

## Getting Started with HFSS™ Silicon Spiral Inductor



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#### 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 the word copy must be typed, then a space must be typed, and then file1 must be typed.
- 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>Exci-tations>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*" the word **copy** must be typed, then a space must be typed, and then name of the file must be typed.
- 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**

For information about ANSYS Technical Support, go to the ANSYS corporate Support website, www.ansys.com/Support. You can also contact your ANSYS account manager in order to obtain this information.

All ANSYS EM 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.

Search - 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.

iv

v

## **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                          | 2-4  |
|    | Set Solution Type                        | 2-4  |
| 3. | Setup Si Spiral Inductor                 |      |
|    | Create 3D Model for Dielectrics          | 3-2  |
|    | Create Substrate                         | 3-2  |
|    | Create Oxide                             | 3-4  |
|    | 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  | 3-10 |
|    | Hide Dielectrics                         | 3-11 |
|    | Create Spiral Inductor Geometry          | 3-11 |
|    | Create Offset Coordinate System          | 3-11 |

Contents-1

|    | Create Spiral Path                    | 3-12 |
|----|---------------------------------------|------|
|    | Assign Thickness to the Spiral        | 3-17 |
|    | Create Underpass                      | 3-19 |
|    | Create Via1                           | 3-20 |
|    | Create Via2                           | 3-20 |
|    | Create Feed                           | 3-21 |
|    | Unite Spiral Objects                  | 3-22 |
|    | Seed Mesh Conductors                  | 3-24 |
|    | Create Ground Ring                    | 3-24 |
|    | Create Inner Ring                     | 3-26 |
|    | Complete the Ring                     | 3-27 |
|    | Create Extension 1                    | 3-28 |
|    | Create Extension 2                    | 3-29 |
|    | Create Source 1                       | 3-30 |
|    | Create Source 2                       | 3-30 |
|    | Group the Conductors                  | 3-31 |
|    | Assign Excitation for Source1         | 3-31 |
|    | Assign Excitation for Source2         | 3-32 |
|    | Show All                              | 3-33 |
|    | Boundary Display (Optional)           | 3-33 |
| 4. | Analyze Spiral Conductor              |      |
|    | Create Analysis Setup                 | 4-2  |
|    | Add a Frequency Sweep                 | 4-3  |
|    | Model Validation                      | 4-4  |
|    | Analyze the Model                     | 4-5  |
|    | Review Solution Data                  | 4-5  |
|    | Review the Profile Panel              | 4-5  |
|    | Review the Convergence Panel          | 4-6  |
|    | Review the Matrix Data Panel          | 4-7  |
|    | Review the Mesh Statistics Panel      | 4-7  |
|    | Generate Reports                      | 4-7  |
|    | Create S-parameter vs. Frequency Plot | 4-7  |

| Custom Equations - Output Variables   | 4-9  |
|---------------------------------------|------|
| Use Output Variables for Next Report  | 4-11 |
| Simulate with Solve Inside Conductors | 4-14 |
| Results With Solve Inside             | 4-16 |

#### 4-Contents

# 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,  $\varepsilon r = 4.0$ .
- Substrate: 300um. εr = 11.9, σ= 10 S/m.

1-2 Introduction

| Passivation |          |
|-------------|----------|
| Oxide       | M6<br>M5 |
|             |          |
|             |          |
| Substrate   |          |

Figure 2. Passivation, Oxide and Substrate

Introduction 1-3

#### 1-4 Introduction

# 2

# Set Up The Project

This chapter contains the following topics:

- 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 launched

**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**.

#### 2-2 Set Up The Project

Polyline -

Automatically cover closed polylines

Figure 3. The option on the Operation tab

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

Edit properties of new primitives

Figure 4. option on the Drawing tab

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

## Insert HFSS design

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

### Ð

Figure 5. 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 6. IHd included

Set Up The Project 2-3

**3** Click **Project1\***, hit **F2**, rename the project as *si\_spiral\_inductor*, 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.

| Select units: um      | •      |
|-----------------------|--------|
| 🔲 Rescale to new unit | \$     |
| ОК                    | Cancel |

Figure 7. 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.

| Driven<br>C Modal<br>C Terminal<br>C Transient | <ul> <li>Composite Excitation</li> <li>Network Analysis</li> </ul> |
|------------------------------------------------|--------------------------------------------------------------------|
| O Eigenmode                                    |                                                                    |
| ОК                                             | Cancel                                                             |

Figure 8. 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

#### 2-4 Set Up The Project

S-matrix solutions will be expressed in terms of terminal voltages and currents.

#### 2-6 Set Up The Project

## 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

#### Setup Si Spiral Inductor 3-1

## **Create 3D Model for Dielectrics**

To create the 3D model, you must draw a number of objects. The following sections contain the steps to create the geometry.

### **Create Substrate**

To create the substrate, first 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 a 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 again, to complete the box.

| 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 shown in Figure 2.

| ( | d) | Viev                  | v / Edit Material                       |        |       |           |  |
|---|----|-----------------------|-----------------------------------------|--------|-------|-----------|--|
|   | M  | ateri<br>Iy_S<br>Pron | al Name<br>ub<br>enties of the Material |        |       |           |  |
|   |    |                       | Name                                    | Туре   | Value | Units     |  |
|   |    |                       | Relative Permittivity                   | Simple | 11.9  |           |  |
|   |    |                       | Relative Permeability                   | Simple | 1     |           |  |
|   |    |                       | Bulk Conductivity                       | Simple | 10    | siemens/m |  |
|   |    |                       | Dielectric Loss Tangent                 | Simple | 0     |           |  |
|   |    | _                     |                                         |        |       |           |  |

Figure 2. View/Edit Material dialog

- 8 Click OK to close the View/Edit Material dialog box and repeat the same on the other dialog boxes to exit.
- Figure 3. Substrate created
- 9 Do Ctrl+D to fit the view.

