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EMX Virtuoso interface tutorial

March 2015

Integrand Software, Inc.

Introduction

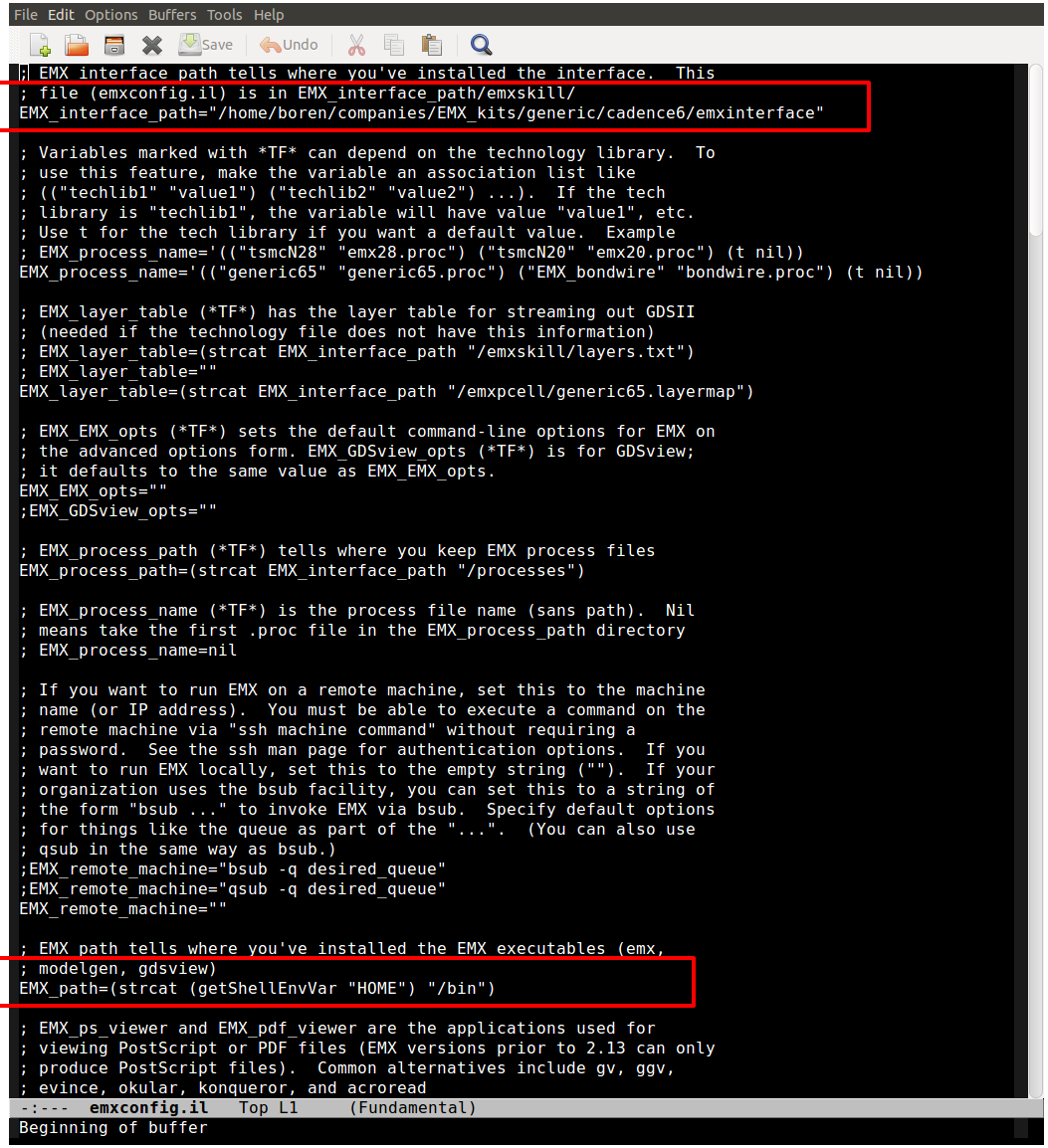
- The Cadence Virtuoso interface is provided along with EMX for users who want the convenience of Virtuoso as the GUI for EMX.
- Several features have been added to allow EMX simulations and Modelgen models to be directly incorporated into a design flow with Cadence.
- The interface supports most of the EMX command-line options
- A suite of examples for a generic 65nm process file has been created. Use these examples as a starting point for learning how to use EMX in the Cadence environment.
- Please refer to the "EMX_Virtuoso_Reference" for more details about the GUI.

Installing EMX and Modelgen

- EMX and Modelgen can be downloaded from
  - http://integrandsoftware.com/emx
  - http://integrandsoftware.com/modelgen
- Contact support@integrandsoftware.com for license files.
- Obtain the EMX interface from Integrand (emxinterface_date.tar.gz)
- The EMX manual is distributed with the tarball and is called “manual.pdf” and there is a gdsview manual called “gdsviewmanual.pdf”. Please read these manuals before using EMX.

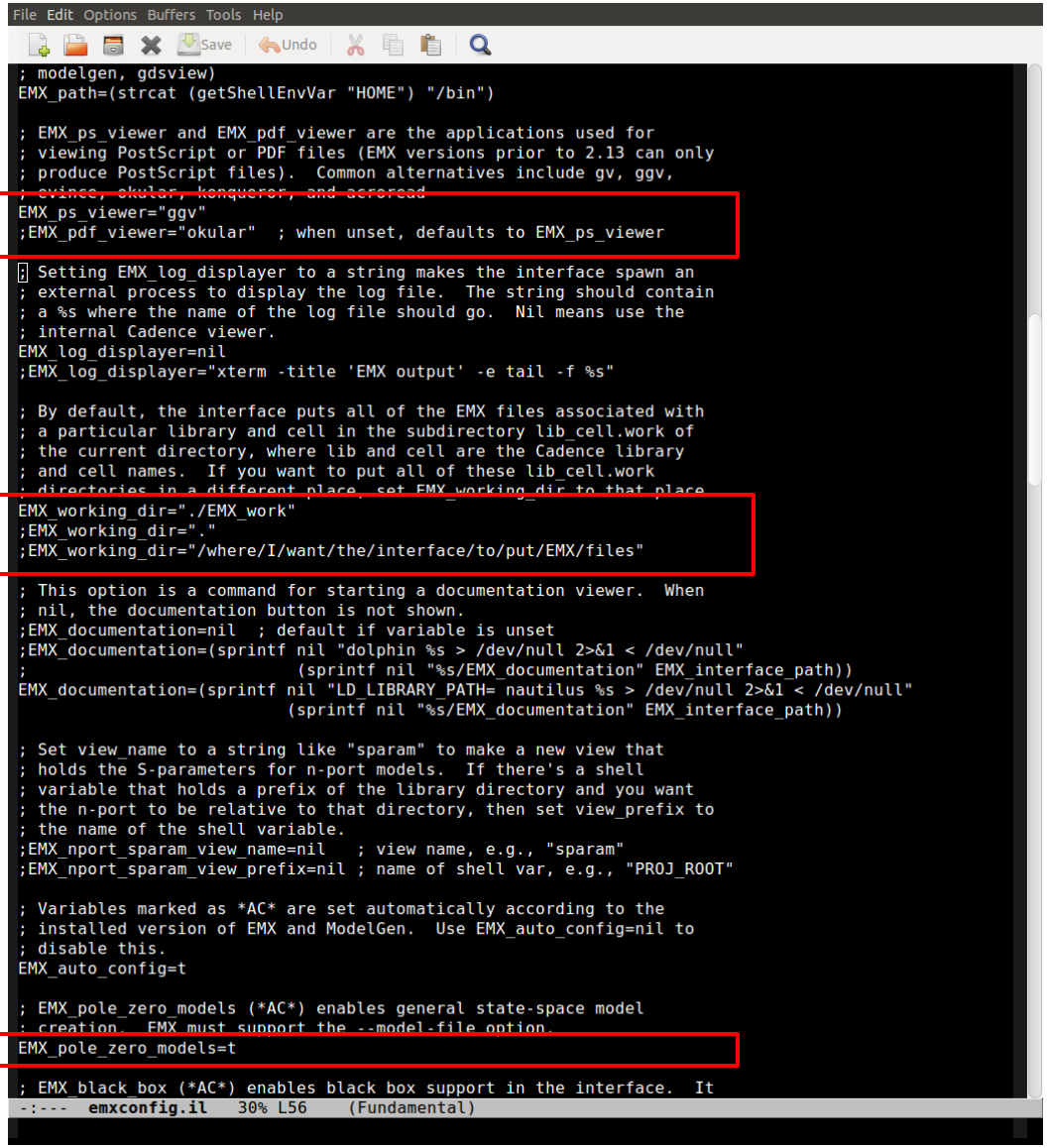
Interface setup

- Install EMX and Modelgen in the **same directory**.
- Modify the file "emxskill/emxconfig.il"
- Set the EMX_interface_path
- Set the EMX_path
- Set the postcript viewer EMX_ps_viewer
- Set the work directory
- There is a .cdsinit file that loads the interface.
- You can modify your .cdsinit file to include the command
  - (load "emxskill/emxconfig.il")



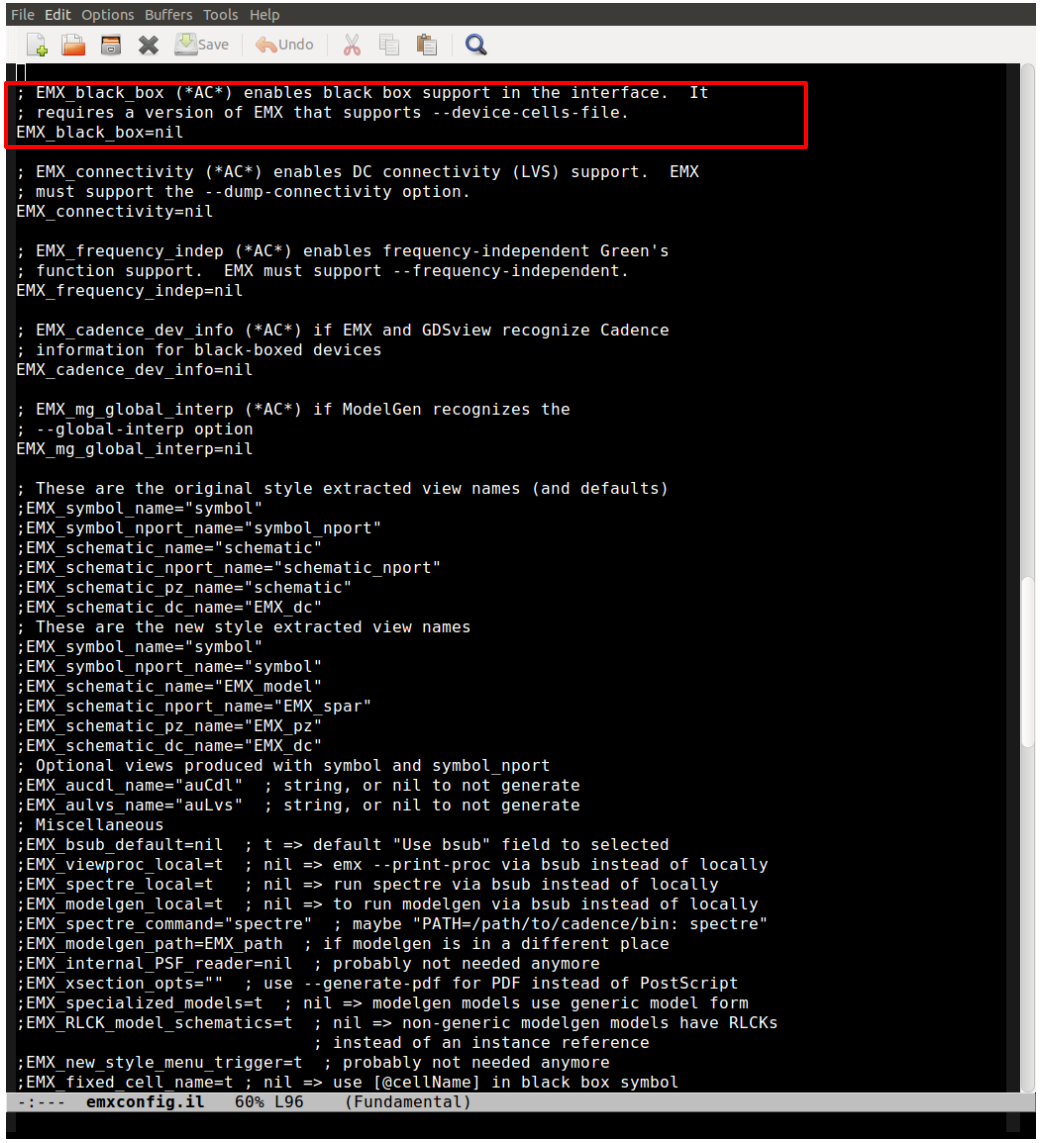
Interface setup (continued)

- Set the work directory
- There is a .cdsinit file that loads the interface.
- Set the pole zero model button to "t" if you have licensed this feature
- You can change the default Linux viewer for the documentation from nautilus to the viewer installed on your system



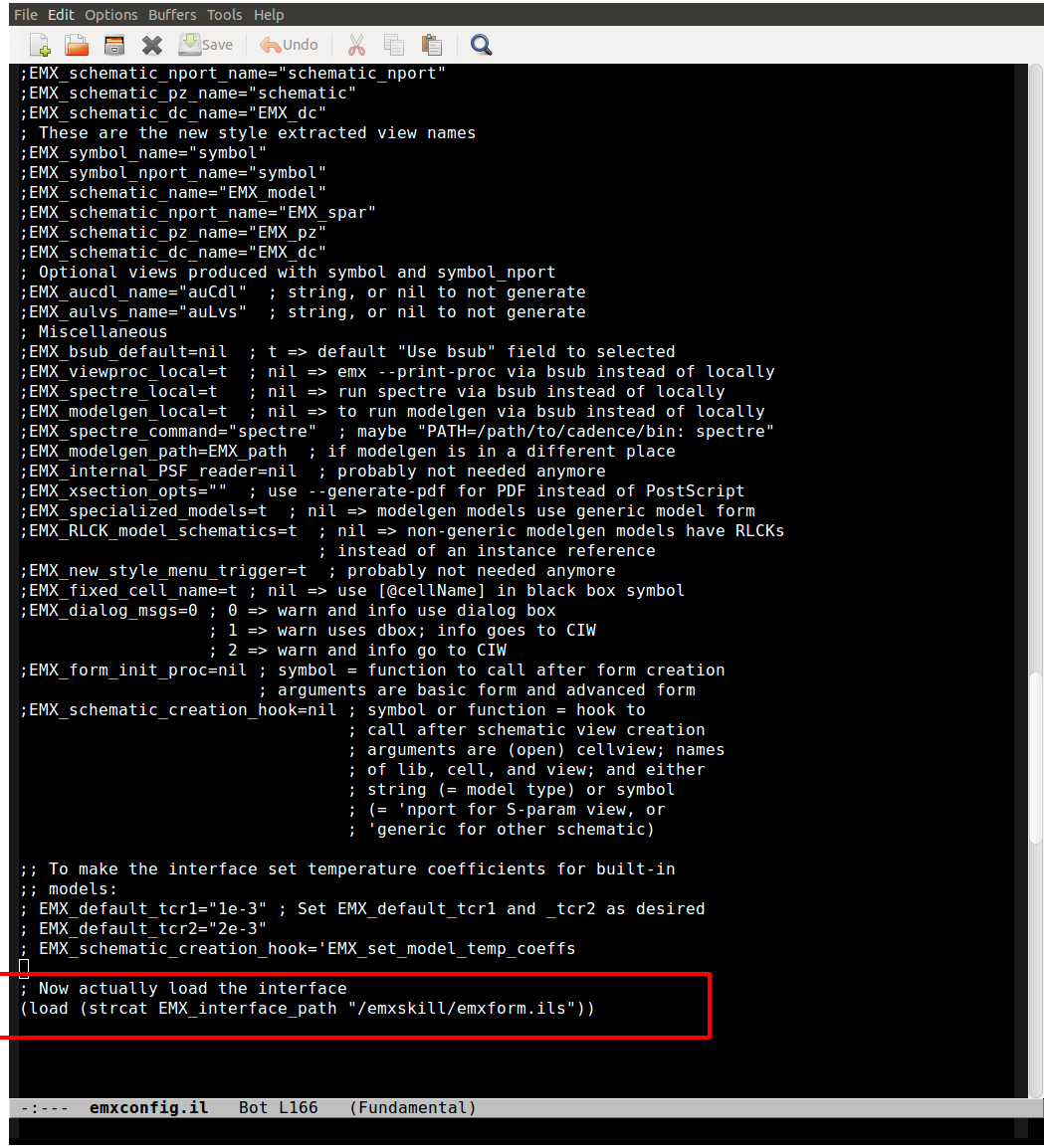
Interface setup (continued)

- Set the black box button to "t" if you want to use black box features.
- There are a number of options that can be modified by the user.
- The options commented out using ";" are the defaults.



Interface setup (continued)

- This emxinterface can be further customized/modified by users by modifying the file emxskill/emxform.ils



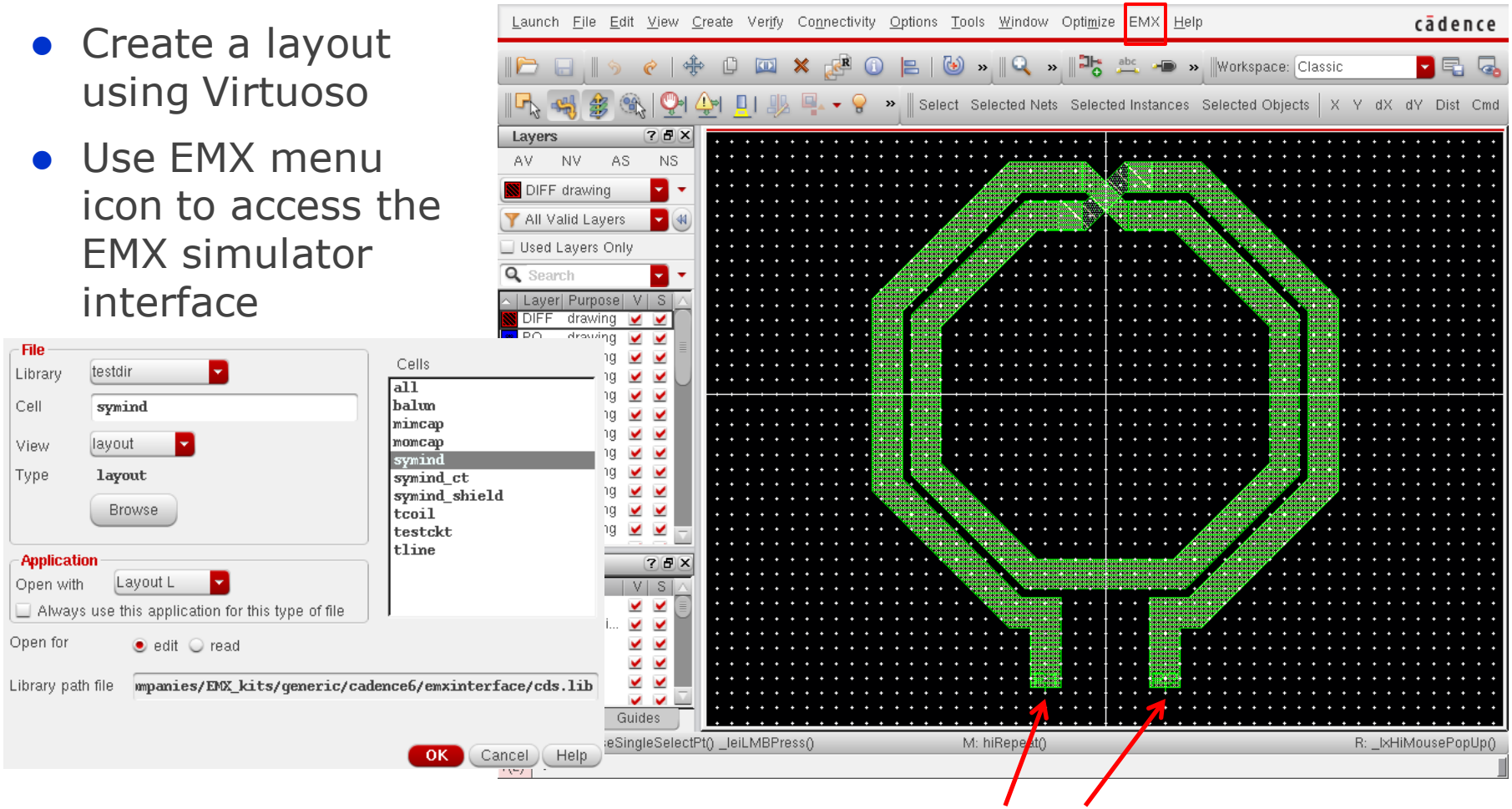
Using the Interface (overview)

Tutorial material

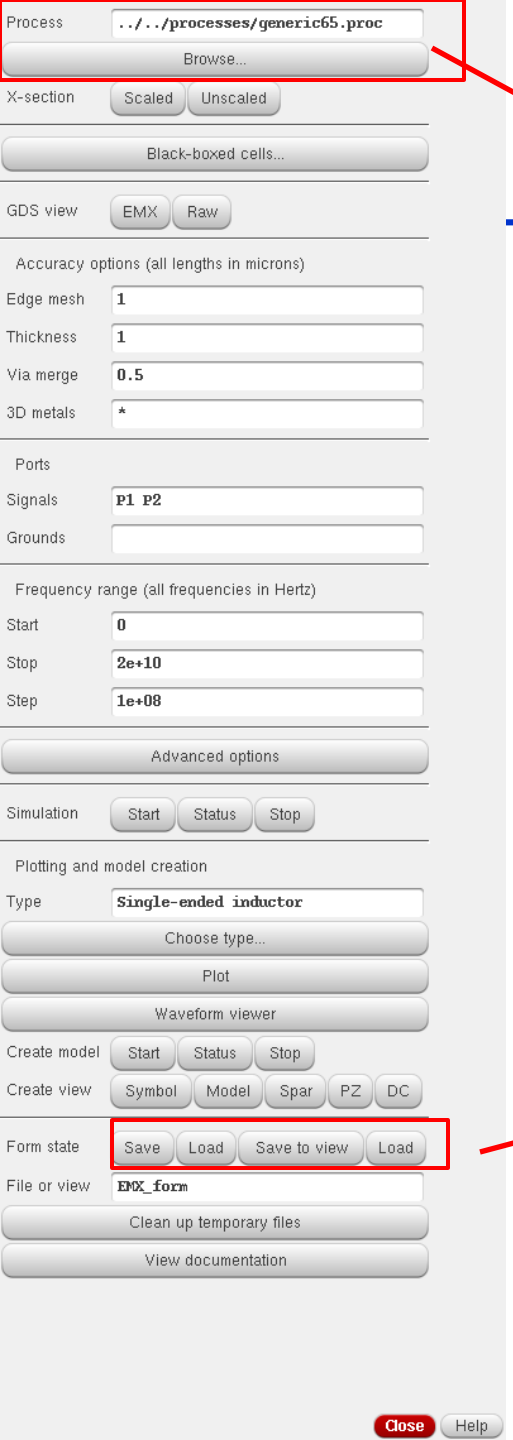
- Several examples have been set up for this tutorial.
- These examples can be used to learn about the various features of the Cadence interface.
- Examples include
  - symind (symmetric inductor)
  - symind_ct (center tapped inductor)
  - symind with shield
  - balun
  - momcap
  - mimcap
  - tcoil
  - transmisson line

Virtuoso Layout

- Create a layout using Virtuoso
- Use EMX menu icon to access the EMX simulator interface



In this example the ports P1 and P2 are labels on the drawing layer



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Generic 65nm .proc file. It is an ASCII file that should be created from the appropriate design manual. See the EMX manual for setting up a process file.

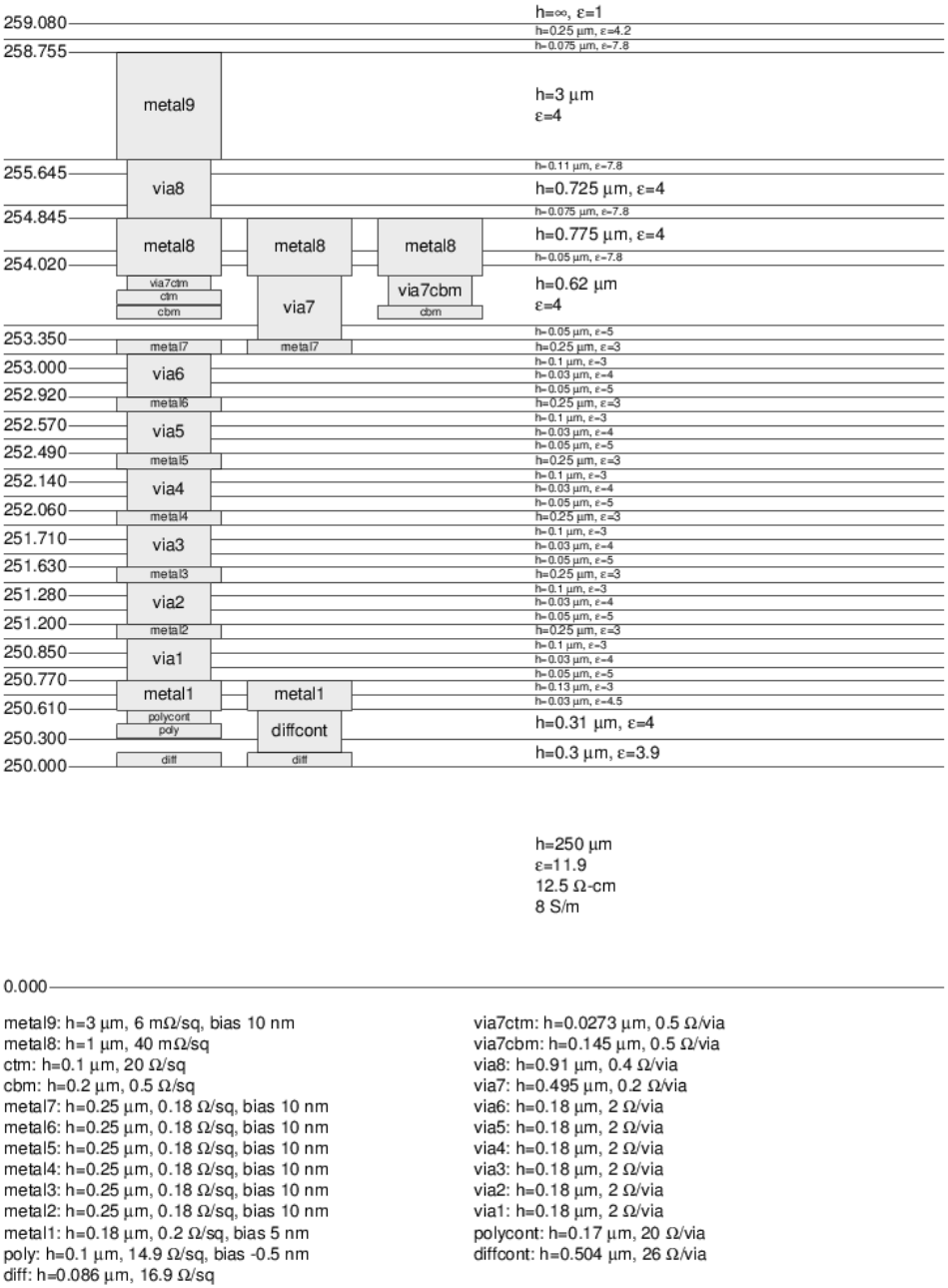
EMX simulator interface

Use load state to get the settings for the various examples. These are text files that can be stored in the EMX_work directory or in the cell view.

Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help

View the process

This is a postscript/PDF file generated by EMX.



metal9: h=3 µm, 6 mΩ/sq, bias 10 nm
metal8: h=1 µm, 40 mΩ/sq
ctm: h=0.1 µm, 20 Ω/sq
cbm: h=0.2 µm, 0.5 Ω/sq
metal7: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal6: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal5: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal4: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal3: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal2: h=0.25 µm, 0.18 Ω/sq, bias 10 nm
metal1: h=0.18 µm, 0.2 Ω/sq, bias 5 nm
poly: h=0.1 µm, 14.9 Ω/sq, bias -0.5 nm
diff: h=0.086 µm, 16.9 Ω/sq

via7ctm: h=0.0273 µm, 0.5 Ω/via
via7cbm: h=0.145 µm, 0.5 Ω/via
via8: h=0.91 µm, 0.4 Ω/via
via7: h=0.495 µm, 0.2 Ω/via
via6: h=0.18 µm, 2 Ω/via
via5: h=0.18 µm, 2 Ω/via
via4: h=0.18 µm, 2 Ω/via
via3: h=0.18 µm, 2 Ω/via
via2: h=0.18 µm, 2 Ω/via
via1: h=0.18 µm, 2 Ω/via
polycont: h=0.17 µm, 20 Ω/via
diffcont: h=0.504 µm, 26 Ω/via

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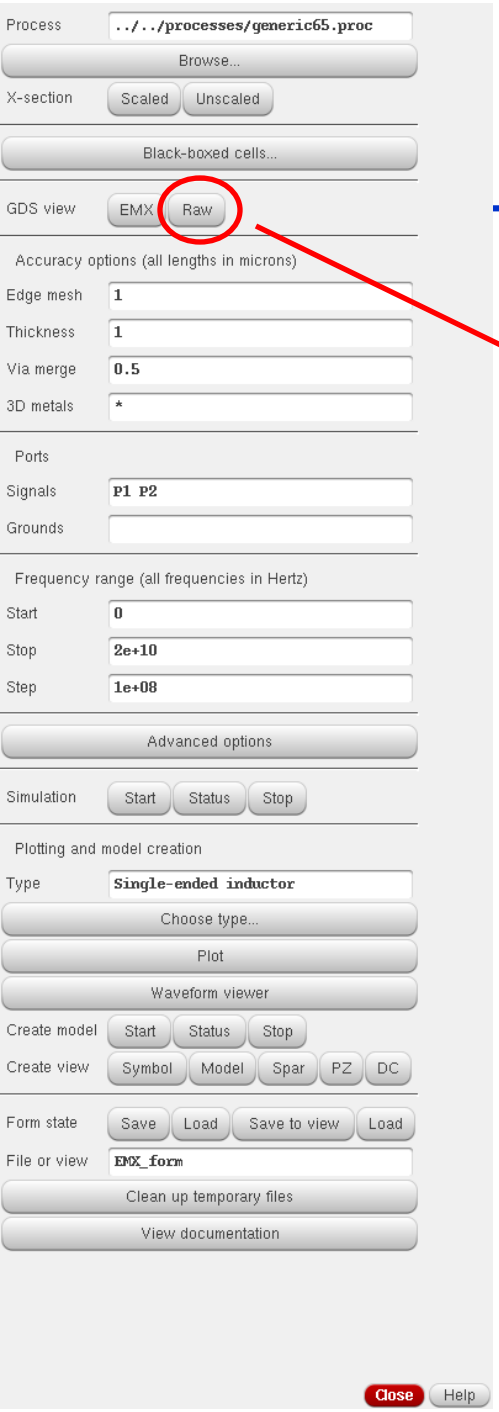
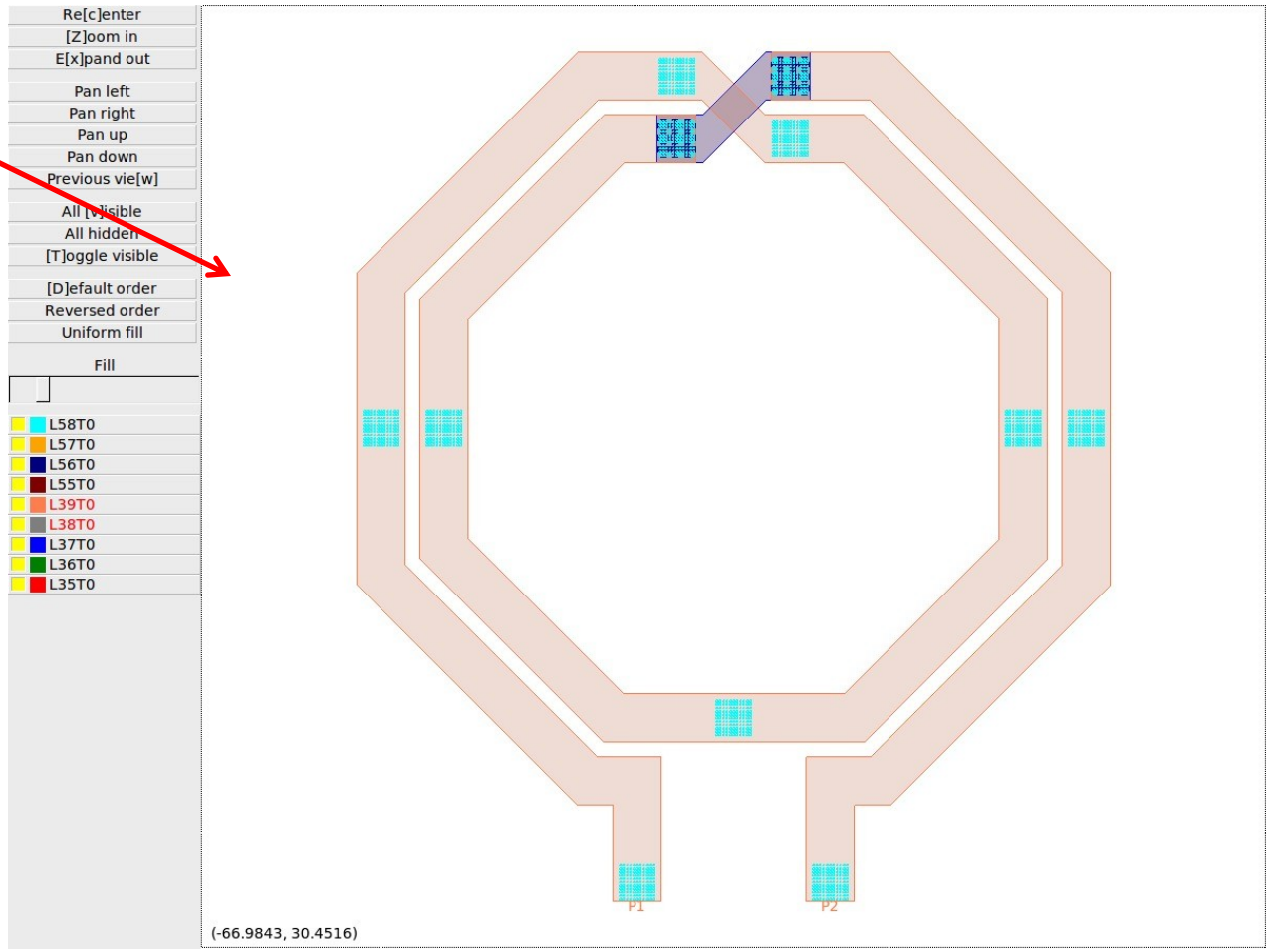
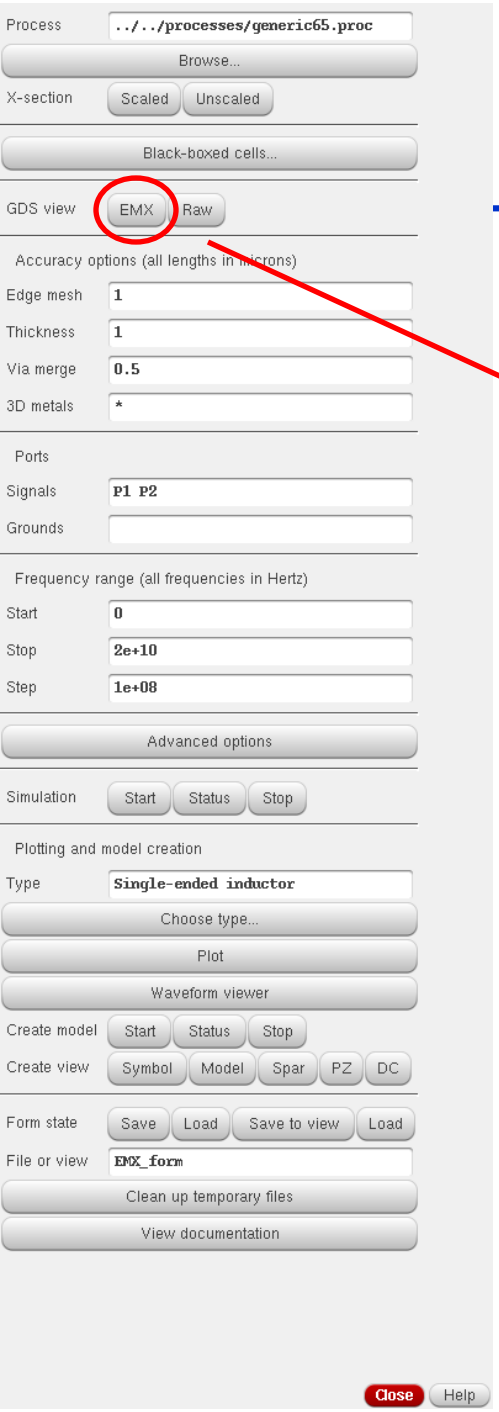
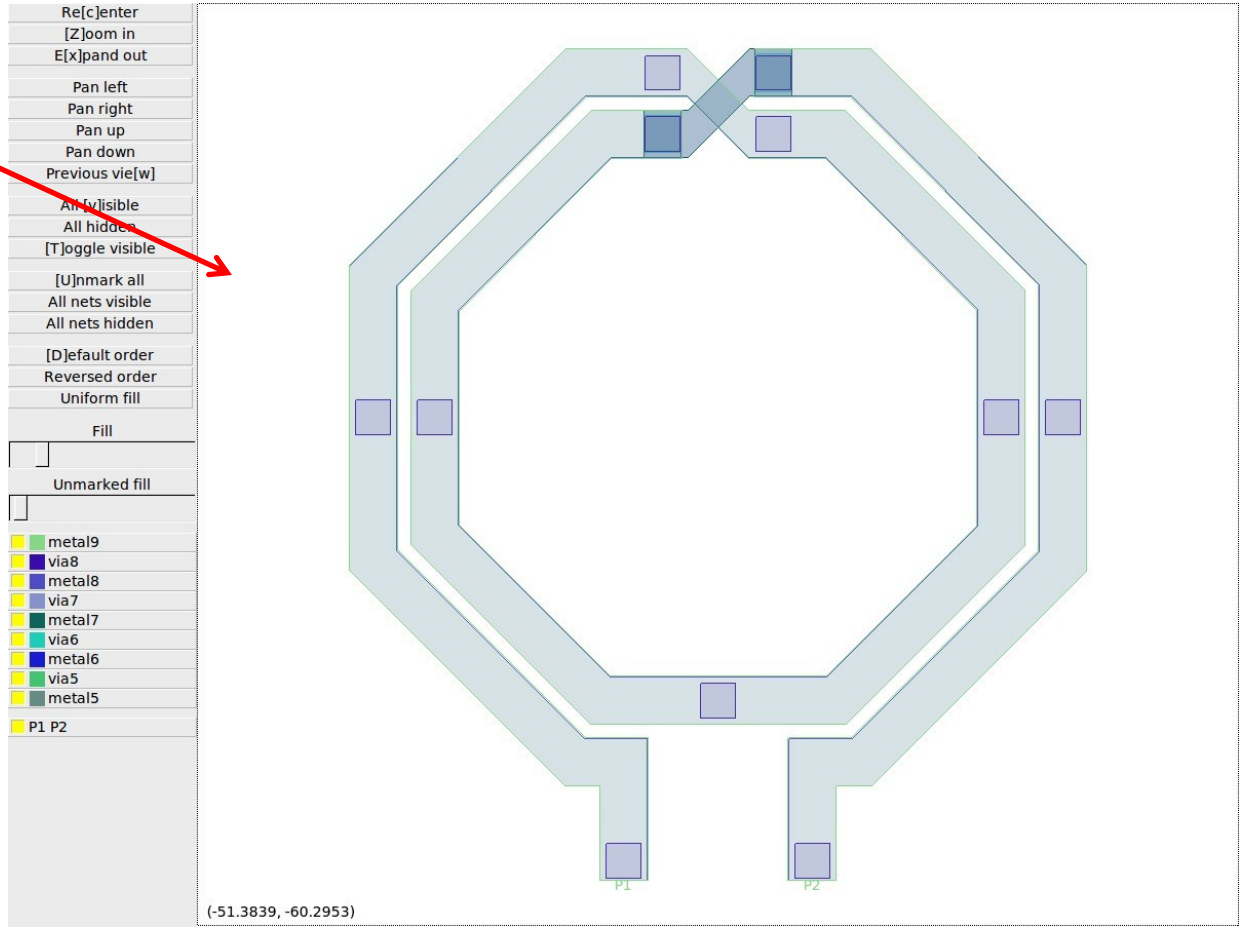




View the raw .gds





View the GDS layout after the rules of the process file are applied (e.g., bias, slotting rules, via merge)

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Run on multi-CPU machine

Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help

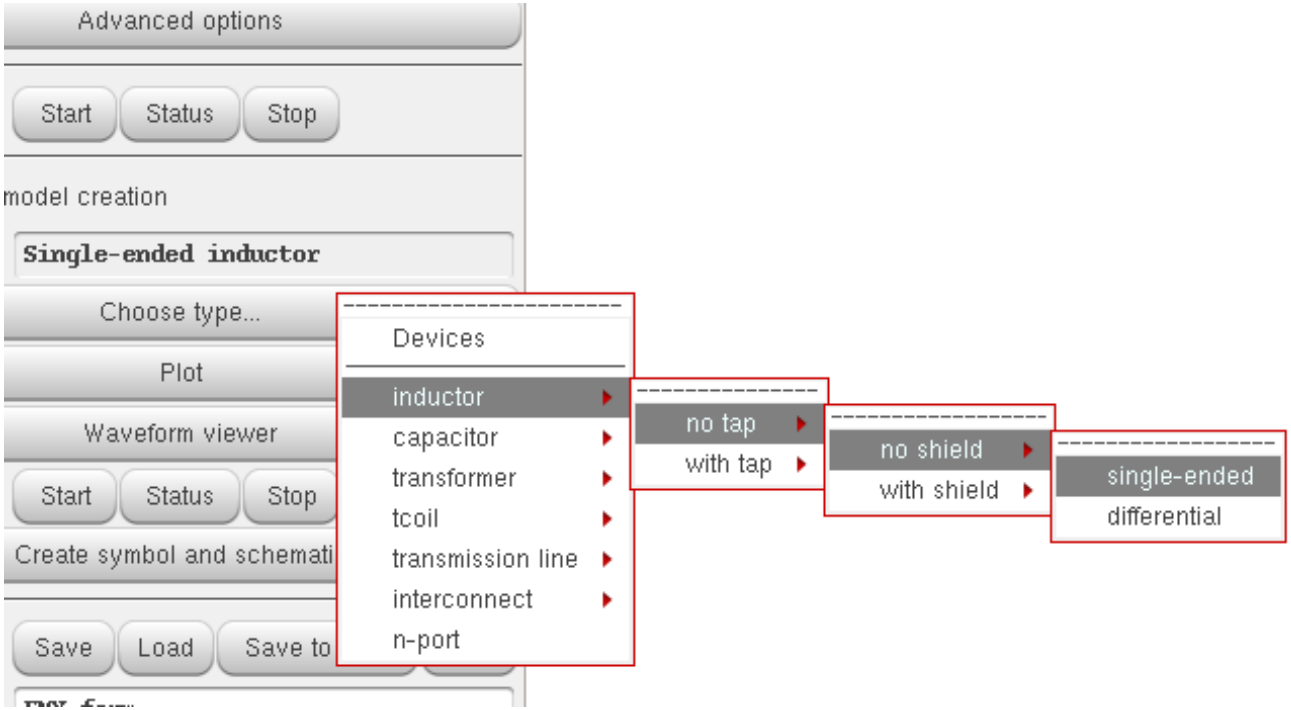
File Help cadence

```
Command line for EMX version 4.4:
-----------------
/home/kapur/emx/emx_v4.4/emx64
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/EMX_work/testdir_symind.work/symind.gds
symind
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/processes/generic65.proc
-e 1 -t 1 -v 0.5 --3d=* -p P000=P1 -p P001=P2 -i P000 -i P001 --sweep 1e+08
2e+10 --sweep-stepsize 1e+08 --verbose=3 --print-command-line -l 2 --quasistatic
--dump-connectivity --parallel=0 --simultaneous-frequencies=2 --format=psf -s
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/EMX_work/testdir_symind.work/symind.raw
-y
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/EMX_work/testdir_symind.work/symind.raw
--format=matlab -y
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/EMX_work/testdir_symind.work/symind.raw/symind.y
--format=touchstone -s
/home/boren/companies/EMX_kits/generic/cadence6/emxinterface/EMX_work/testdir_symind.work/symind.s2p
-----------------
64 CPUs detected
Using soft memory limit of 244.30 GB out of 252.30 GB
Creating mesh...done
13593 basis functions
19582 vector potential elements
7048 scalar potential elements
Ports: P000 P001
6 frequencies for scalar potential interpolation
Building...done
7048 total shapes
Shape memory 55.06 KB
Direct memory 40.99 MB for 19392636 nonzeros
M2L op memory 4.75 MB
Shift op memory 64.22 KB
Moments memory 1.00 MB
Total multipole memory 46.86 MB
Building...done
5626 total shapes
Shape memory 43.95 KB
Direct memory 2.25 MB for 1991636 nonzeros
M2L op memory 0.37 MB
Shift op memory 43.44 KB
Moments memory 0.81 MB
Total multipole memory 3.52 MB
Estimated solve memory per block 10.37 MB
Estimated basis memory 1.87 MB
Available memory 243.92 GB
Up to 2 simultaneous blocks
Simulating at frequency 1.000000e+08...
Simulating at frequency 2.000000e+10...
Ports: P000 P001 @ 1.000000e+08 [0]
```

3

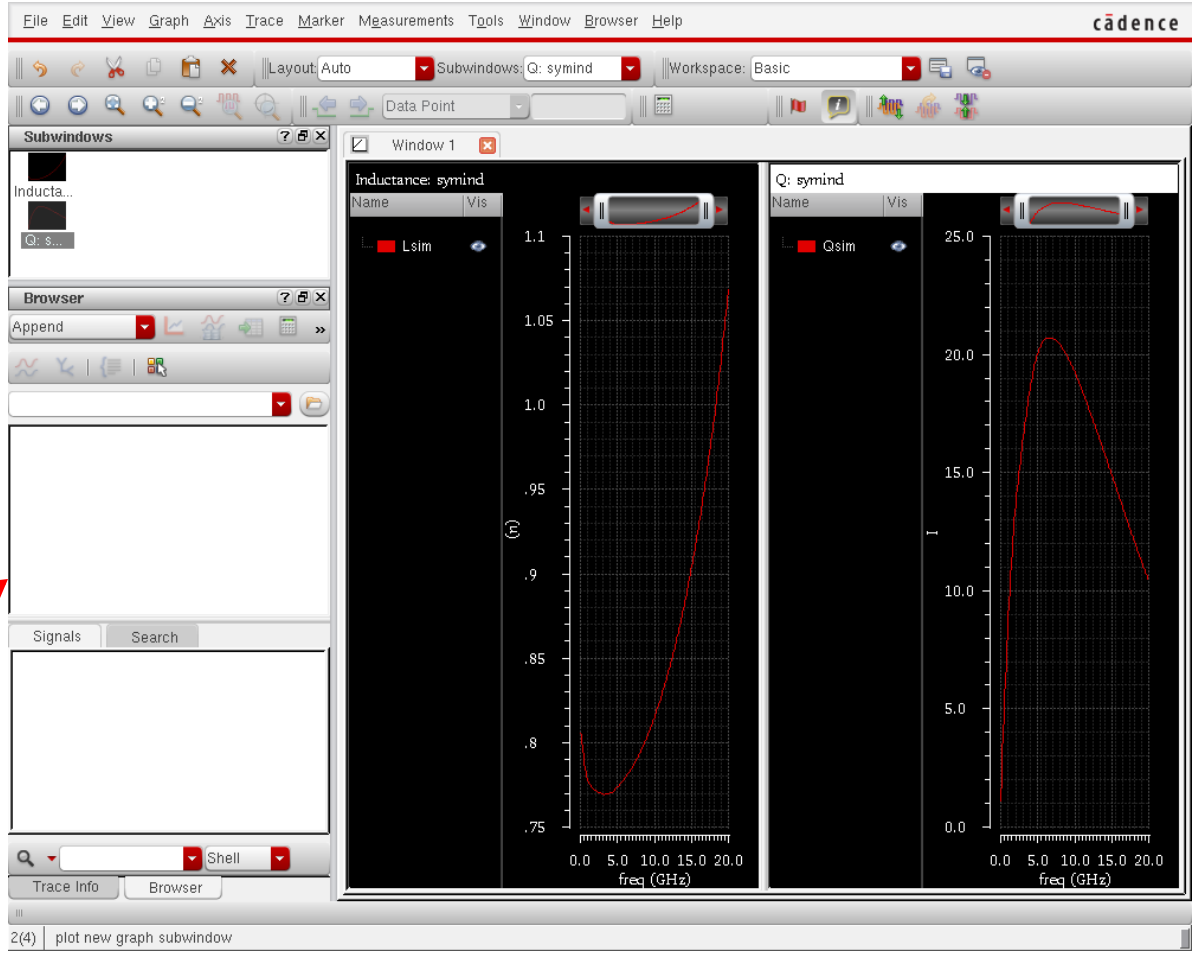
Run EMX to generate S-parameters

Choose model

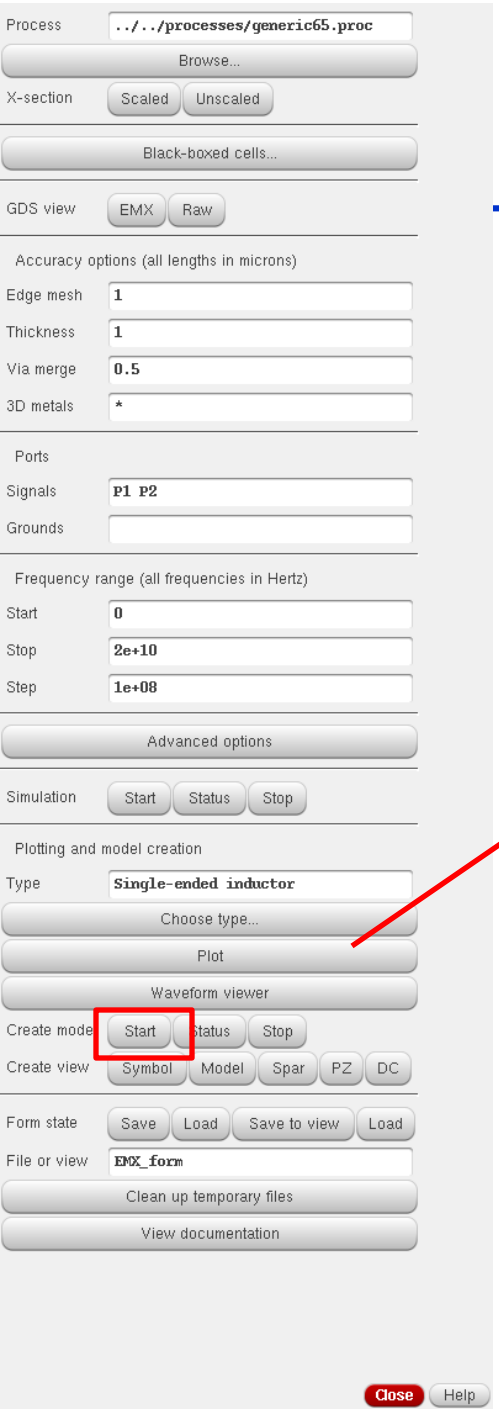


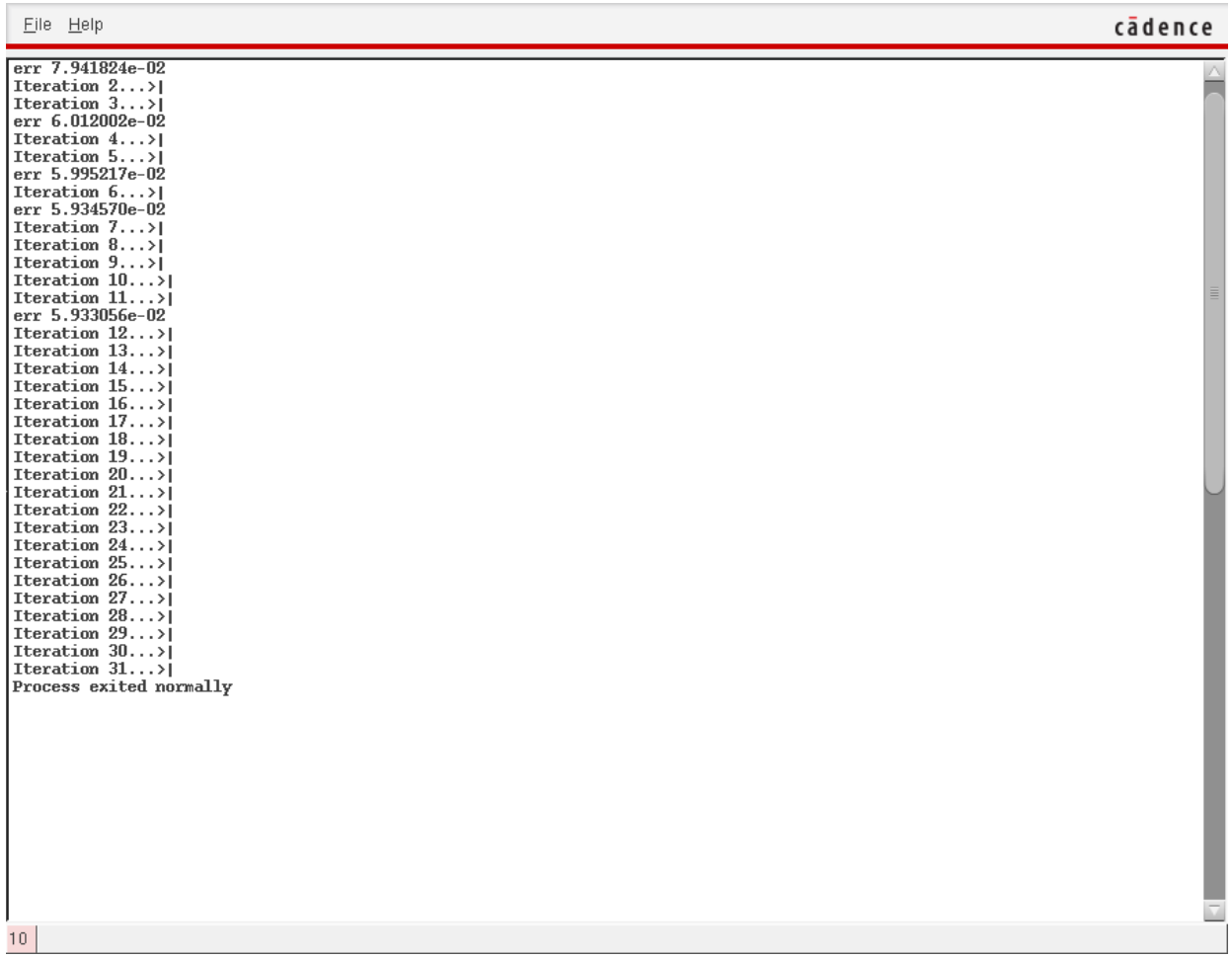
A specific model topology can be chosen using devices, tap,shield, and mode. The model topology that best matches the layout should be chosen.

Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



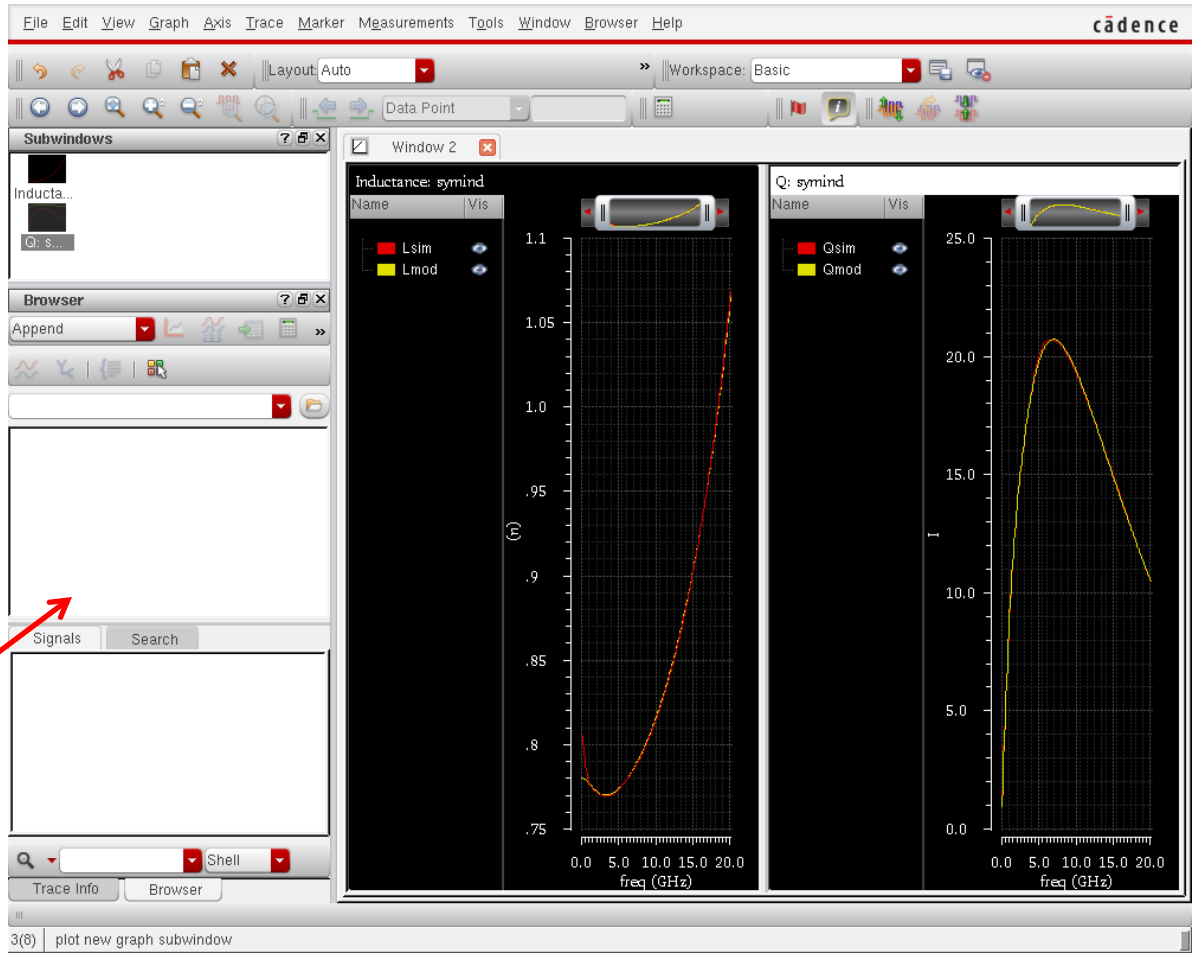
View the L and Q results in single-ended mode





Generate circuit model

Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Compare Model vs EMX simulation: Spectre is used to playback model to check model vs EMX accuracy

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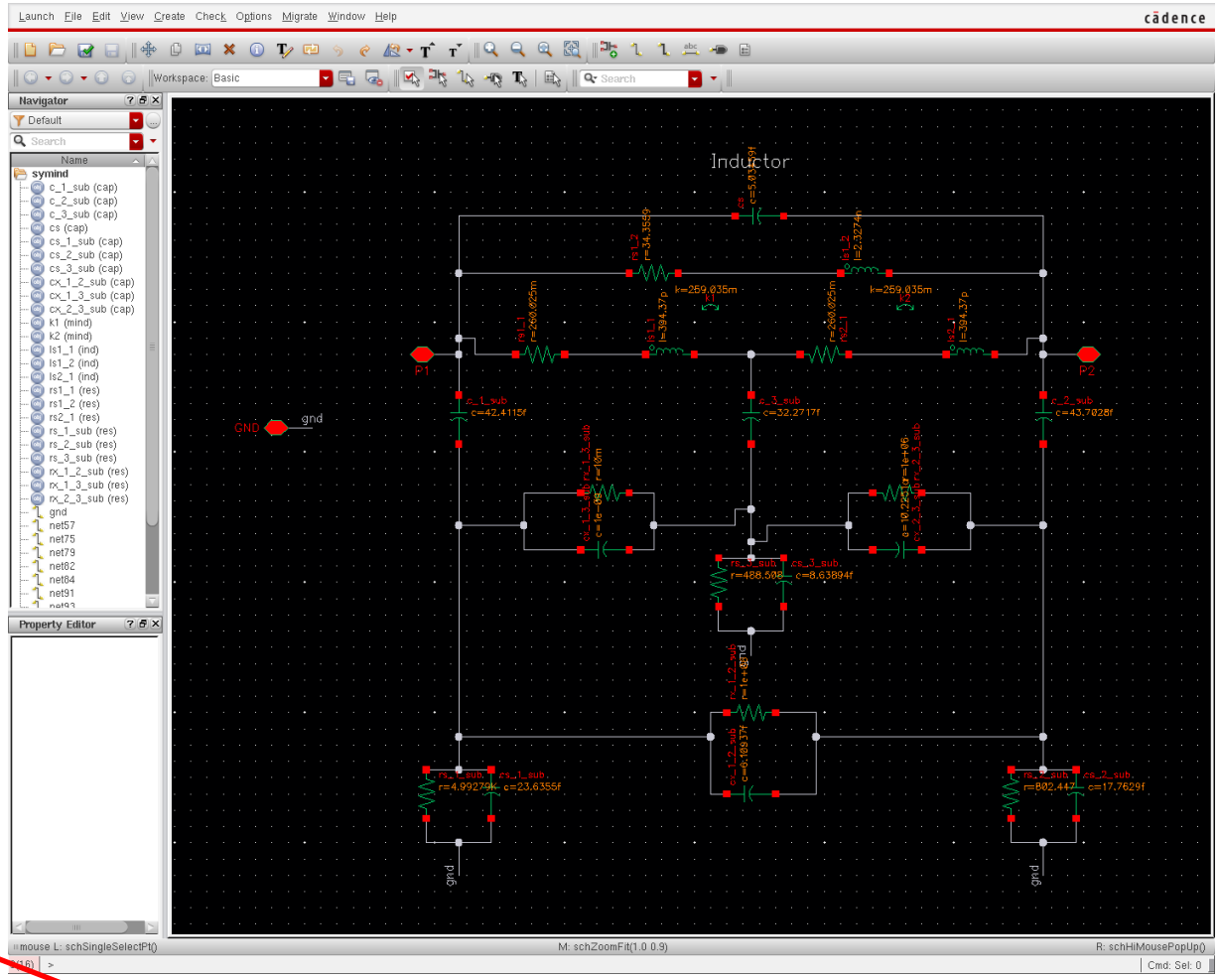
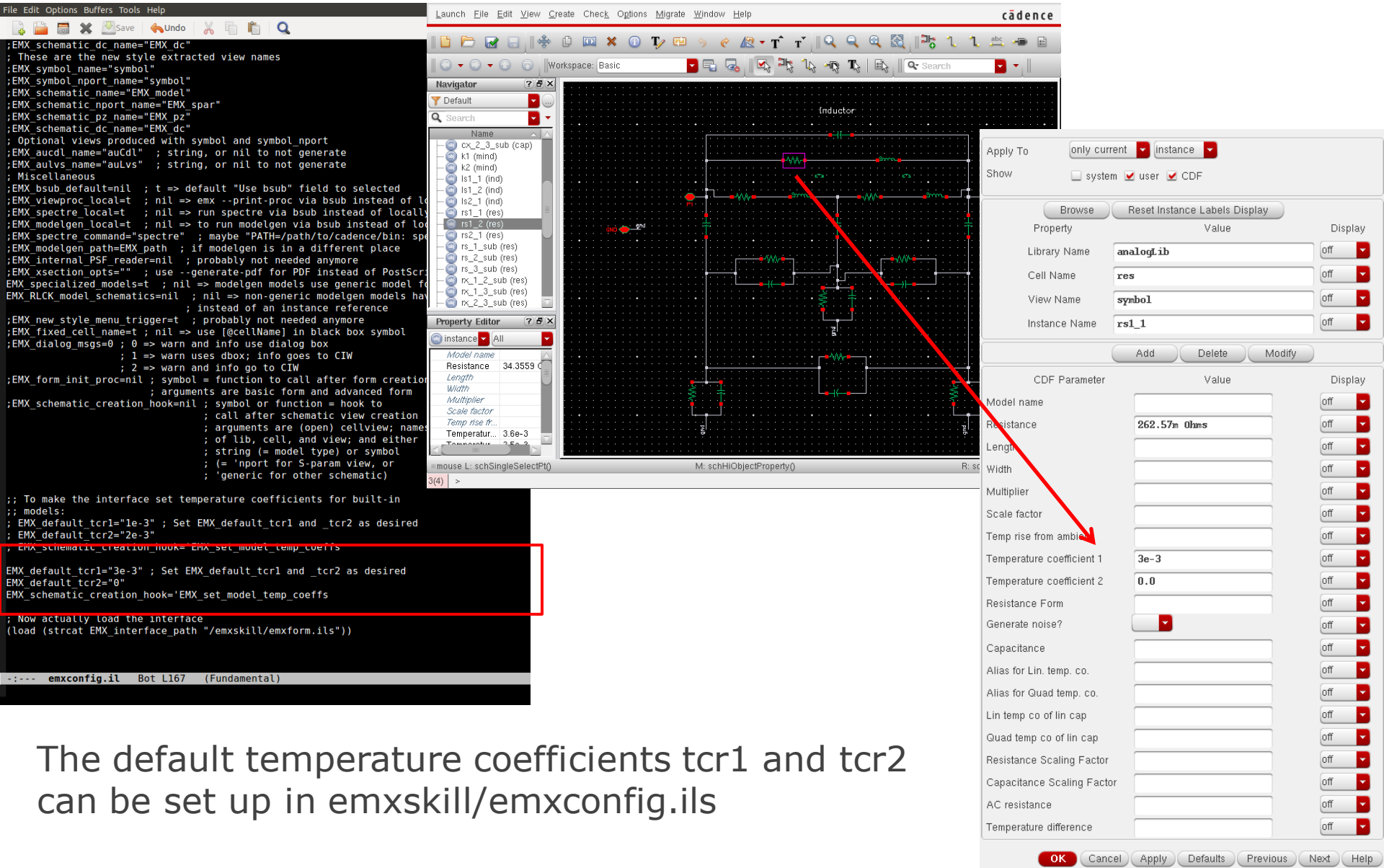
Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Generate Schematic

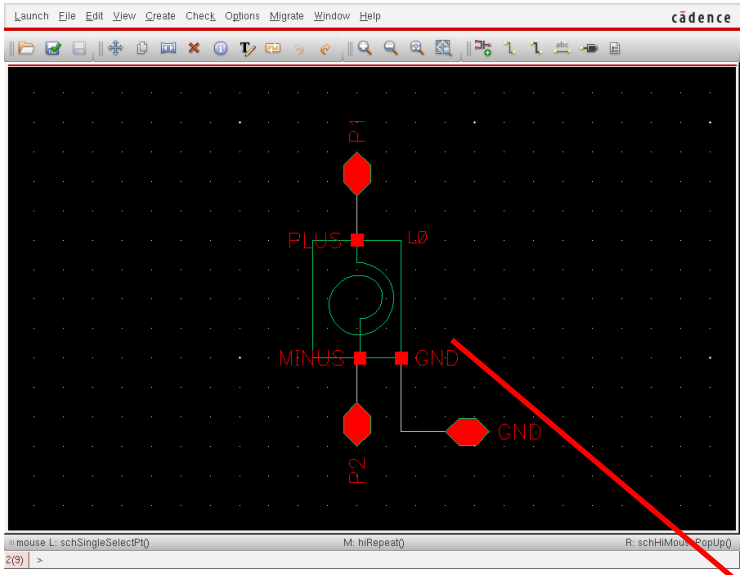
Schematic with temp coefficients



The default temperature coefficients tcr1 and tcr2 can be set up in emxskill/emxconfig.ils

Using symbol/cdf instead of schematic

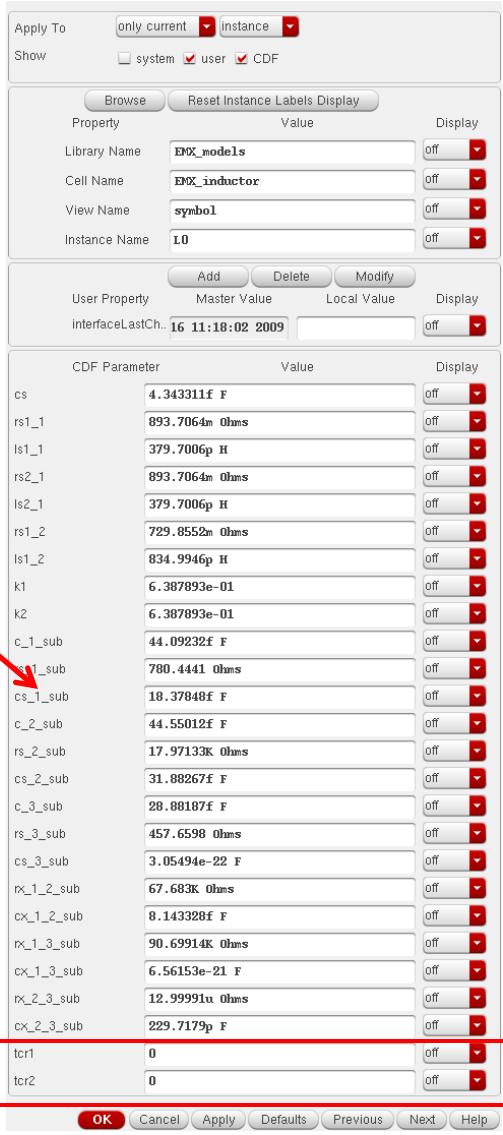
Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Generate symbol with CDF parameters for the model
NOTE:the configuration option

EMX_RLCK_model_schematics=nil
will have to be set)

Temperature coefficients can be set



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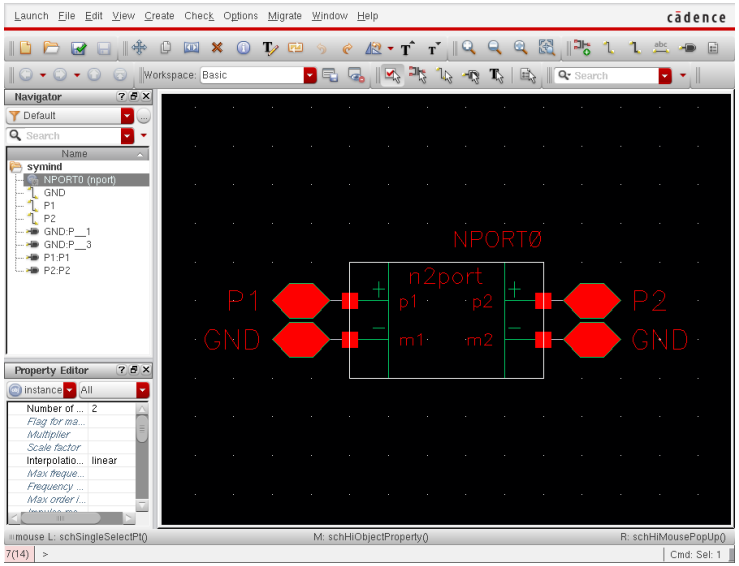
Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar P2 DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Generate schematic_nport which points to S=parameters

Apply To only current instance
Show system user CDF
Browse Reset Instance Labels Display

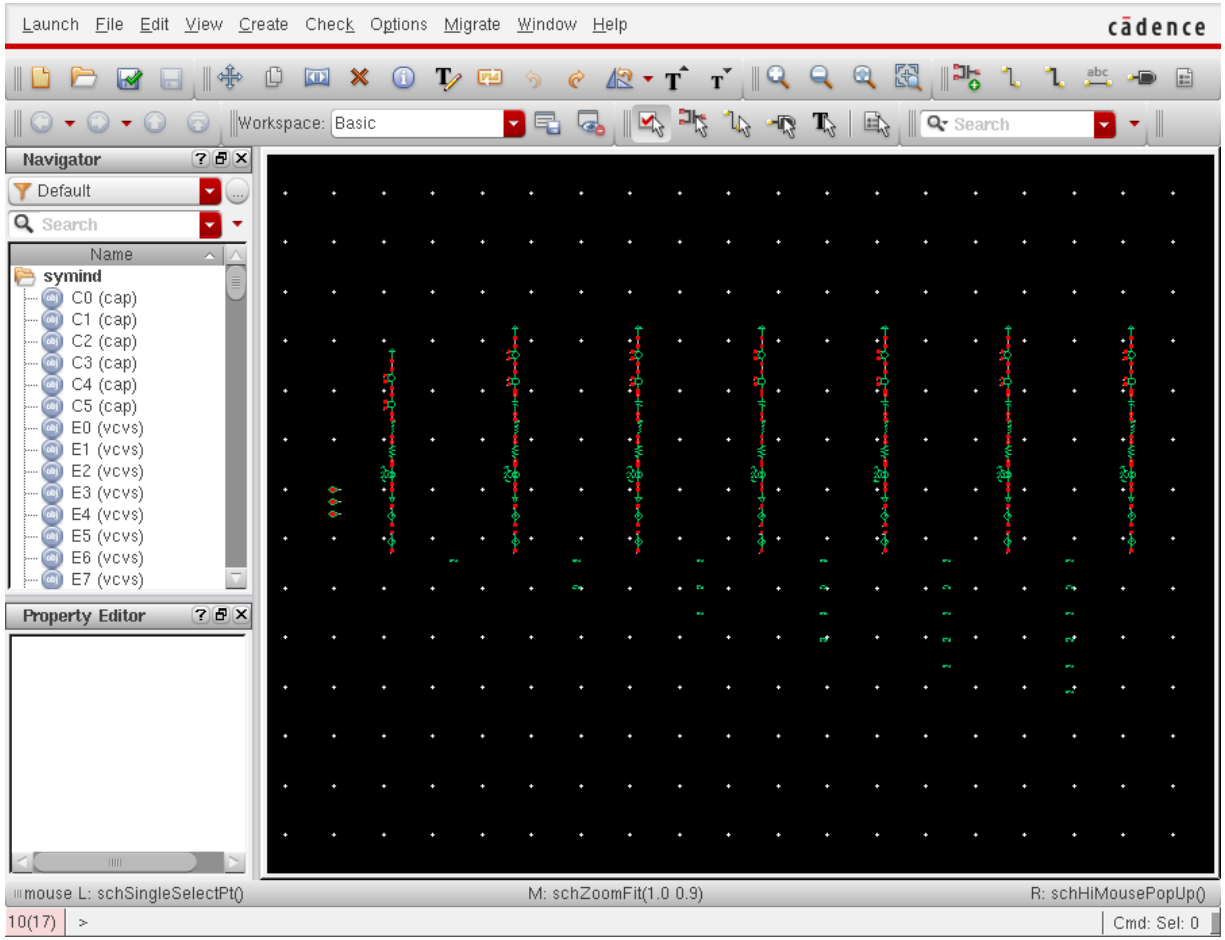
Property	Value	Display
Library Name	analogLib	off
Cell Name	nport	off
View Name	symbol	off
Instance Name	NPORT0	off

Add Delete Modify

CDF Parameter	Value	Display
Number of Ports	2	off
Flag for matrix form input		off
Multiplier		off
Scale factor		off
Interpolation method	linear	off
Max frequency of interest		off
Frequency sampling interval		off
Max order impulse response		off
Impulse response trunc thresho		off
Data Truncation threschold		off
Thermal Noise	yes	off
Use smooth data windowing		off
S-parameter data format	touchstone	off
Thermal noise model		off
Noise Correlation	real	off
DC extrapolation	constant	off
High Frequency Extrapolation	constant	off
Check Passivity	no	off
Passivity Tolerance	1e-06	off
Causality Correction	no	off
S-parameter data file	_symind.work/symind.s2p	off

OK Cancel Apply Defaults Previous Next Help

Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Generate Schematic using EMX PZ model

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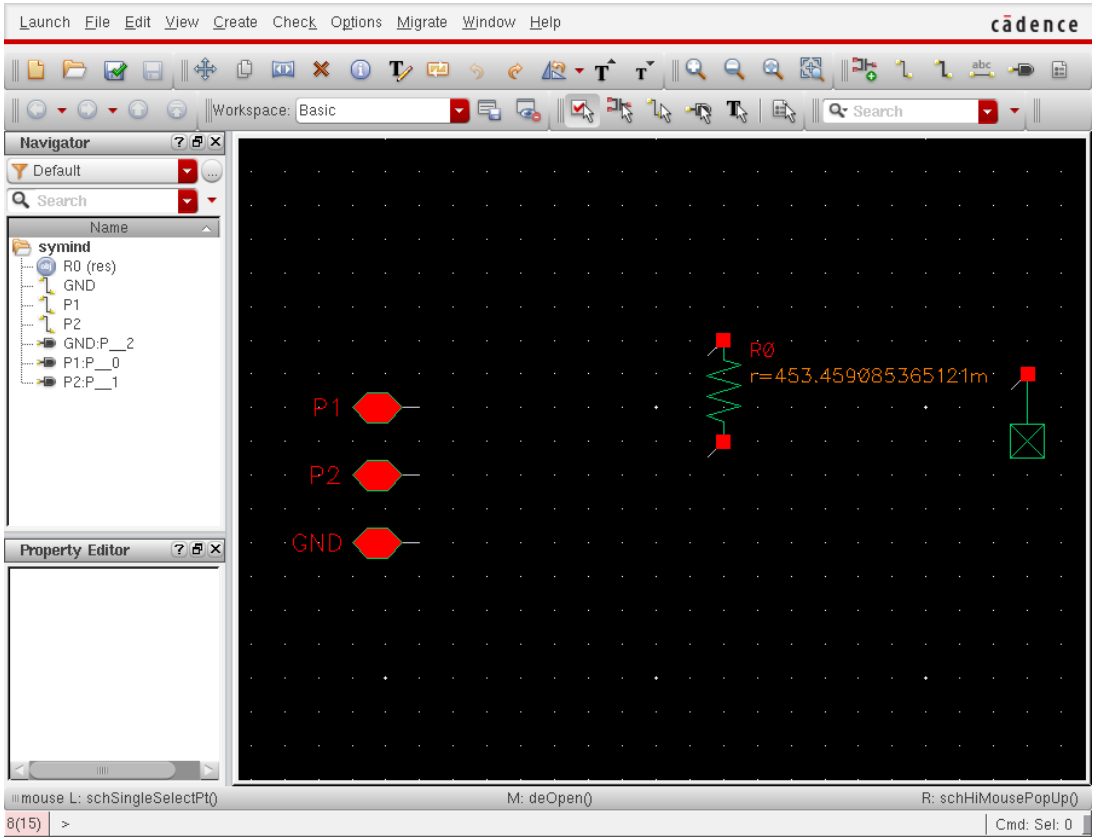
Process ../../processes/generic65.proc
Browse...
X-section Scaled Unscaled
Black-boxed cells...
GDS view EMX Raw
Accuracy options (all lengths in microns)
Edge mesh 1
Thickness 1
Via merge 0.5
3D metals *
Ports
Signals P1 P2
Grounds
Frequency range (all frequencies in Hertz)
Start 0
Stop 2e+10
Step 1e+08
Advanced options
Simulation Start Status Stop
Plotting and model creation
Type Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model Start Status Stop
Create view Symbol Model Spar PZ DC
Form state Save Load Save to view Load
File or view EMX_form
Clean up temporary files
View documentation
Close Help



Generate schematic at DC which can be used for LVS purposes

Using Cadence pins (symind_ct example)

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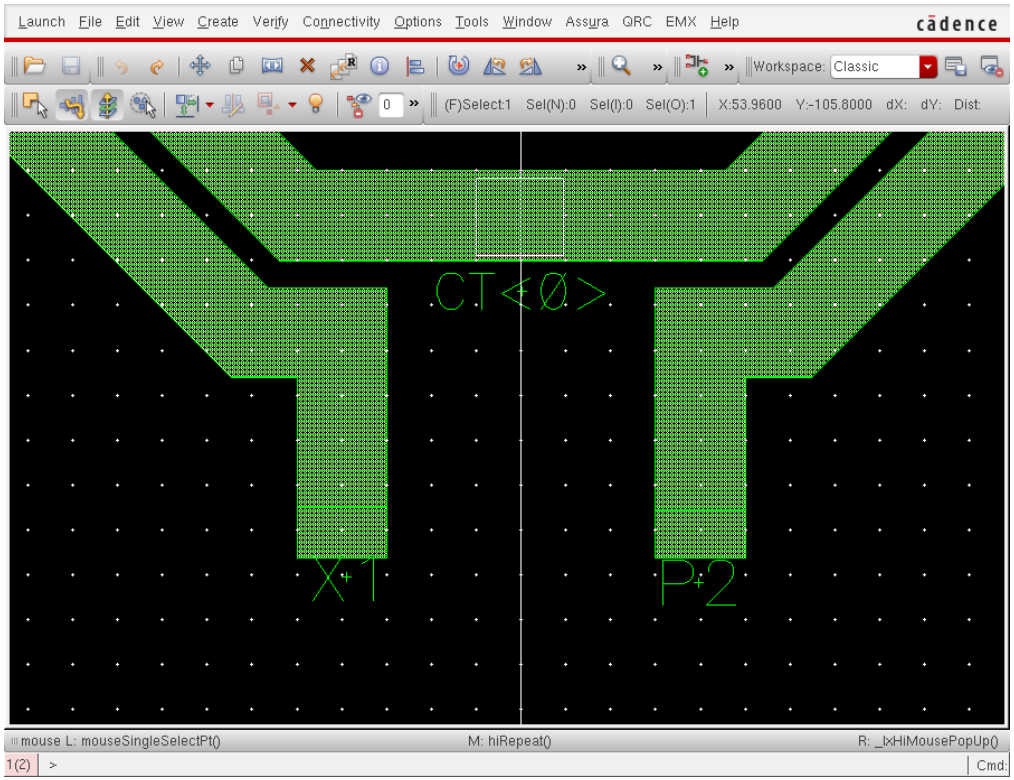
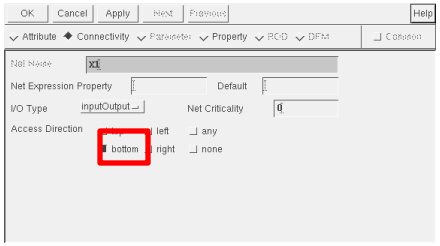
Cadence pins can be used for ports. The pin layer should be included in the process file

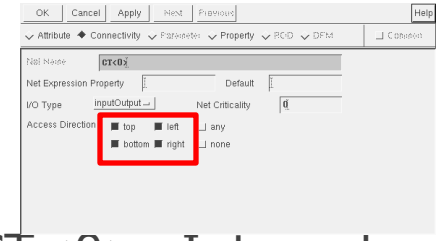
Pins with a direction only will be treated as an EMX edge port

Pins with properties for all directions will be treated as internal ports with the size of the pin rectangle being the size of the port





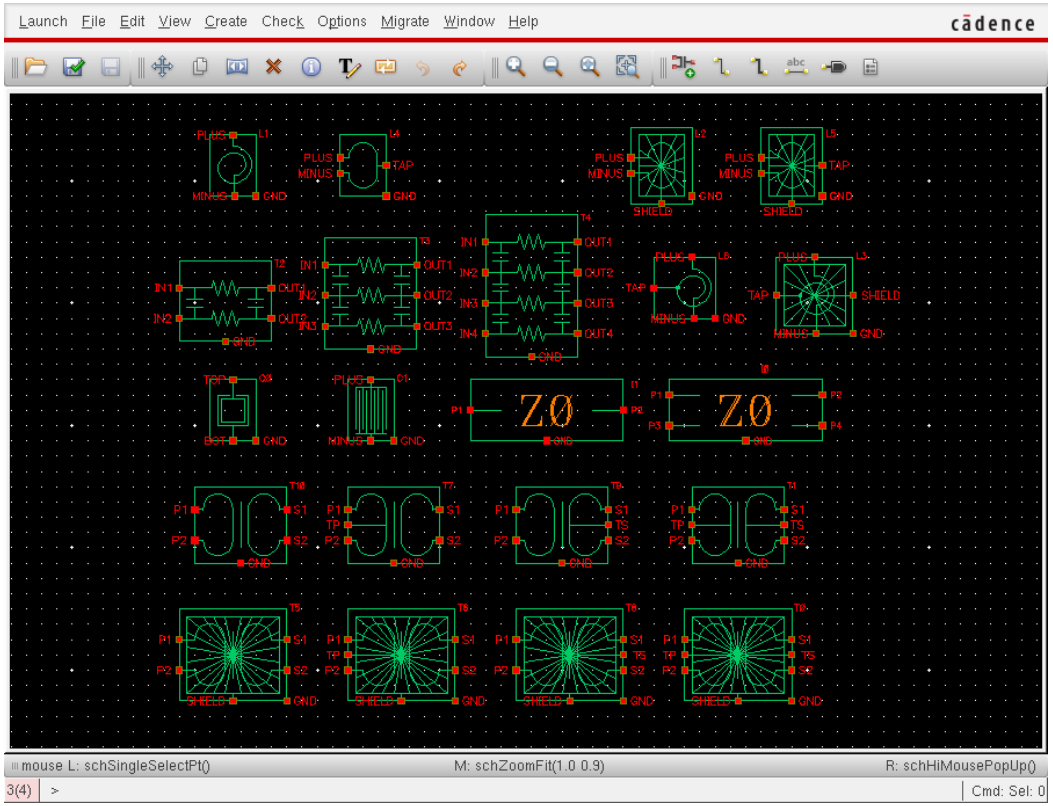
X1: Edge port



CT<0>: Internal port

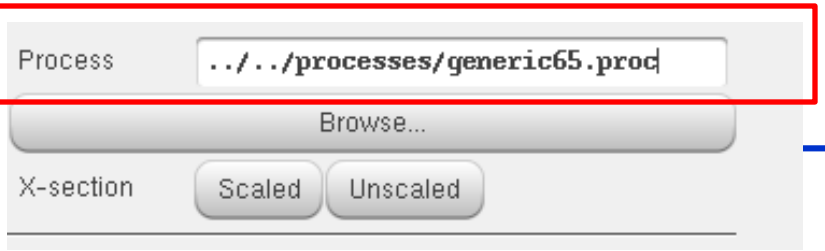
The devices

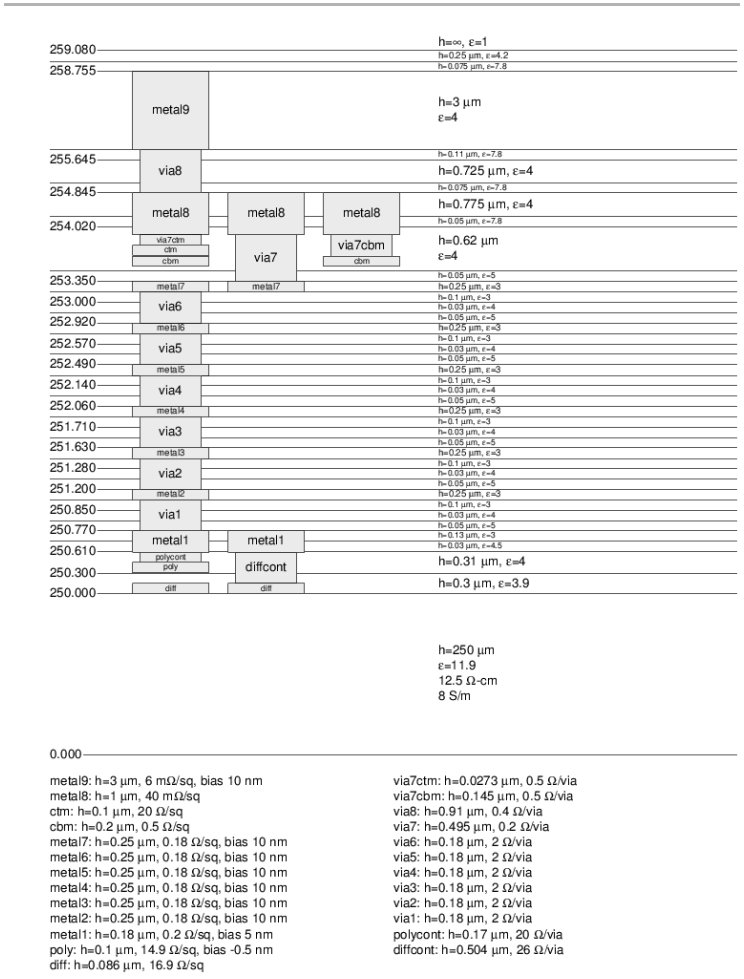
- Inductor
- Tapped inductor
- Shield inductor
- Tapped shield inductor
- Interconnect2
- Interconnect3
- Interconnect4
- Tcoil
- Shield tcoil
- Mim capacitor
- Mom capacitor
- Transmission line
- Differential transmission line
- Transformer
- Tapped primary transformer
- Tapped secondary transformer
- Dual tapped transformer
- Shield transformer
- Tapped primary shield transformer
- Tapped secondary shield transformer
- Dual tapped shield transformer



