Mühlhaus RFIC Inductor Model Fit
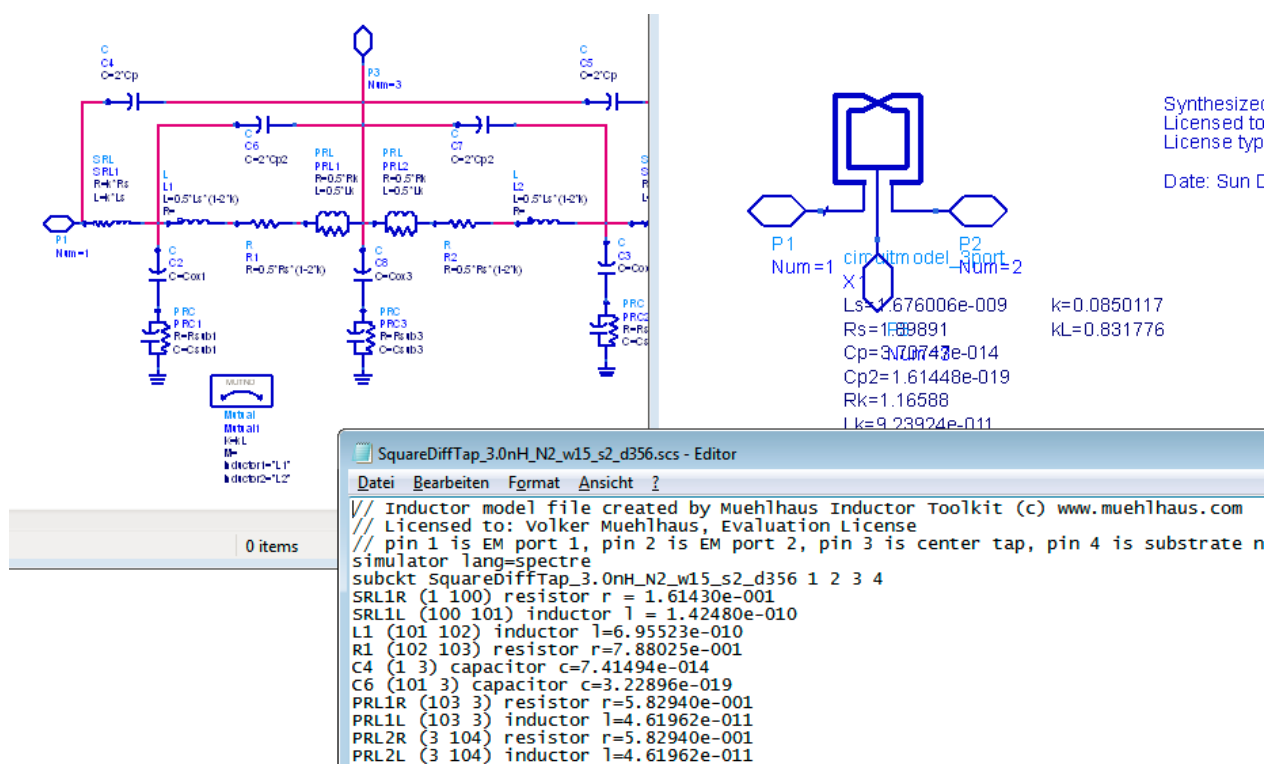
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Introduction

Mühlhaus InductorModelFit creates equivalent circuit models from measured or simulated RFIC inductor S-parameters. It supports symmetric and asymmetric inductors, with or without center tap.

Your input:

- S-parameter data file (*.s2p or *.s3p) for the inductor

InductorModelFit does all this automatically:

- Analyze the input data, choose equivalent circuit model and good starting values
- Automatically set up goals and optimization parameters, optimize in ADS
- Create Spectre *.scs netlist file from optimized equivalent circuit model

Mühlhaus InductorModelFit is implemented as an ADS design kit. To use it, add the Circuit Model Fit PDK to your workspace. After you have created the lumped model in your working library, you can remove the PDK from your workspace.

How is Mühlhaus InductorModelFit different from other inductor modelling tools?

- Proprietary equivalent circuit models, which are accurate over a wider frequency range.
- Creates ADS circuit model and Spectre *.scs netlist file
- Fully integrated to the ADS framework.
- Can be customized by the user as needed.

What is the advantage over using Broad Band SPICE models?

