Cell size and box size in Sonnet RFIC inductor analysis

Purpose of this document:

This document describes the effect of some analysis settings in Sonnet:

- Influence of the cell size
- Influence of thick metal vs. thin metal for conductors
- Influence of the box size
- Influence of the box cover

The purpose of this document is to assist you in choosing appropriate settings. In case of doubt, it is strongly recommended that you analyse models with different settings, to find out what effect that setting has on your circuit, with your requirements and with your acceptable tolerances.

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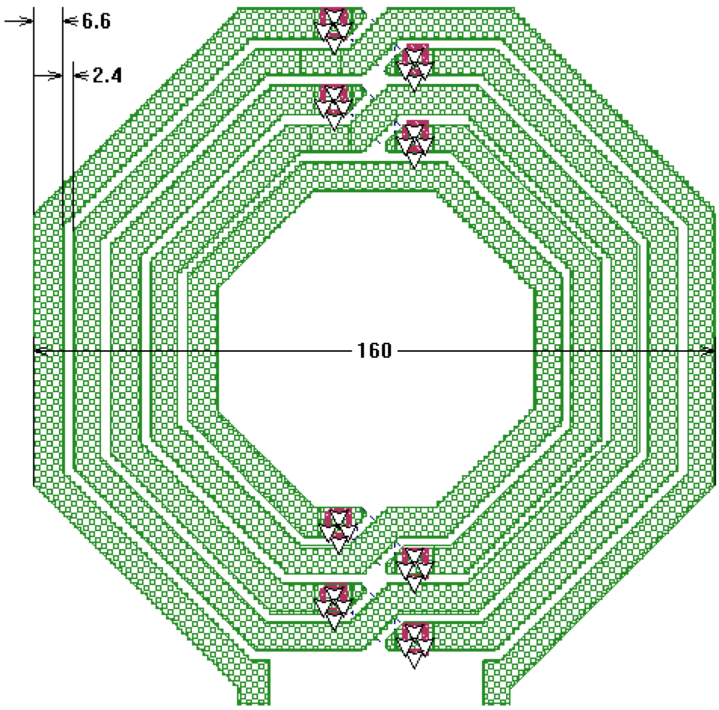
Device under test

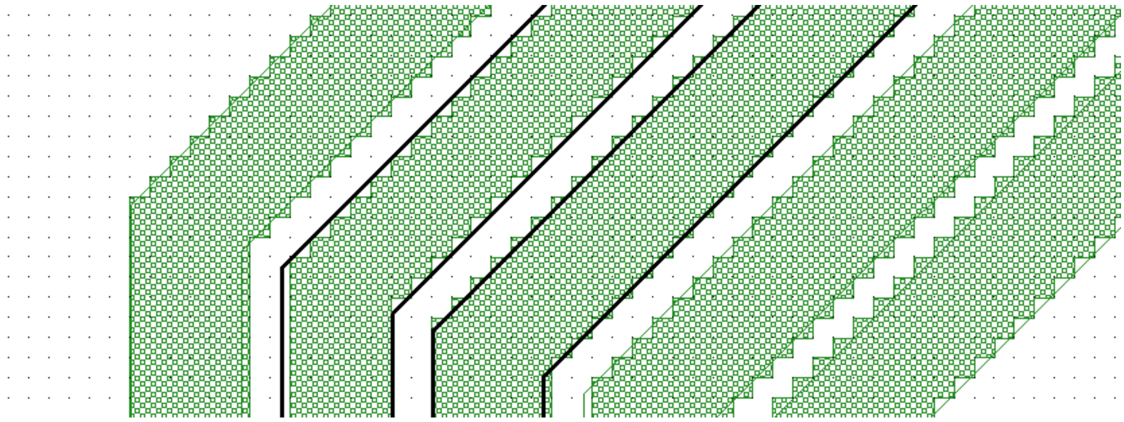
The device under test is a differential inductor as shown below. The trace width is 6.6µm, the gap width is 2.4µm and the diameter is 160µm. The metal thickness is 2µm for the coil and 0.6µm for the underpass. The technology used herein is artificial, for demonstration purposes only, but the conclusions for that coil are typical for many RFIC inductors we have seen over the past years.



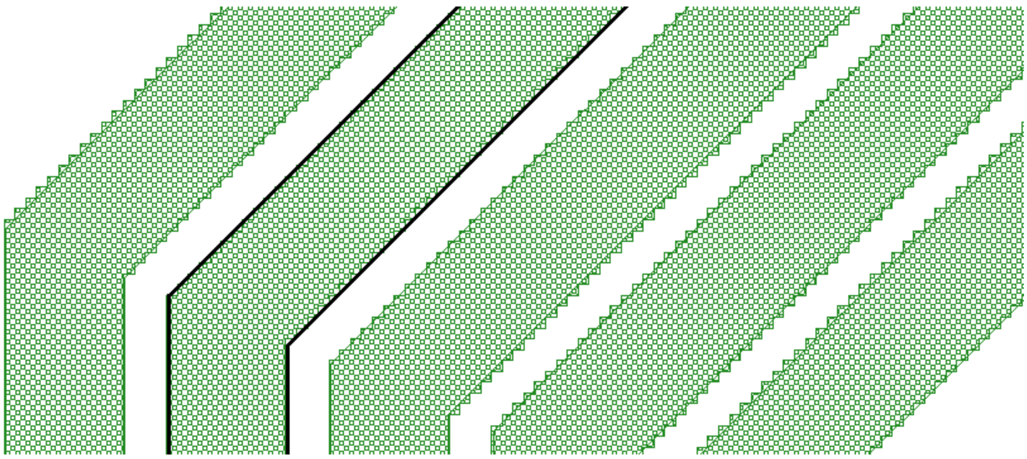
Influence of the cell size

With the given 6.6µm trace width and 2.4µm gap width, there is no obvious setting for the cell size.

To keep the gap width at the correct value, we have used a cell size of 1.2µm. This gives a reasonable, but not perfect, agreement between the original geometry and the Sonnet mesh.