This is the list of currently supported passive components for which EMX can create RLCK lumped models. The models can be optimized for single-ended, differential or common-model behavior.
The schematics are in the document model_schematics.pdf

Using the Interface (detailed)





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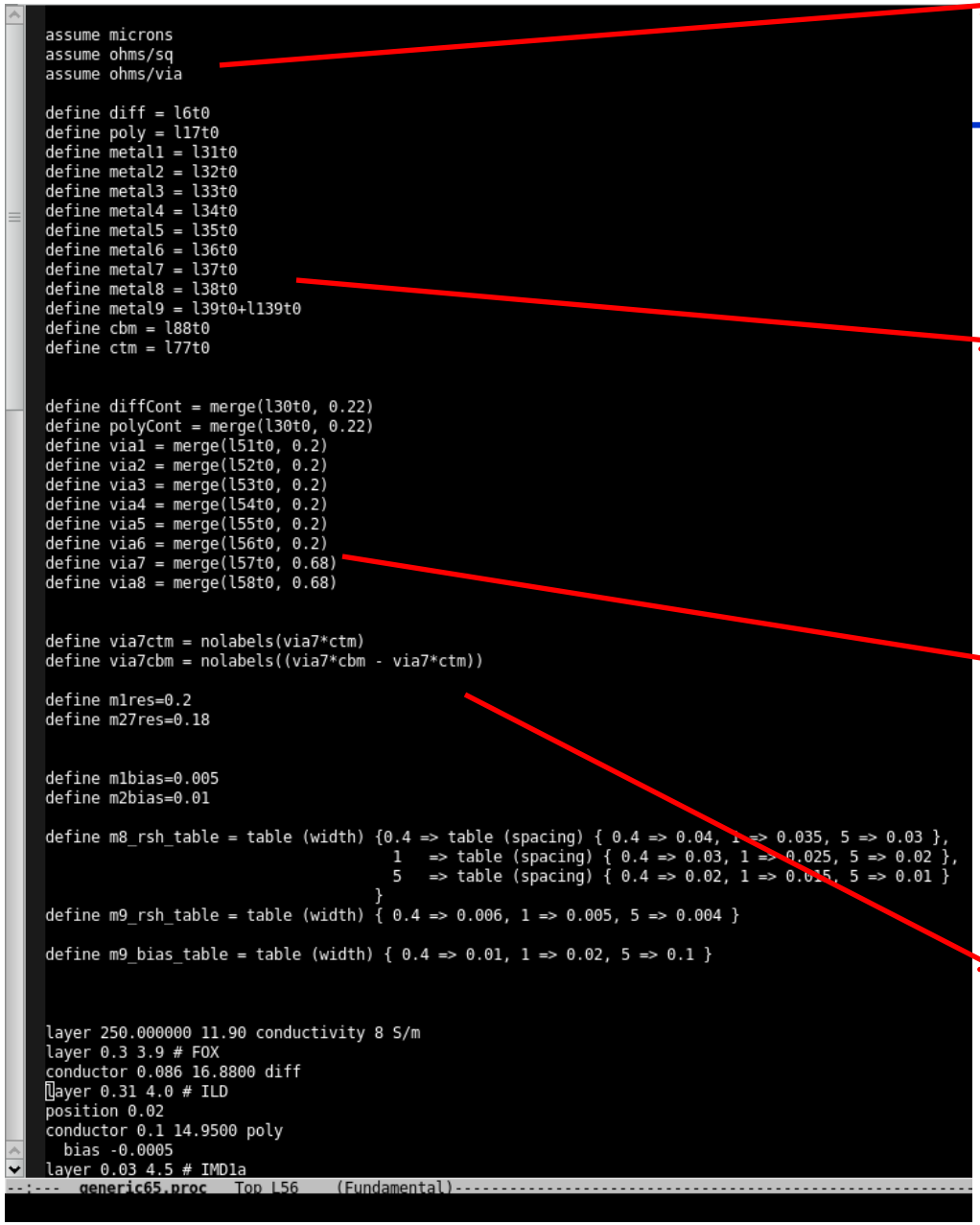
The .proc technology file is an ASCII file which contains all the material properties of the technology

The cross section picture is generated by EMX to provide a detailed visualization of the ASCII .proc file



Default units

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Metal layer to GDSII mapping.

Via layer to GDSII mapping and via merge setting.

Boolean operations for defining via for MIM capacitor. E.g., When the via7 is in the ctm region it connects to CTM.

Definitions of parameters (no units allowed)

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```
define via8 = merge(l58t0, 0.68)


define via7ctm = nolabels(via7*ctm)
define via7cbm = nolabels((via7*cbm - via7*ctm))

define m1res=0.2
define m27res=0.18


define m1bias=0.005
define m2bias=0.01

define m8_rsh_table = table (width) {0.4 => table (spacing) { 0.4 => 0.04, 1 => 0.035, 5 => 0.03 },
                                     1   => table (spacing) { 0.4 => 0.03, 1 => 0.025, 5 => 0.02 },
                                     5   => table (spacing) { 0.4 => 0.02, 1 => 0.015, 5 => 0.01 }
                                    }
define m9_rsh_table = table (width) { 0.4 => 0.006, 1 => 0.005, 5 => 0.004 }

define m9_bias_table = table (width) { 0.4 => 0.01, 1 => 0.02, 5 => 0.1 }



layer 250.000000 11.90 conductivity 8 S/m
layer 0.3 3.9 # FOX
conductor 0.086 16.8800 diff
```

Metal8 sheet resistance is defined in a table as a function of width and spacing

Metal9 sheet resistance is only a function of width

Metal9 has a bias as a function of width

```
layer 250.000000 11.90 conductivity 8 S/m
layer 0.3 3.9 # FOX
conductor 0.086 16.8800 diff
layer 0.31 4.0 # ILD
position 0.02
conductor 0.1 14.9500 poly
  bias -0.0005
layer 0.03 4.5 # IMD1a
layer 0.13 3.0 # IMD1b
layer 0.05 5 # IMD1c
position -0.18
conductor 0.18 m1res*(1+0.00265*dtemp) metal1
  bias m1bias
layer 0.03 4.0 # IMD1d
layer 0.1 3.0 # IMD2a
layer 0.25 3.0 # IMD2b
conductor 0.25 m27res*(1+0.003*dtemp) metal2
  bias m2bias
layer 0.05 5 # IMD2c
```

Substrate definition

Conductor definition

Dielectric definition and location

Grow or shrink the metals to account for metal bias

Temperature coefficient of metal

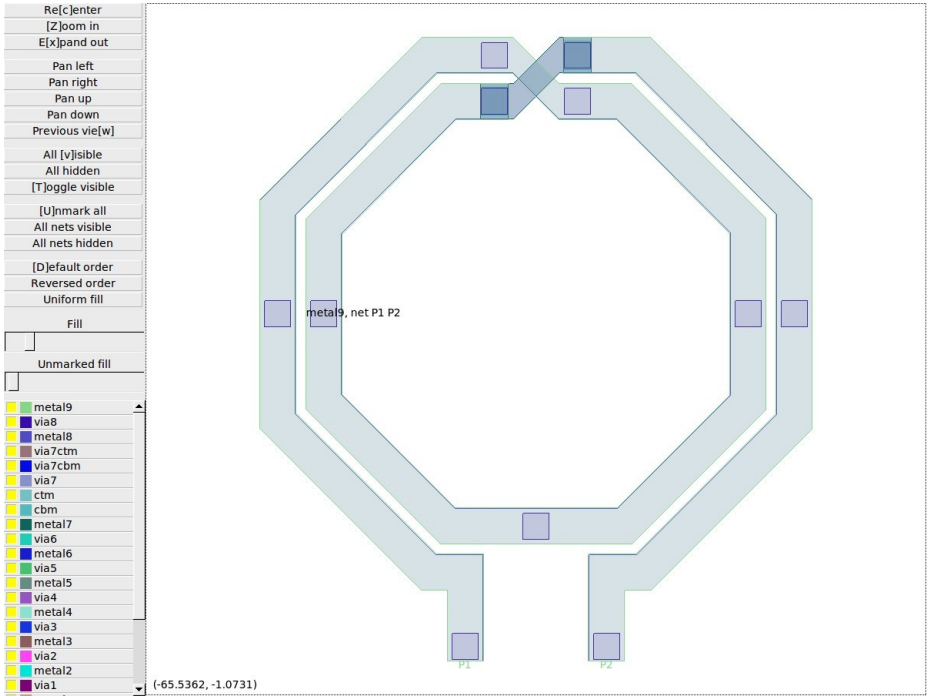
MiM cap definition

```
# MIM CAP
offset 0.4
conductor 0.2       0.5   cbm # MIM cap bottom metal
offset 0.2177
conductor 0.1       20.0   ctm # MIM cap top metal

layer 0.05 5 # IMD7c
layer 0.62 4.0 # IMD8a
layer 0.05 7.8 # IMD8b
layer 0.775 4.0 # IMD8c
layer 0.075 7.8 # IMD8d
position -1
conductor 1 m8_rsh_table*(1+0.0035*dtemp) metal8
layer 0.725 4.0 # IMD9a
layer 0.11 7.8 # IMD9b
layer 3.0 4.0 # IMD9c
layer 0.075 7.8 # PASS1
position -3.0
conductor 3.0 m9_rsh_table*(1+0.005*dtemp) metal9
bias m9_bias_table
layer 0.25 4.2 # PASS4
layer infinity 1

via diff metal1 26 diffCont
via poly metal1 20 polyCont
via metal1 metal2 2*(1+0.001*dtemp) via1
via metal2 metal3 2*(1+0.001*dtemp) via2
via metal3 metal4 2*(1+0.001*dtemp) via3
via metal4 metal5 2*(1+0.001*dtemp) via4
via metal5 metal6 2*(1+0.001*dtemp) via5
via metal6 metal7 2*(1+0.001*dtemp) via6
via metal7 metal8 0.2 via7
via metal8 metal9 0.4 via8
via     cbm  metal8   0.5   Ohms/via  via7cbm
via     ctm  metal8   0.5   Ohms/via  via7ctm

capacitor cbm   ctm  cbm*ctm
```


Via definitions and temperature coefficients of vias

Identify the MIM layers

GDSview



GDSview is used to see what EMX is simulating

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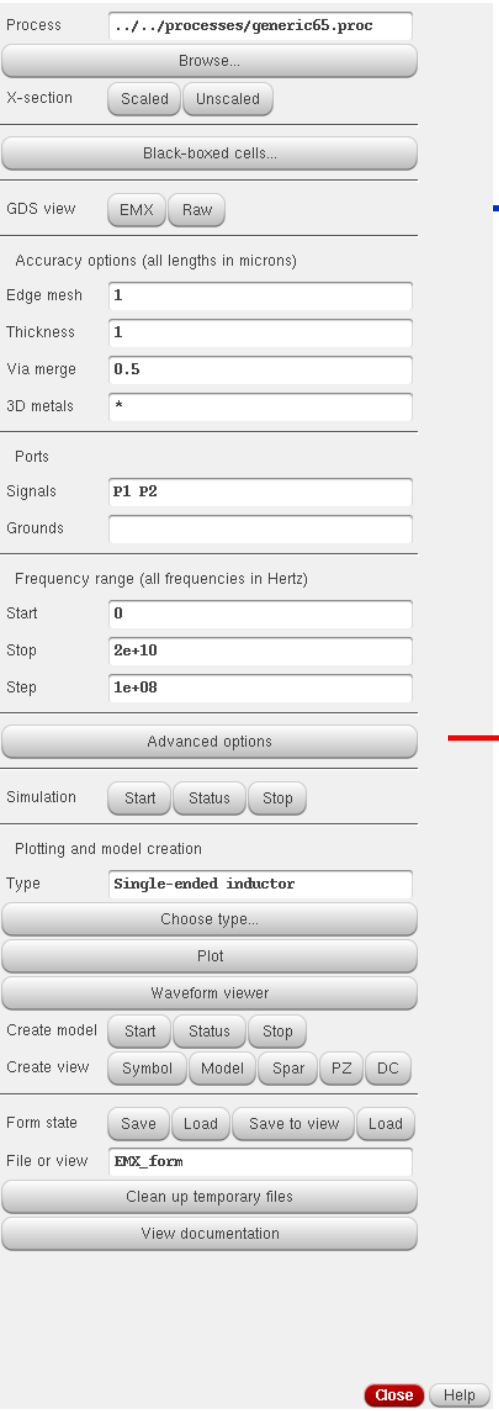
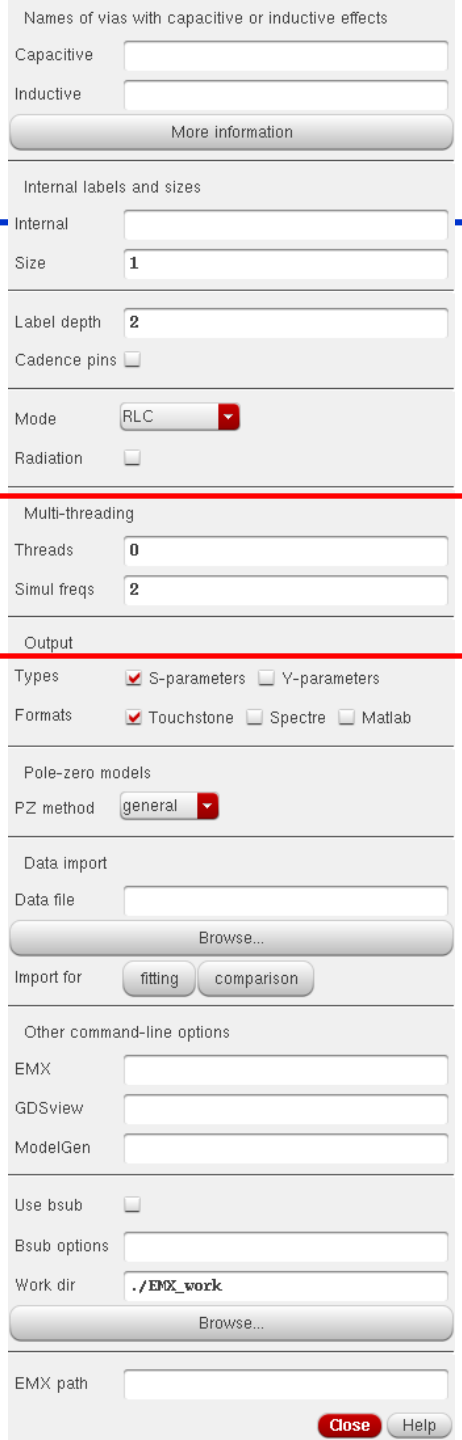
GDSview

- GDSview is used to view the "processed structures" as input to EMX
  - processed means, bias applied, via-merging applied, etc.
- GDSview quick commands
  - **left mouse button**: zoom
  - **right mouse button**: get dimensions
  - **h**: come close to an metal edge, when a label appears, input "h" and the layer is hidden
  - **v**: make all the layers re-appear
  - **z:** zoom in
  - **c**: re-center the layout
  - **x**: zoom out

NOTE: Read the GDSview manual to learn more about this tool in detail





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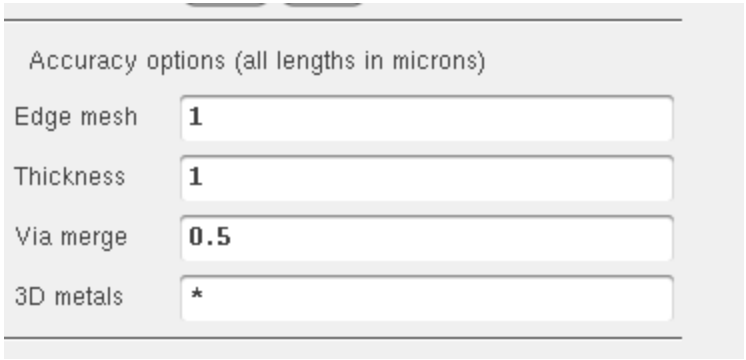
Advanced options GUI can be used to set features that are not frequently used

For example the number of threads in a multi-thread simulation can be set here.

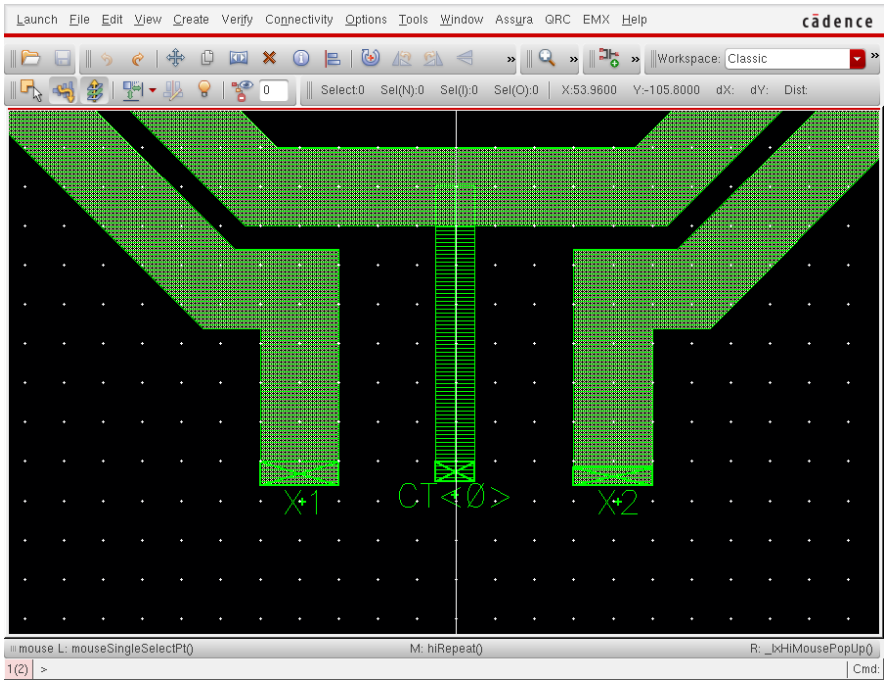
Accuracy options (Edge and thickness mesh)



Edge mesh and thickness mesh should roughly correspond to skin depth. Setting 1um should give good accuracy with reasonable speed. Decreasing this number to 0.5 or lower will reduce the speed and increase accuracy. These settings can be used for structures like inductors, transformers where the routing metal is reasonably wide.

For MOM capacitors use the edge mesh to be the same as the width of the finger (e.g., 0.1um).

Cadence Pins

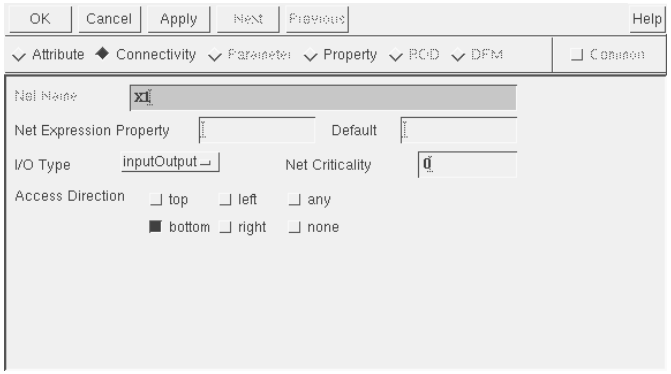


Cadence pins can be used instead of labels in the layout

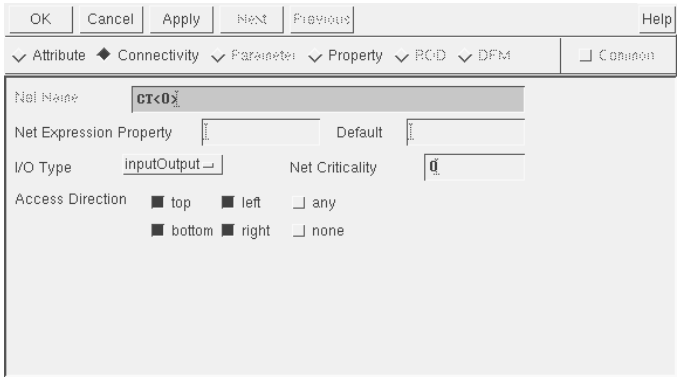
The pins need to be at the 0th level in the layout hierarchy

The edge port injects current uniformly into the entire edge

The internal port injects current into the shape the size of the pin rectangle



X1: Edge port



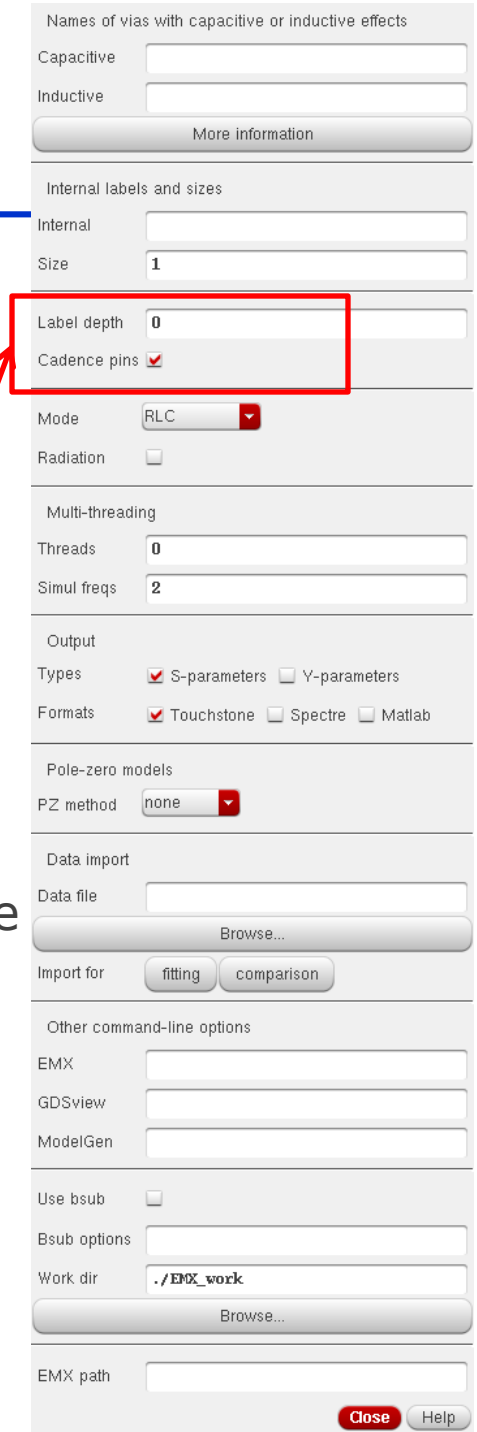
CT<0>: Internal port

Cadence Pins

```
assume microns
assume ohms/sq
assume ohms/via

define diff = l6t0
define poly = l17t0
define metal1 = l31t0+l131t0
define metal2 = l32t0+l132t0
define metal3 = l33t0+l133t0
define metal4 = l34t0+l134t0
define metal5 = l35t0+l135t0
define metal6 = l36t0+l136t0
define metal7 = l37t0+l137t0
define metal8 = l38t0+l138t0
define metal9 = l39t0+l139t0
define cbm = l88t0
define ctm = l77t0
```

In the EMX .proc file make sure that the pin layers are Identified (metal1 drawing + metal1 pin)



In the Advanced Options GUI choose label pins and label depth 0

Automatic pin order

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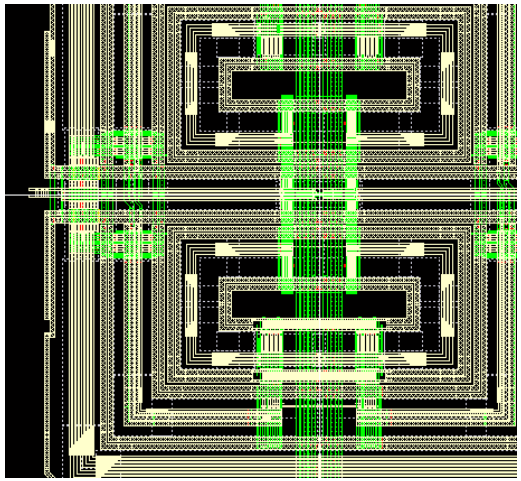
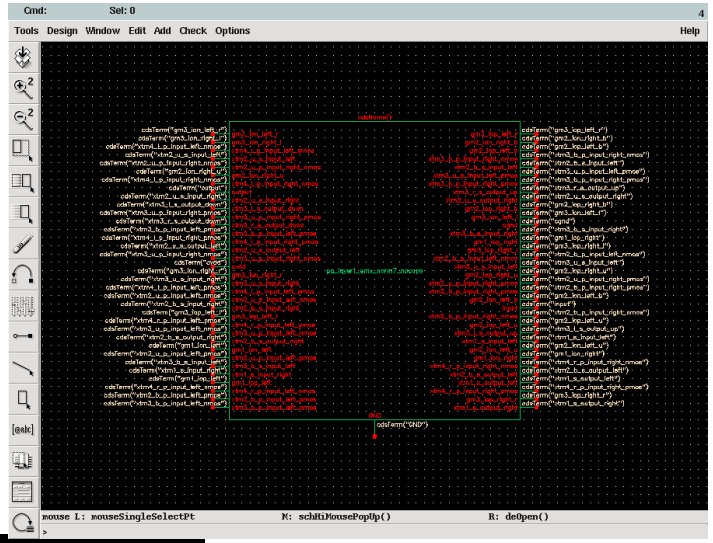





```
emx xxx.gds pa_layer1_emx_norm7_nocaps xxx.proc
-e 1 -t 1 -v 0.5 --3d=m7,m8 -p P000=gm3_ion_left_r -p P001=gm3_ion_right_l -p
P002=xtm4_l_p_input_left_nmos -p P003=xtm2_u_s_input_left -p
P004=xtm2_u_p_input_right_nmos -p P005=gm2_ion_right_u -p
P006=xtm4_l_p_input_right_nmos -p P007=output -p P008=xtm2_u_s_input_right -p
P009=xtm3_l_s_output_down -p P010=xtm3_u_p_input_right_pmos -p
P011=xtm3_r_s_output_down -p P012=xtm3_b_p_input_left_pmos -p
P013=xtm4_l_p_input_right_pmos -p P014=xtm2_u_s_output_left -p
P015=xtm3_u_p_input_right_nmos -p P016=cvdd -p P017=gm3_ion_right_r -p
P018=xtm3_u_s_input_right -p P019=xtm4_l_p_input_left_pmos -p
P020=xtm2_u_p_input_left_nmos -p P021=xtm2_b_s_input_right -p
P022=gm3_iop_left_l -p P023=xtm4_r_p_input_left_pmos -p
P024=xtm3_u_p_input_left_nmos -p P025=xtm2_b_s_output_right -p P026=gm1_ion_left
...
...
P063=xtm2_b_s_output_left -p P064=xtm1_s_output_left -p
P065=xtm4_r_p_input_right_pmos -p P066=gm3_iop_right_r -p
P067=xtm1_s_output_right -i P000 -i P001 -i P002 -i P003 -i P004 -i P005 -i P006
-i P007 -i P008 -i P009 -i P010 -i P011 -i P012 -i P013 -i P014 -i P015 -i P016
-i P017 -i P018 -i P019 -i P020 -i P021 -i P022 -i P023 -i P024 -i P025 -i P026
-i P027 -i P028 -i P029 -i P030 -i P031 -i P032 -i P033 -i P034 -i P035 -i P036
-i P037 -i P038 -i P039 -i P040 -i P041 -i P042 -i P043 -i P044 -i P045 -i P046
-i P047 -i P048 -i P049 -i P050 -i P051 -i P052 -i P053 -i P054 -i P055 -i P056
-i P057 -i P058 -i P059 -i P060 -i P061 -i P062 -i P063 -i P064 -i P065 -i P066
-i P067 --sweep 1e+08 1e+10 --sweep-stepsize 1e+08 --verbose=3
--print-command-line -l 0 --cadence-pins=1 --quasistatic --parallel=0
--simultaneous-frequencies=2 --selected-sweep --format=psf -s
...
```

The pin order is sorted alphabetically in the n-port block

Visualization in Matlab

- EMX can generate Matlab .m files for
  - Structure mesh
  - Current plots
- The option "--matlab-mesh" is used to generate meshes
- The option "--print-currents" is used to generate current plots
- The resulting .m files are in the appropriate EMX_work directory

Mesh

Names of vias with capacitive or inductive effects
Capacitive
Inductive
More information

Internal labels and sizes
Internal
Size 1

Label depth 0
Cadence pins

Mode RLC
Radiation

Multi-threading
Threads 0
Simul freqs 2

Output
Types S-parameters Y-parameters
Formats Touchstone Spectre Matlab

Pole-zero models
PZ method none

Data import
Data file
Browse...
Import for fitting comparison

Other command line options
EMX --matlab-mesh
GDSview
ModelGen

Use bsub
Bsub options
Work dir ./EMX_work
Browse...

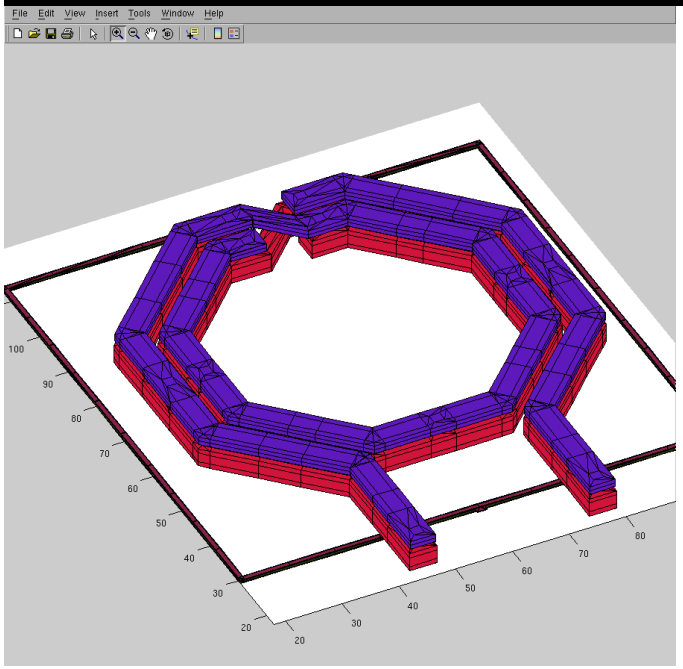
EMX path
Close Help

```
matlab

                    < M A T L A B >
        Copyright 1984-2006 The MathWorks, Inc.
                Version 7.2.0.294 (R2006a)
                    January 27, 2006


  To get started, type one of these: helpwin, helpdesk, or demo.
  For product information, visit www.mathworks.com.