- Stable and well behaved in transient and PSS simulations
- Accurate for noise and phase noise
- Equivalent circuit models are physically meaningful, and give a physical understanding of the device.

Installation

Before you can use Mühlhaus InductorModelFit, you have to install it to your favourite designkits. The procedure for that is similar to other ADS PDKs: in the ADS main windows, go to *DesignKits > Unzip Design Kit ...* and install the PDK.

You must install InductorModelFit with <u>write access</u> for the users at file level, because users can customize settings and schematics. For example, if you store your ADS workspaces to $HOME/ads2012.08, you could create a new directory $HOME/designkits and unzip the InductorModelFit PDK to that location.

Requirements

InductorModelFit is implemented as an ADS designkit, and is compatible with ADS releases 2012.08 or newer. Models are compatible with a wide range of Silicon based technologies, e.g. RF-CMOS and BiCMOS technologies.

The following input data is required:

- Touchstone s2p files for inductors **without** center tap
- Touchstone s3p files for inductors **with** center tap,
  with the center tap connected at port 2 or 3.
- Center tapped inductors measured with grounded center tap
  are not supported in this release.

Note: Mühlhaus InductorModelFit is not designed for extraction of SMT inductors or inductors on GaAs technologies. The model topology is specifically designed for Silicon based technologies.

How it works

Here is a brief overview of the method, so that you can use InductorModelFit efficiently. After you have selected an input file, the topology is analysed and a first raw model is generated, with approximate values. These are then optimized using the ADS optimizer, with full automation, so that you don't need to set up anything yourself. You only need to start the optimizer and save back the optimized results. Results are shown in the data display (inductor_parameters_2port/ inductor_parameters_2port) and also written to a Spectre netlist file[1] (*.scs) in the workspace data directory.

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[1] This netlist output is programmed specifically for this data display and this equivalent circuit model in InductorModelFit, so it cannot be used with other input data.

Getting started

Step 1: Read in the data

The first step is to read in the S-parameters of the model that you want to extract. In the InductorModelFit menu, click on "1:Choose input file...". This will bring up a dialog box where you can select the input file from all *.s2p/*.s3p files in the workspace data directory.
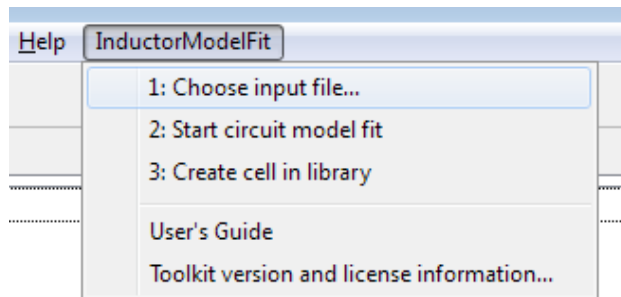
When have selected an input file, InductorModelFit will read the file and automatically start a simulation to extract the indictor model parameters. A data display windows will come up where you see the effective series inductance, series resistance and Q factor for differential mode operation.
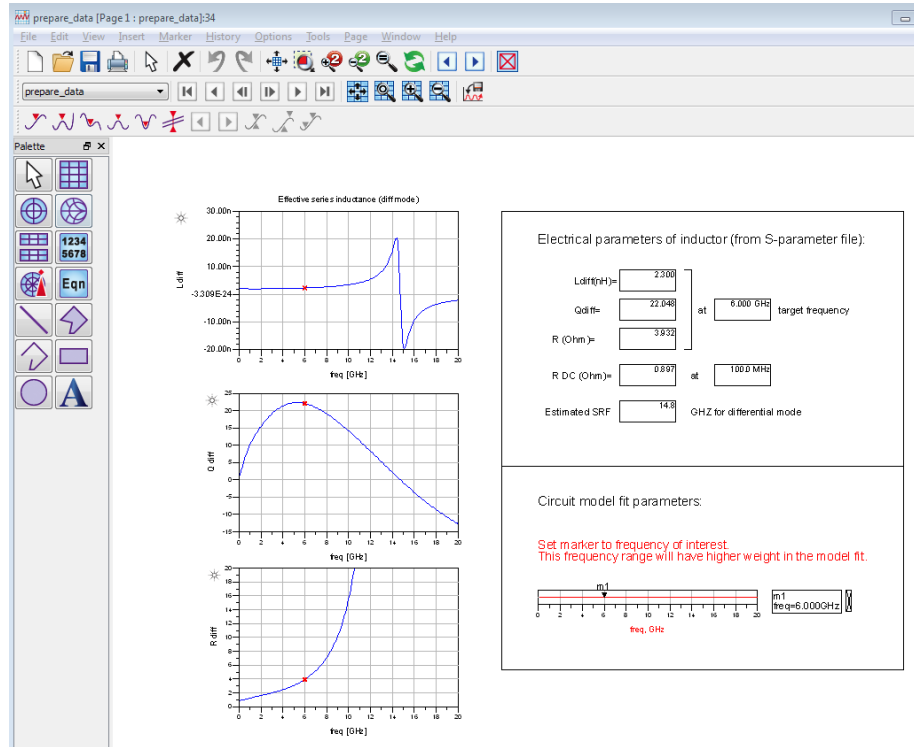
On the bottom right side, you see a frequency slider. Select your frequency of interest, i.e. the operating frequency where you want best accuracy for your extracted model. This frequency will be used to extract initial values for the equivalent circuit mode fit.