## **Create Oxide**

To create the oxide, first draw a box and specify its size and location as follows:

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

| М | ater | ial Name                    |      |       |   |
|---|------|-----------------------------|------|-------|---|
| Μ | 1y_C | )xide                       |      |       |   |
| 1 |      |                             |      |       |   |
| _ | Pror | and a state when the second |      |       |   |
|   | 04   | percies or the Material     |      |       |   |
|   |      | Name                        | Туре | Value | U |

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**

To create passivation, draw a box and specify its size and location as follows:

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.

| d) I | Viev                       | v / Edit Material     |        |       |  |
|------|----------------------------|-----------------------|--------|-------|--|
| м    | Material Name              |                       |        |       |  |
| M    | ly_P                       | ass                   |        |       |  |
|      | Properties of the Material |                       |        |       |  |
|      |                            | Name                  | Туре   | Value |  |
|      |                            | Relative Permittivity | Simple | 7.9   |  |

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**

To create an air body, draw a box and specify its size and location as follows:

- **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 Enclosure drawn

## Assign Radiation Boundary

Now assign the radiation boundary to the air box.

**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**.

| Name: Rad1       |  |  |
|------------------|--|--|
| Radiating Only   |  |  |
| C Incident Field |  |  |
| C Enforced Field |  |  |
|                  |  |  |

Figure 12. Radiation Boundary

### **Create Ground**

To create the ground, draw a rectangle as described below.

- 1 Click Draw> Rectangle.
- **2** Draw a rectangle freehand.

The **Properties** dialog box appears.

- 3 Click OK to accept the values in the Properties dialog box.
- **4** 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

**5** Edit the fields as shown in Figure 13.

The rectangle updates itself with the new settings.

6 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

- Click outside the structure to deselect 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.

| ٨ | Name: PerfE_Ground    |
|---|-----------------------|
|   |                       |
|   | Infinite Ground Plane |

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 re-prioritize 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, 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 16.

| M | ateri<br>ly_M<br>Pror | al Name<br>let        |        |       |           |
|---|-----------------------|-----------------------|--------|-------|-----------|
|   |                       | Name                  | Туре   | Value | Units     |
|   |                       | Relative Permittivity | Simple | 1     |           |
|   |                       | Relative Permeability | Simple | 1     |           |
|   |                       | Bulk Conductivity     | Simple | 2.8e7 | siemens/m |

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 spiral draw a Polyline using one of the following methods:

- Create Polyline Freehand
- Create Polyline From the Status Bar

#### **Create Polyline Freehand**

This section shows how to create the spiral by drawing it free hand and then, editing its coordinates.

- 1 Click Draw>Line.
- **2** Click anywhere in the modeler to establish the first point and drag the cursor to draw a line and click again, to establish the second point as shown in the figure below.



Figure 17.

- **3** Continue to drag and click the mouse to establish 13 such points as shown in the figure below where we have labeled all the 13 points.
- **4** Right click and select **Done** from the short cut menu.



Figure 18. Polyline with 13 points

**5** Double-click **CreateLine** from the history tree and edit the coordinates for the vertices in its Segment tab as shown below.

| • | •   |     | - |
|---|-----|-----|---|
|   | 11  | 10  |   |
| L | /11 | IC. | 1 |

|   | Name         | Value           | Unit | Evaluated Value         |
|---|--------------|-----------------|------|-------------------------|
| ĺ | Segment Type | Line            |      |                         |
| ĺ | Point1       | -67.5 ,7.5 ,1   | um   | -67.5um , 7.5um , 1um   |
| Ì | Point2       | -67.5 ,-67.5 ,1 | um   | -67.5um , -67.5um , 1um |

Figure 19. Coordinates for Line1

**6** Edit the fields for each of the 12 **CreateLine** options on their corresponding **Segment** tabs as shown below.

|         | Name         | Value           | Unit | Evaluated Value                         |
|---------|--------------|-----------------|------|-----------------------------------------|
|         | Segment Type | Line            |      |                                         |
| Line 2  | Point1       | -67.5 ,-67.5 ,1 | um   | -67.5um , -67.5um , 1um                 |
|         | Point2       | 84 ,-67.5 ,1    | um   | 84um , -67.5um , 1um                    |
|         |              |                 |      |                                         |
|         | Name         | Value           | Unit | Evaluated Value                         |
| Line 3  | Segment Type | Line            |      |                                         |
|         | Point1       | 84 ,-67.5 ,1    | um   | 84um , -67.5um , 1um                    |
|         | Point2       | 84 ,84 ,1       | um   | 84um , 84um , 1um                       |
|         | 1            | 1               | 1    | 1                                       |
|         | Name         | Value           | Unit | Evaluated Value                         |
| I ine A | Segment Type | Line            |      |                                         |
| Line 4  | Point1       | 84 .84 .1       | um   | 84um , 84um , 1um                       |
|         | Point2       | -84 ,84 ,1      | um   | -84um , 84um , 1um                      |
|         | 1            |                 | 1    | · · · · · · · · · · · · · · · · · · ·   |
|         | Name         | Value           | Unit | Evaluated Value                         |
| Line 5  | Segment Type | Line            |      |                                         |
|         | Point1       | -84 ,84 ,1      | um   | -84um , 84um , 1um                      |
|         | Point2       | -84 ,-84 ,1     | um   | -84um , -84um , 1um                     |
|         | 1            |                 | 1    | · - · · · · · · · · · · · · · · · · · · |
|         | Name         | Value           | Unit | Evaluated Value                         |
| Line 6  | Segment Type | Line            |      |                                         |
| 2       | Point1       | -84 ,-84 ,1     | um   | -84um , -84um , 1um                     |
|         | Point2       | 1, 84-, 100.5   | um   | 100.5um , -84um , 1um                   |
|         |              |                 |      |                                         |
|         | Name         | Value           | Unit | Evaluated Value                         |
| Line 7  | Segment Type | Line            |      |                                         |
| Line /  | Point1       | 100.5 ,-84 ,1   | um   | 100.5um , -84um , 1um                   |
|         | Point2       | 1, 100.5, 100.5 | um   | 100.5um , 100.5um , 1um                 |

