to run the simulation and generate reports.

This chapter contains the following topics:

- Create Analysis Setup
- Add Frequency Sweep
- Model Validation
- Analyze the Model
- Solution Data
- Profile
- Convergence
- Matrix Data
- Mesh Statistics
- Generate Reports
- Create S-Parameter vs Frequency Plot
- Custom Equations – Output Variables
- Use Output Variables for Next Report

Create Analysis Setup

To create an analysis setup:

1 Click **HFSS>Analysis Setup>Add Solution Setup**

The **Add Solution Set-up** dialog box appears.

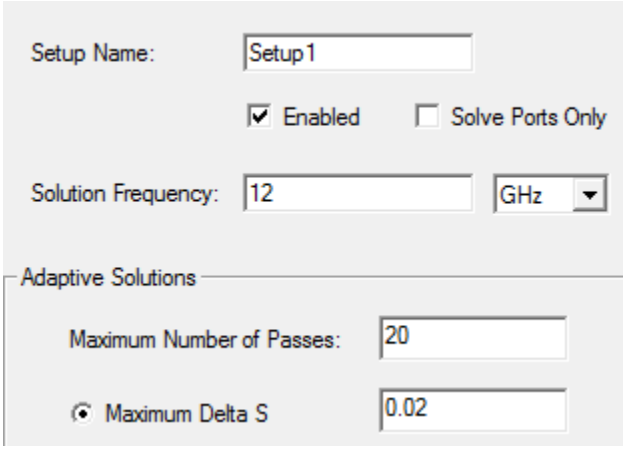

Figure 1. Solution Set-up window.

2 In the **Solution Setup** window: click the **General** tab.

3 Edit the fields as shown in Figure 1.

4 Click **Options**, edit the fields as in Figure 2 and click **OK**.

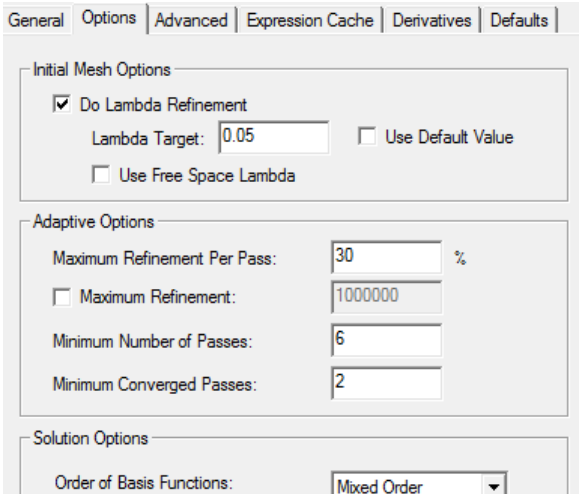

Figure 2. Options tab

Add a Frequency Sweep

1 Click **HFSS>Analysis Setup>Add Sweep**

The **Edit Frequency Sweep** dialog box appears.

2 Enter the following fields as shown in Figure 3.

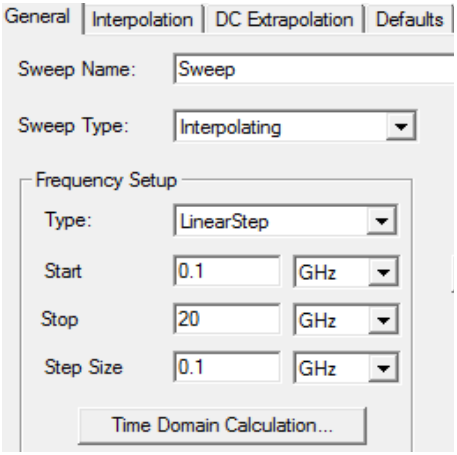

Figure 3. Edit Frequency Sweep

3 Click the **Interpolation** tab and edit the fields as in Figure 4 and click **OK**.

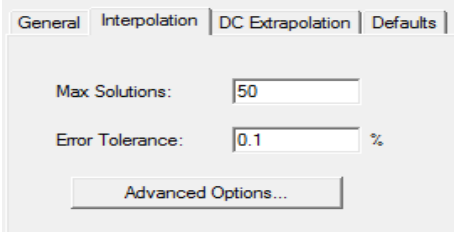

Figure 4. Interpolation

Model Validation

Before running the simulation your model must pass the **Validation Check**.