Step 2: Start circuit model fit

After reading in the data, the circuit model fit can start.

When you click on "Start circuit model fit", a schematic for optimization will open. The schematic is set up for ADS optimization, to fit an equivalent circuit model to the input data. The circuit model topology is automatically set based on your input file: center tapped model for s3p files, regular inductor model without center tap for s2p files.

You don't need to make any changes, the various fit parameters and goals and frequency settings are already configured for your inductor.

If optimization does not start automatically, please start it manually by clicking on the optimizer button or choosing "Simulate > Optimize" from the menu.[2]
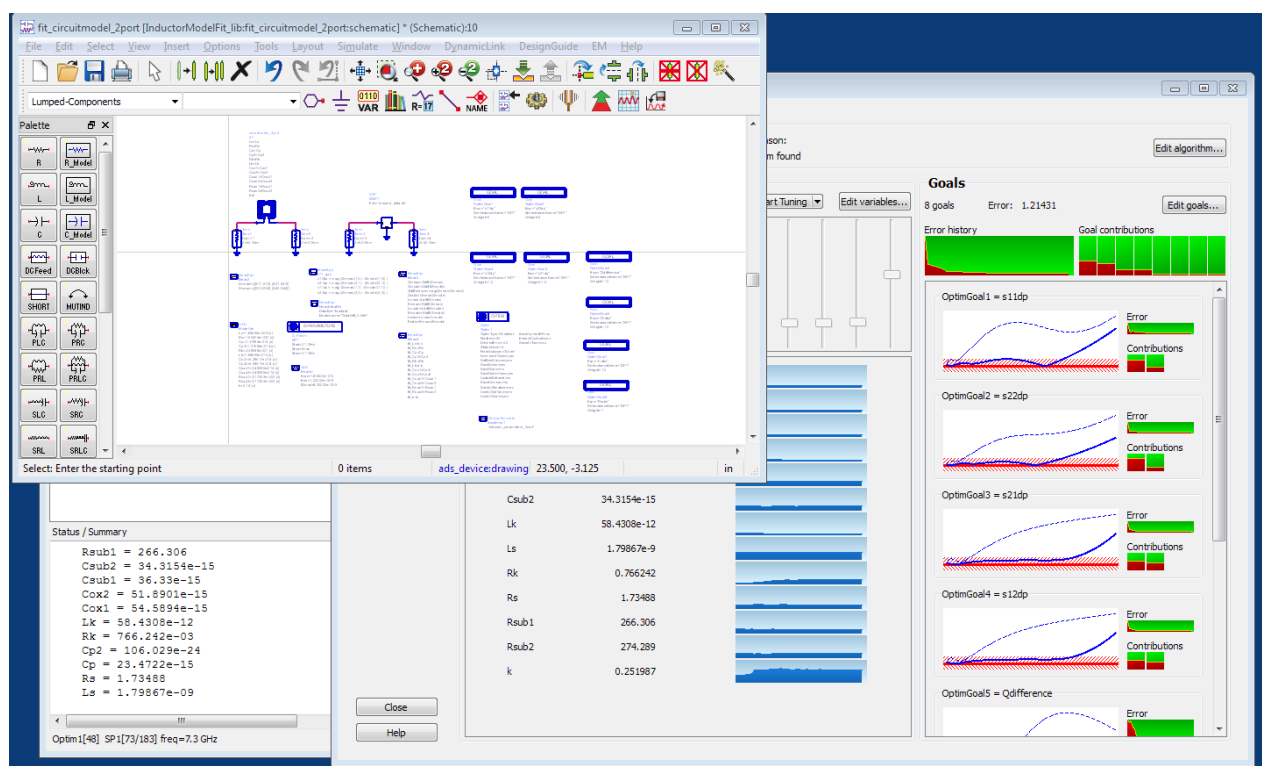

When the optimization has finished, close the optimizer cockpit and update the schematic with the optimized values[3].