Figure 20. Coordinates for Line 2 through Line 7

#### 3-14 Setup Si Spiral Inductor

|        | Name         | Value            | Unit | Evaluated Value          |  |
|--------|--------------|------------------|------|--------------------------|--|
| Line 8 | Segment Type | Line             |      |                          |  |
|        | Point1       | 1, 100.5, 100.5  | um   | 100.5um , 100.5um , 1um  |  |
|        | Point2       | -100.5 ,100.5 ,1 | um   | -100.5um , 100.5um , 1um |  |

| _ |     | - |
|---|-----|---|
| L | ine | 9 |

| ] | Name         | Value             | Unit | Evaluated Value           |
|---|--------------|-------------------|------|---------------------------|
|   | Segment Type | Line              |      |                           |
|   | Point1       | -100.5 ,100.5 ,1  | um   | -100.5um , 100.5um , 1um  |
|   | Point2       | -100.5 ,-100.5 ,1 | um   | -100.5um , -100.5um , 1um |

|         | Name         | Value             | Unit | Evaluated Value           |  |
|---------|--------------|-------------------|------|---------------------------|--|
| Line 10 | Segment Type | Line              |      |                           |  |
|         | Point1       | -100.5 ,-100.5 ,1 | um   | -100.5um , -100.5um , 1um |  |
|         | Point2       | 117 ,-100.5 ,1    | um   | 117um , -100.5um , 1um    |  |

|         | Name         | Value          | Unit | Evaluated Value        |
|---------|--------------|----------------|------|------------------------|
|         | Segment Type | Line           |      |                        |
| Line 11 | Point1       | 117 ,-100.5 ,1 | um   | 117um , -100.5um , 1um |
|         | Point2       | 117 .0 .1      | um   | 117um , Oum , 1um      |

| т :  | 10 |
|------|----|
| Line | 12 |

|   | Name         | Value     | Unit | Evaluated Value   |  |
|---|--------------|-----------|------|-------------------|--|
| 2 | Segment Type | Line      |      |                   |  |
|   | Point1       | 117 .0 .1 | um   | 117um , Oum , 1um |  |
|   | Point2       | 131 ,0 ,1 | um   | 131um , Oum , 1um |  |

Figure 21. Coordinates for Line 8 through Line 12

#### **Create Polyline From the Status Bar**

In this method, enter the coordinates of the points in the status bar as described below.

1 Click Draw>Line.

**2** Edit the coordinate entry fields as follows: Enter the vertex field for point 1: X: -67.5, Y: 7.5, Z: 1.0 Press the Enter key. Enter the vertex field for point 2: X: -67.5, Y: -67.5, Z: 1.0 Press the Enter key. Enter the vertex field for point 3: X: 84.0, Y: - 67.5, Z: 1.0 Press the Enter key. **Enter the vertex** field for point 4: X: 84.0, Y: 84.0, Z: 1.0 Press the Enter key. Enter the vertex field for point 5: X: - 84.0, Y: 84.0, Z: 1.0 Press the Enter kev. **Enter the vertex** field for point 6: X: - 84.0, Y: -84.0, Z: 1.0, Press the Enter key. Enter the vertex field for point 7: X: 100.5, Y: -84.0, Z: 1.0, Press the Enter key. Enter the vertex field for point 8: X: 100.5, Y: 100.5, Z: 1.0, Press the Enter key. Enter the vertex field for point 9: X: - 100.5, Y: 100.5, Z: 1.0, Press the Enter key. Enter the vertex field for point 10: X: - 100.5, Y: - 100.5, Z: 1.0, Press the Enter key. Enter the vertex field for point 11: X: 117.0, Y: -100.5, Z: 1.0, Press the Enter key. **Enter the vertex** field for point 12: X: 117.0, Y: 0.0, Z: 1.0, Press the Enter key. Enter the vertex field for point 13: X: 131.0, Y: 0.0, Z: 1.0, Press the Enter key. **3** Using the mouse, right-click and from the short-cut menu

**3** Using the mouse, right-click and from the short-cut select **Done**.







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.


|                    |                |      |                 | - |
|--------------------|----------------|------|-----------------|---|
| Name               | Value          | Unit | Evaluated Value |   |
| Command            | CreatePolyline |      |                 |   |
| Coordinate System  | RelativeCS1    |      |                 |   |
| Number of points   | 13             |      |                 |   |
| Number of curves   | 12             |      |                 |   |
| Cross Section      |                |      |                 |   |
| Туре               | Rectangle      |      |                 |   |
| Orientation        | Auto           |      |                 |   |
| Width/Diameter     | 15             | um   | 15um            |   |
| Top Width          | 0              | um   | 0um             |   |
| Height             | 2              | um   | 2um             |   |
| Number of Segments | 0              |      | 0               |   |
| Bend Type          | Comer          |      |                 |   |
|                    |                |      |                 |   |

Figure 24. Command dialog box

**3** Edit the fields as shown in Figure 24 and click **OK** to close the **Properties** dialog box.

The spiral is assigned the thickness that you set.



