Introduction:

Modern RFIC's depend upon passive elements such as inductors for proper operation. The characterization/simulations of these passive devices is ideally suited to modeling with HFSS. The following guide provides a consistent, robust, and repeatable methodology with which an HFSS user, when solving these types of problems, can achieve a high degree of accuracy. Intended for experienced users, these tips provide the fundamental starting points for these types of simulations, and can be easily adapted to your own processes.

Spiral Inductor: Key Modeling Considerations

Ground Return Path: To properly model the inductance of a spiral inductor, an appropriate current return path must be included in the simulation. The current return path is typically a guard ring, the connection between signal and ground pads, or a combination of both. An inappropriate current return path can lead to erroneous results.

Skin Depth: Proper calculation of inductor Q is critically dependent on the accurate calculation of dielectric and conduction loss. *HFSS allows the explicit calculation of the current distribution inside a conductor enabling an accurate calculation of volumetric conductor losses.*

A skin depth calculation will determine if this explicit calculation is required. The skin depth for good conductors is given by this equation:

$$\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$$

If the skin depth is one tenth or greater of the metal thickness, then explicit calculation of the volumetric current loss is required. This calculation is activated by selecting the "*Solve Inside*" option for each spiral metal object. This option is accessible through the objects' *Properties* dialog under the *Attributes* tab.

Dielectric Stackup Simplification: Typically, the stackup for a spiral inductor consists of thin dielectric layers with similar dielectric properties. A simulation can be simplified by combining these thin layers into fewer thicker layers, with equivalent volumetric material properties.

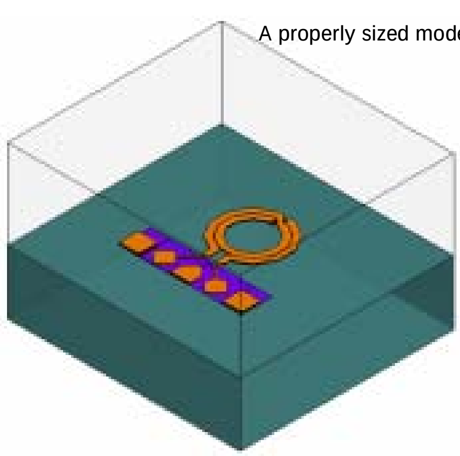
Via Field Simplification: In a spiral inductors design it is common to have via fields consisting of tens to hundreds of vias that are used to connect metal layers. The many individual vias in a via field can be merged into a single large via improving simulation speed while not affecting simulation results.

Spiral Inductor Checklist:

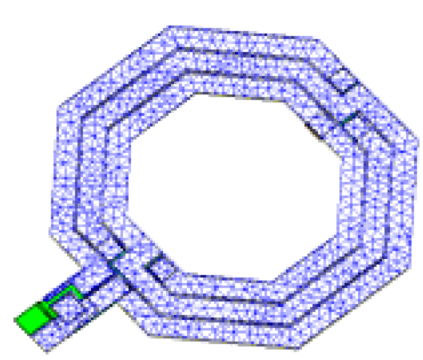
Before starting a spiral simulation it is recommended that the following checklist be completed. The details of this checklist are given on the reverse page of this modeling guide.

- Model is properly sized.
- Radiation Boundary on all outer faces except ground of Silicon.
- All metal objects have "solve inside" activated if needed.
- Manual mesh applied to all metal objects and,
    - Skin depth mesh set or
    - DC thickness assigned
- Ports applied between spiral input/output and appropriate current return path.
- Low Order Basis Function option is activated.

A properly sized model



A manually meshed spiral inductor



Spiral Inductor Model Setup

Model Size: To properly simulate a spiral the solution space should be constructed in relation to the size of the spiral with its associated current return path. For example, if the diameter of the spiral is D, then the solution space should extend past the guard ring by D/2. If no guard ring is present then the solution space should extend a distance D from all metal objects including signal and ground pads. The air region should extend a distance D/2 above the top of the spiral inductor. The substrate below should include all dielectric layers including the silicon substrate.