This will now bring up a data display that shows two curves for each parameter: the EM simulated data and the result of the equivalent circuit model fit. If you are satisfied with the agreement, no further action is needed.

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[2] Optimization will start automatically if *lumpedmodel_start_optimizer* is set to *TRUE* in the inductor mode fit *preferences.ael* file. This file is located at <InductorModelFit PDK directory>/ *de/ael/ preferences.ael*
[3] If you stop the optimization manually, before reaching the maximum number of iterations, you have to manually start a re-simulation of the optimized schematic. Otherwise, the circuit model fit curves will be empty and no model is created.

red = data from input file
blue with index m = model = fitted data
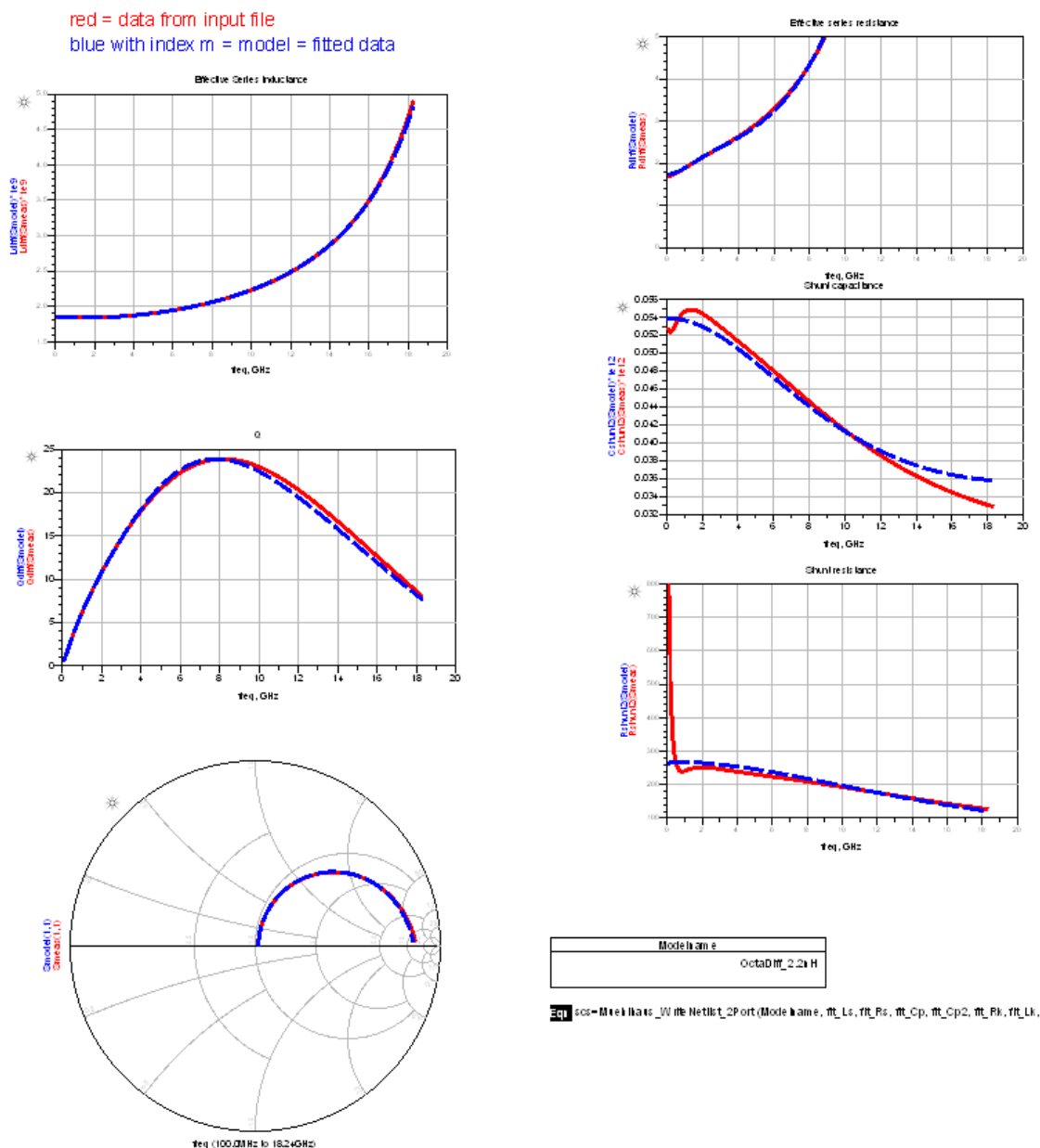
Plots show the comparison for differential L,Q,R and shunt capacitance and shunt esistance and single ended S11. The data display is configured to automatically write an *.scs netlist for Spectre to the same directory where the S-parameter file is located.