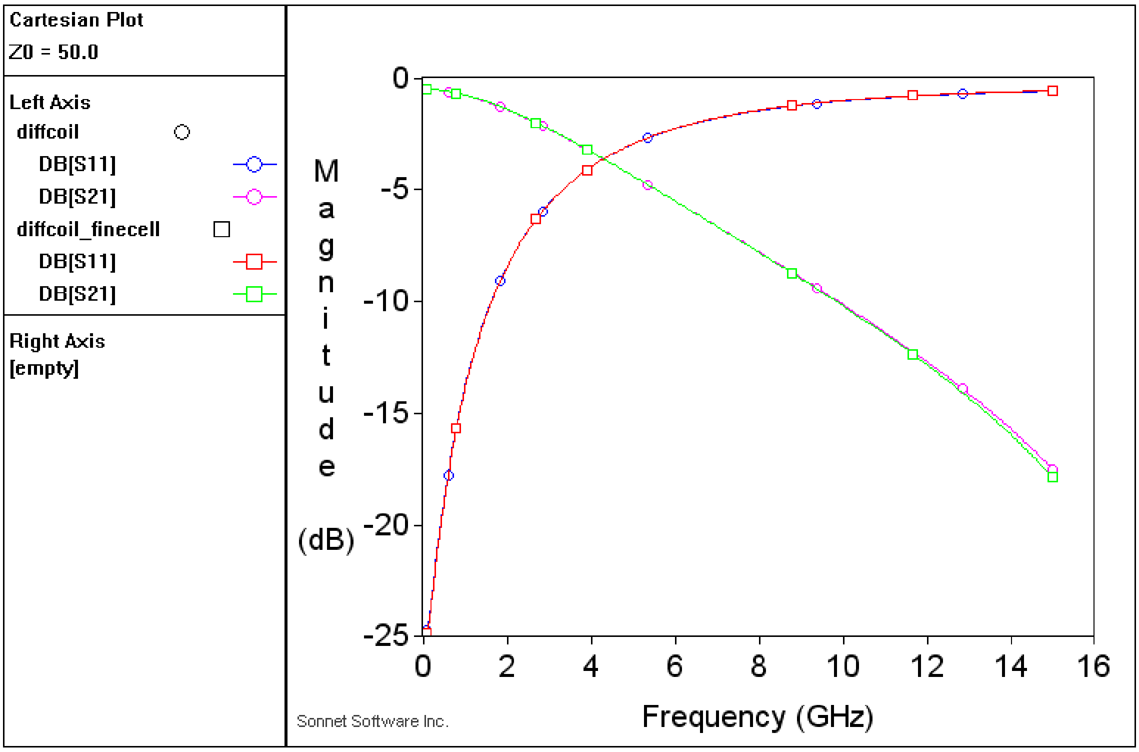
To study the effect of a finer cell size, we cut the cell size in half. Now, we have a 0.6µm cell size, which means a finer staircase approximation for the diagonal lines and also means a perfect fit for the 6.6µm wide traces (11 x 0.6µm = 6.6µm).



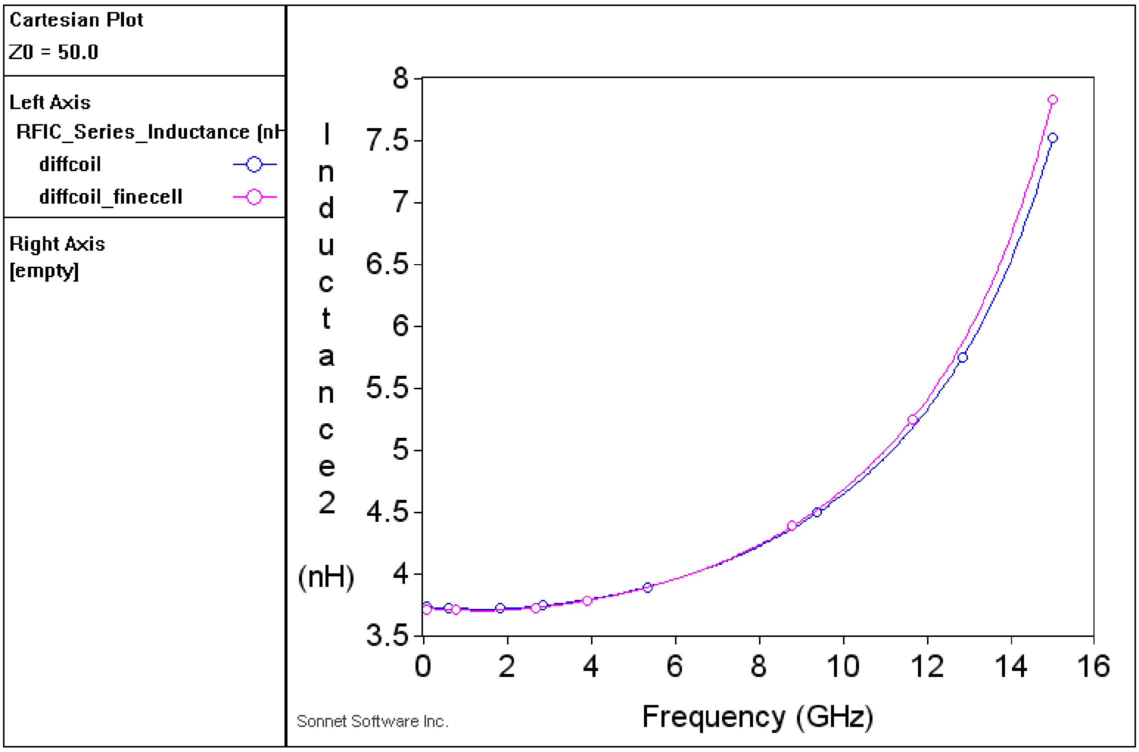
The following diagrams compare the analysis results of these two models:

diffcoil is the original model with 1.2µm cell size (63MB, 0h:09m total analysis time)
diffcoil_finecell is the model with 0.6µm cell size (151MB, 1h:17m total analysis time)