Figure 25. The updated spiral

# **Create Underpass**

Before creating the underpass ensure the grid plane is *XY* as follows:

- Name Value Unit Evaluated Value Command CreateBox Coordinate System RelativeCS1 Position -60.7.5.-0.8 -60um , 7.5um , -0.8um um XSize -75 -75um um YSize -15 -15um um ZSize -0.5 -0.5um um
- 1 Click Modeler>Grid Plane>XY.

Figure 26. Properties dialog (underpass)

- **2** Draw a box freehand and edit the fields on the **Command** tab as shown in Figure 26.
- **3** On the **Attribute** tab rename object as *Underpass* and click **OK** to close the **Properties** dialog box.



Figure 27. The Underpass

Create Via1

To create the Via, first draw a box.

- **1** Draw a box freehand and on the **Command** tab edit the fields as shown in Figure 28.
- **2** On the **Attribute** tab enter *Via1* in the **Name** field and click **OK**.

| Name              | Value       | Unit | Evaluated Value     |
|-------------------|-------------|------|---------------------|
| Command           | CreateBox   |      |                     |
| Coordinate System | RelativeCS1 |      |                     |
| 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 28. Properties dialog Via1



Figure 29. Via1 applied

# Create Via2

- To create another via, again, draw a box.
- 1 Draw a box freehand and edit the fields on the Command

#### 3-20 Setup Si Spiral Inductor

tab as shown in Figure 30.

| Name              | Value        | Unit | Evaluated Value      |
|-------------------|--------------|------|----------------------|
| Command           | CreateBox    |      |                      |
| Coordinate System | RelativeCS1  |      |                      |
| Position          | -120 ,7.5 ,0 | um   | -120um , 7.5um , 0um |
| XSize             | -15          | um   | -15um                |
| YSize             | -15          | um   | -15um                |
| ZSize             | -0.8         | um   | -0.8um               |



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



Figure 31. Via2 applied.

### **Create Feed**

**1** Draw a box freehand.

The **Properties** dialog box appears.

| Name              | Value        | Unit | Evaluated Value      | Ī |
|-------------------|--------------|------|----------------------|---|
| Command           | CreateBox    |      |                      | Ī |
| Coordinate System | RelativeCS1  |      |                      |   |
| Position          | -120 ,7.5 ,0 | um   | -120um , 7.5um , 0um |   |
| XSize             | -22          | um   | -22um                |   |
| YSize             | -15          | um   | -15um                |   |
| ZSize             | 2            | um   | 2um                  |   |

Figure 32. Feed Properties

- 2 Edit the fields as shown in Figure 32 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 33. 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 34. The pieces united

**Note** The order in which you select the objects determines the name of the united structure. For example if you select **spiral** first followed by the rest, the united structure will be named spiral. If you select **Feed** first, then, the united structure will be named as **Feed**.

### 2 Click Modeler>Boolean>Unite



Figure 35. The united object names itself as spiral

- **3** Do Ctrl+D to fit the view.
- **4** Double-click **spiral** from the history tree and make sure **Solve Inside** is unchecked on the **Attribute** tab.

Note The conductive material is represented by a boundary condition that removes the need to solve inside metal.

### Seed Mesh Conductors

In this section you will set HFSS to refine the length of the tetrahedral elements until 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**.

| Element Length Based Refinement                       | 23       |
|-------------------------------------------------------|----------|
| Name: Length1                                         | 🔽 Enable |
| Length of Elements                                    |          |
| Restrict Length of Elements                           |          |
| Maximum Length of Elements:                           | ~        |
| Number of Elements<br>Restrict the Number of Elements |          |
| Maximum Number of Elements:                           |          |
|                                                       |          |

Figure 36. Element Length Based Refinement settings

### **Create Ground Ring**

To create a ground ring, first draw a box freehand.

- 1 Click Draw>Box.
- **2** Draw a box freehand.

The **Properties** dialog box appears.

| Name              | Value         | Unit | Evaluated Value       |
|-------------------|---------------|------|-----------------------|
| Command           | CreateBox     |      |                       |
| Coordinate System | RelativeCS1   |      |                       |
| Position          | -225 ,-225 ,0 | um   | -225um , -225um , 0um |
| XSize             | 450           | um   | 450um                 |
| YSize             | 450           | um   | 450um                 |
| ZSize             | 2             | um   | 2um                   |

Figure 37. Ring Properties

- **3** On the **Command** tab edit the fields as shown in Figure 37.
- 4 On the Attribute tab enter *Ring* in the Name field and select Edit from the Materials drop-down menu.

The Select Definition window appears.