>> emxmesh
emxmesh
>> help emxmesh
help emxmesh
  emxmesh
    Display the mesh produced by EMX.
  emxmesh('m1')
    Display the mesh for a single conductor layer.
  emxmesh({'m1', 'm2'})
    Display the mesh for the conductor layers specified in the list.
```



Current plotting

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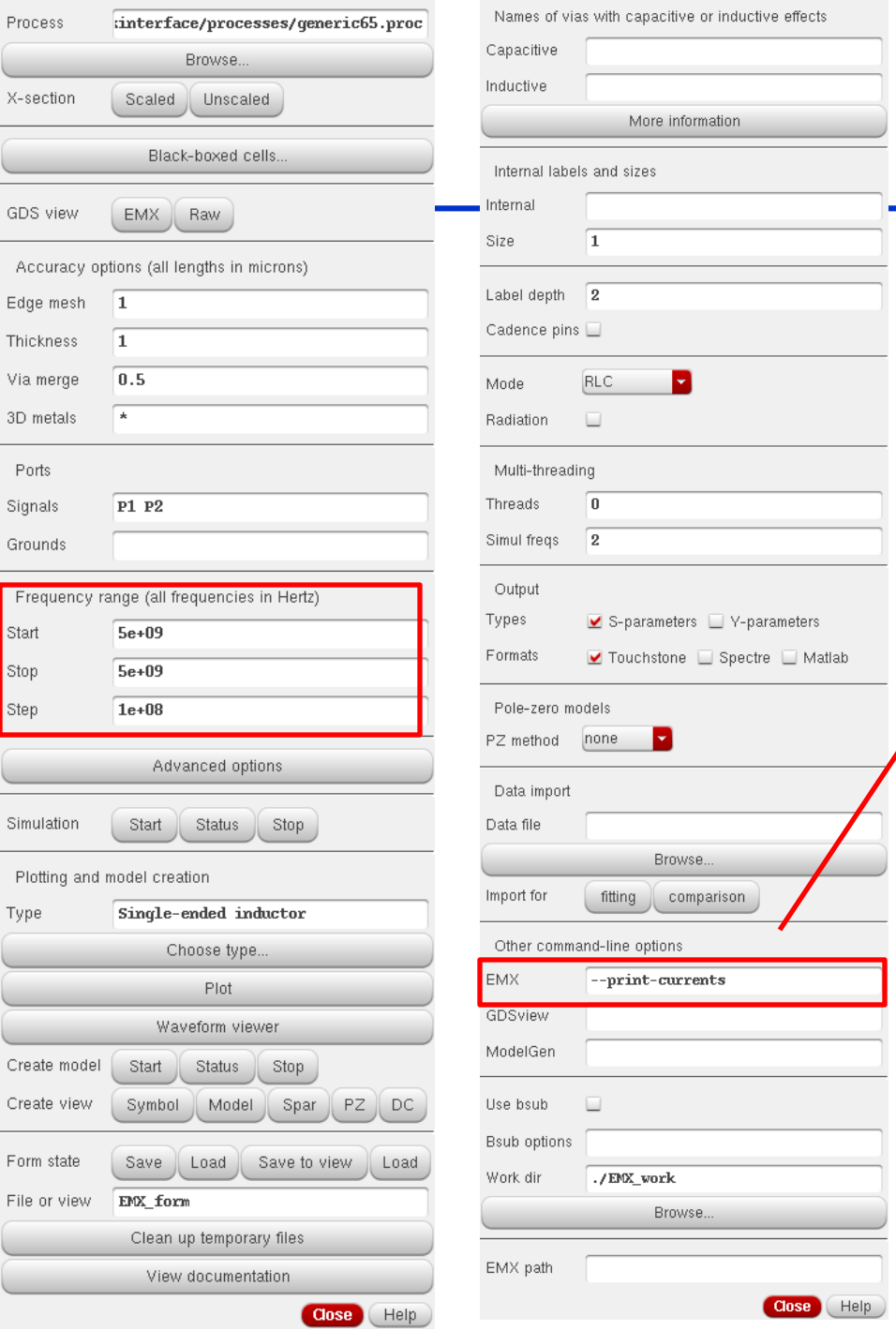
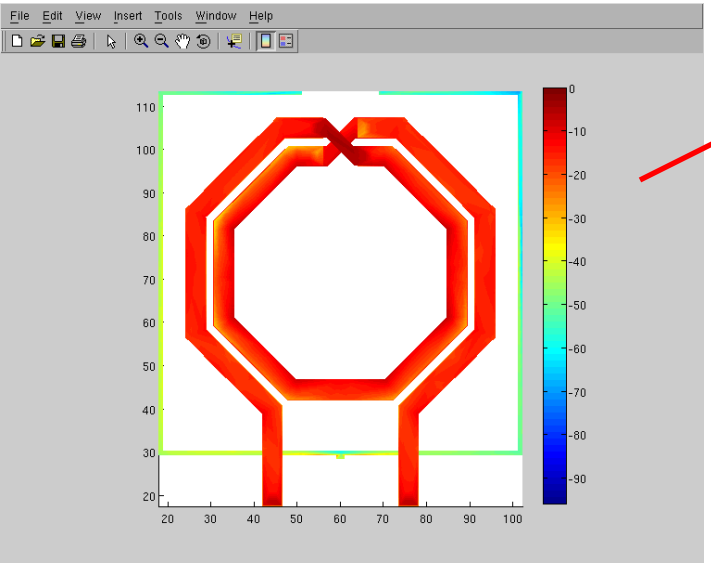
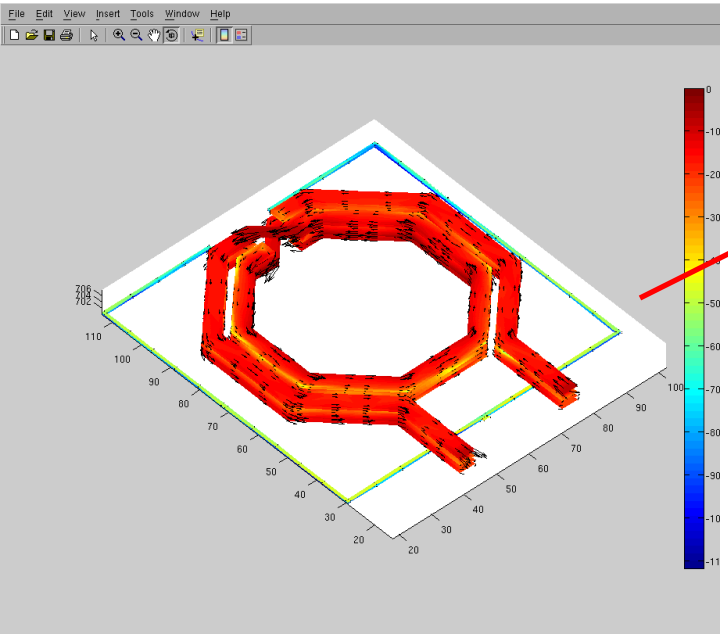
Run EMX at a single frequency

Add the option "--print-currents"



Current plotting





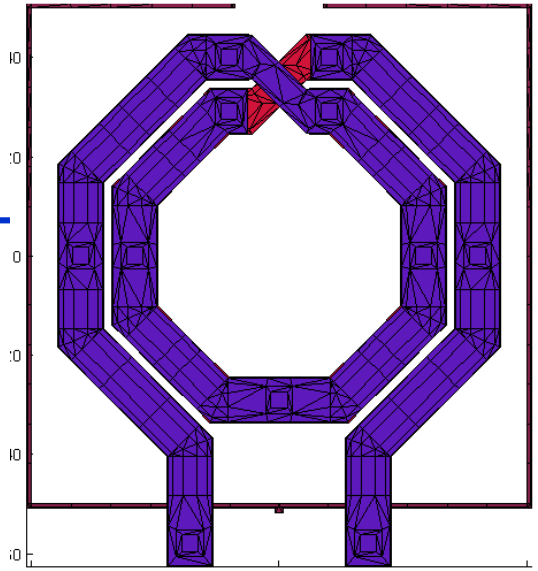

```
>> emxcurrent
emxcurrent
>> help emxcurrent
help emxcurrent
  emxcurrent
    Display the current density when the first port is active.
  emxcurrent('ports', [0 1 0])
    Display the current density when port two of three is active.
  emxcurrent('layers', 'm1')
    Display the current density for a single layer.
  emxcurrent('layers', {'m1', 'm2'})
    Display the current density for the layers in the list.
  emxcurrent('phase', 0.1)
    Display the time-varying current density at time 0.1/omega.
  emxcurrent('phase', 0.1, 'arrows', 1)
    Display the time-varying current density at time 0.1/omega, and
    also plot arrows showing the direction and magnitude of the,
    currents.
  emxcurrent('phase', 0.1, 'arrows', 2.3)
    As above, but scale length of the arrows by a factor of 2.3.
  emxcurrent('ports', [+0.5 -0.5], 'layers', 'm1', 'phase', 0.1)
    Display the time-varying current density on m1 under differential drive.

>> emxcurrent('phase', 1, 'arrows', 2)
```

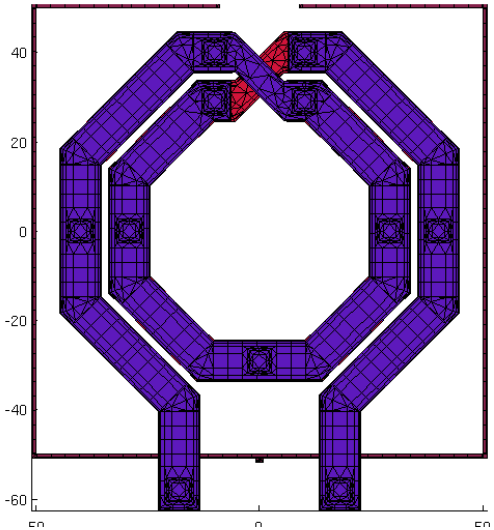
--print-currents This option makes EMX write a MATLAB-format output file `emxcurrent.m` showing the horizontal current density in the structure. The plot shows the ratio in dB of the horizontal current density to the maximum horizontal current density. Horizontal current density is calculated by integrating the current density over the vertical thickness of the conductors. So if two wires have the same current density and one is twice as thick as the other, then the plot will show a difference of 6 dB. To view the plot, start MATLAB in the directory where `emxcurrent.m` resides, and type `emxcurrent`. Type `help emxcurrent` to see other options.

Inductor Meshing

- For inductors, transformers, baluns,etc.
  - Usually sufficient to have an edge mesh and thickness mesh roughly the order of the skin depth at the highest frequency (usually 1um for default accuracy and 0.5um for higher accuracy)
  - The mesh is finest on the edges and corners to capture current crowding most efficiently
  - For narrow routing should have at least **3** mesh elements across the side to ensure that EMX captures the current crowding
  - Refining the mesh will lead to convergence (a tradeoff with simulation time).
  - Inductance converges quickly, Q more slowly



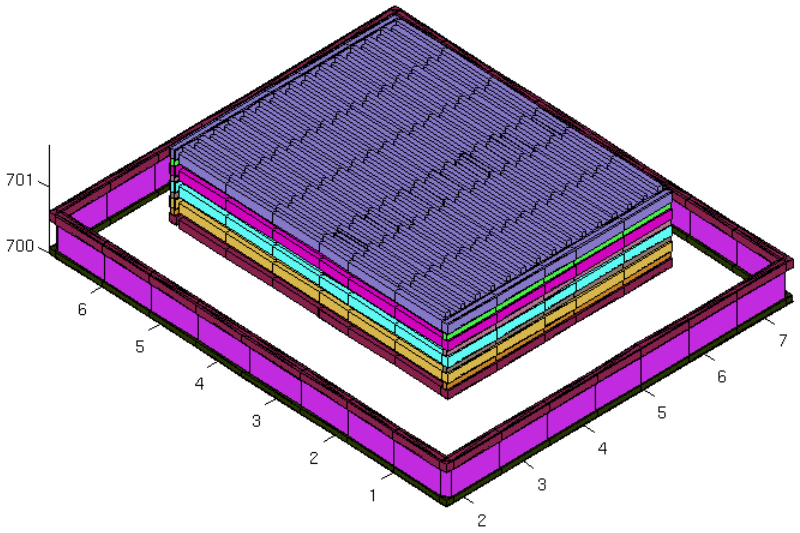
edge-mesh=1
thickness-mesh=1



edge-mesh=0.4
thickness-mesh=0.4

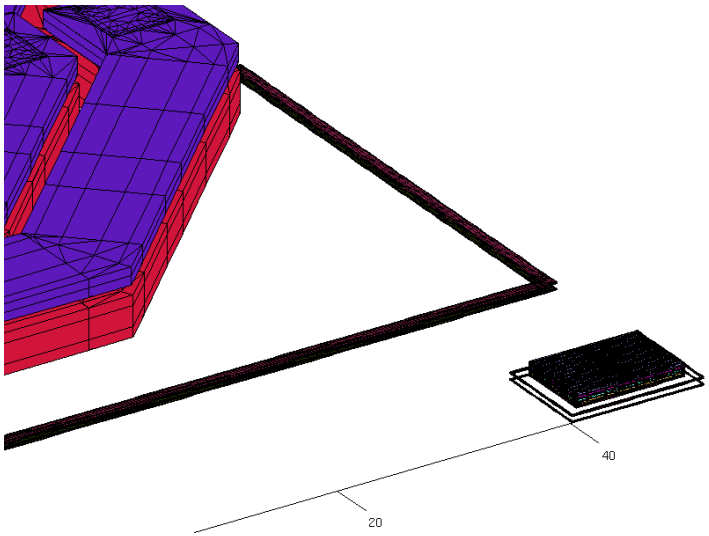
Capacitor meshing

- Meshing should be on the order of the finger width, e.g.,
  - Edge-mesh=0.1
  - Thickness-mesh=1
  - 3d=*
- Q is determined a lot by the substrate and the shield under the capacitor at higher frequencies not just metal loss



Combined structures

- When you have inductors and capacitors in the same structure it is possible to have different meshes for different metals
- Fine mesh by default, coarse mesh for specific metals



Process: :interface/processes/generic65.proc
Browse...
X-section: Scaled | Unscaled
Black-boxed cells...
GDS view: EMX | Raw
Accuracy options (all lengths in microns)
Edge mesh: 0.1
Thickness: 1
Via merge: 0
3D metals: *
Ports
Signals: P1 P2
Grounds:
Frequency range (all frequencies in Hertz)
Start: 1e+08
Stop: 2e+10
Step: 1e+08
Advanced options
Simulation: Start | Status | Stop
Plotting and model creation
Type: Single-ended inductor
Choose type...
Plot
Waveform viewer
Create model: Start | Status | Stop
Create view: Symbol | Model | Spar | PZ | DC
Form state: Save | Load | Save to view | Load
File or view: EMX_form
Clean up temporary files
View documentation
Close | Help

Names of vias with capacitive or inductive effects
Capacitive:
Inductive:
More information
Internal labels and sizes
Internal:
Size: 1
Label depth: 0
Cadence pins
Mode: RLC
Radiation
Multi-threading
Threads: 0
Simul freqs: 2
Output
Types: S-parameters | Y-parameters
Formats: Touchstone | Spectre | Matlab
Pole-zero models
PZ method: none
Data import
Data file:
Browse...
Import for: fitting | comparison
Other command-line options
EMX: --edge-width=metal6,1
GDSview:
ModelGen:
Use bsub
Bsub options:
Work dir: ./EMX_work
Browse...
EMX path:
Close | Help

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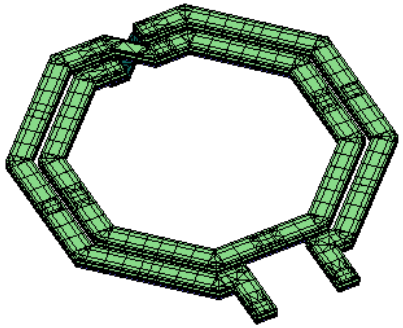
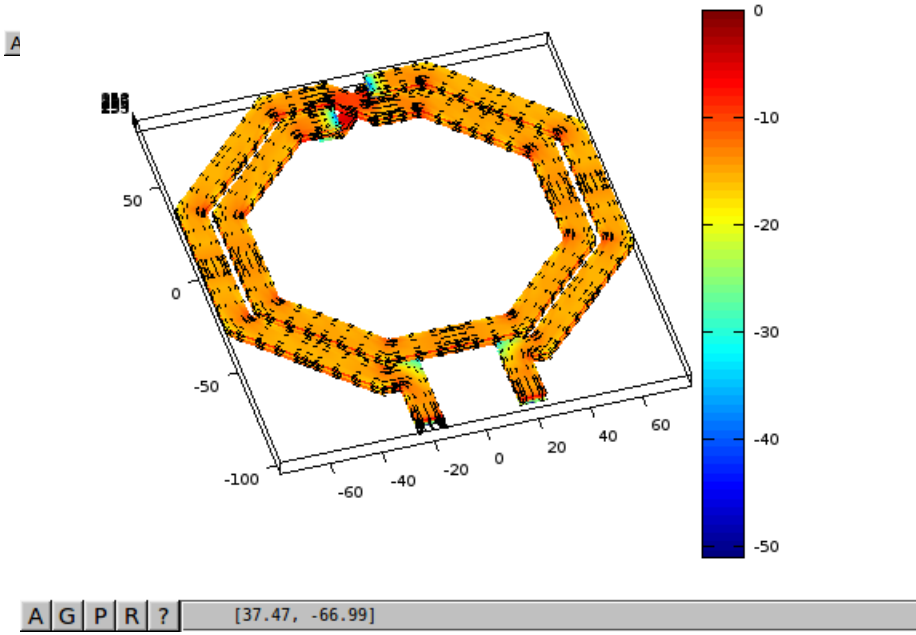
Octave support

- Recent Octave versions (3.6.4).
- Almost as good as Matlab for graphics
- graphics_toolkit('fltk')
- **Free.**
- Viewing meshes and currents and charges
- Support for Linux and Windows





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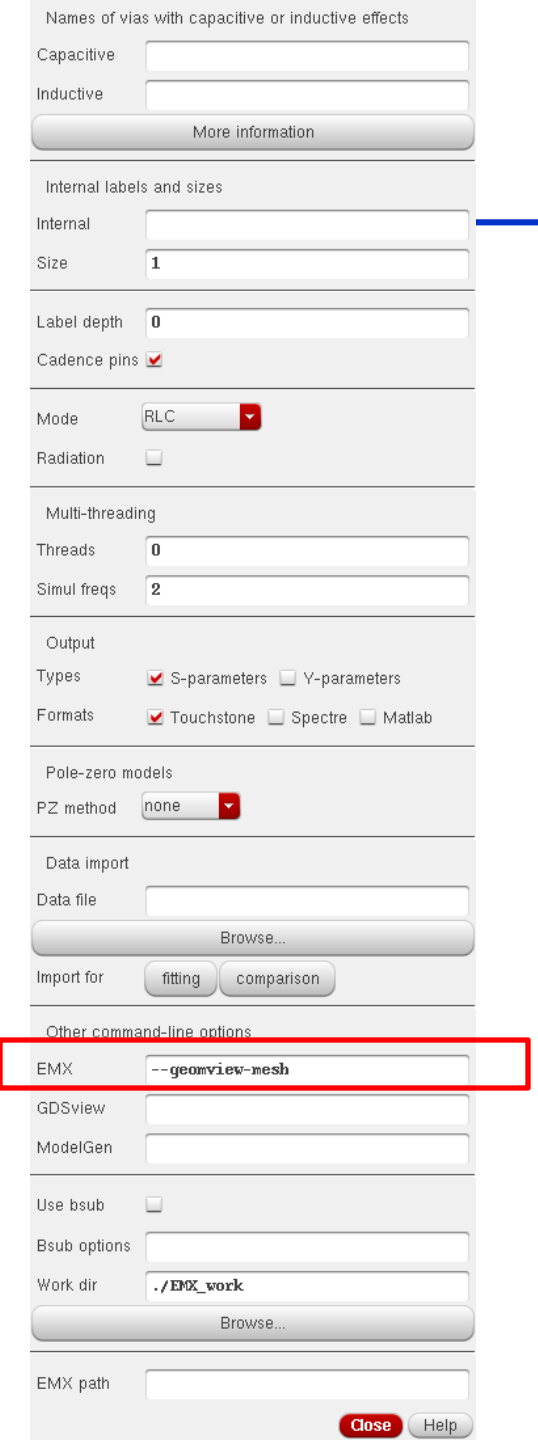
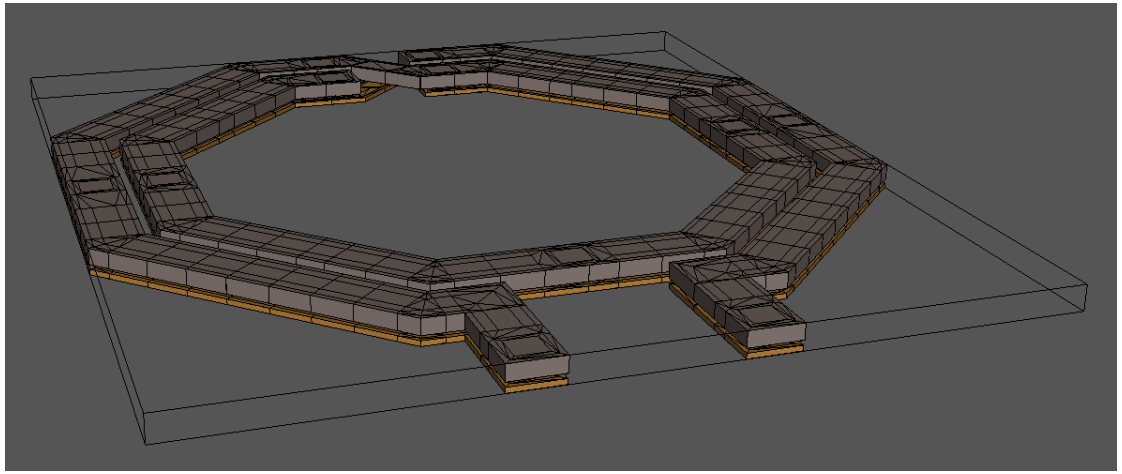
View of Mesh (using geomview)



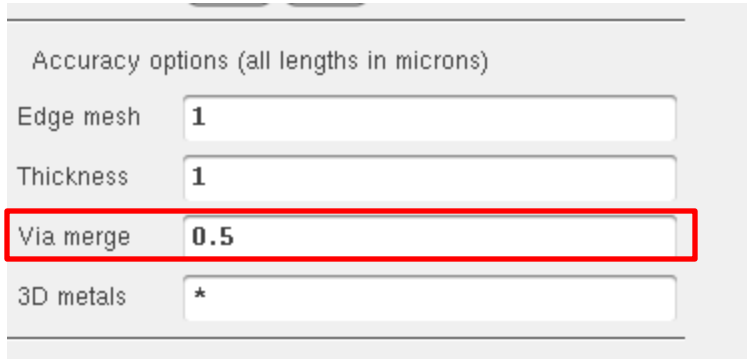


EMX also creates a geomview mesh file mesh.list

Execute “geomview mesh.list”

Geomview can be obtained from http://www.geomview.org/

Accuracy options (Via merge)



Global via merge setting

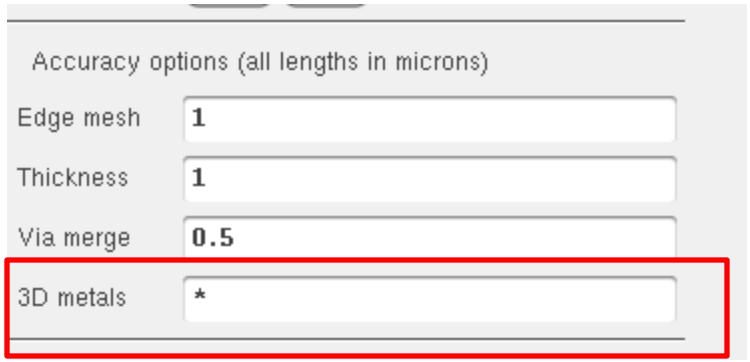
```
define diffCont = merge(l30t0, 0.22)
define polyCont = merge(l30t0, 0.22)
define via1 = merge(l51t0, 0.2)
define via2 = merge(l52t0, 0.2)
define via3 = merge(l53t0, 0.2)
define via4 = merge(l54t0, 0.2)
define via5 = merge(l55t0, 0.2)
define via6 = merge(l56t0, 0.2)
define via7 = merge(l57t0, 0.68)
define via8 = merge(l58t0, 0.68)