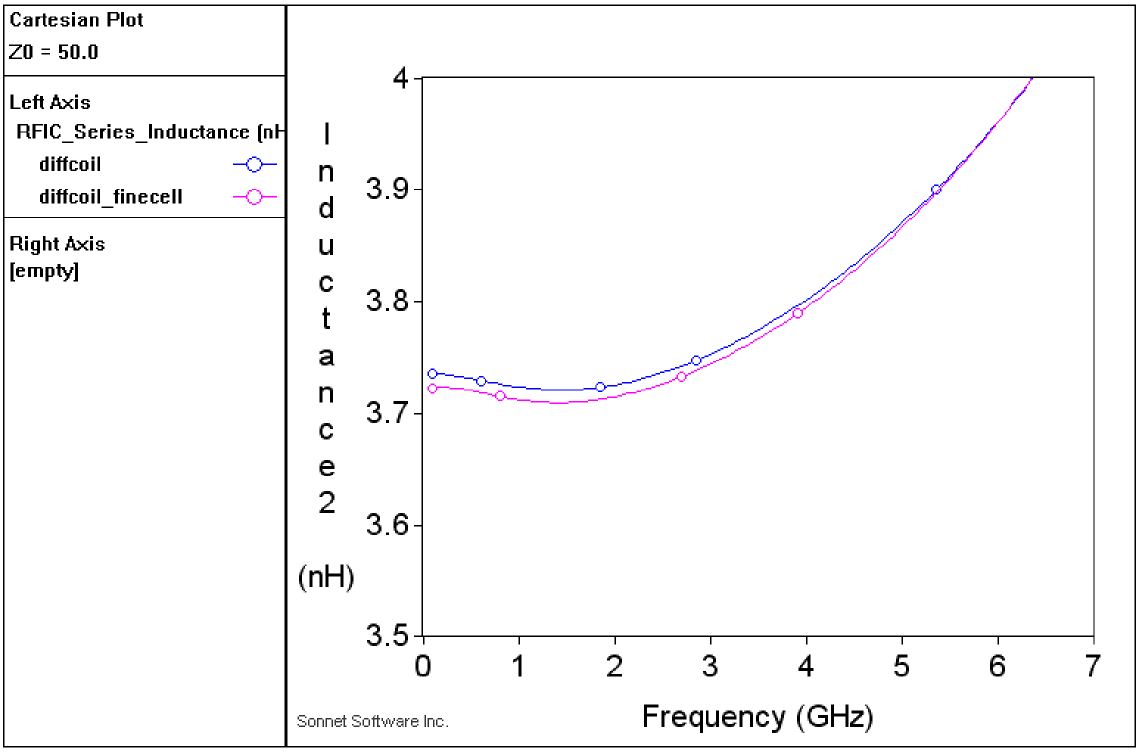
S11 and S21



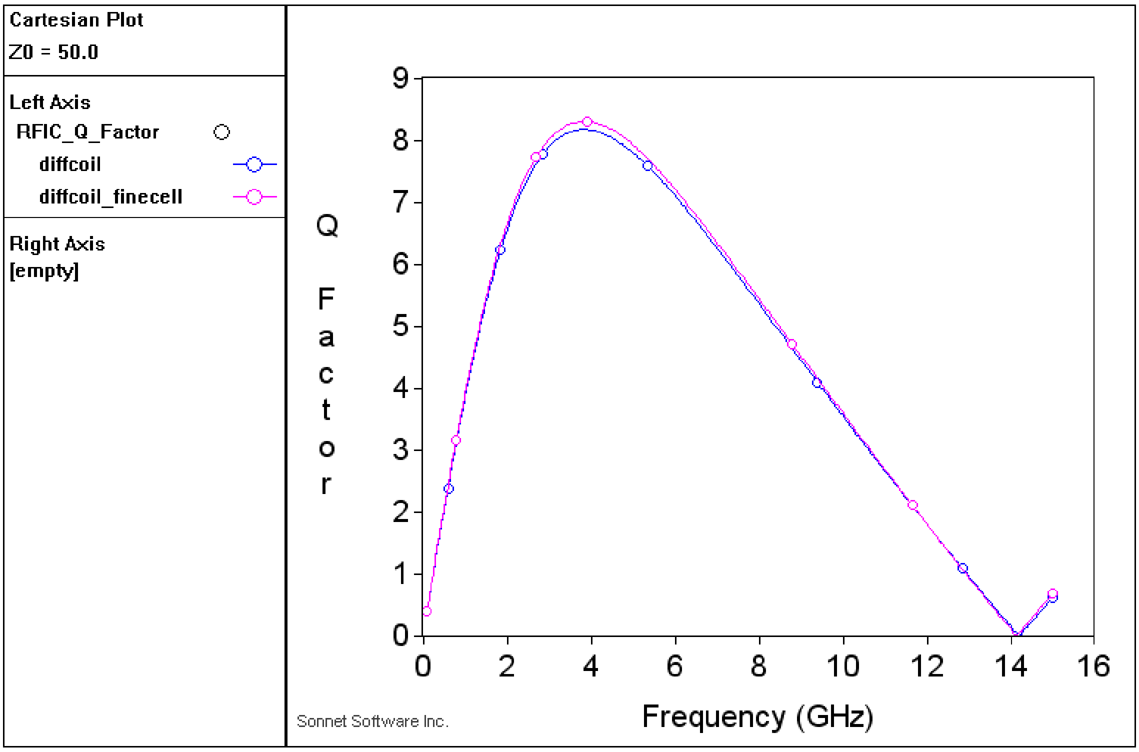
Effective series inductance



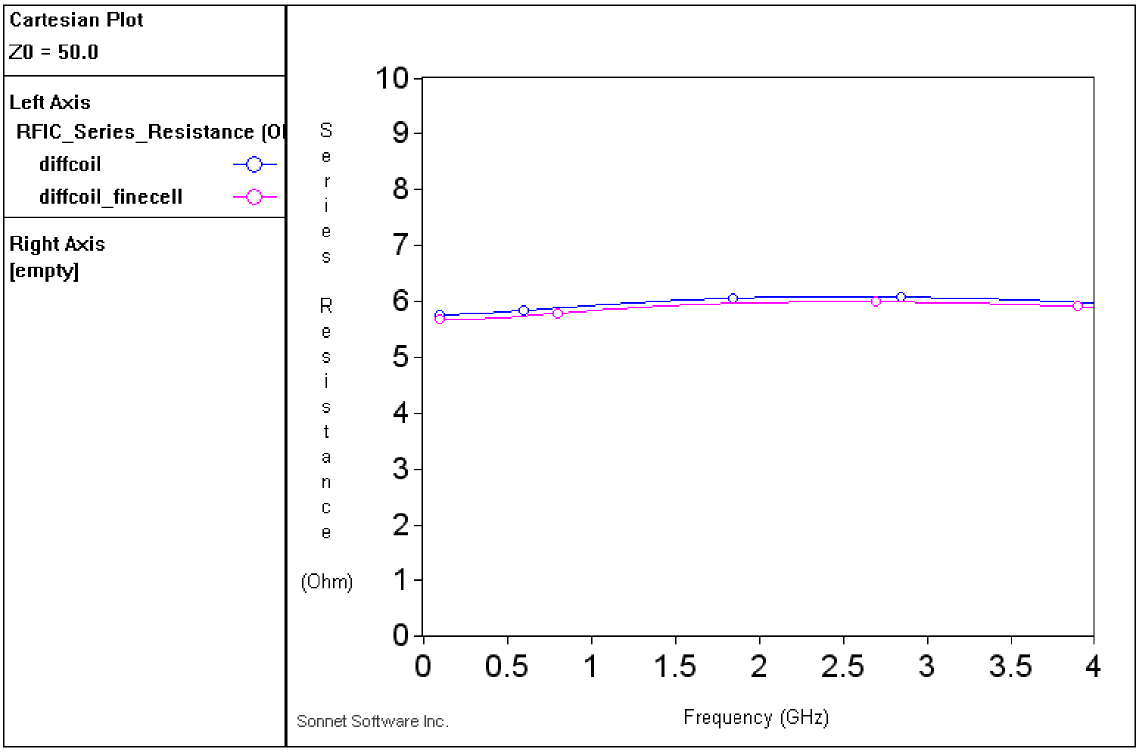
Effective series inductance (zoomed in)


Cartesian Plot
Z0 = 50.0
Left Axis
RFIC_Series_Inductance (nH
diffcoil
diffcoil_finecell
Right Axis
[empty]
Inductance2 (nH)
Frequency (GHz)
Sonnet Software Inc.

Q factor


Cartesian Plot
Z0 = 50.0
Left Axis
RFIC_Q_Factor
diffcoil
diffcoil_finecell
Right Axis
[empty]
Q Factor
Frequency (GHz)
Sonnet Software Inc.

Effective series resistance



With the smaller cell, the mesh looks much nicer and is a better approximation of the physical layout, but analysis results tell a different story.

We can see than in all parameters that we have compared, the difference between the basic cell size and the refined cell size is small. For practical purposes, the results obtained with the 1.2µm cell size are just fine. It is important to do such a test, to know how much difference we can expect from a refined cell size. Now that we have done the comparison, and verified that 1.2µm is appropriate here, we can use that cell size and obtain results 8x faster than with the 0.6µm cell size.