- **5** Type *pec* in the **Search by Name** field.
- **6** Click **OK** to close the **View/Edit Materia**l dialog box and repeat the same on the other dialog boxes to exit.

| Material Filters Search Parameters Search by Name pec Search |               | Search Cr<br>by Na | C by Property | ′          |           |   |
|--------------------------------------------------------------|---------------|--------------------|---------------|------------|-----------|---|
|                                                              | 7             | Name               |               | Location   | Origin    |   |
| pall                                                         | adium         |                    |               | SysLibrary | Materials | 1 |
| peo                                                          | :             |                    |               | SysLibrary | Materials | 1 |
| perf                                                         | ect conductor |                    |               | SysLibrary | Materials | 1 |
|                                                              |               |                    |               |            |           |   |

Figure 38. Select Definition window



Figure 39. Ring applied

### **Create Inner Ring**

To create the inner ring, again draw a box.

- 1 Click Draw>Box.
- **2** Draw a box freehand.

The **Properties** dialog box appears.

**3** On the **Command** tab, edit the fields as shown in Figure 40.

| Name              | Value         | Unit | Evaluated Value       |
|-------------------|---------------|------|-----------------------|
| Command           | CreateBox     |      |                       |
| Coordinate System | RelativeCS1   |      |                       |
| Position          | -210 ,-210 ,0 | um   | -210um , -210um , 0um |
| XSize             | 420           | um   | 420um                 |
| YSize             | 420           | um   | 420um                 |
| ZSize             | 2             | um   | 2um                   |

Figure 40. The Properties dialog box for Inner Ring

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



Figure 41. Inner ring drawn

# Complete the Ring

1 Click Edit>Select>By Name

The Select Object dialog box appears.



Figure 42. 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 44.



### Figure 43. Subtract dialog box



Figure 44. 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 45.
- 3 On the Attribute tab enter the Name as *Ring\_Ext1*, ensure that *pec* is selected from the Material drop-down and click OK.

| Name              | Value        | Unit | Evaluated Value      |
|-------------------|--------------|------|----------------------|
| Command           | CreateBox    |      |                      |
| Coordinate System | RelativeCS1  |      |                      |
| Position          | -157 ,7.5 ,0 | um   | -157um , 7.5um , 0um |
| XSize             | -53          | um   | -53um                |
| YSize             | -15          | um   | -15um                |
| ZSize             | 2            | um   | 2um                  |

Figure 45. Extension1 properties

#### 3-28 Setup Si Spiral Inductor



Figure 46. The Ring\_Ext1 applied

# **Create Extension 2**

1 Draw a box freehand.

The **Properties** dialog box appears.

**2** Edit the fields as shown in Figure 47.

| Name              | Value       | Unit | Evaluated Value     |
|-------------------|-------------|------|---------------------|
| Command           | CreateBox   |      |                     |
| Coordinate System | RelativeCS1 |      |                     |
| Position          | 146 ,7.5 ,0 | um   | 146um , 7.5um , 0um |
| XSize             | 64          | um   | 64um                |
| YSize             | -15         | um   | -15um               |
| ZSize             | 2           | um   | 2um                 |

Figure 47. Properties dialog box for Ring\_Ext2

**3** On the **Attribute** tab enter the **Name** as *Ring\_Ext2* and click **OK**.



Figure 48. 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 49.

| Name              | Value           | Unit | Evaluated Value      |  |
|-------------------|-----------------|------|----------------------|--|
| Command           | CreateRectangle |      |                      |  |
| Coordinate System | RelativeCS1     |      |                      |  |
| Position          | -142 ,7.5 ,1    | um   | -142um , 7.5um , 1um |  |
| Axis              | Z               |      |                      |  |
| XSize             | -15             | um   | -15um                |  |
| YSize             | -15             | um   | -15um                |  |

Figure 49. 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

### 3-30 Setup Si Spiral Inductor

history tree.

**4** Edit the fields as shown in Figure 50.

| Name              | Value           | Unit | Evaluated Value     |  |
|-------------------|-----------------|------|---------------------|--|
| Command           | CreateRectangle |      |                     |  |
| Coordinate System | RelativeCS1     |      |                     |  |
| Position          | 131 ,7.5 ,1     | um   | 131um , 7.5um , 1um |  |
| Axis              | Z               |      |                     |  |
| XSize             | 15              | um   | 15um                |  |
| YSize             | -15             | um   | -15um               |  |

Figure 50. 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.

| Port Name:                                                             |                                       |
|------------------------------------------------------------------------|---------------------------------------|
| Terminal Naming                                                        |                                       |
| Use conductor name                                                     |                                       |
| O Use port object name                                                 |                                       |
| NOTE: Multiple reference conduc<br>port must all be connected in the p | tors touching a<br>blane of the port. |
| Conductor                                                              | Use as Reference                      |
| Ring                                                                   | <b>~</b>                              |
| Spiral                                                                 |                                       |
|                                                                        |                                       |
|                                                                        |                                       |

Figure 51. 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 51 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 52. History Tree

#### 3-32 Setup Si Spiral Inductor

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 51 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 53.

The choices made here will show the boundaries in the **Modeler** field. See Figure 54.

| Name   | Туре         | Solver Visibility                                    | Visibility | Color |
|--------|--------------|------------------------------------------------------|------------|-------|
| Rad1   | User Defined | Visible to solver.                                   |            |       |
| PerfE1 | User Defined | Visible to solver.                                   | ~          |       |
| 1      | User Defined | Visible to solver.                                   | ~          |       |
| 2      | User Defined | Visible to solver.                                   | ~          |       |
| outer  | Default      | Overridden by other boundaries. Invisible to solver. | ~          |       |
| smetal | Default      | Visible to solver.                                   | ~          |       |

Figure 53. Solver View of Boundaries dialog box



Figure 54. 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.