To validate the model:

1 Click **HFSS>Validation Check**

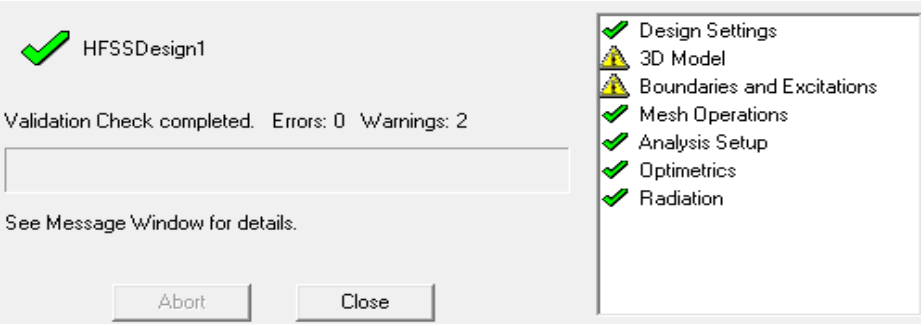

Figure 5. Validation Check

2 Verify whether your dialog box is the same as Figure 5.

3 Click **Close.**

Note: For this project, ignore warnings as no action is required.

Analyze the Model

To start the solution process:

1 Click **HFSS>Analyze All**

Note Save the project.

Review Solution Data

To view the Solution Data:

1 Click **HFSS>Results>Solution Data**

2 Click **Profile**, **Convergence**, **Matrix Data** etc to see those panels and the results they contain.

Review the Profile Panel

The Profile window lets you view a synopsis of the simulation results ranging from mesh creation and refinement to information about the different adaptive passes, the matrix assembly and solve along with extraction of electromagnetic field and SYZ parameter data. The more highly refined the mesh, i.e. higher the number of tetrahedra, more accurate is HFSS' solution of the design generating optimum results.

However, there is a trade-off in the number of tetrahedra used and the computational resources required. Higher the number of tetrahedra the more accurate the solutions. Keep in mind that increased accuracy requires more computational resources and more time.

Mesh Refinement				Lambda Based
Mesh (lambda based)	00:00:00	00:00:00	32.9 M	2919 tetrahedra
Mesh Refinement				Manual Seed Based
Mesh (volume, seed)	00:00:00	00:00:00	34.2 M	4441 tetrahedra
				Length1
Mesh Refinement				Port Adapt
Simulation Setup	00:00:00	00:00:00	28.8 M	Disk = 0 KBytes
Port Adaptation	00:00:00	00:00:00	40.3 M	Disk = 2 KBytes, 4310 tetrahedra
Mesh (port based)	00:00:01	00:00:01	33.6 M	4530 tetrahedra
Adaptive Pass 1				Frequency: 12 GHz
Simulation Setup	00:00:00	00:00:00	28.8 M	Disk = 0 KBytes
Matrix Assembly	00:00:00	00:00:00	44.1 M	Disk = 67 KBytes, 4392 tetrahedra , 1: 16 triangles , 2: 16 tria
Solver MCS1	00:00:00	00:00:00	71.7 M	Disk = 0 KBytes, matrix size 15556 , matrix bandwidth 29.1
Field Recovery	00:00:00	00:00:00	71.7 M	Disk = 4812 KBytes, 2 excitations , Average Order 0.207878
Adaptive Pass 2				Frequency: 12 GHz
Mesh (volume, adapti...	00:00:00	00:00:00	35 M	5849 tetrahedra
Simulation Setup	00:00:00	00:00:00	30.3 M	Disk = 0 KBytes
Matrix Assembly	00:00:01	00:00:01	63.5 M	Disk = 0 KBytes, 5706 tetrahedra , 1: 16 triangles , 2: 16 trian
Solver MCS1	00:00:02	00:00:02	158 M	Disk = 0 KBytes, matrix size 37461 , matrix bandwidth 33.6
Field Recovery	00:00:00	00:00:00	158 M	Disk = 1574 KBytes, 2 excitations , Average Order 0.506134
Adaptive Pass 3				Frequency: 12 GHz
Mesh (volume, adapti...	00:00:00	00:00:00	36.6 M	7564 tetrahedra
Simulation Setup	00:00:00	00:00:00	32.2 M	Disk = 0 KBytes
Matrix Assembly	00:00:01	00:00:01	80.5 M	Disk = 0 KBytes, 7417 tetrahedra , 1: 16 triangles , 2: 16 trian

Figure 6. Profile

Review the Convergence Panel

To view the Convergence data click the **Convergence** tab.