Influence of thick metal vs. thin metal for conductors

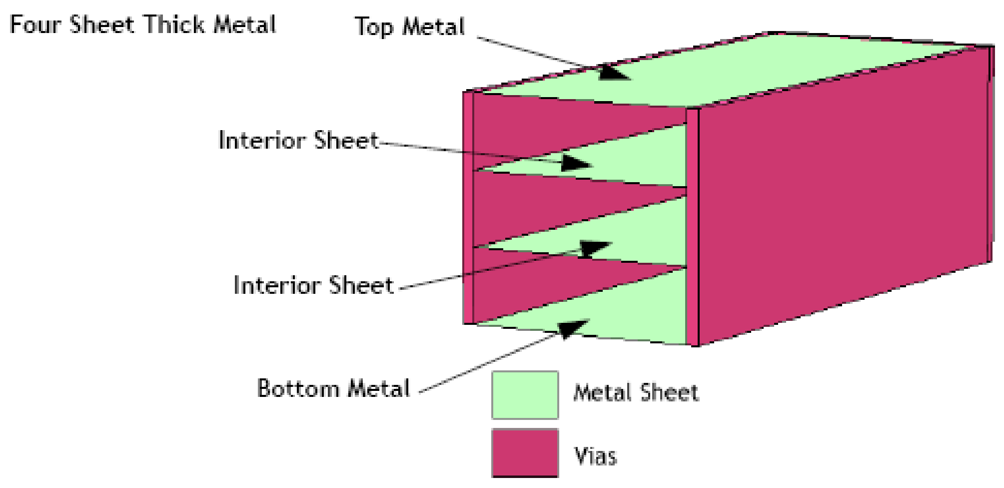
Conductors can be simulated with metal type "Normal" or with "Thick Metal Model".

The simulation with metal type "Normal", also called thin metal, is solving the field distribution with infinitely thin conductors, but uses the equivalent surface impedance to include the conductor properties. For thin metal, a "current ratio" parameter can be set to tell Sonnet about the current distribution between top and bottom of the conductors in the skin effect regime. Please refer to the User's Guide for detailed information.

The simulation with metal type "Thick Metal Model" allows us to include the effect of metal thickness on the field distribution. The metal thickness is included when solving the field distribution. Sonnet internally uses multiple conducting sheets, connected with vias, to represent the thick metal conductor. The default number of sheets is two, representing the top and bottom of the conductor, but the user can choose a different number of sheets if needed.

This is what the Sonnet User's Guide tells about the number of sheets:

For most cases, using the default of two sheets provides a high accuracy solution. However for very tightly coupled lines, where the gap between the lines is much less than the metal thickness, the coupling between them may be underestimated. In these cases, you may need to increase the number of sheets. However, increasing the number of sheets increases the memory requirements and processing time.



This is a cross section of thick metal modeled using four sheets; note that the sidewalls are vias.

For our inductor, we have a metal height to gap ratio of ~ 1:1. That is a case where typically, a thick metal analysis is used with two sheets (NS=2).

The following diagrams compare the analysis results of these two models:

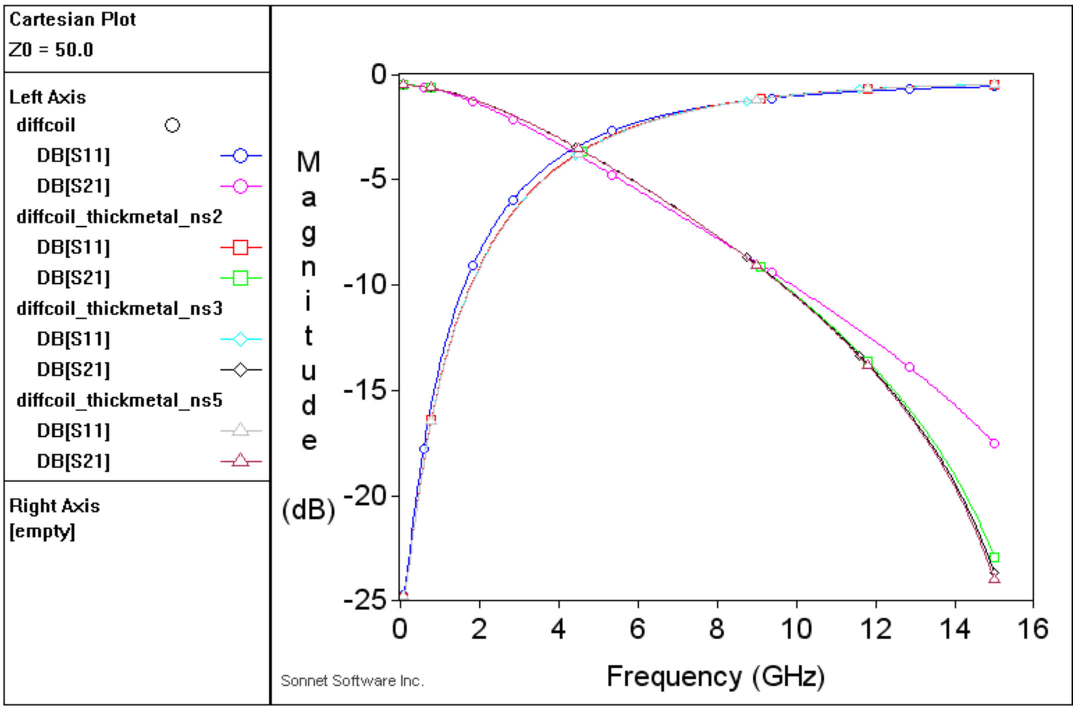
diffcoil is the original model with metal type Normal, T=2µm, CR=0
diffcoil_cr1 is a variation with metal type Normal, T=2µm, CR=1
diffcoil_thickmetal_ns2 is the model with Thick Metal Model, T=2µm, NS=2
diffcoil_thickmetal_ns3 is the model with Thick Metal Model, T=2µm, NS=3
diffcoil_thickmetal_ns5 is the model with Thick Metal Model, T=2µm, NS=5

Memory requirement and simulation time[1]:

diffcoil: 63MB, 0h:09m total analysis time
diffcoil_cr1: 63MB, 0h:09m total analysis time
diffcoil_thickmetal_ns2: 189MB: 0h:25m total analysis time
diffcoil_thickmetal_ns3: 392MB, 0h:55m total analysis time
diffcoil_thickmetal_ns5: 1024MB, 2h:55m total analysis time

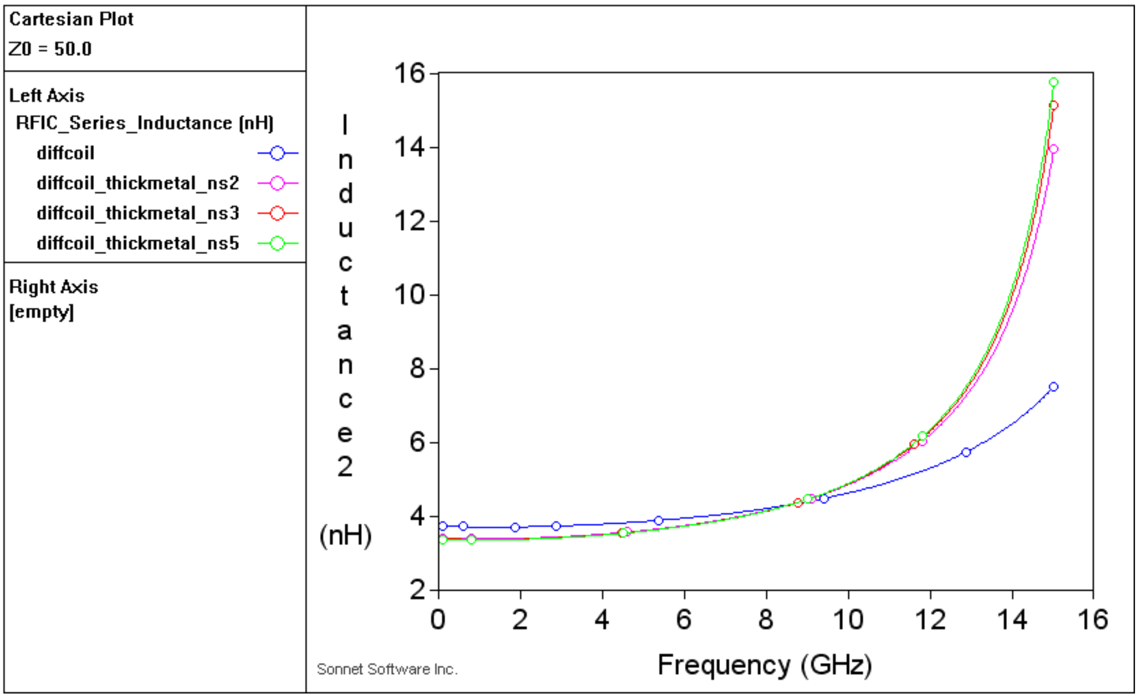
For the thick metal models, the oxide height above the coil was increased from 2µm to 4µm, compared to the thin metal model, to give room for the thick metal that now penetrates 2µm into the dielectric above.