define via7ctm = nolabels(via7*ctm)
define via7cbm = nolabels((via7*cbm - via7*ctm))
```

Via specific merge settings

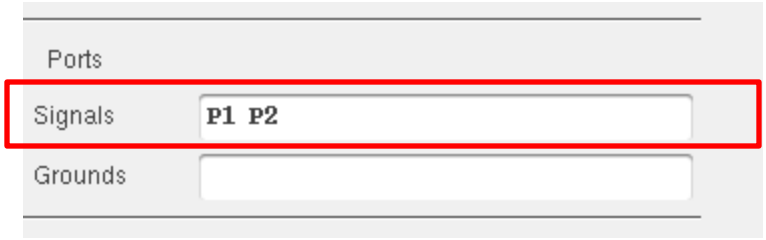
The via merge setting can be applied globally (all vias within 0.5um will be merged), or it can be controlled on a layer by layer basis within the process file. It is recommended to use the process files to control the via merging.

Accuracy options (3D metals)



By default metals in EMX are assumed to be 2.5D. If you set 3D metals to "*" then all metals are treated as 3D. For structures like inductors it is sufficient to make only the thick metals 3D (e.g., metal8 metal9). For MOM capacitors all metals need to be treated 3D to ensure that the sidewall capacitance is captured accurately.

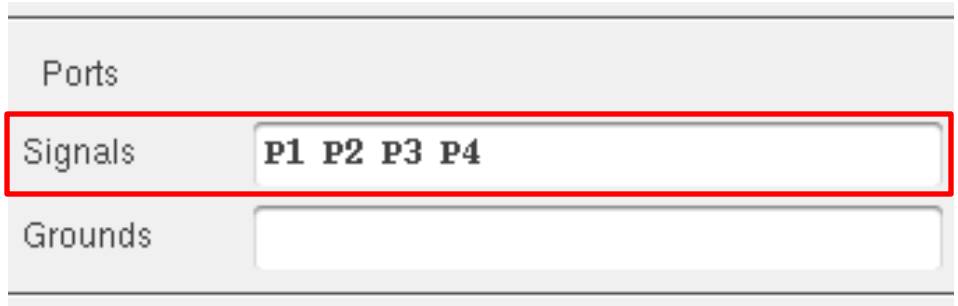
Ports



By default ports in EMX are assumed to be “edge ports”. Current is injected uniformly into the closest edge. With the GUI you can specify signal ports and ground ports. By default ground is assumed to be the bottom of the substrate. See the user manual for more information on ports.

Internal ports can be specified using the advanced option of the interface. Internal ports have a certain size and the assumption is that the current is locally injected into that location.

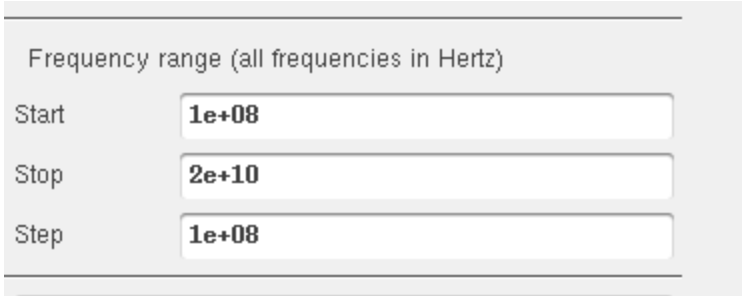
Port ordering



The ports are order in the same sequence as that entered in the GUI.

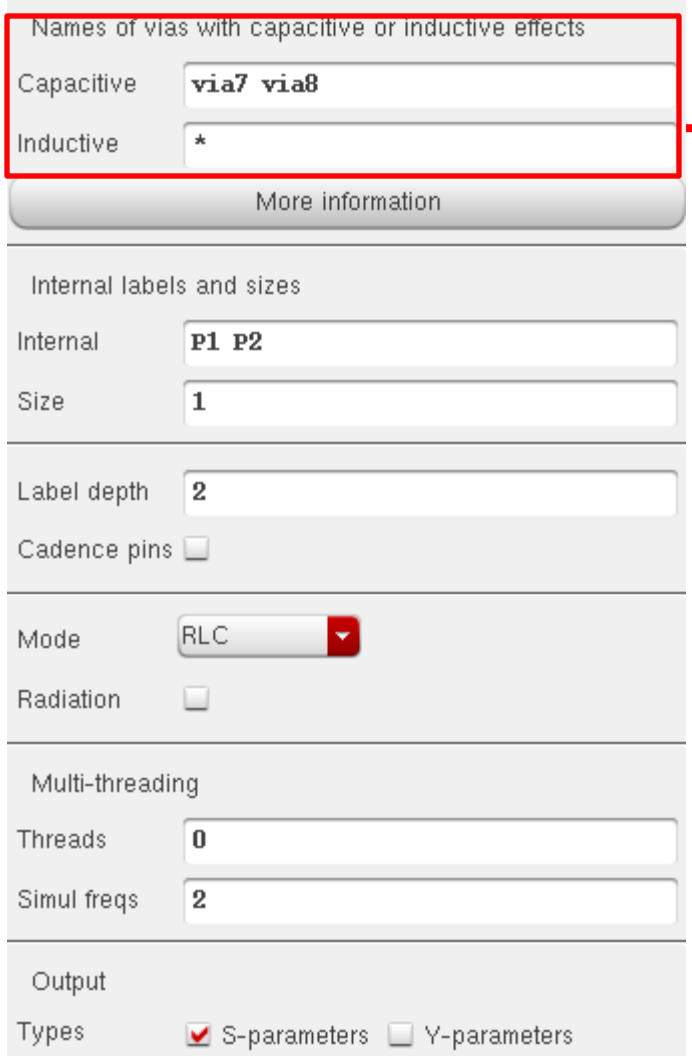
If Cadence Pins are used then you do not need to specify the ports and can simply use "*" and the Cadence internal port ordering will be used. This is only useful if you use the S-parameter output. Note: In order to create models and generate plots the order needs to follow the EMX convention order.

Frequencies



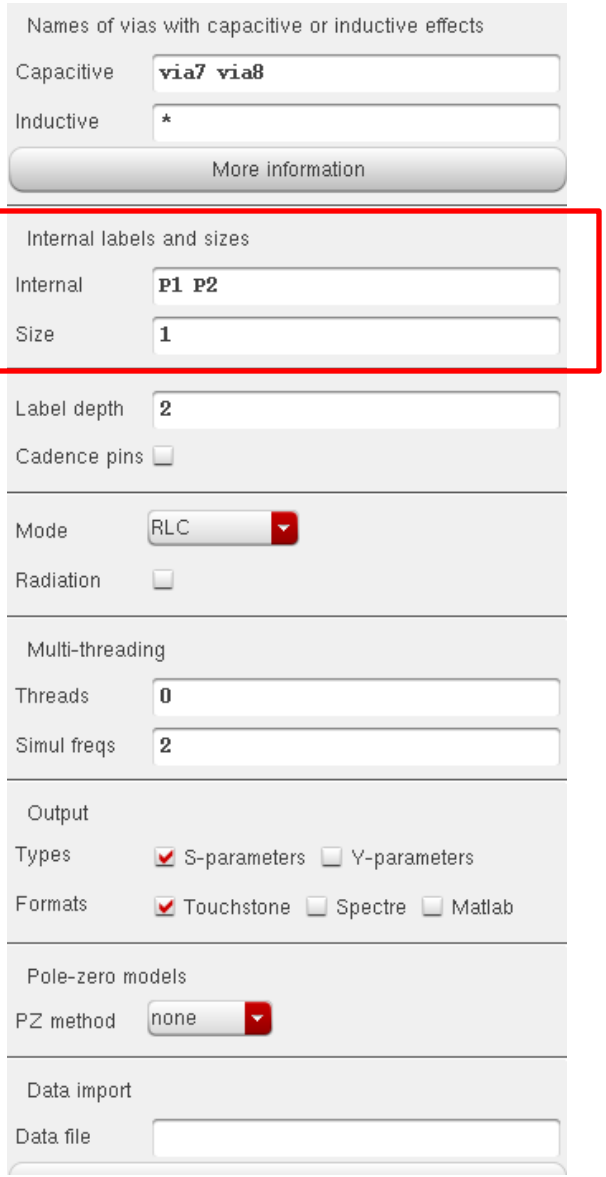
You can set the frequency range from DC (0) to any high frequency and provide the step size. EMX is stable at DC.

Advanced options



By default EMX only accounts for via resistance. In order to include via capacitance and inductance enter the via name. For all vias use "*".

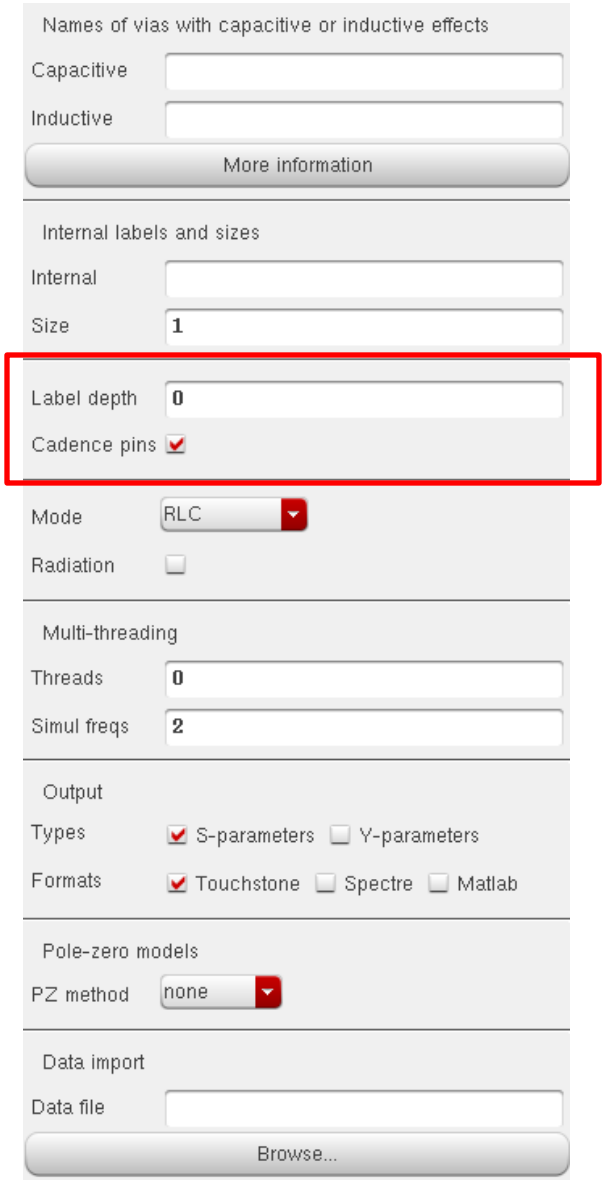
Advanced options



Internal ports can be used instead of the default edge ports. Port sizes can be specified.

Internal ports are like having current injected from the top through a via of the size specified

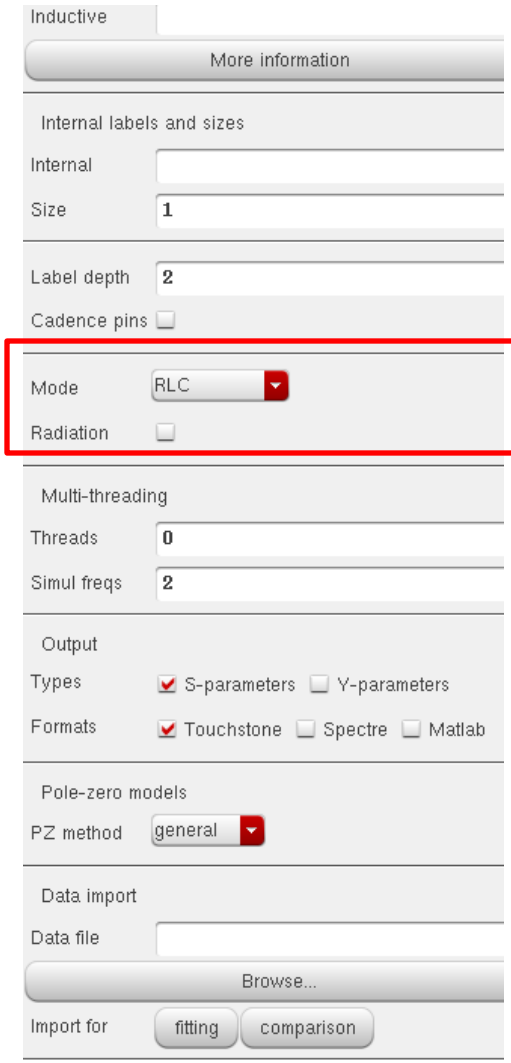
Advanced options



The port labels can be set at any level in the hierarchy. If the label depth is 0 then only labels at the top layer will be seen. GDSview will show you the labels that EMX is going to see.

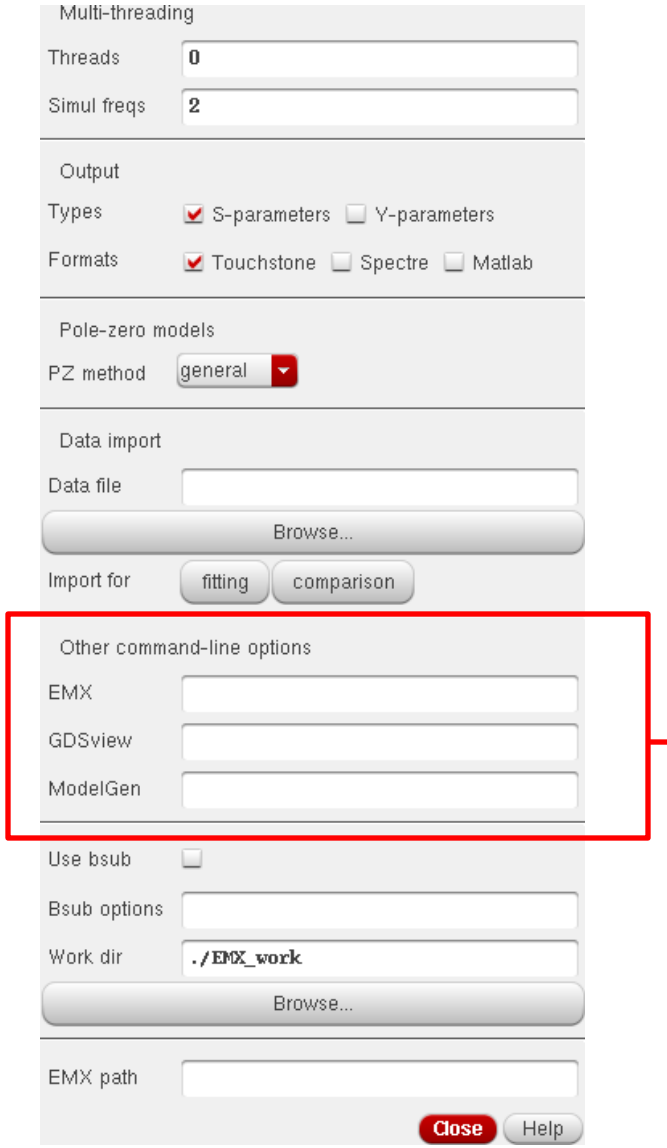
Cadence pins can be used to specify labels for ports. Needed for Black-box LVS.

Advanced options



RLC mode is quasi-static. To run EMX in full-wave mode turn on Radiation.

Advanced options