Note: The default view is for convergence is **Table**. Select the **Plot** radio button to view a graphical representations of the convergence data.

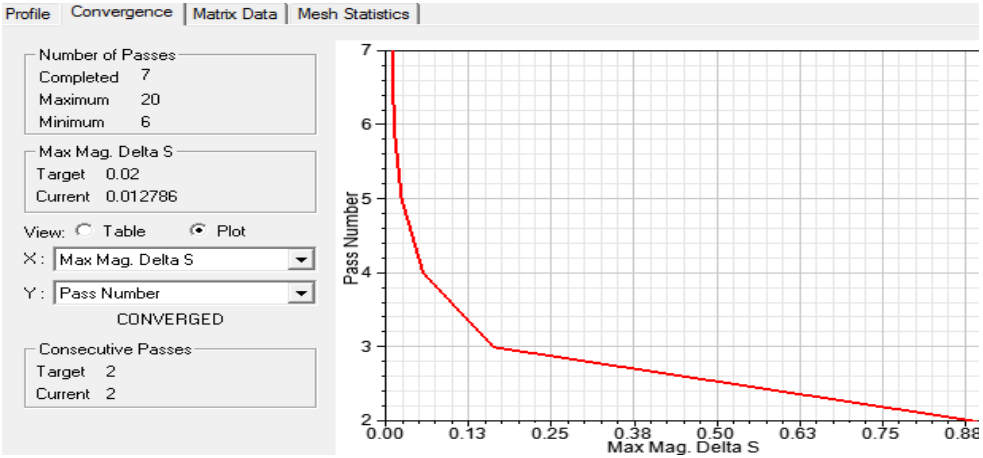

Figure 7. Covergence dialog box

Review the Matrix Data Panel

To view matrices computed for the S-parameters, impedances, and propagation constants during each adaptive, non-adaptive, or sweep solution, click the **Matrix Data** tab.

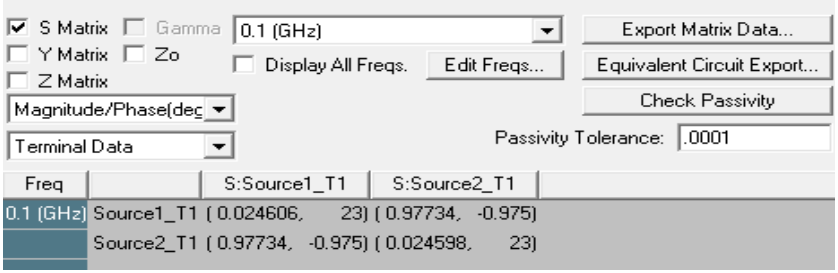

Figure 8. Matrix Data

Note: To view a real-time update of the Matrix Data, set the Simulation to **Setup1, Last Adaptive**

Review the Mesh Statistics Panel

As the title indicates this panel shows statistics of the mesh, more specifically, it gives break-ups of the tets used to solve the different components of the model and their size and data.

Total number of mesh elements: 21372

	Num Tets	Min edge length	Max edge length	RMS edge length	Min tet vol	Max tet vol
Air	2077	18.1675	244.229	90.3272	313.429	623282
Oxide	10635	2.50861	210.535	30.6294	0.0577002...	9922.5
Pass	2383	7.6146	155.069	38.9621	1.0351	1268.96
Ring	181	16.8003	210.545	97.7059	33.125	1050
Spiral	2903	4.15068	21.081	10.6134	0.0872529...	88.6951
Sub	3193	8.92106	223.981	73.0084	52.2547	664268

Figure 9. Mesh Statistics

Generate Reports

The subsequent sections describe how to create different reports, customize the equations for the Y axis and create output variables.

Create S-parameter vs. Frequency Plot

1 Click **HFSS>Results>Create Terminal Solution Data Report>Rectangular Plot**

The Report dialog box appears.