S11 and S21

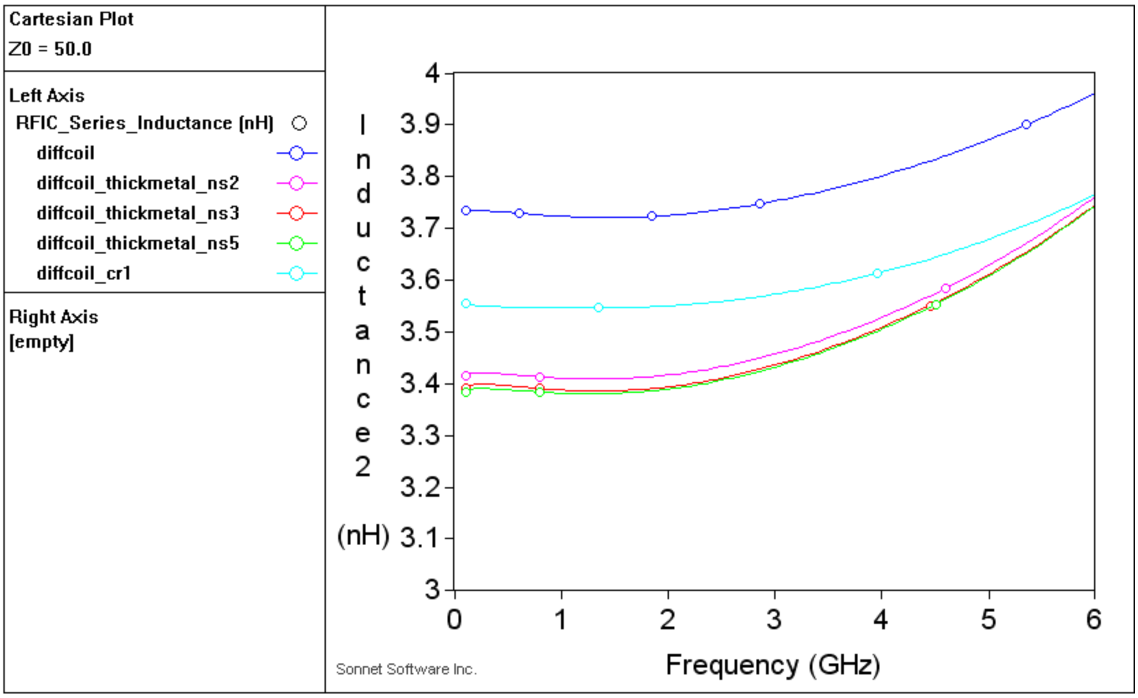


[1] Analysis times are given for Sonnet Version 11.52 running on a single core 3GHz system.

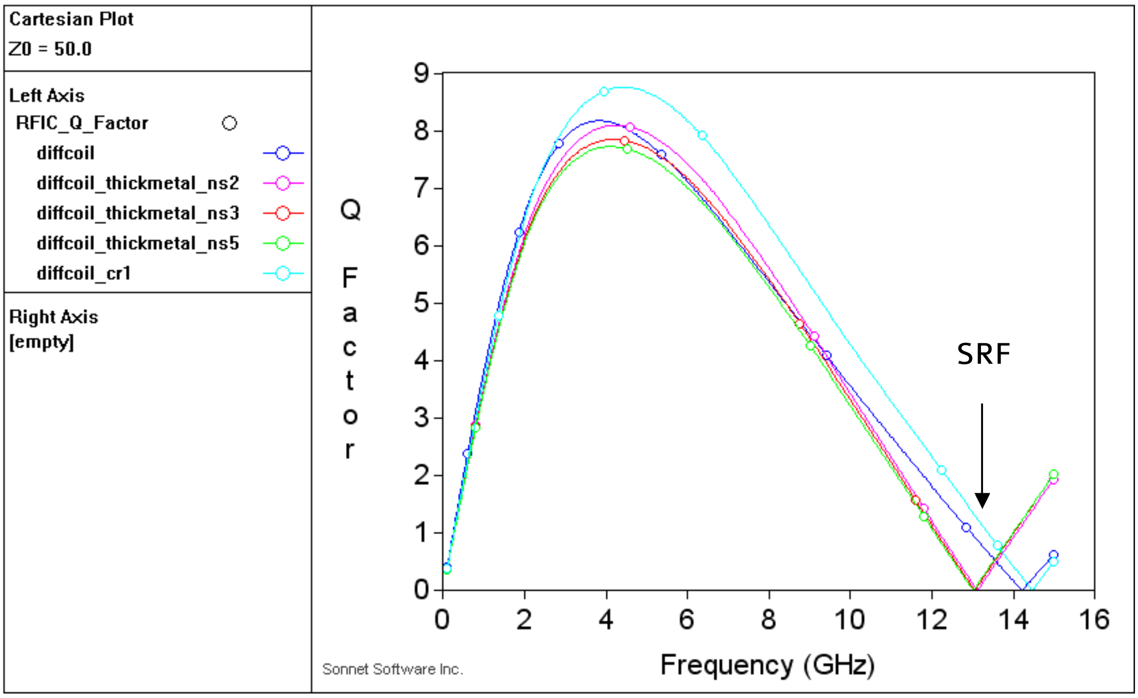
Effective series inductance



Effective series inductance (zoomed in)



Q factor



The results show that for this inductor, results of a thin metal analysis differ significantly from thick metal analysis results. For the thick metal models, we see that a two sheet model gives pretty good results, and the changes from 2 to 3 and from 3 to 5 sheets are getting smaller and smaller. This convergence is expected and seen in Sonnet in many situations. For practical purposes, we can conclude that the two sheet model (NS=2) is a good compromise between accuracy and analysis time.

In the operating frequency range, the difference for thin metal with CR=0 is approximately 10% in series inductance, compared to the thick metal models, and decreases to ~5% for thin metal with CR=1. CR=1 assumes that current is equally distributed between top and bottom of the conductors.

The Q factor shows some differences, too. Here, we see that the thin metal model with CR=1, assuming equal current on top and bottom of the conductors, gives the most optimistic Q factor. When we tell Sonnet that skin current is only flowing on one side (CR=0), the Q drops as expected. When we use a thick metal model, Sonnet can find out the right current distribution itself, as a result of the field analysis, thus we can expect more accurate values with a thick metal model. By increasing the number of sheets, we increase the accuracy of the analysis, but even the default value of two sheets (NS=2) gets us really close. Again, we see convergence as we increase the number of sheets.