The values are also used to create an **additional** ADS schematic view in step 3, Create cell in library.

Important: When you start "Create lumped model" from the menu, this will reset all parameters to the starting values, and overwrite previous optimization results. If you want to re-open the schematic without resetting the values, open it from the ADS file browser and not from the Inductor Toolkit menu!
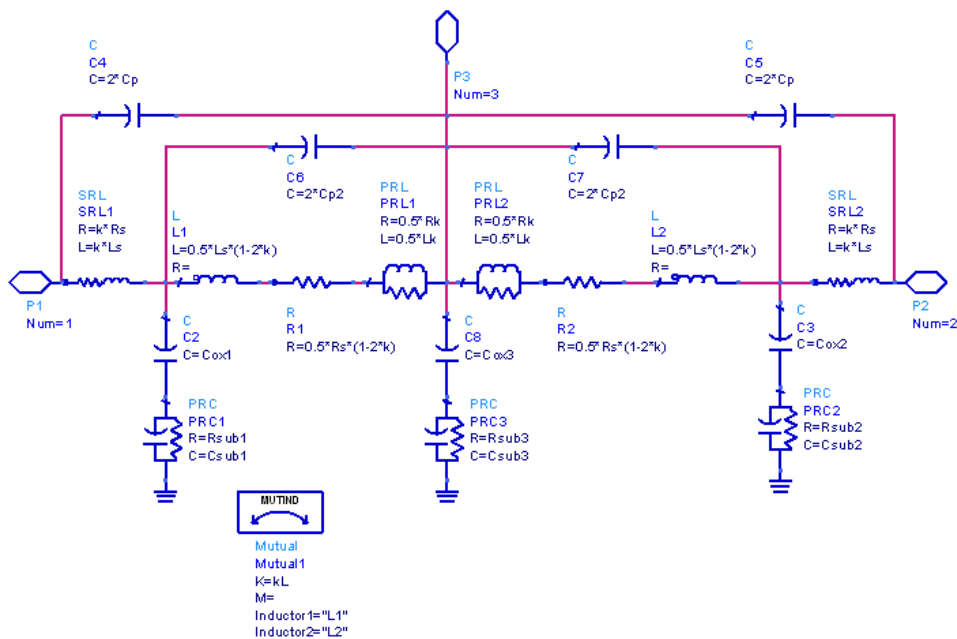
Lumped model topologies

There are two equivalent circuit model types, with and without center tap. In this release, equivalent circuit models are not yet available for patterned ground shield inductors.

Inductor without center tap (2 ports):
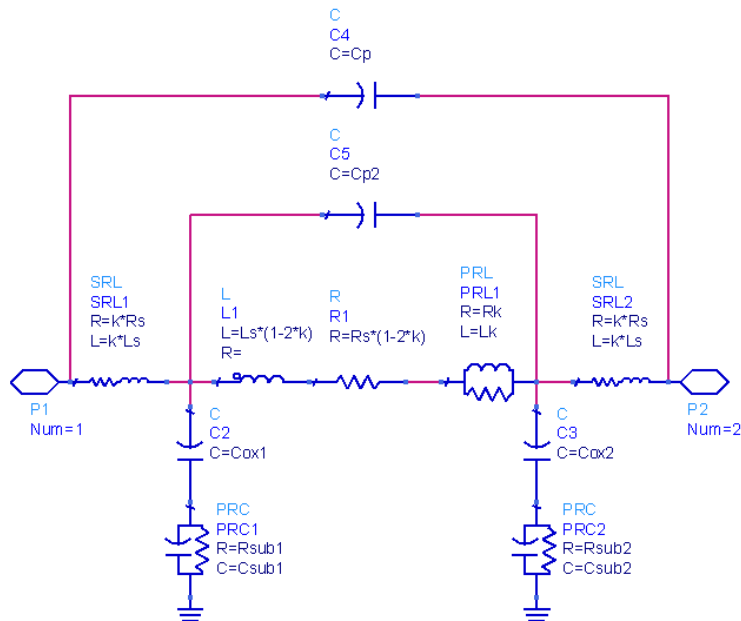
## Inductor with center tap (3 ports):