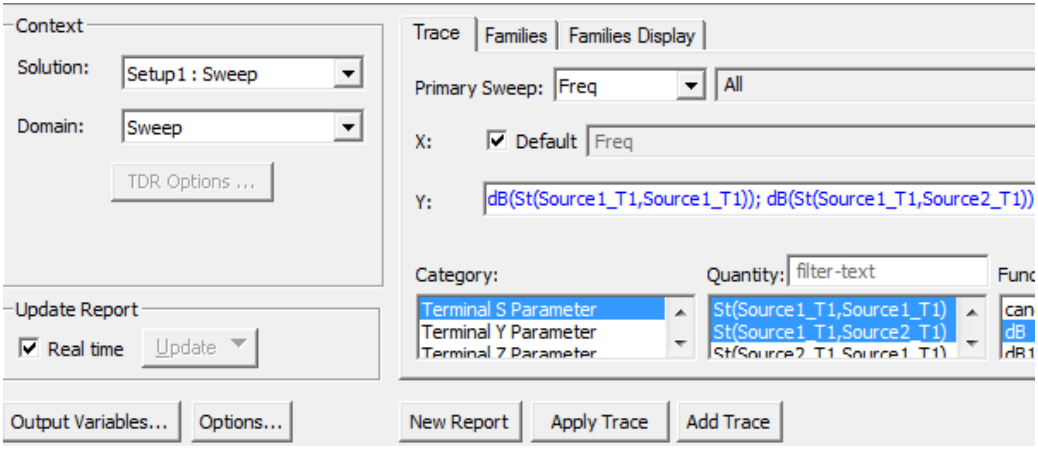

Figure 10. Report dialog box

2 Edit the fields as shown in Figure 10.

3 Click **New Report and** Click **Close**.

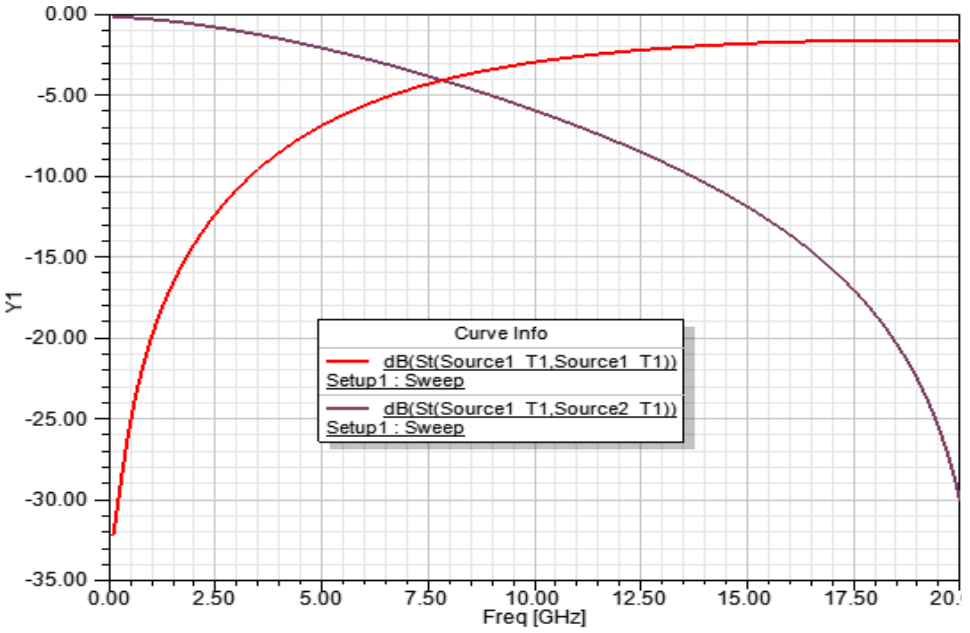

Figure 11. The XY Plot

Custom Equations – Output Variables

1. Click **HFSS>Results>Create Terminal Solution Data Report>Rectangular Plot**

   The **New Report** dialog box appears.
2. Click **Output Variables.**

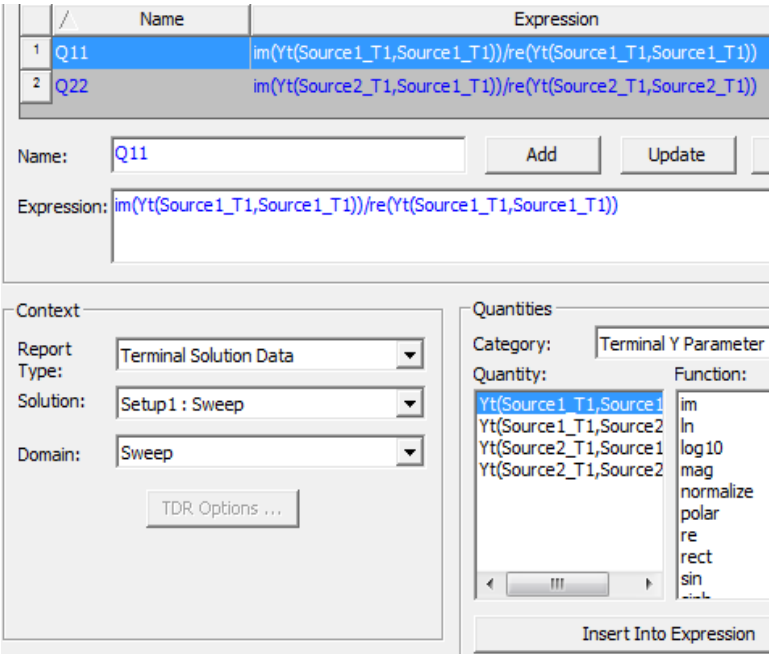

Figure 12. Output Variables dialog box

3 Enter *Q11* in the **Name** field.

4 Select *Terminal Y Parameters* from **Category**.

5 Select *Yt(Source1_T1, Source1_T1)* as **Quantity.**

6 Select *im* from the **Function** list.

7 Click **Insert Quantity into Expression**.

8 Type the forward slash(**/**).

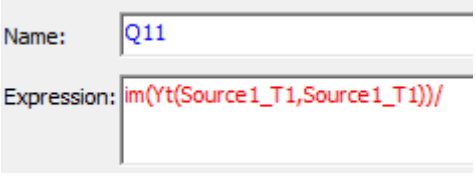

Figure 13. Expression

Note Notice the expression is in red ink because it is incomplete. The slash causes HFSS to expect another function. Red ink indicates inaccuracy or incompleteness.

9 Select *Yt(Source1_T1, Source1_T1)* in the **Quantity** field.

10 Select **Function:** *re*

11 Click **Insert Quantity into Expression**.

12 Click **Add**.

The output variable **Q11** is added to the list.

13 Create **Q22** with *Yt(Source2_T1, Source2_T1)* as quantity.

14 Click **Add.**

Figure 14. Output Variables set

15 Click **Done.**

The **Output Variables** dialog box closes.