For the self resonance frequency, we observe that the SRF decreases when we go from thin metal to thick metal. This is expected, as we consider the metal height which means more inter-winding capacitance across the inductor, thus decreasing the SRF.

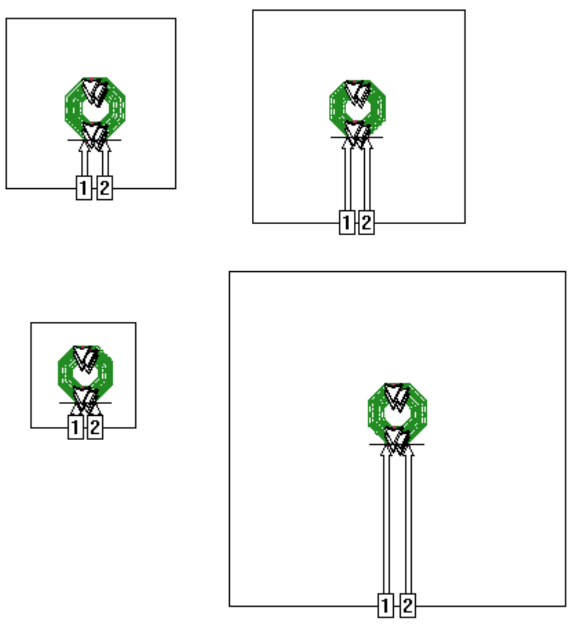
Influence of the box size

A common question from users who are new to Sonnet is:
"What should be the size of my analysis box?"

Remember that the Sonnet analysis box is a conducting metal box around your inductor. If it is too close, you will see an interaction between the inductor and the box. So you must make the box big enough so that the interaction between inductor and box is small enough. But what box size is big enough, what influence is small enough? We can easily test that.

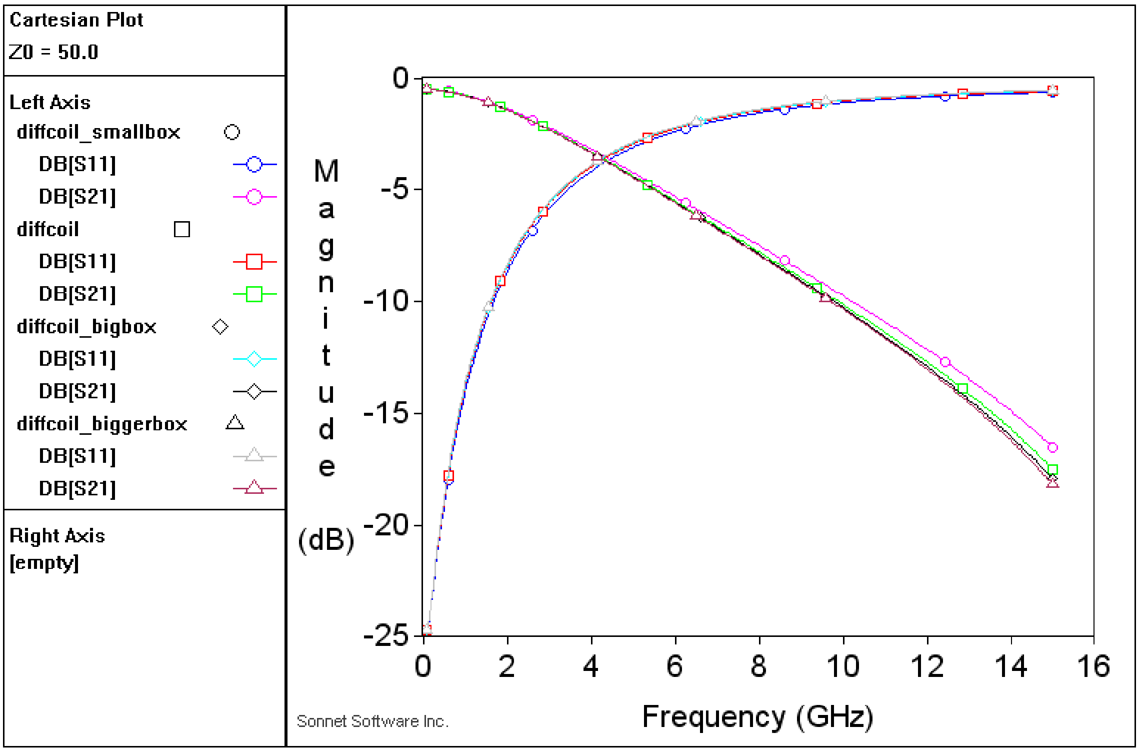
Why don't we make the box really really wide? There are a couple of reasons not to do this. Firstly, we would approximate what the planar solvers with numerical integration do, and give up some of the advantages of Sonnet's FFT method. We would loose simulation speed, because the matrix fill time would become slower. Secondly, depending on the simulation details, a large box might create box resonances in Sonnet that can be reduced or avoided when using a smaller box size. So the goal is to choose the right box size for a given device under test.

As a rule of thumb, we would start with a box size where the x and y dimensions are +/- 3 times the diameter of the inductor. Now, we can test that against a simulation model where we change the box size. If there is an effect of the box size on the analysis results, we will see it.

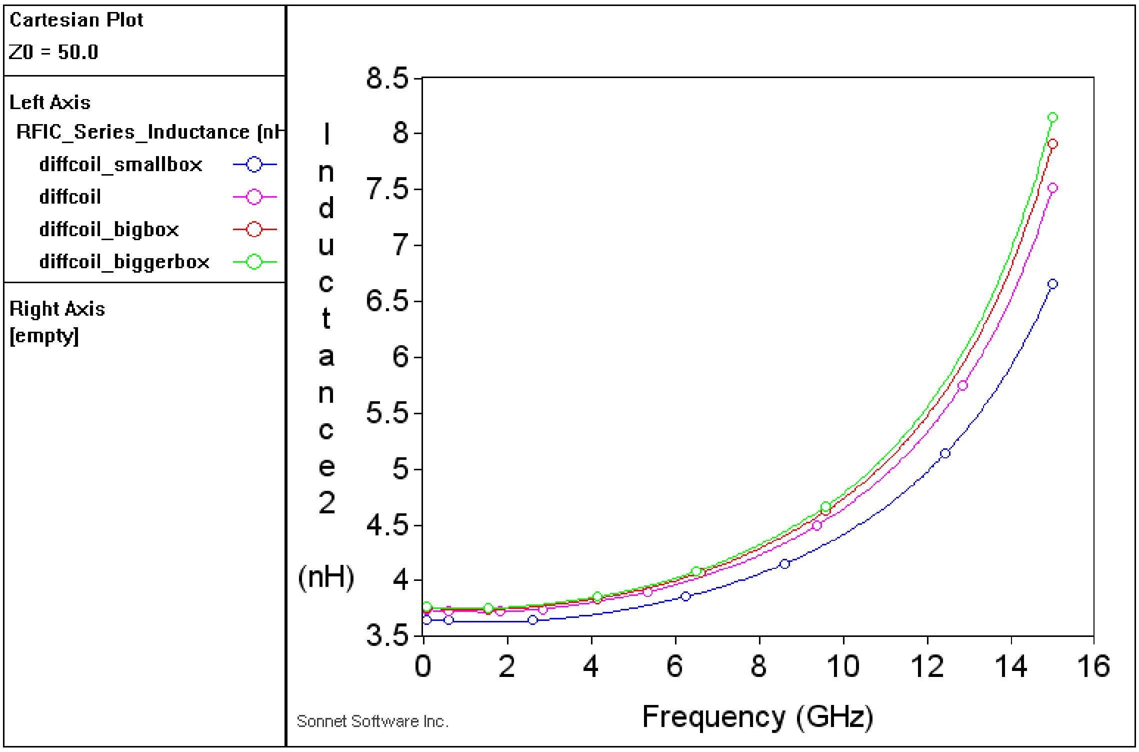


diffcoil_smallbox: box size = 1.7 coil diameters, 60MB, 0h:07m total analysis time
diffcoil: box size = 2.8 coil diameters, 63MB, 0h:09m total analysis time
diffcoil_bigbox: box size = 3.8 coil diameters, 66MB, 0h:09m total analysis time
diffcoil_biggerbox: box size = 5.8 coil diameters, 73MB, 0h:13m total analysis time