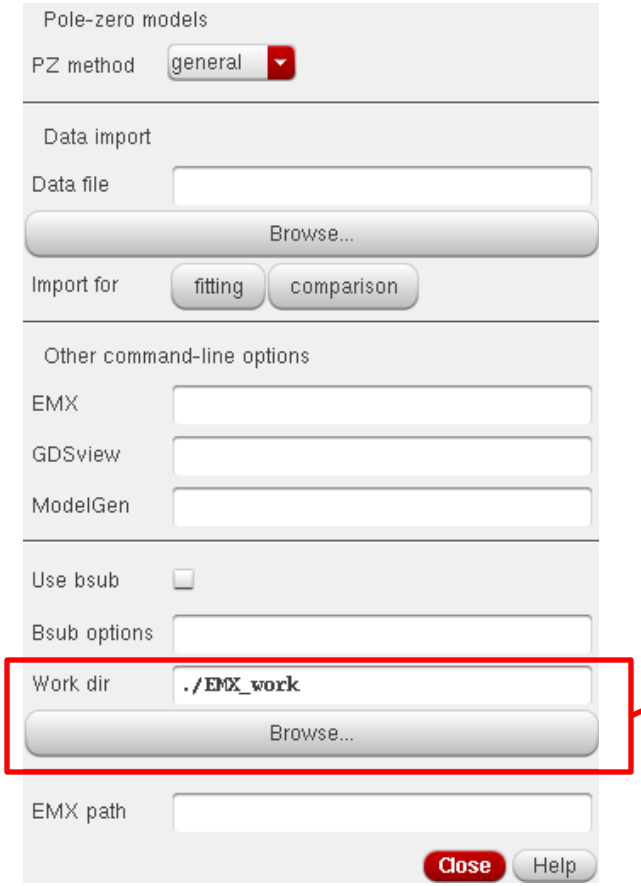


Most commands from the EMX manual or gdsview manual can be used here. Read the EMX user manual for details.

For example,

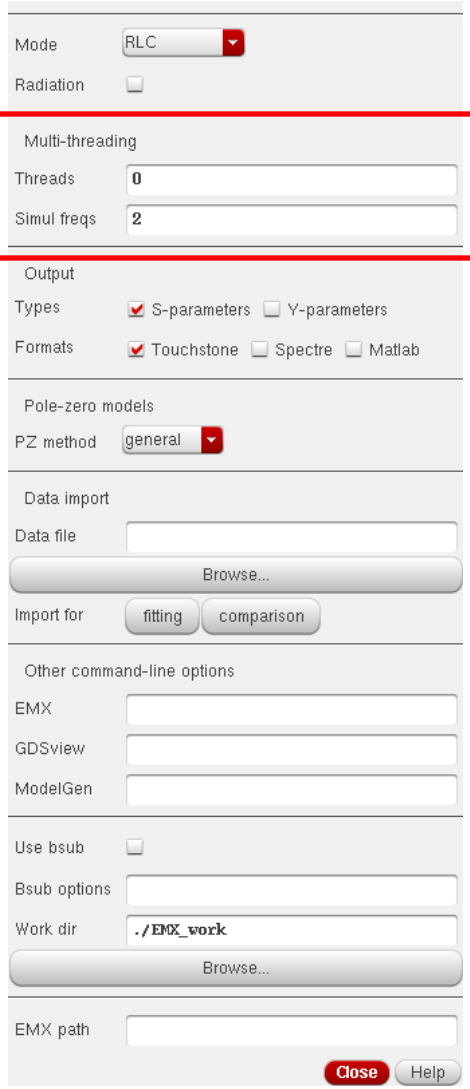
"--matlab-mesh" to generate a mesh
"--scaling=0.9" to run EMX on a half-node.
"--temperature=100" to run EMX at 100 degrees

Advanced options



The location where all the work and temporary files are kept can be changed

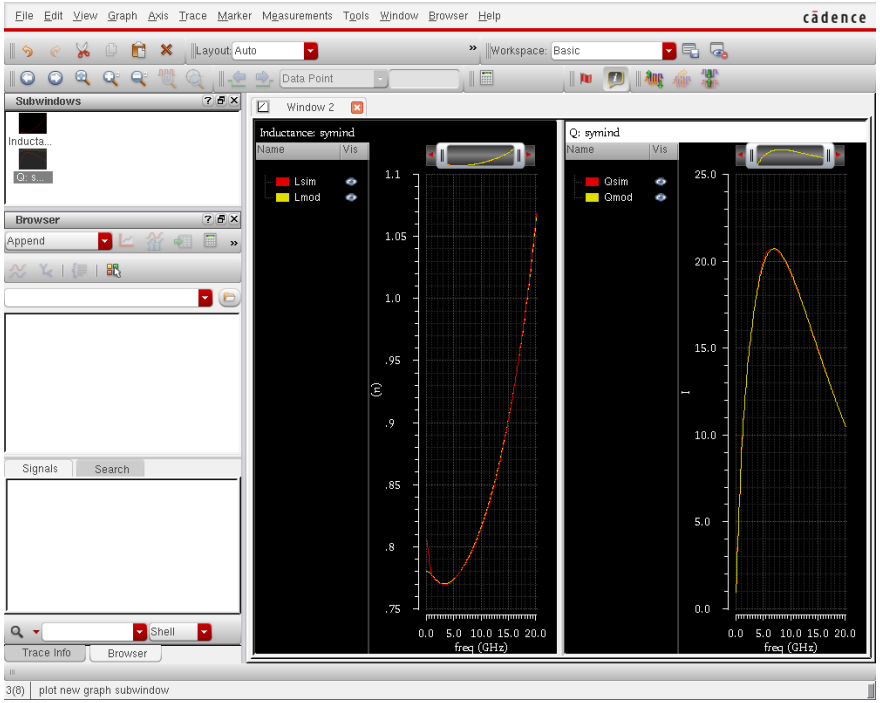
Advanced options (multi-threading)



With the appropriate license EMX can be run in multi-threaded mode.

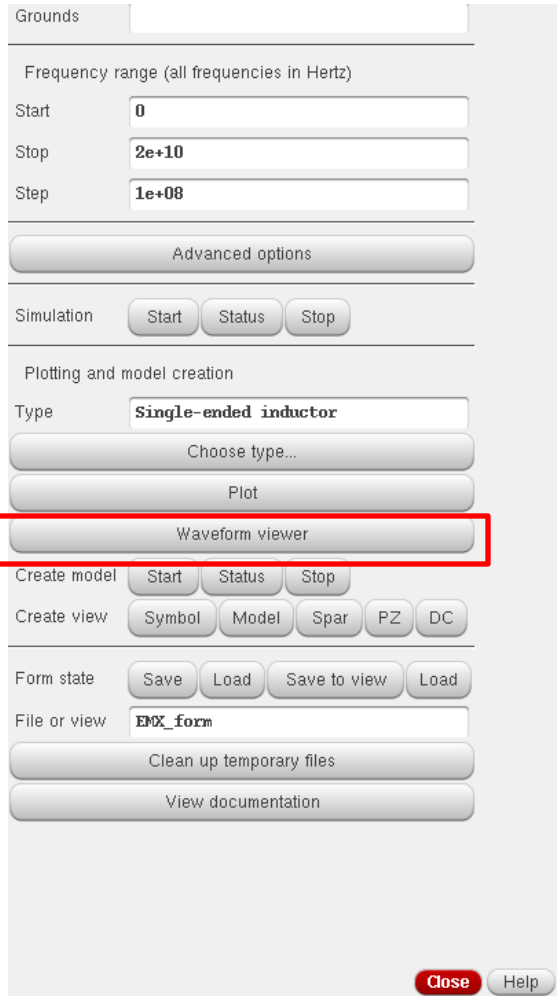
The number of threads can be specified (if you input 0) then it determines the number of CPUs on the machine. The Simul frequencies can be used to do multiple frequencies at a time. Typically you can use "Threads=0, Simul freqs=2" for optimum speed.

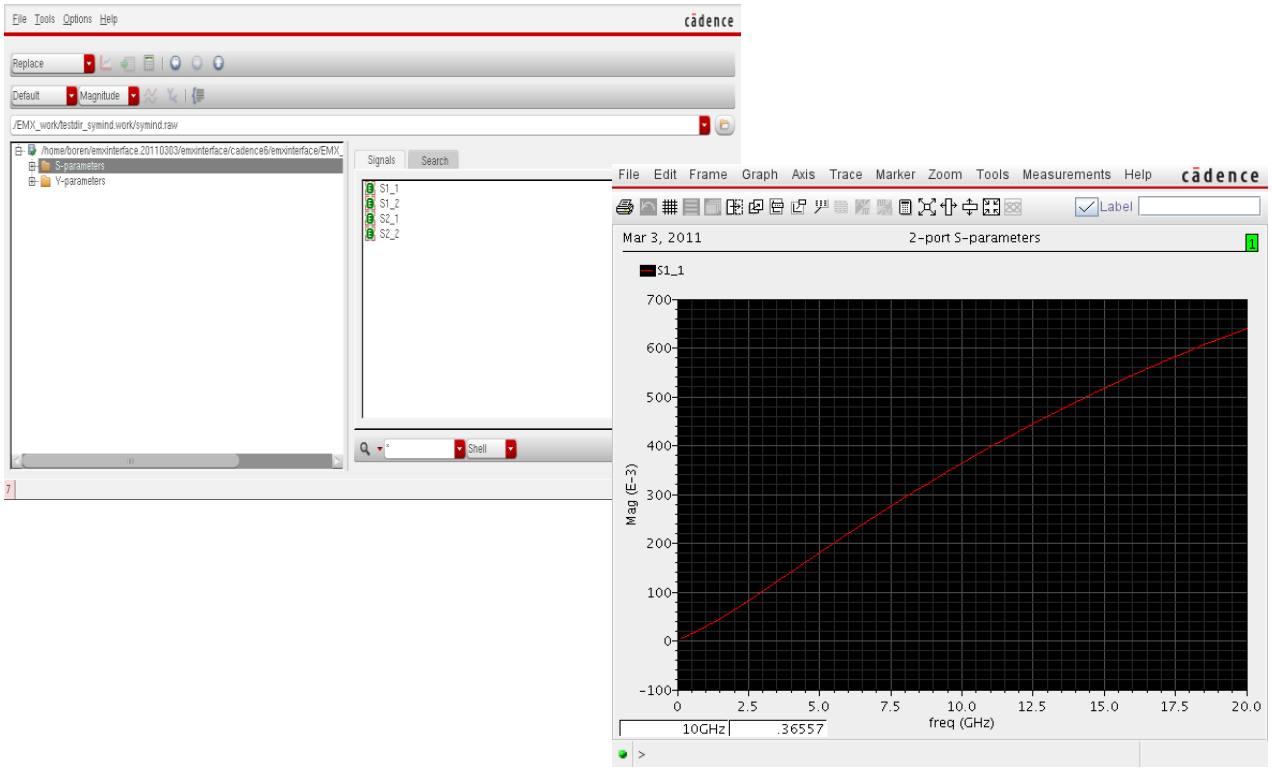
Fitting and comparison



Simulations can be compared with other data files for either comparison purposes or for building a models. For example simulation can be compared to measurements.

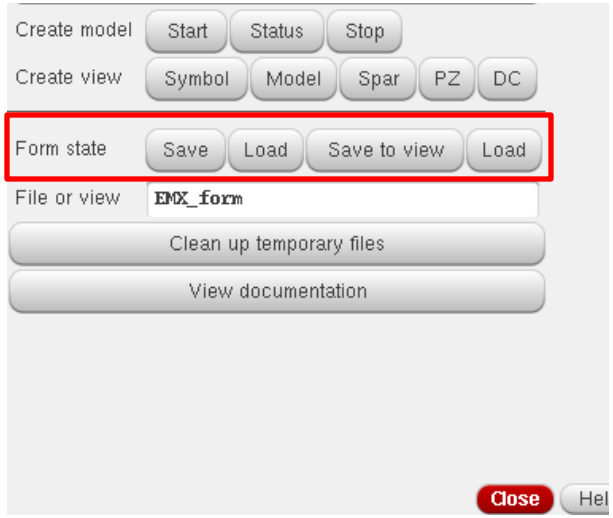
Cadence Waveform viewer

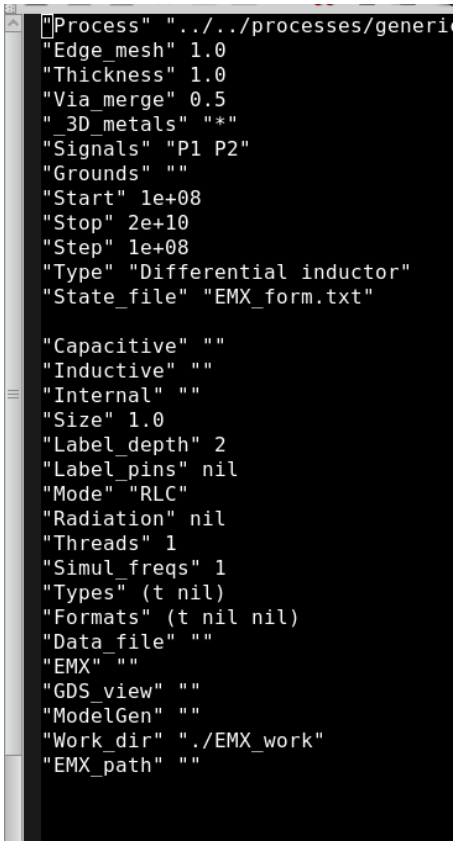




The Waveform viewer uses the native plotting capabilities of Virtuoso. The calculator and other functions of WaveScan can be used.

Saving form state





The simulation settings can be saved to a text file which can be reloaded later using load. The form states for these examples are in the directory "states" and need to be copied to the working directory. The state can be stored in the cell view.

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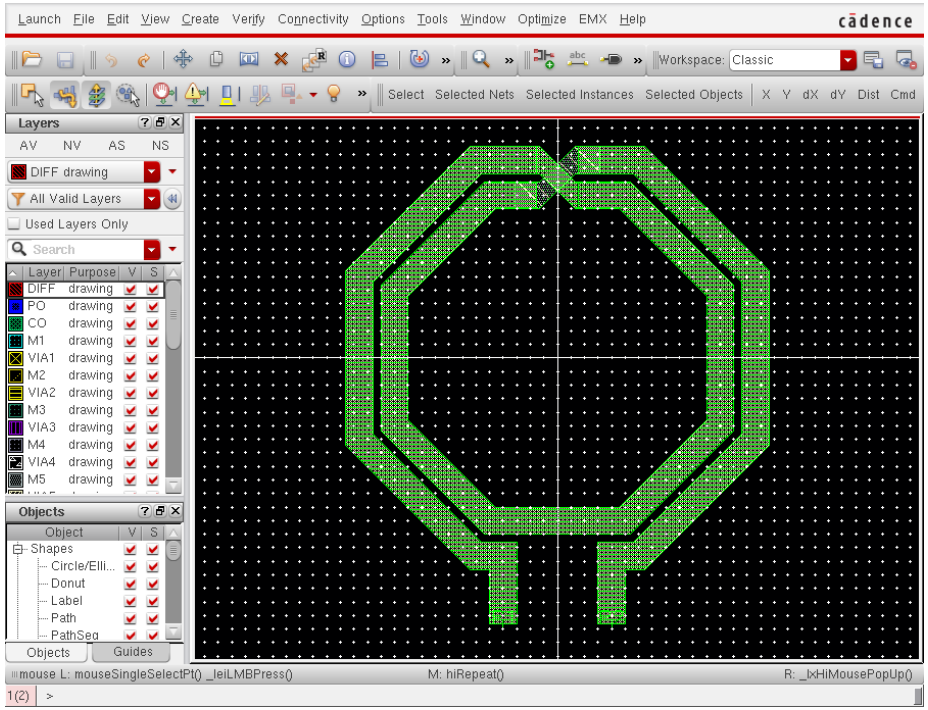
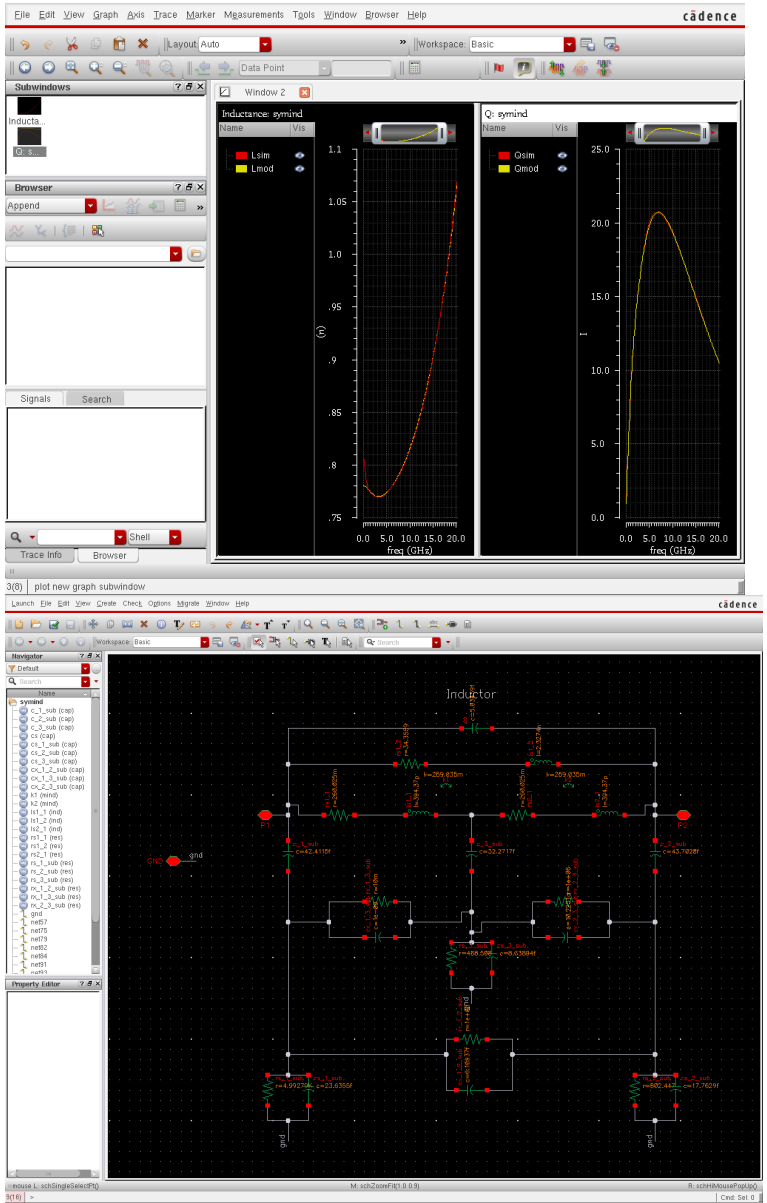
Summary of examples





2 port inductor (single-ended)

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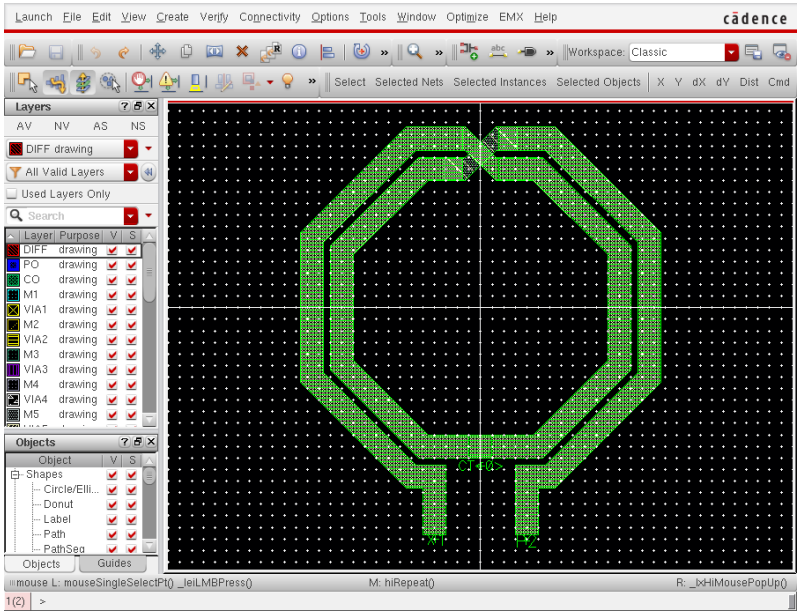
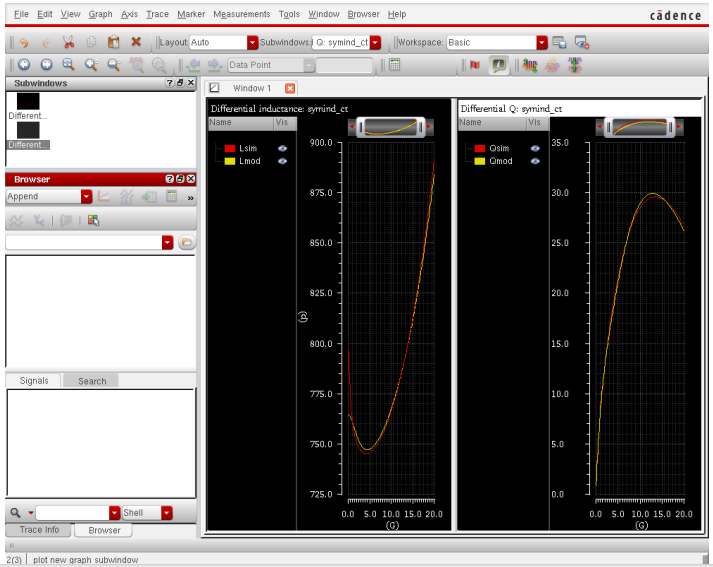
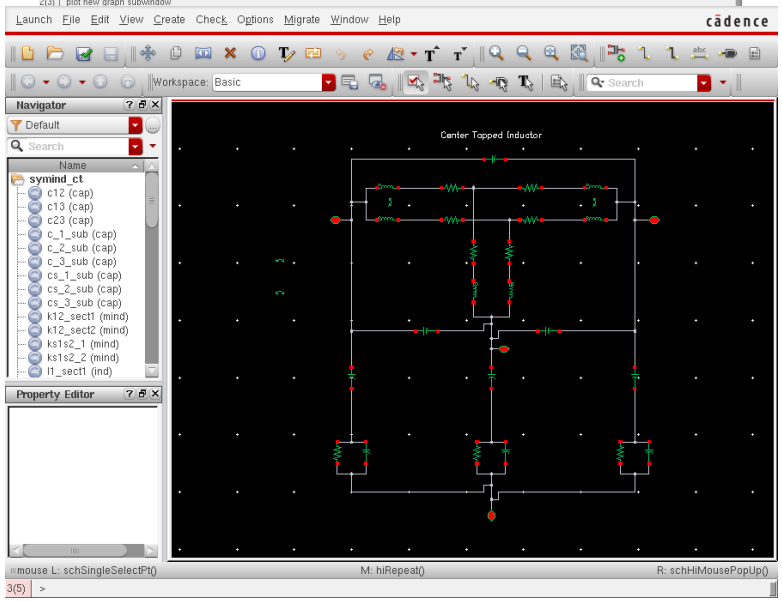
Summary of examples

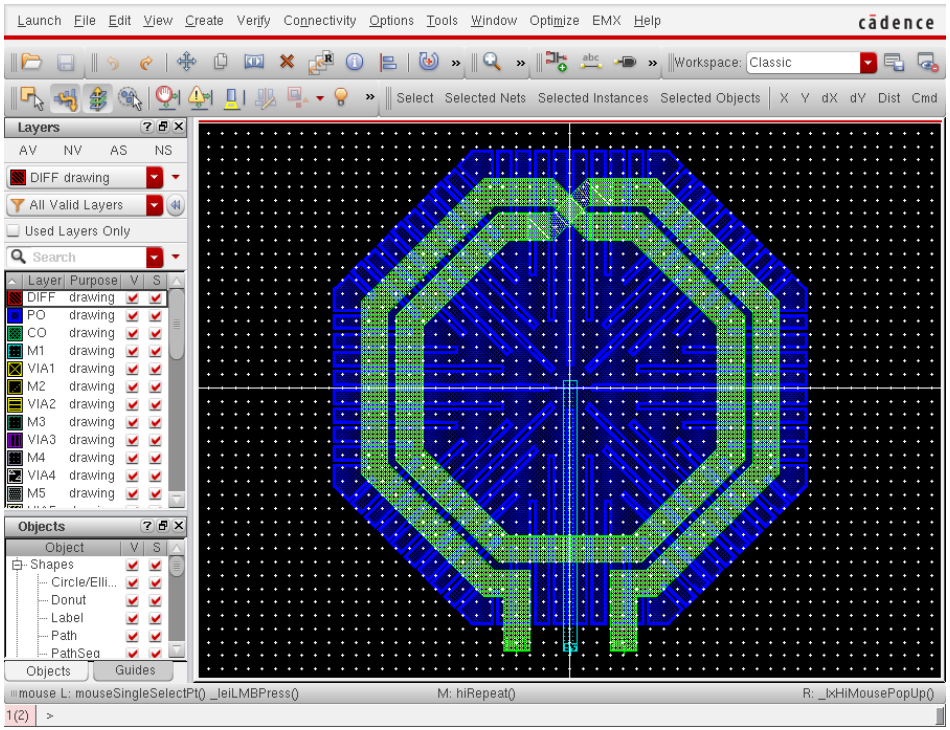


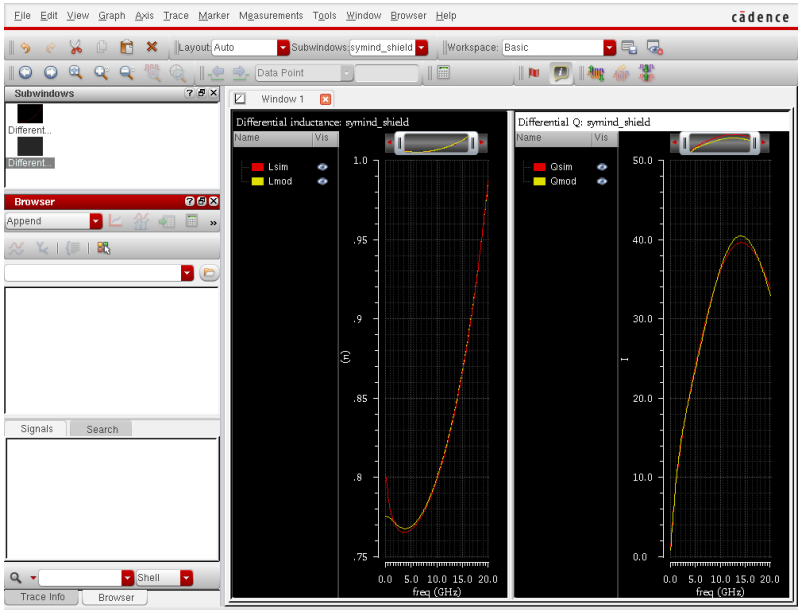


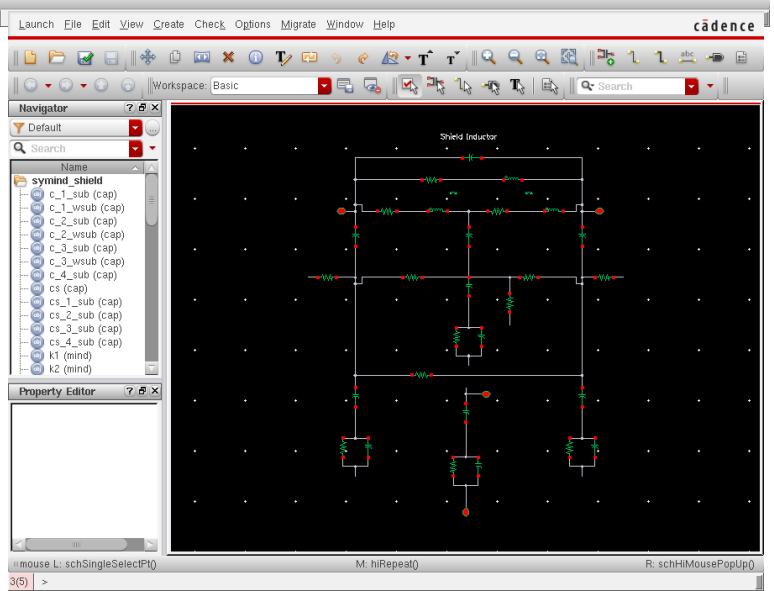


Center-tapped inductor (differential)

Summary of examples

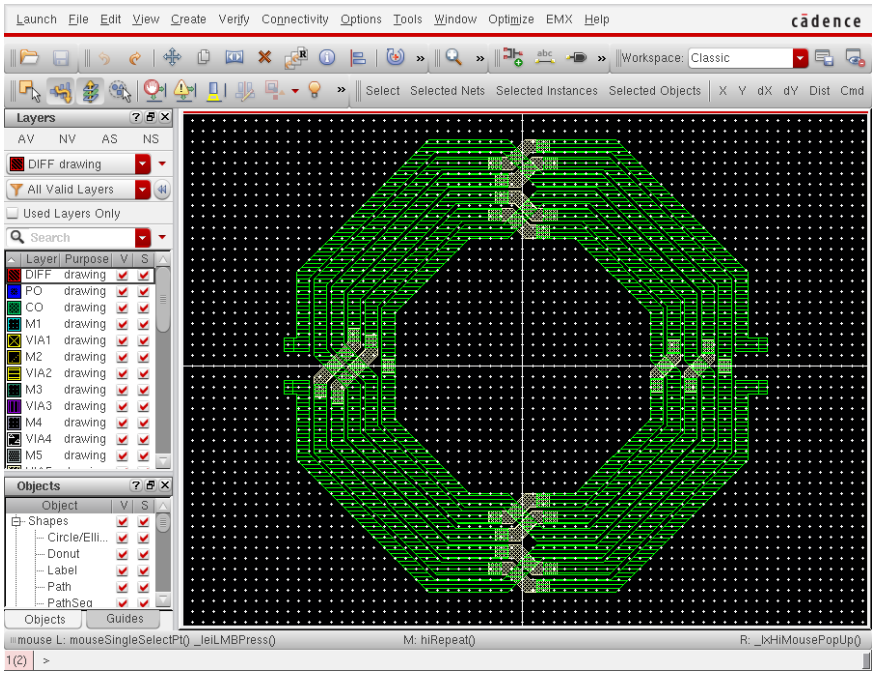


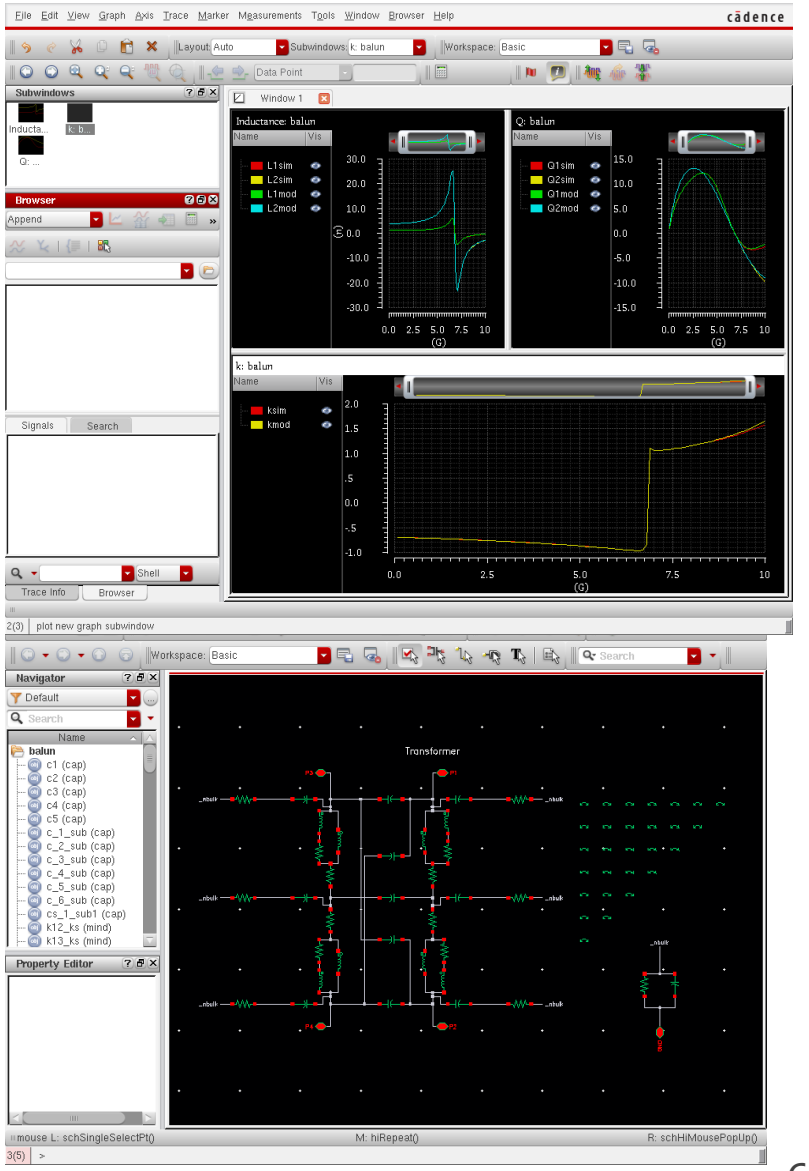




Inductor with shield (single-ended)

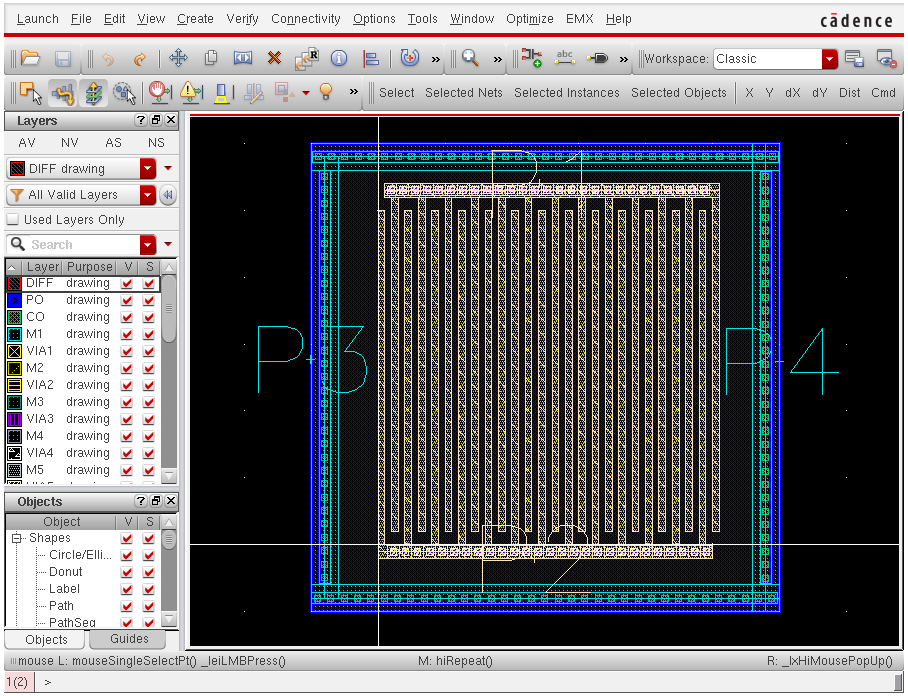
Summary of examples

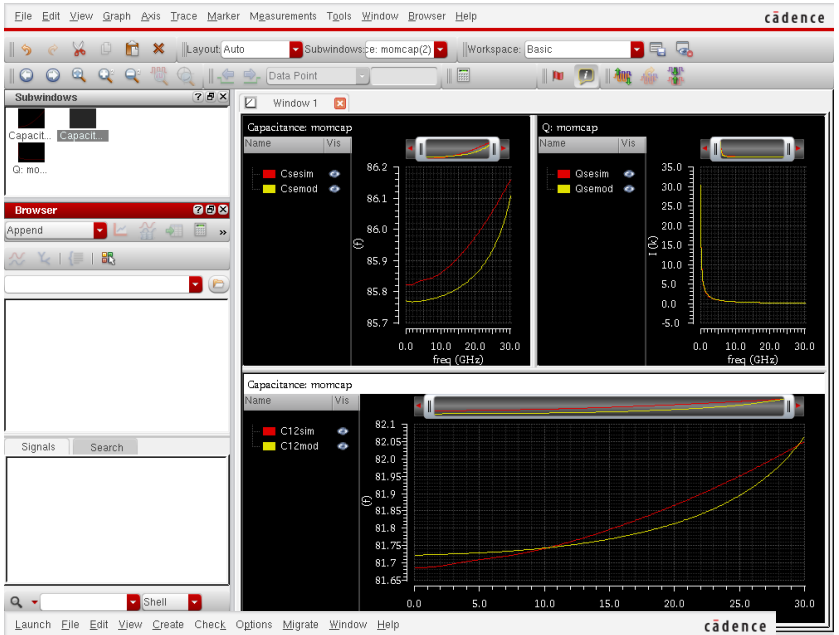


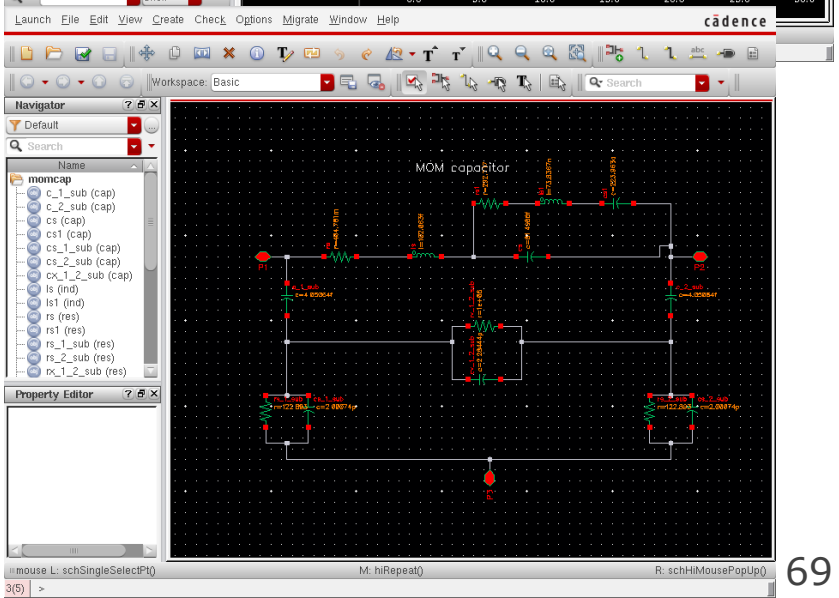


4 port transformer

Summary of examples







MOM capacitor

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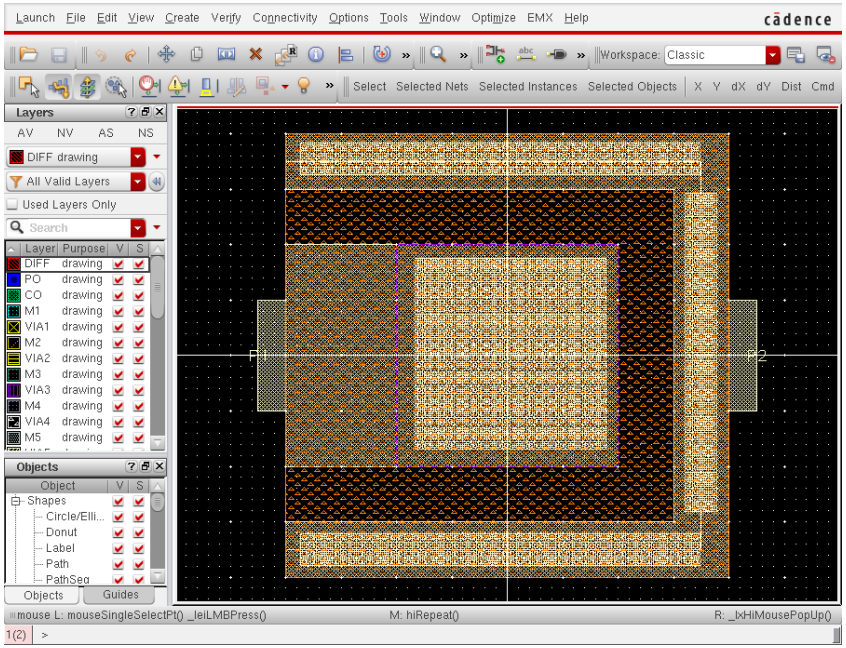
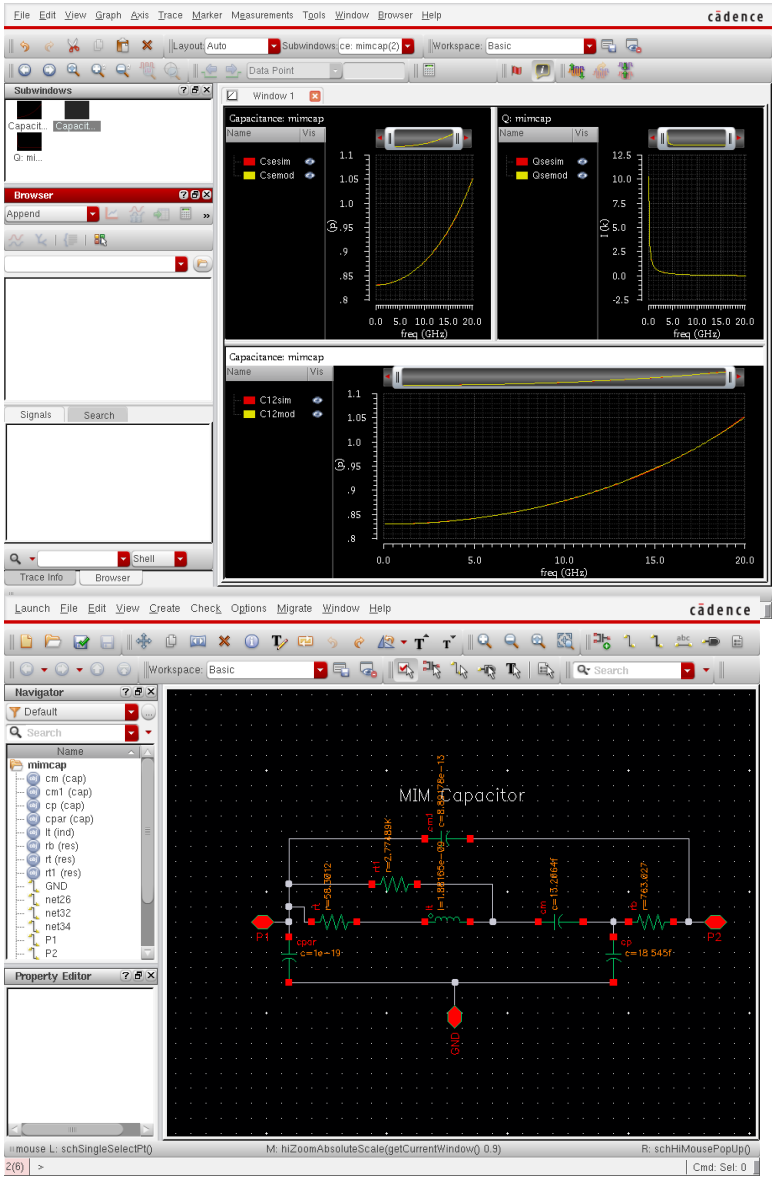
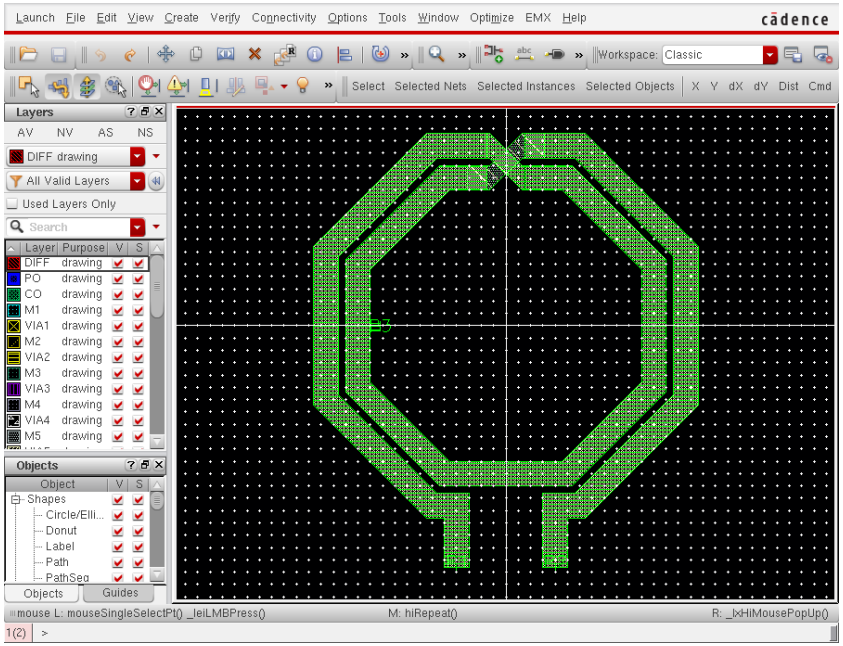
Summary of examples

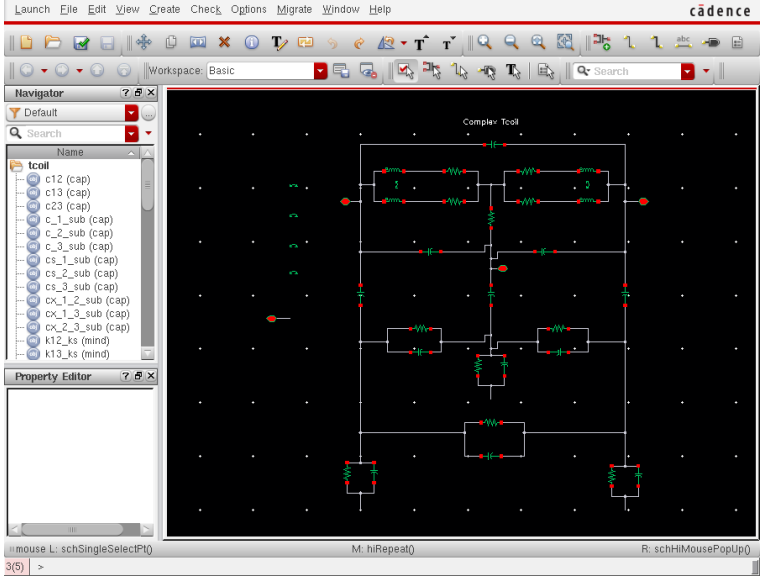




MIM capacitor

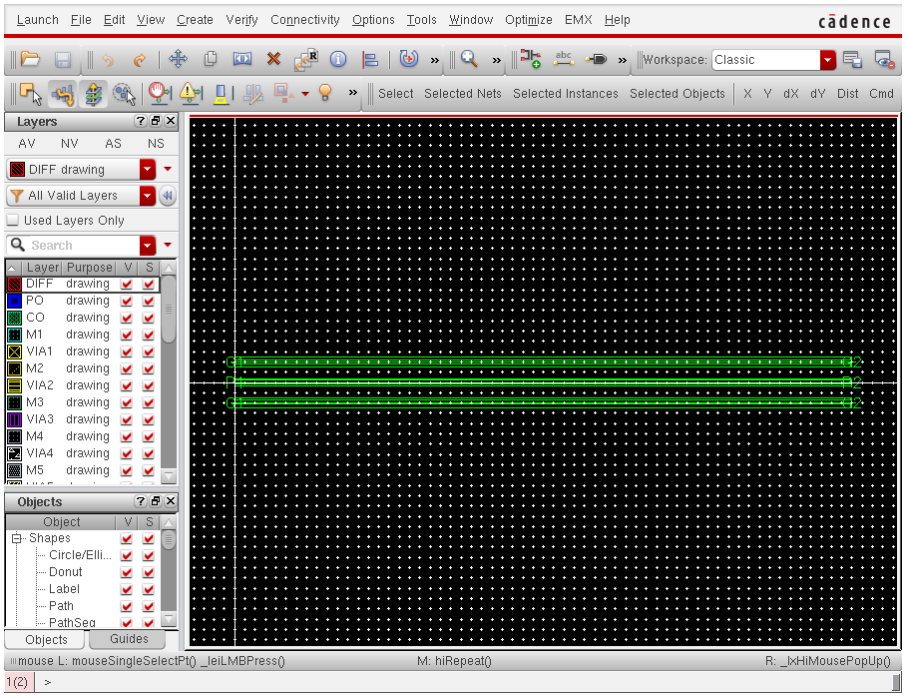
Summary of examples