16 Edit the fields in the **Report** dialog box as in Figure 15.

17 Click **New Reports** and click **Close**.

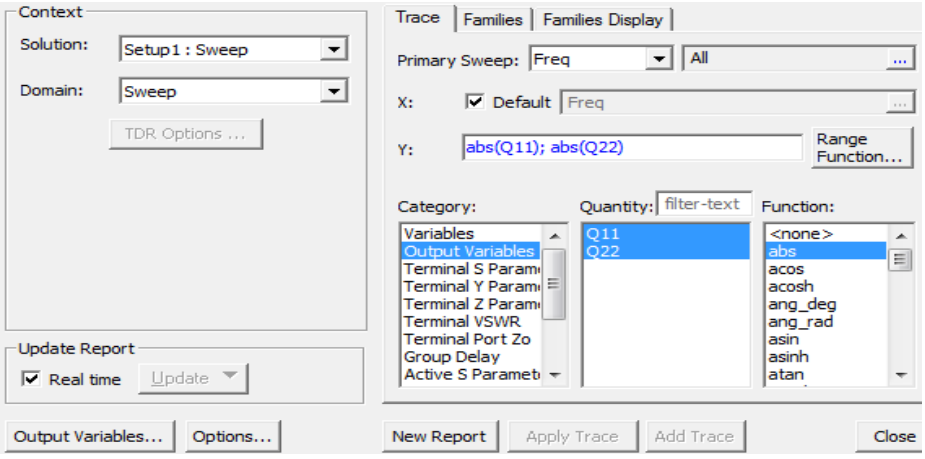

Figure 15. Report dialog box

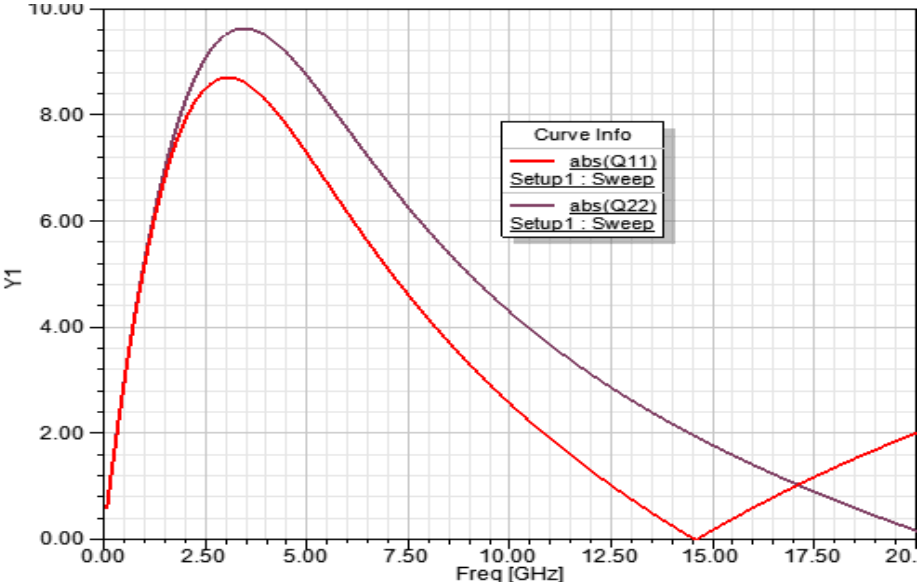

Figure 16. Y parameters versus Frequency

Use Output Variables for Next Report

To use Output Variables for another report:

1. Click **HFSS>Results>Create Terminal Solution Data Report>Rectangular Plot**
2. In the **New Report** window**, Trace Tab** click the **Output Variables** button
3. In the **Output Variables** dialog box enter these values:
   - **Name:** *L11*
   - Type **-1/(2*pi*freq*** in the **Expression** field**.**
   - Select *Terminal Y Parameters* from **Category.**
   - Select *Yt(Source1_T1, Source1_T1)* from **Quantity**.
   - Click *im* from the **Function** list.
4. Click **Insert into Expression**.
5. Type a bracket “)” key and click **Add.**