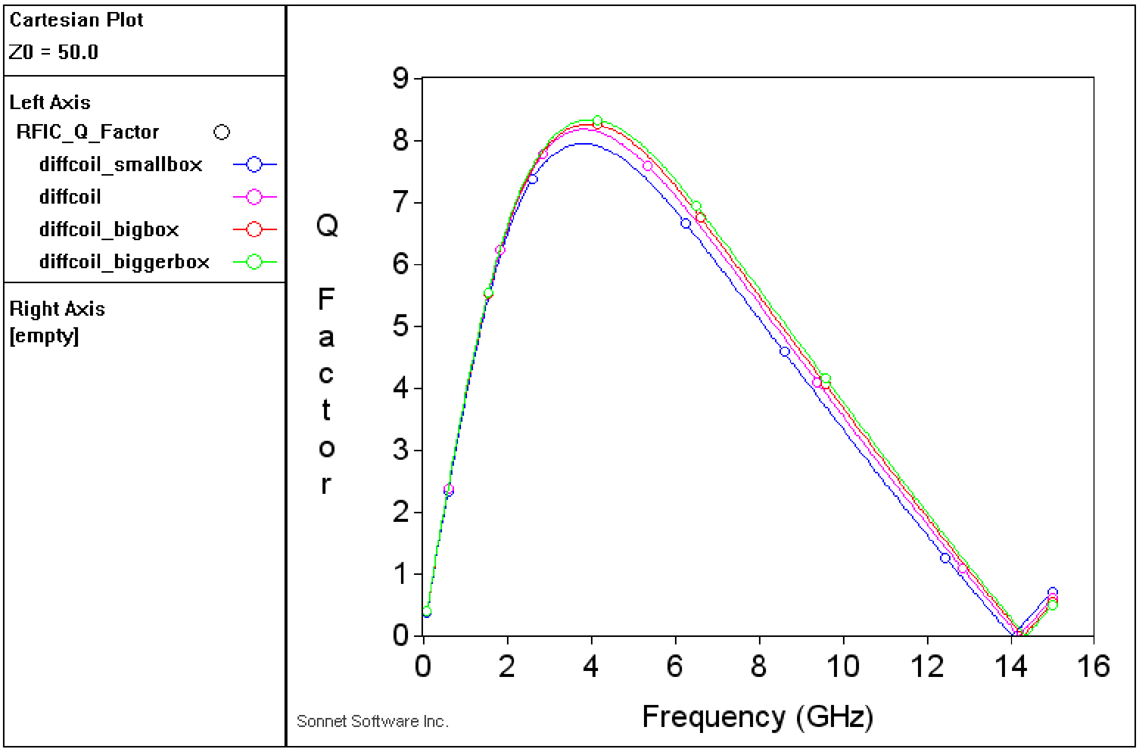
S11 and S21



Effective series inductance



Q factor



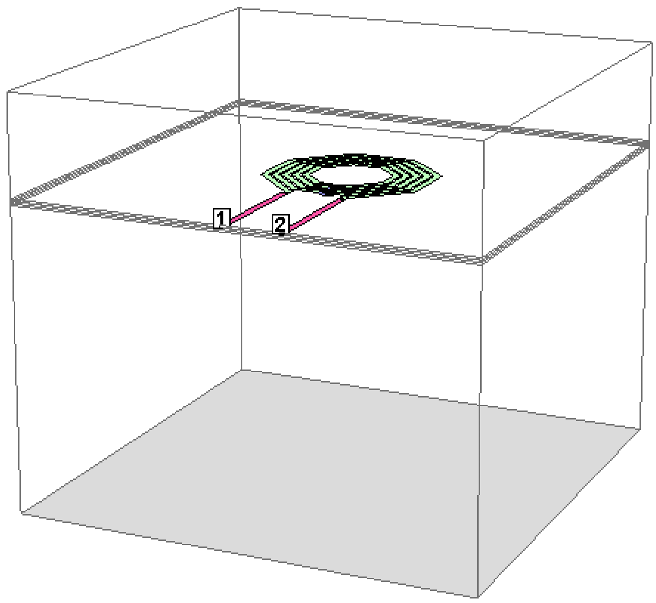
The effect of a small box is a reduction in L and Q.

The difference in inductance between the smallest box size used here (1.7 coil diameters) and the biggest box size (5.8 coil diameters) is 0.15nH or 4%.
The difference between our initial box size (2.8 coil diameters) and the biggest box size is 0.04nH or 1%.

Influence of the box cover

A common question is: what should be the height of my Sonnet analysis box,
what should be the thickness of the air layer between the circuit and the top cover?

For RFIC, a rule of thumb could be to use a few substrate heights. We want to avoid that the inductors feels a capacitance to the top cover, which is grounded like all other box walls. Thus, we want to put the top cover at a distance far enough away, just like the box walls. What is far enough? We can test that by comparing results with different air layer thickness.



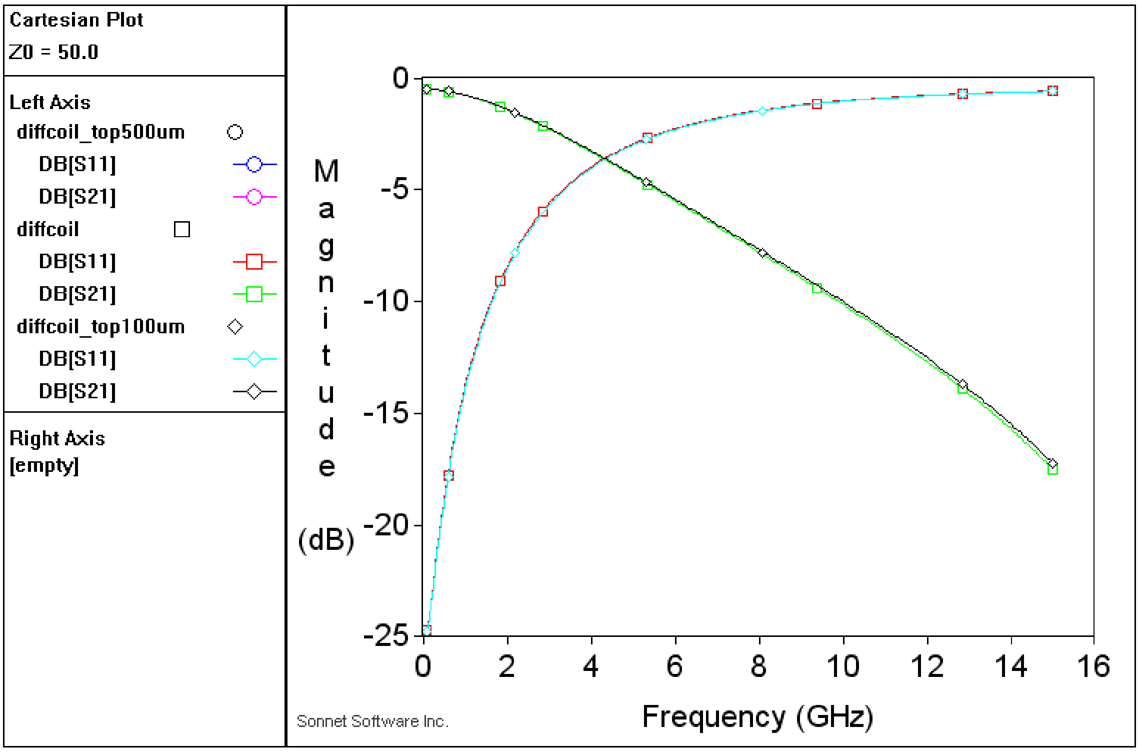
The image above shows 100µm air thickness.