Step 3: Create cell in library

After the optimized geometry parameters are calculated, we can create a library cell with these inductor parameters. From the menu, choose "Create cell in library".

This cell will be created in the **first writable library of the workspace** (excluding the InductorModelFit libraries). The name of the cell is derived from the S-parameter input file name.

The cell has **two** schematic views: **schematic** with the S-parameter (input) data block, and **schematic_lumpedmodel** with the extracted equivalent circuit model.
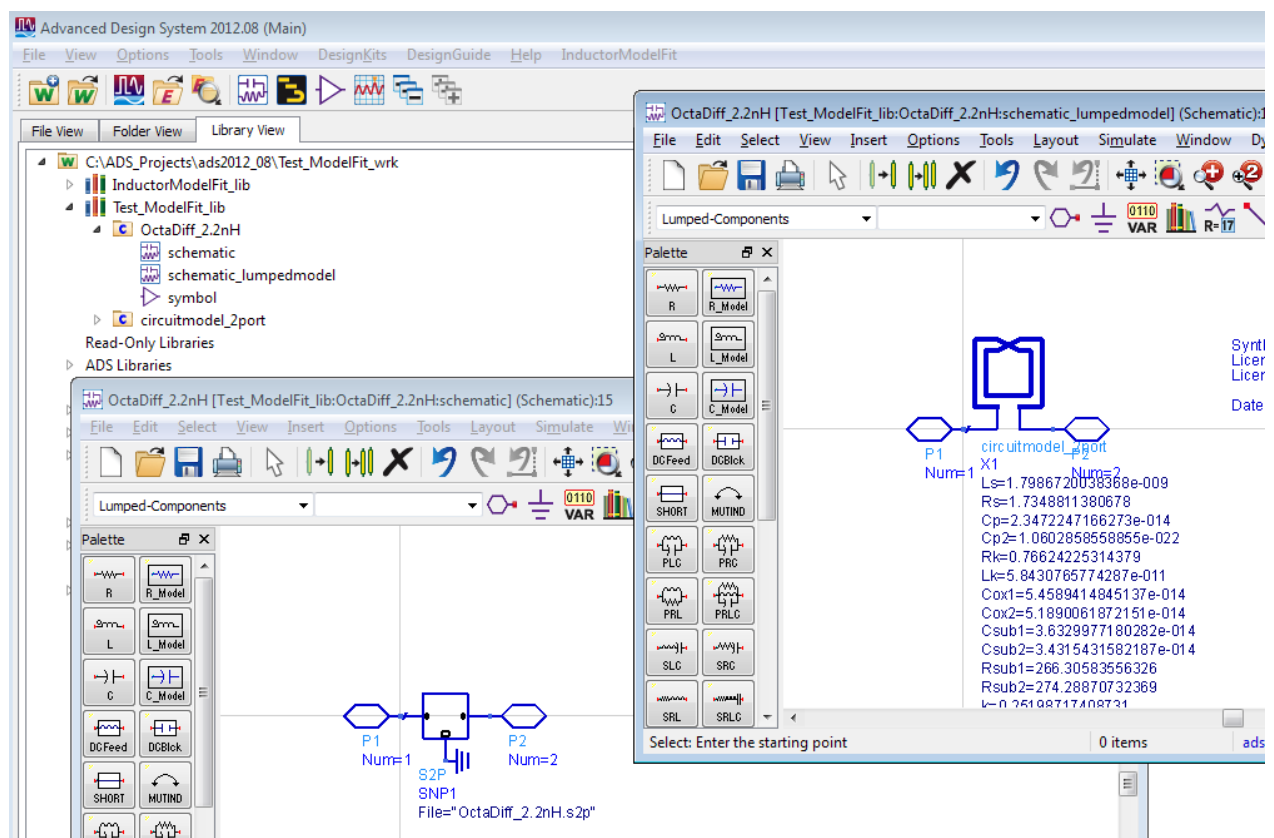
For simulations where you use this cell, you can now use ADS feature Dynamic Model Selection to choose between the S-parameter and equivalent circuit model views with:

If you place the symbol for this cell on a schematic, the simulation will default to the schematic view, which in our case holds the S-parameters. You can switch the simulation to use the schematic_lumpedmodel view by right clicking on an instance on the schematic, and select *Component > Choose View for Simulation...* from the right mouse button menu. See ADS help topic "Dynamic Model Selection".