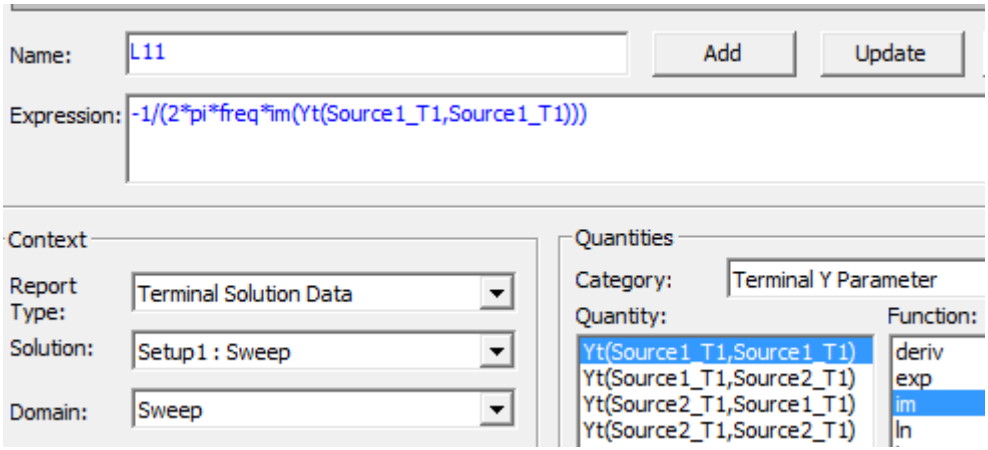

Figure 17. New Report dialog box

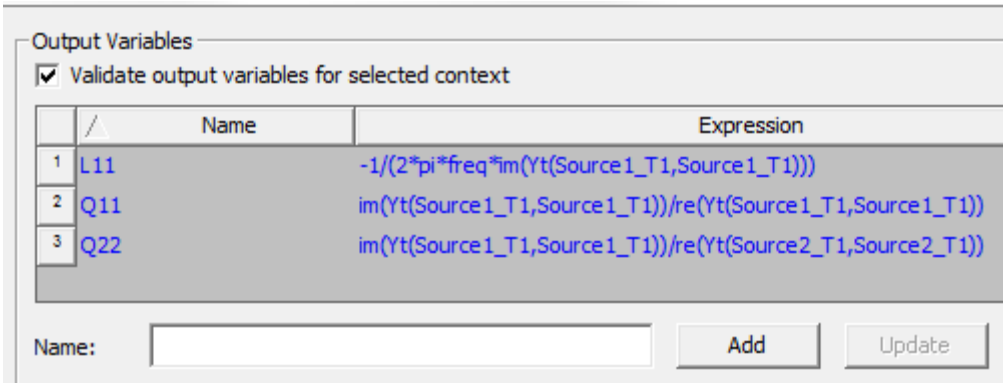

Figure 18. Output Variables dialog box

6 Click **Done** to close the **Output Variables** dialog box.

7 Edit the fields in **Report** dialog box as shown inFigure 19.

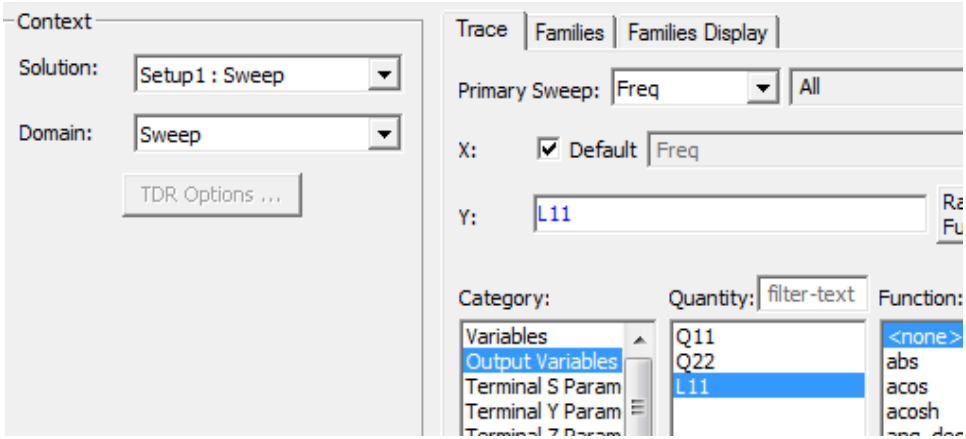

Figure 19. Report dialog box

8 Click **New Report** and click **Close**.

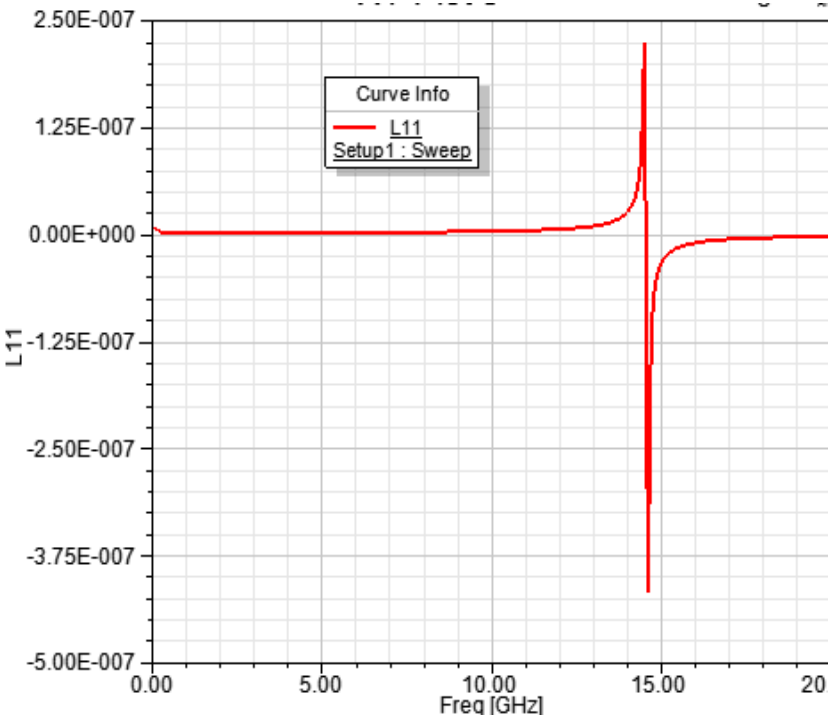

Figure 20. L11 versus Frequency