# Analyze Spiral Conductor

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

4

- Convergence
- Matrix Data
- Mesh Statistics
- Generate Reports
- Create S-Parameter vs Frequency Plot
- Custom Equations Output Variables
- Use Output Variables for Next Report

#### **Analyze Spiral Conductor 4-1**

# **Create Analysis Setup**

To create an analysis setup:

1 Click HFSS>Analysis Setup>Add Solution Setup

The Add Solution Set-up dialog box appears.

| D | Priven Solution Setup |                  |                        |  |  |  |  |  |
|---|-----------------------|------------------|------------------------|--|--|--|--|--|
|   | General Options Adv   | anced   Expressi | on Cache   Derivatives |  |  |  |  |  |
|   | Setup Name:           | Setup1           |                        |  |  |  |  |  |
|   |                       | Enabled          | Solve Ports Only       |  |  |  |  |  |
|   | Solution Frequency:   | 12               | GHz 💌                  |  |  |  |  |  |
|   | Adaptive Solutions    |                  |                        |  |  |  |  |  |
|   | Maximum Numbe         | r of Passes:     | 20                     |  |  |  |  |  |
|   | Maximum Delt          | 0.01             |                        |  |  |  |  |  |

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.

#### 4-2 Analyze Spiral Conductor

| General                     | Options                                   | Advance    | ed Express | sion Cac | he Derivat | tives Defaults |  |  |  |
|-----------------------------|-------------------------------------------|------------|------------|----------|------------|----------------|--|--|--|
| - Initial                   | Mesh Opti                                 | ons —      |            |          |            |                |  |  |  |
|                             | Do Lambo                                  | da Refiner | ment       |          |            |                |  |  |  |
|                             | Lambda Target: 0.6667 🔽 Use Default Value |            |            |          |            |                |  |  |  |
|                             | 🗌 Use                                     | Free Spa   | ice Lambda |          |            |                |  |  |  |
| Adapt                       | tive Option                               | s          |            |          |            |                |  |  |  |
| Ma                          | ximum Ref                                 | finement F | 30         |          | %          |                |  |  |  |
|                             | Maximum                                   | Refineme   | 10         | 00000    |            |                |  |  |  |
| Mir                         | nimum Nur                                 | nber of Pa | sses:      | 1        |            |                |  |  |  |
| Minimum Converged Passes: 1 |                                           |            |            |          |            |                |  |  |  |
| Soluti                      | on Options                                |            |            |          |            |                |  |  |  |
| Or                          | der of Basi                               | s Functior | ns:        | Mi       | xed Order  | •              |  |  |  |

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.

| General Interpolation DC Extrapolation Defaults |                         |     |   |  |  |  |  |
|-------------------------------------------------|-------------------------|-----|---|--|--|--|--|
| Sweep Name:                                     | Sweep                   |     |   |  |  |  |  |
| Sweep Type: Interpolating                       |                         |     |   |  |  |  |  |
| Frequency Setup                                 |                         |     |   |  |  |  |  |
| Туре:                                           | LinearStep              |     | • |  |  |  |  |
| Start                                           | 0.1                     | GHz | • |  |  |  |  |
| Stop                                            | 20                      | GHz | • |  |  |  |  |
| Step Size                                       | 0.1                     | GHz | • |  |  |  |  |
| Time                                            | Time Domain Calculation |     |   |  |  |  |  |

Figure 3. Edit Frequency Sweep

#### **Analyze Spiral Conductor 4-3**

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

| Edit Frequency Sweep  |          |  |  |  |  |  |
|-----------------------|----------|--|--|--|--|--|
| General Interpolation | Defaults |  |  |  |  |  |
|                       |          |  |  |  |  |  |
| Max Solutions:        | 250      |  |  |  |  |  |
| Error Tolerance:      | 0.3 %    |  |  |  |  |  |

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

| V HFSSDesign2               | <ul> <li>Design Settings</li> <li>3D Model</li> <li>Boundaries and Excitations</li> </ul>           |
|-----------------------------|-----------------------------------------------------------------------------------------------------|
| Validation Check completed. | <ul> <li>Mesh Operations</li> <li>Analysis Setup</li> <li>Optimetrics</li> <li>Radiation</li> </ul> |
| Abort Close                 |                                                                                                     |

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.

#### 4-4 Analyze Spiral Conductor

# Analyze the Model

To start the solution process:

1 Click HFSS>Analyze All

**Note** Change the design name to *No\_Solve\_Inside(Driven Terminal)* and then, save the project *si\_spiral\_inductor*.

# **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.

#### Getting Started with HFSS:Silicon Spiral Inductor

| 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 trian |
| 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 triang |

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.





#### 4-6 Analyze Spiral Conductor

### **Review the Matrix Data Panel**

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

| 🗹 S Matrix 🔲 Gamma              | 0.1 (GHz)               | Export Matrix Data     |                           |
|---------------------------------|-------------------------|------------------------|---------------------------|
| □ Y Matrix □ Zo  <br>□ Z Matrix | 🔲 Display All Freqs.    | Edit Freqs             | Equivalent Circuit Export |
| Magnitude/Phase(deg 💌           | 1                       |                        | Check Passivity           |
| Terminal Data 💌                 | Ī                       | Passivity <sup>-</sup> | Folerance: 0001           |
| Freq S                          | S:Source1_T1 S:So       | ource2_T1              |                           |
| 0.1 (GHz) Source1_T1 ( 0.       | .024606, 23) ( 0.977    | 734, -0.975)           |                           |
| Source2_T1 ( 0.                 | .97734, -0.975) ( 0.024 | 4598, 23)              |                           |