Data Display Templates and Expressions

InductorModelFit includes several custom expressions for plotting inductor parameters. These are described below.

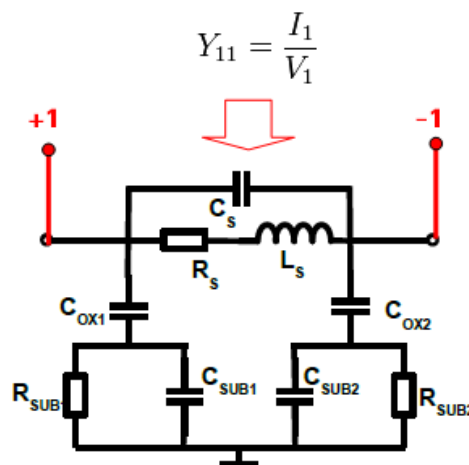## *Single ended and differential operation*

Inductors are simulated with ports on each terminal, so that we have 2-port results for a regular inductor without center tap. From this, we can calculate the results for single ended operation (measured into port 1, with port 2 grounded) or for differential operation (measured differentially between port 1 and 2).

Results depend on this choice, which represents two different ways of using the inductor. The Q factor for single ended configuration is lower, with a lower self resonance frequency (SRF).

Single ended configuration:

$$Y_{11} = \left. \frac{I_1}{V_1} \right|_{V_2=0}$$
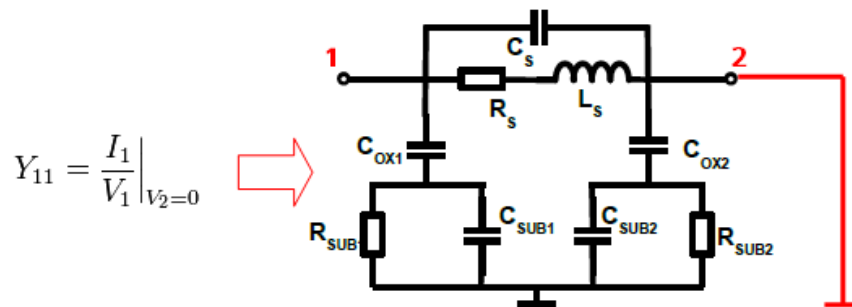
Differential configuration (here shown with one differential port).

$$Y_{11} = \frac{I_1}{V_1}$$

InductorModelFit comes with equations to calculate both single ended and differential results from the 2-port configuration shown above. You do not need to assign differential ports in the ADS simulations. The differential results are obtained by calculation in the data display.

Custom expressions

The following custom expressions are included with InductorModelFit:

Expression	Description
Ldiff(S)	Series inductance for differential mode between port 1 and 2, with all other ports open
Qdiff(S)	Q factor for differential mode between port 1 and 2, with all other ports open
Rdiff(S)	Effective series resistance for differential mode between port 1 and 2, with all other ports open
L1port(S)	Series inductance for a 1-port
Q1port(S)	Q factor for a 1-port
Lser(S)	Effective series inductance between port 1 and 2, excluding shunt effects $Lser = imag((Z(1,1)*Z(2,2)-Z(1,2)*Z(2,1))/Z(2,1)) / \omega$
Rser(S)	Effective series resistance between port 1 and 2, excluding shunt effects $Rser = real((Z(1,1)*Z(2,2)-Z(1,2)*Z(2,1))/Z(2,1))$
Qser(S)	Single ended Q factor from Y11 (with all other ports shorted)
Cshunt2(S)	Shunt capacitance to ground for 2-port data (one side)
Rshunt2(S)	Shunt resistance to ground for 2-port data (one side)

You can use these on your data display forms to plot inductor parameters.
A data display template is supplied to plot the L,R,Q curves using these expression, for single ended and differential operation.

Changes

Document version 1.2 of 12. March 2014:
Updated for software version 1.2.0 with new file selection dialog.

Document version 1.0 of 14. January 2014:
Initial version