Boundaries: All outer faces, other than the bottom of the silicon substrate, should have a radiation boundary applied to them.

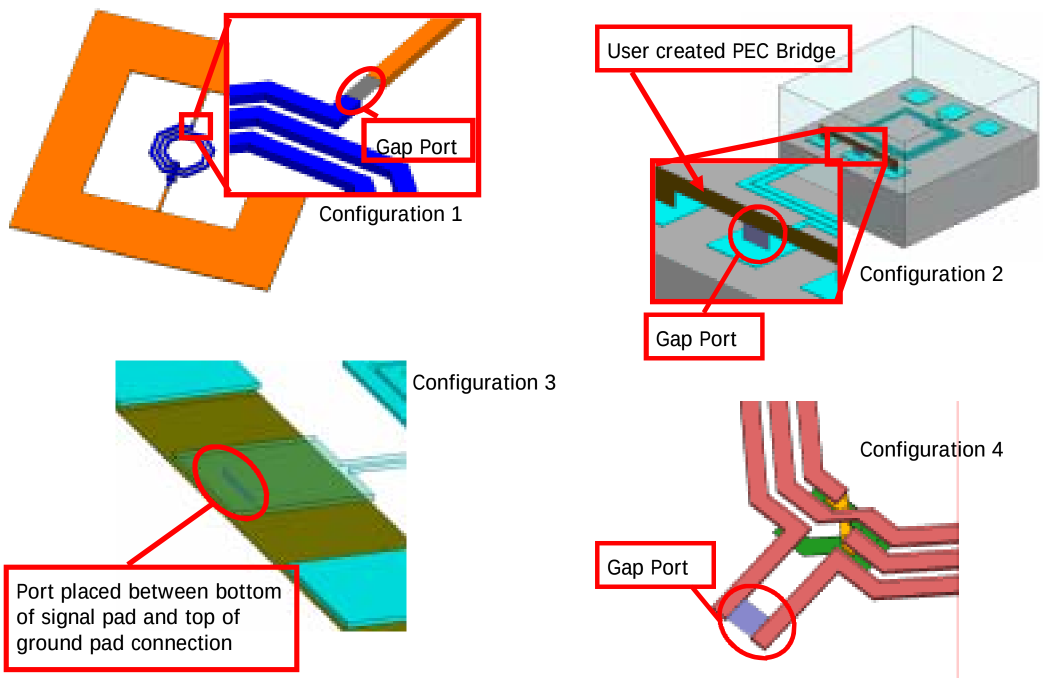
Excitations: Lumped ports should be used in the vast majority of cases. There are four typical port configurations for spiral inductor simulations:

1) Ports placed between ground ring and input/output traces;

2) Ports placed between signal pad and ground pads bridging structure;

3) Ports placed between signal pad and ground pad connection;

4) Port placed directly between input and output traces (differential sourcing).



Manual Meshing: In order to speed the convergence of a spiral simulation, manual meshing is encouraged. Depending on user preference one of two manual meshing schemes should be employed. It is not necessary to apply both schemes. The schemes are:

Manual mesh with skin depth meshing.

Step 1) Select all metal objects and apply a "***On Selection->Length Based***" mesh operation. Uncheck the length based criterion and place a check in the *Number of Elements* section. Set the maximum number of elements to be N times 4000, where N is the number of turns of the spiral.

Step 2) Select all metal objects and apply an "***On Selection->Skin Depth Based***" mesh operation. Let HFSS calculate the skin depth and use two or three layers. Restrict the number of elements to N times 1000, where N is the number of turns of the spiral.

Manual mesh with DC thickness option set.

Step 1) Same as step 1) above.

Step 2) Select all metal objects and click on **HFSS** in main menu. Select Assign DC thickness from menu and specify the thicknesses of all metal objects. Metals for which the DC thickness is set do not need require the "*Solve Inside*" option.

Solution Setup: The solution setup should follow the standard HFSS setup with the addition of setting the "***Low-Order Basis Function***" by placing a checkmark in the appropriate check box. This feature is found under the Option tab in the solution setup menu.