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 tetrahedra used to solve the different components of the model and their size and data.

| rotarnun | rotai number of mesmielements. 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

Total number of mask elements: 21272

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.

| -Context                  |                 |              |               | Trace Fa                               | milies   Familie                    | es Display |                                              |                                            |                                 |
|---------------------------|-----------------|--------------|---------------|----------------------------------------|-------------------------------------|------------|----------------------------------------------|--------------------------------------------|---------------------------------|
| Solution:                 | Setup1:         | Sweep        | •             | Primary Sw                             | eep: Freq                           | •          | All                                          |                                            |                                 |
| Domain:                   | Sweep           |              | -             | x: 🔽                                   | Default Fre                         | eq         |                                              |                                            |                                 |
|                           | TDR Opt         | ions , , ,   |               | Y: de                                  | 8(St(Source1_                       | T1,Source1 | _T1)); dB(St(                                | Source1_T1,S                               | Source2_T1))                    |
|                           |                 |              |               | Category:                              |                                     |            | Quantity: filte                              | er-text                                    | Fund                            |
| -Update Rep<br>↓ Real tin | ne <u>U</u> pda | ite 🔻        |               | Terminal S<br>Terminal Y<br>Terminal 7 | Parameter<br>Parameter<br>Parameter | *          | St(Source1_1<br>St(Source1_1<br>St(Source2_1 | 1,Source1_T<br>1,Source2_T<br>11 Source1_T | 1) 🔺 can<br>1) 👻 dB<br>1) 👻 dB1 |
| Output Varia              | ables           | Options      |               | New Report                             | t Apply Tr                          | ace Ad     | d Trace                                      |                                            |                                 |
|                           |                 |              | Fig           | ure 10. Re                             | port dialog                         | box        |                                              |                                            |                                 |
|                           |                 | <b>2</b> Edi | it the fi     | elds as s                              | hown in                             | Figure     | 10.                                          |                                            |                                 |
|                           |                 | 3 Cli        | ck <b>New</b> | Report                                 | and Clicl                           | k Close    | •                                            |                                            |                                 |
| 0.00                      | )               |              |               |                                        |                                     |            |                                              |                                            |                                 |
| -5.00                     | , _<br>         |              |               | >~                                     | <                                   |            |                                              |                                            |                                 |
| -10.00                    | )               | /            |               |                                        |                                     |            |                                              |                                            |                                 |
| -15.00                    | )               | /            |               |                                        |                                     |            |                                              |                                            |                                 |
| ⊊<br>-20.00               | ·]/             |              |               | Cu<br>dB(St(Sou                        | rve Info<br>rce1 T1,Sou             | rce1 T1))  |                                              | $\setminus$                                |                                 |
| 25.00                     | . 1/-           |              | Setu          | <u>dB(St(Sou</u>                       | rce1 T1,Sou                         | rce2 T1))  |                                              |                                            | $\mathbf{X}$                    |
| -25.00                    | 1               |              | Setu          | p1:Sweep                               |                                     |            |                                              |                                            |                                 |
| -30.00                    | ) <del> </del>  |              |               |                                        |                                     |            |                                              |                                            |                                 |
| -35.00                    | 0.00            | 2.50         | 5.00          | 7.50                                   | 10.00<br>Freq [GHz]                 | 12.50      | 15.00                                        | 17.50                                      | 20.                             |
|                           |                 |              | F             | igure 11.                              | The XY Pl                           | ot         |                                              |                                            |                                 |

#### 4-8 Analyze Spiral Conductor

**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**.

|                  | Name              |                         | Expres                   | ssion                     |             |
|------------------|-------------------|-------------------------|--------------------------|---------------------------|-------------|
| 1 Q11            |                   | im(Yt(Source1_T1,Sour   | ce1_T1))/re(Yt(S         | ource1_T1,S               | ource1_T1)) |
| <sup>2</sup> Q22 |                   | im(Yt(Source2_T1,Sour   | ce1_T1))/re(Yt(S         | ource2_T1,S               | ource2_T1)) |
| Name:            | Q11               |                         | Add                      | Up                        | odate       |
| Expression:      | im(Yt(Source1_T   | L,Source1_T1))/re(Yt(So | urce1_T1,Source          | ±1_T1))                   |             |
|                  |                   |                         |                          |                           |             |
|                  | ,                 |                         |                          |                           |             |
| -Context         |                   |                         | Quantities -             |                           |             |
| Report           | Terminal Solution | Data 👻                  | Category:                | Terminal                  | Y Parameter |
| Type:            |                   |                         | Quantity:                |                           | Function:   |
| Solution:        | Setup1:Sweep      | <b>•</b>                | Yt(Source 1              | T1,Source1                | im          |
| Demains          | Sween             | -                       | Yt(Source1<br>Yt(Source2 | _11,Source2<br>T1.Source1 | log 10      |
| Domain:          | Isweep            | <b>_</b>                | Yt(Source2               | T1,Source2                | mag         |
|                  | TDP Option        | -                       |                          |                           | normalize   |
|                  |                   | 2                       |                          |                           | polar       |
|                  |                   |                         |                          |                           | rect        |
|                  |                   |                         |                          | •                         | sin         |
|                  |                   |                         |                          | Insert Into               | Expression  |

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(/).

| Name:       | Q11                            |
|-------------|--------------------------------|
| Expression: | im(Yt(Source1_T1,Source1_T1))/ |
|             |                                |

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.