Models compared here:

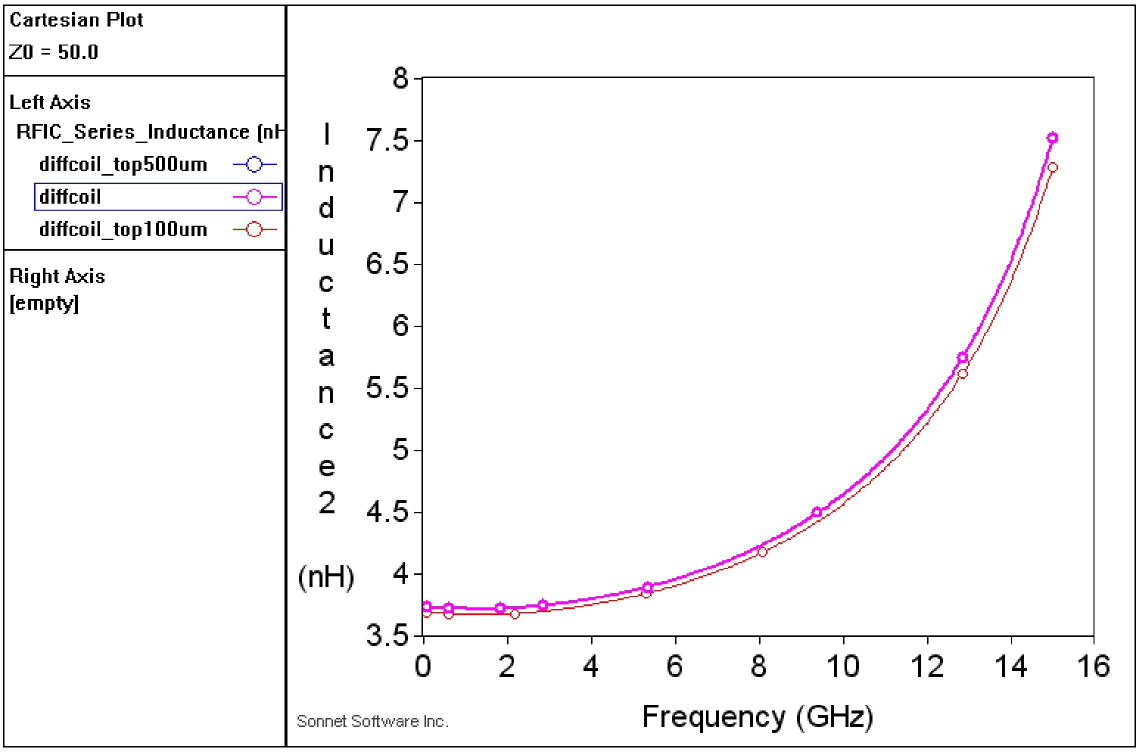
diffcoil: air layer thickness 2000µm
diffcoil_500um: air layer thickness 500µm
diffcoil_100um: air layer thickness 100µm

The height of the air layer has no effect on the analysis time or memory requirement.

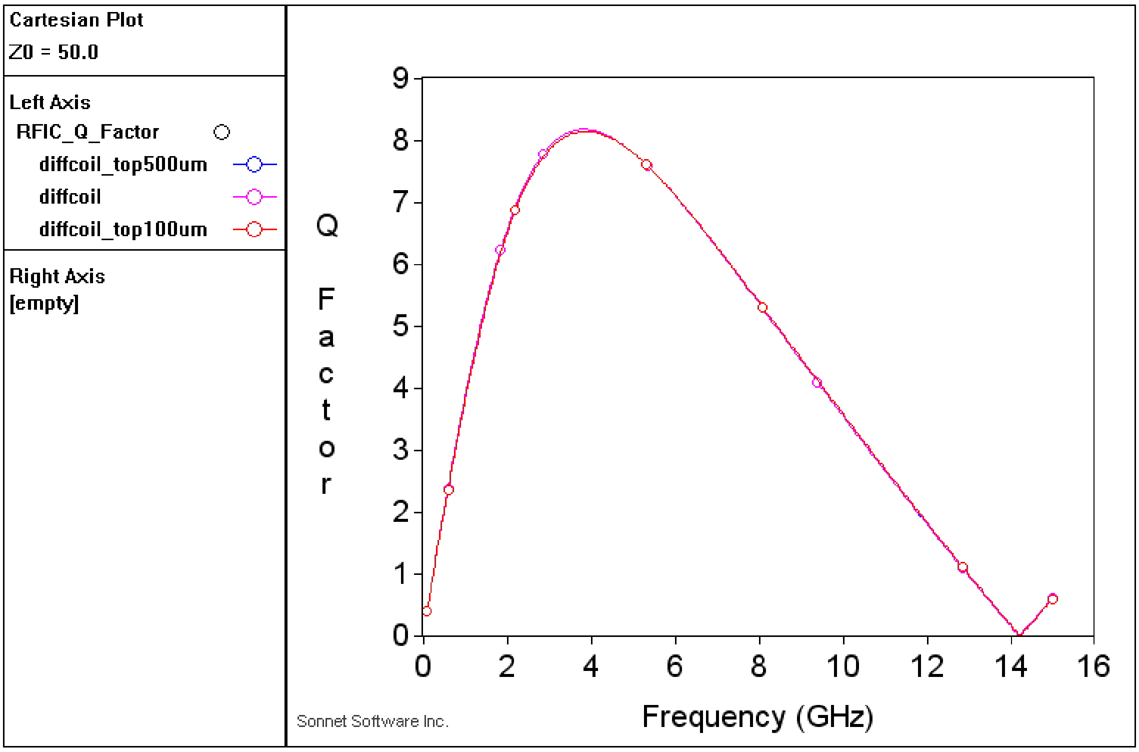
S11 and S21



Effective series inductance



Q factor



The effect of a box top cover that is very close above the inductor box is a reduction in L and Q.

The difference in inductance between the 100µm layer of air and the 2000µm layer of air above the inductor is 1%. The difference between the 500µm layer of air and the 2000µm layer of air above the inductor is so small that we cannot measure it.