✓ Validate output variables for selected context

|     | Δ   | Name | Expression                                                             |  |  |
|-----|-----|------|------------------------------------------------------------------------|--|--|
| 1   | Q11 |      | <pre>im(Yt(Source1_T1,Source1_T1))/re(Yt(Source1_T1,Source1_T1))</pre> |  |  |
| 2   | Q22 |      | m(Yt(Source2_T1,Source1_T1))/re(Yt(Source2_T1,Source2_T1))             |  |  |
|     |     |      |                                                                        |  |  |
|     |     |      |                                                                        |  |  |
|     |     |      |                                                                        |  |  |
|     |     |      |                                                                        |  |  |
|     |     |      |                                                                        |  |  |
| Nam | e:  |      | Add Update                                                             |  |  |
|     |     |      | Figure 14 Output Variables set                                         |  |  |

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.

#### 4-10 Analyze Spiral Conductor

| Context -   |                | Trace                                                          | Families Far                                                                                                                         | milies Display   |                                                                                             |                   |
|-------------|----------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------|------------------|---------------------------------------------------------------------------------------------|-------------------|
| Solution:   | Setup1:Sweep   | ] Prima                                                        | ry Sweep: Free                                                                                                                       | A                | 11                                                                                          |                   |
| Domain:     | Sweep          |                                                                | Default                                                                                                                              | Freq             |                                                                                             |                   |
|             | TDR Options    | Y:                                                             | abs(Q11); ab                                                                                                                         | os(Q22)          |                                                                                             | Range<br>Function |
| Update Re   | port<br>me     | Categ<br>Varia<br>Outr<br>Term<br>Term<br>Term<br>Term<br>Grou | gory:<br>ables<br>uit Variables<br>ininal S Paramu<br>ininal S Paramu<br>ininal VSWR<br>ininal Port Zo<br>Ip Delay<br>ve S Paramet + | Quantity: filter | -text Function<br><none<br>abs<br/>acosh<br/>ang_de<br/>ang_ra<br/>asinh<br/>atan</none<br> | n:                |
| Output Vari | iables Options | New R                                                          | Apply Apply                                                                                                                          | / Trace Add Ti   | race                                                                                        | Close             |

Figure 15. Report dialog box



# 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

Analyze Spiral Conductor 4-11

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**.

| Name:      | L11                                        |              | Add Up          | odate     |
|------------|--------------------------------------------|--------------|-----------------|-----------|
| Expression | : -1/(2*pi*freq*im(Yt(Source1_T1,Source1_T | 1)))         |                 |           |
|            | ·                                          |              |                 |           |
| Context    |                                            | Quantities - |                 |           |
| Report     | Terminal Solution Data                     | Category:    | Terminal Y Para | ameter    |
| Type:      |                                            | Quantity:    |                 | Function: |
| Solution:  | Setup1: Sweep 🔹                            | Yt(Source 1  | _T1,Source1_T1) | deriv     |
|            |                                            | Yt(Source 1  | _T1,Source2_T1) | exp       |
| Domain:    | Sweep 🗸                                    | Yt(Source2   | _T1,Source1_T1) | im        |
|            |                                            | Yt(Source2   | _T1,Source2_T1) | In        |

Figure 17. New Report dialog box

|       | Name | Expression                                                             |  |  |
|-------|------|------------------------------------------------------------------------|--|--|
| 1 L11 |      | -1/(2*pi*freq*im(Yt(Source1_T1,Source1_T1)))                           |  |  |
| 2 Q11 |      | <pre>im(Yt(Source1_T1,Source1_T1))/re(Yt(Source1_T1,Source1_T1))</pre> |  |  |
| 3 Q22 |      | <pre>im(Yt(Source1_T1,Source1_T1))/re(Yt(Source2_T1,Source2_T1))</pre> |  |  |

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 in Figure 19.

#### 4-12 Analyze Spiral Conductor

#### Getting Started with HFSS:Silicon Spiral Inductor

| -Context - |                 | Trace Families Families Display                                                                                                                                                                                |
|------------|-----------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Solution:  | Setup1: Sweep 💌 | Primary Sweep: Freq  All                                                                                                                                                                                       |
| Domain:    | Sweep           | X: 🔽 Default Freq                                                                                                                                                                                              |
|            | TDR Options     | Y: L11 Ra                                                                                                                                                                                                      |
|            |                 | Category:     Quantity:     filter-text     Function:       Variables     Q11     abs       Output Variables     Q22     abs       Terminal S Param     11     acos       Terminal Y Param     acosh     acosh |

Figure 19. Report dialog box

8 Click New Report and click Close.



Figure 20. L11 versus Frequency

# Simulate with Solve Inside Conductors

In this section, we will select simulate the design with **Solve Inside** selected for the 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 may require a large mesh. **Solve Inside** can be useful for low frequency analysis of electrically small projects for enhanced accuracy of sensitivity design parameters such as the Q factor.

**1** In the **Project Manager** window select the design and copy it.





**2** Go the project folder and paste the design.

| Project Manager   |
|-------------------|
| B-@ si_spiral_ind |
| Base No_Solve     |



**3** Rename the pasted design.



4 Double-click spiral from the history tree and select Solve Inside in the Attribute dialog box.

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.

**5** Right click the design and select **Analyze All** from the short-cut menu.



### Figure 24. Results With Solve Inside

All the plots get updated real time as the simulation takes place. For this design it may take more passes to converge than when **Solve Inside** was unchecked.



Figure 25. Convergence Plot

#### 4-16 Analyze Spiral Conductor







Figure 28.
## 4-20 Analyze Spiral Conductor