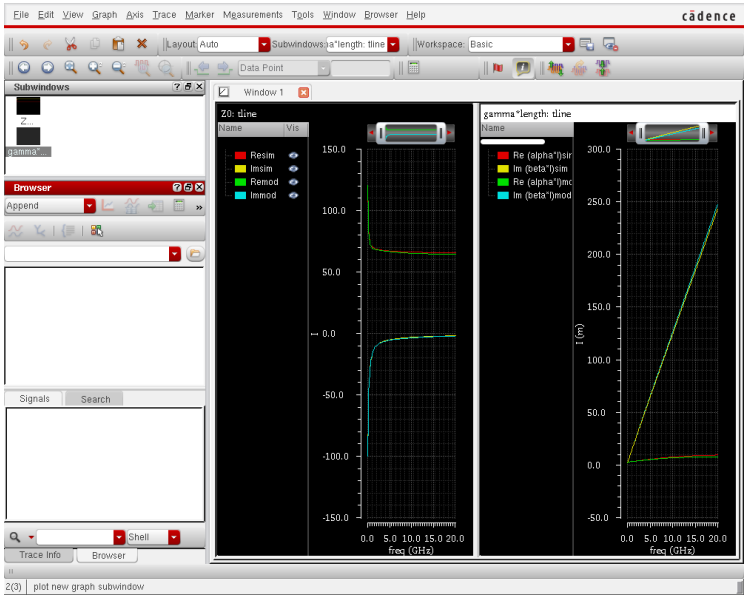


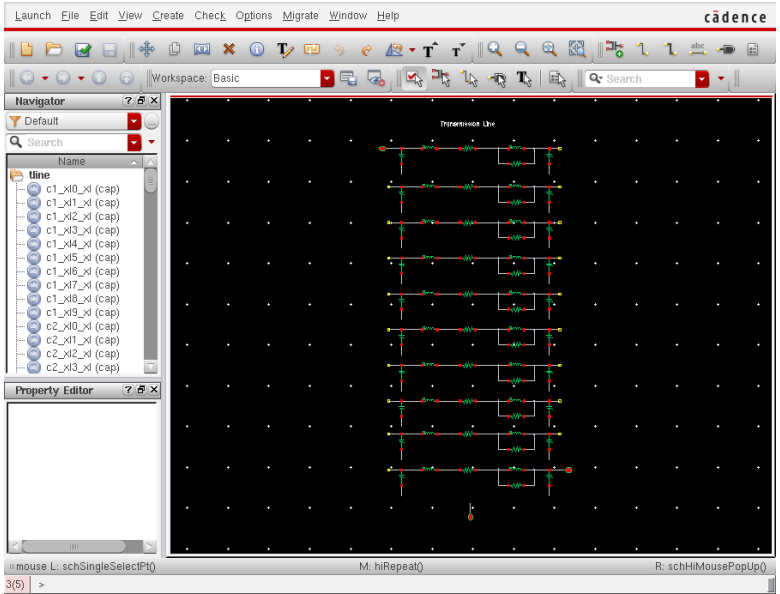
Tcoil

Summary of examples



Tline





EMX Misc Features

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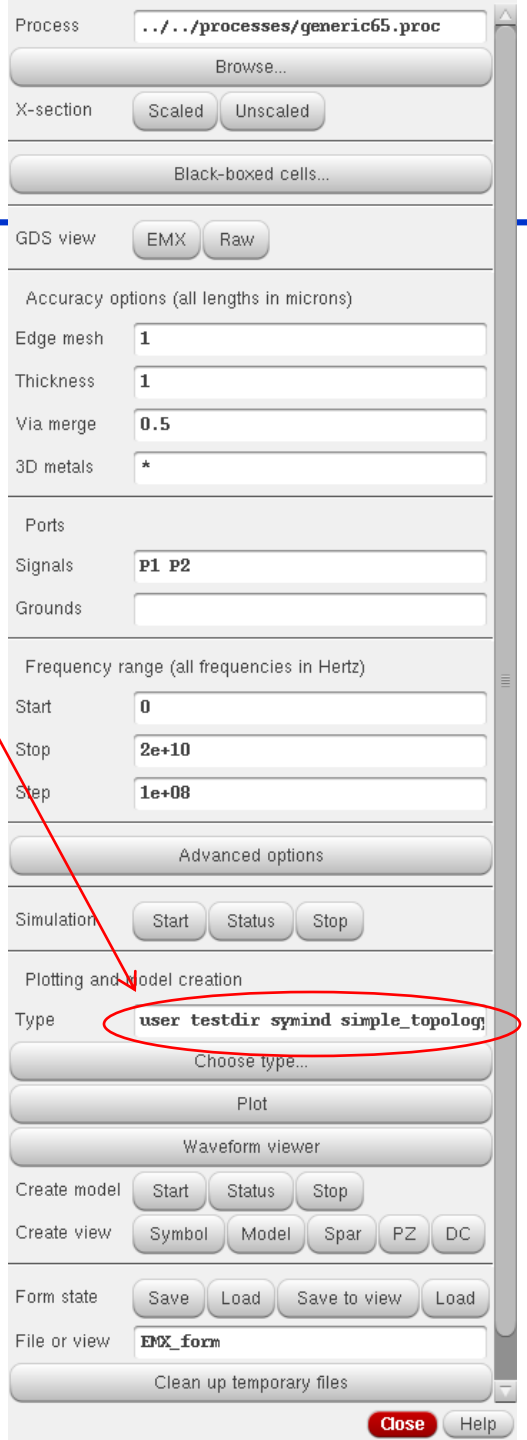
User defined topologies

- When using Modelgen the user has a list for predefined topologies that can be used to generate a RLCK model
- It is now possible for the user to generate a model based on their own topology (and their own fitting risk)
- EMX will also generate a schematic associated with this user defined topology

User defined model

- The capabilities for user defined models has been enhanced
- The designer can create a schematic view that EMX will use to build the model



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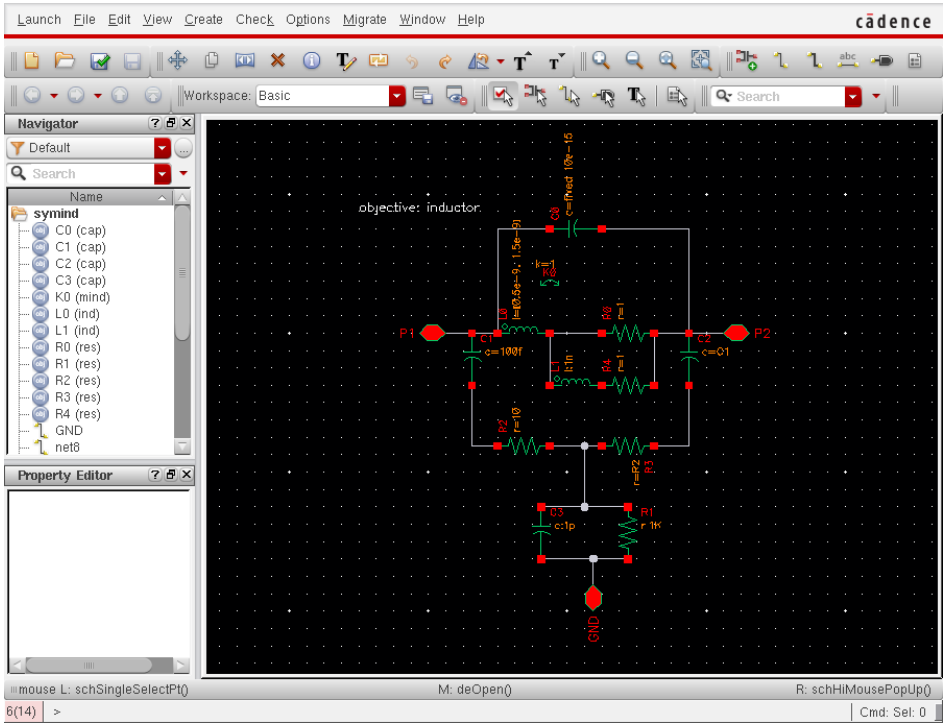
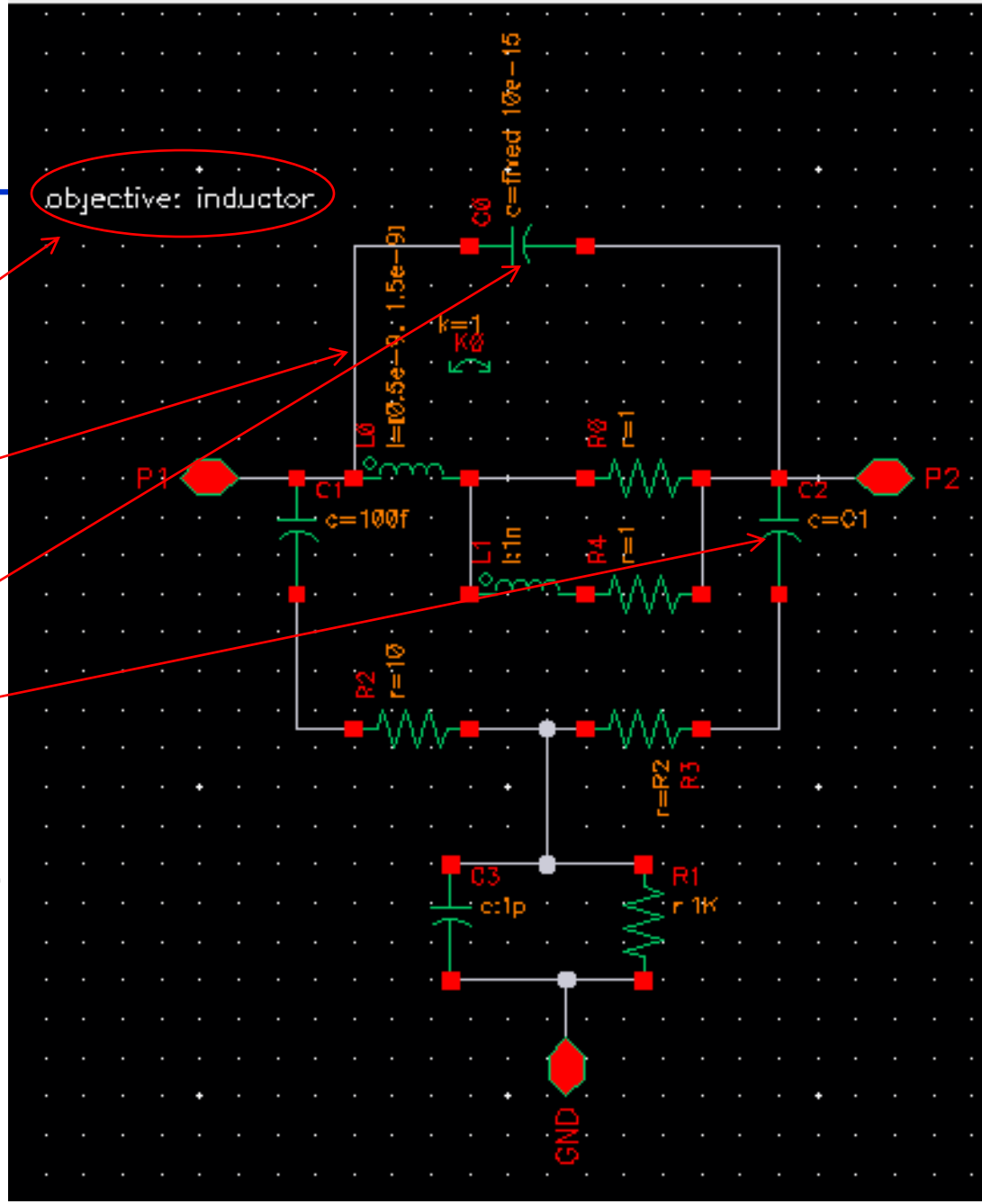
A generic schematic for a simple inductor

- A simple schematic is drawn by the designer
- Various constraints can be use to help with the model generation



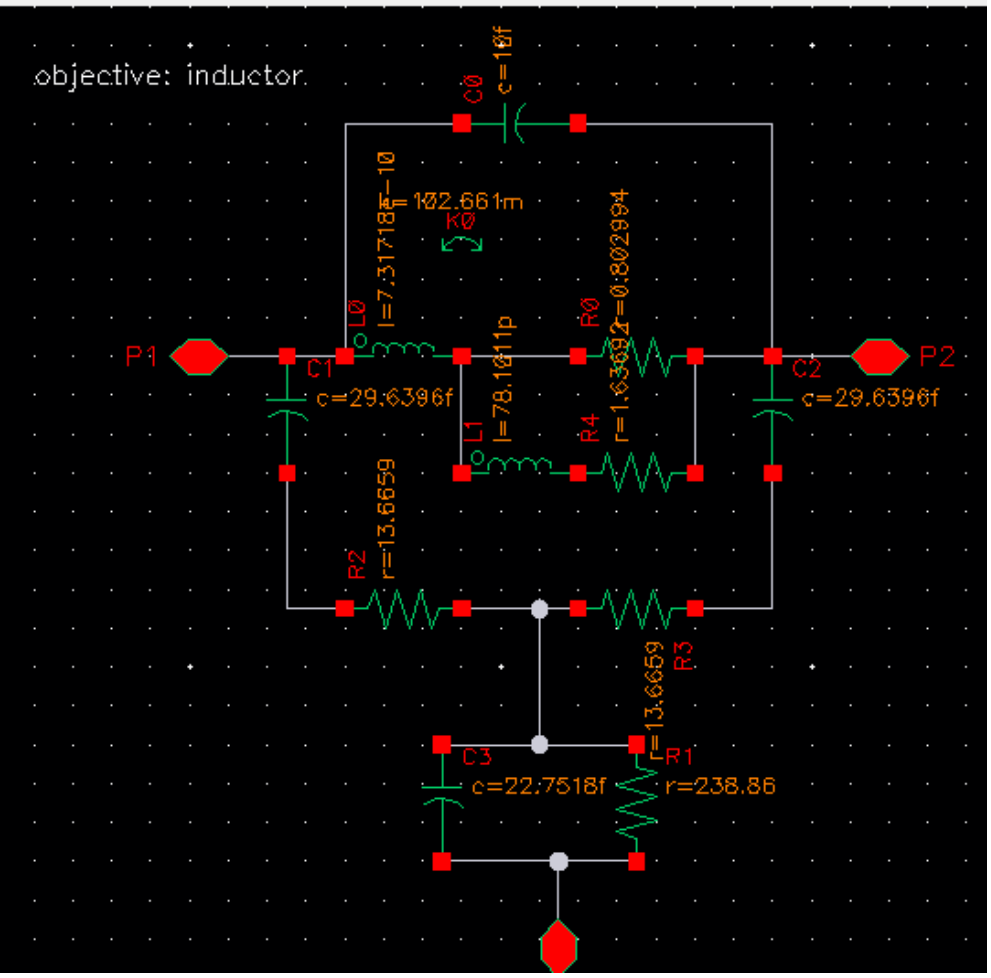
Constraints

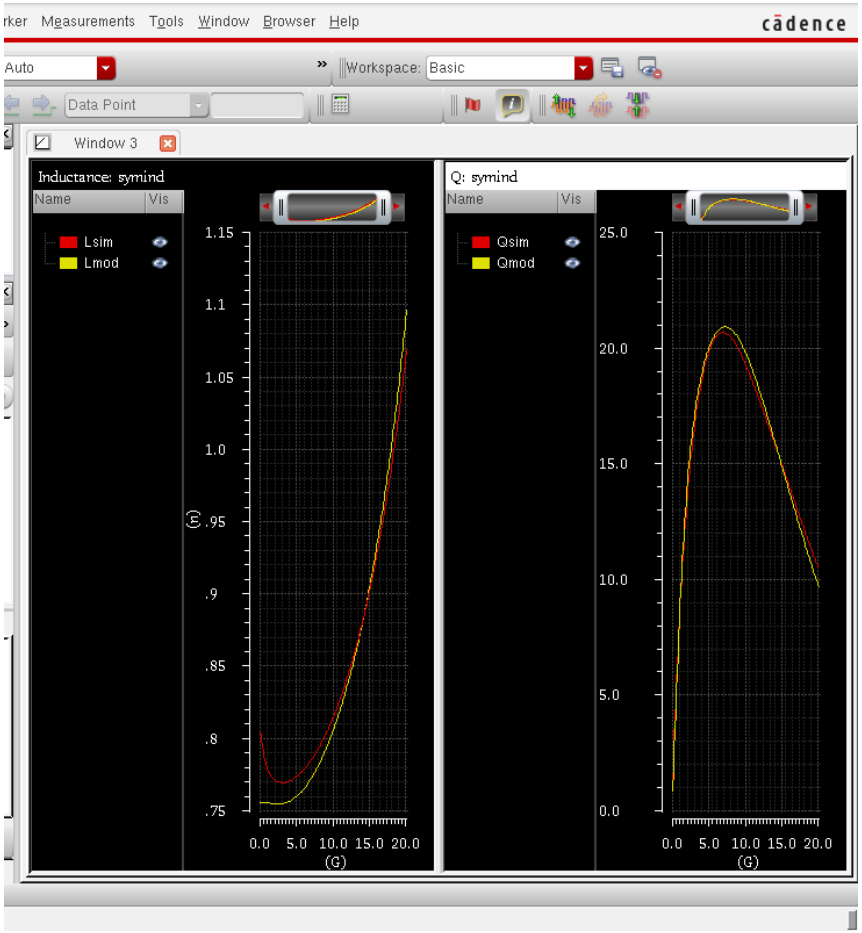
- Objective function can be chosen to be one of the supported topologies
- Ranges can be set for components
- Individual components can have values assigned
- Symmetric can be enforced
- Order of magnitude can be assigned to help optimizer



Resulting model

- The final model will be generated using the constraints





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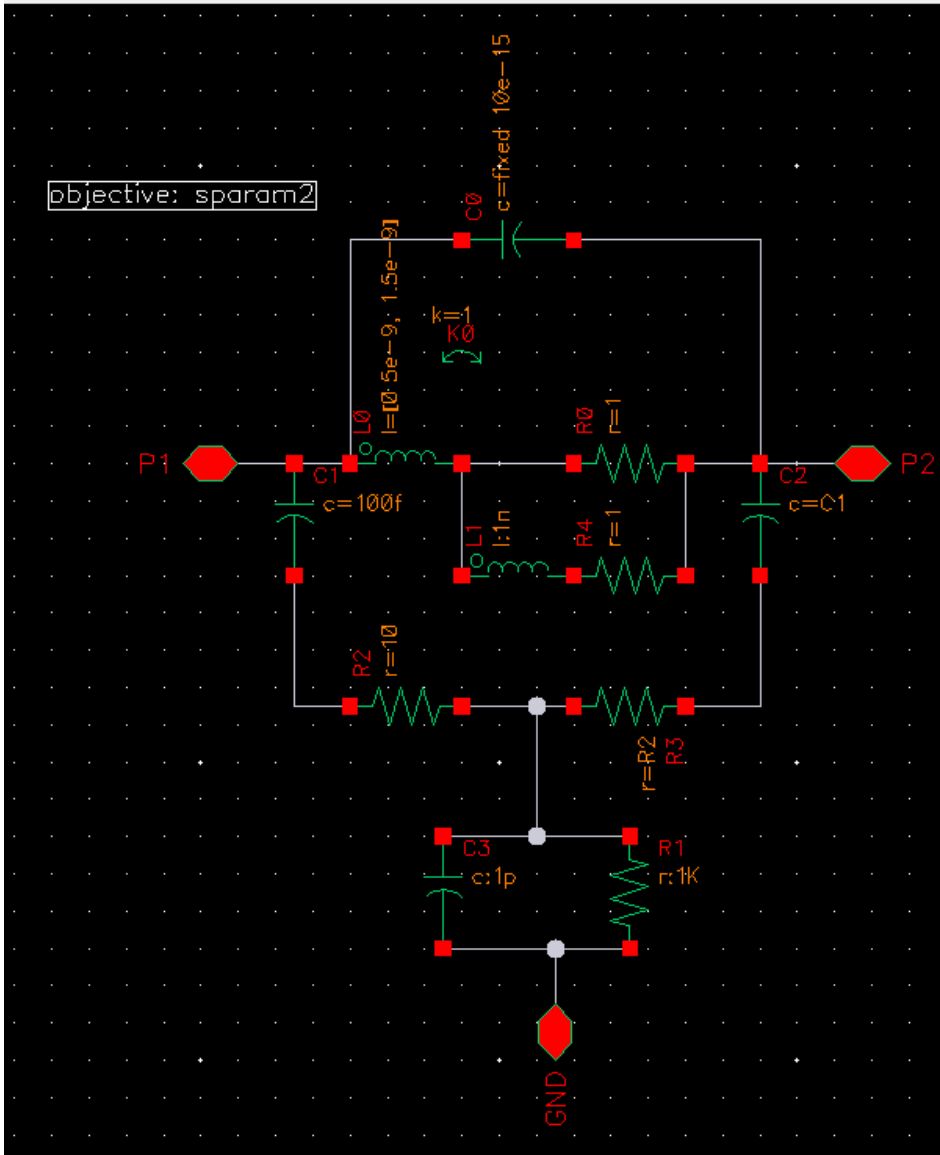
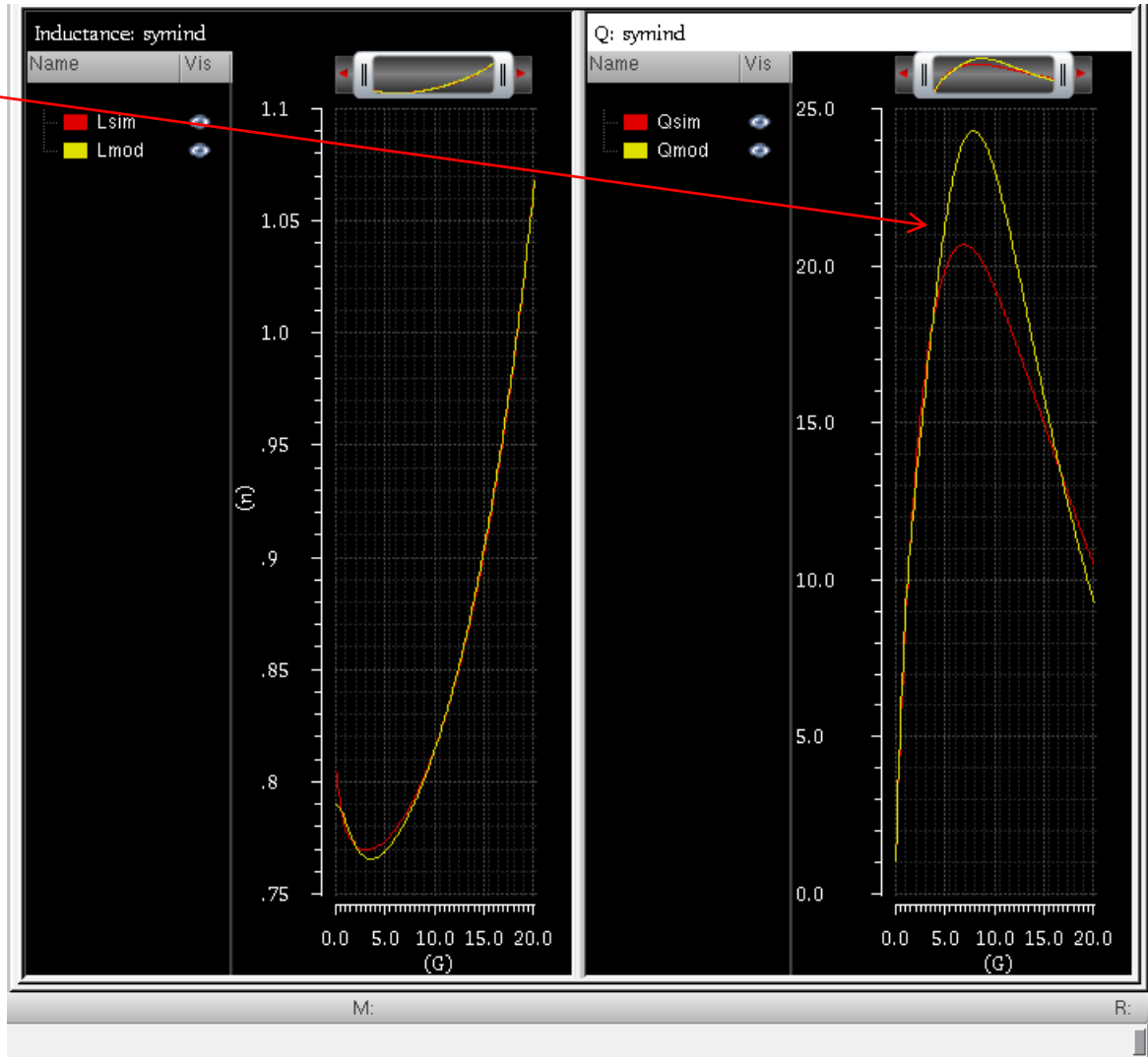
S-parameters objective function

- The individual devices have a complicated objective function for fitting (e.g., inductors fit, S-params, Z-params, L, Q, etc.).
- When the designer does non know the underlying topology S-parameters alone can be fit.
- In this case “sparam2” was used.



S-param fit

- S-parameter fit may not be as good an inductor objective function but may be acceptable depending on context



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EMX black box flow

- Designers often use EMX to simulate component ensembles (e.g., VCOs, LNAs).
- Typically the active circuitry is omitted from the layout and EMX is used only on the passive blocks
- The EMX results are then manually stitched together with the schematics for the active circuitry. This step can be somewhat error prone.
- The EMX interface and EMX has been modified to be able to use EMX on a real circuit layout
  - EMX is used for the passive circuitry/interconnect
  - The foundry models are extracted for the actives
  - The user chooses the cells that EMX is going to simulate
  - Multiple EMX views are now supported (S-pars, PZ, Model)
  - A final integrated netlist and schematic is generated that includes the EMX results combined with the foundry models

Setting up the EMX interface

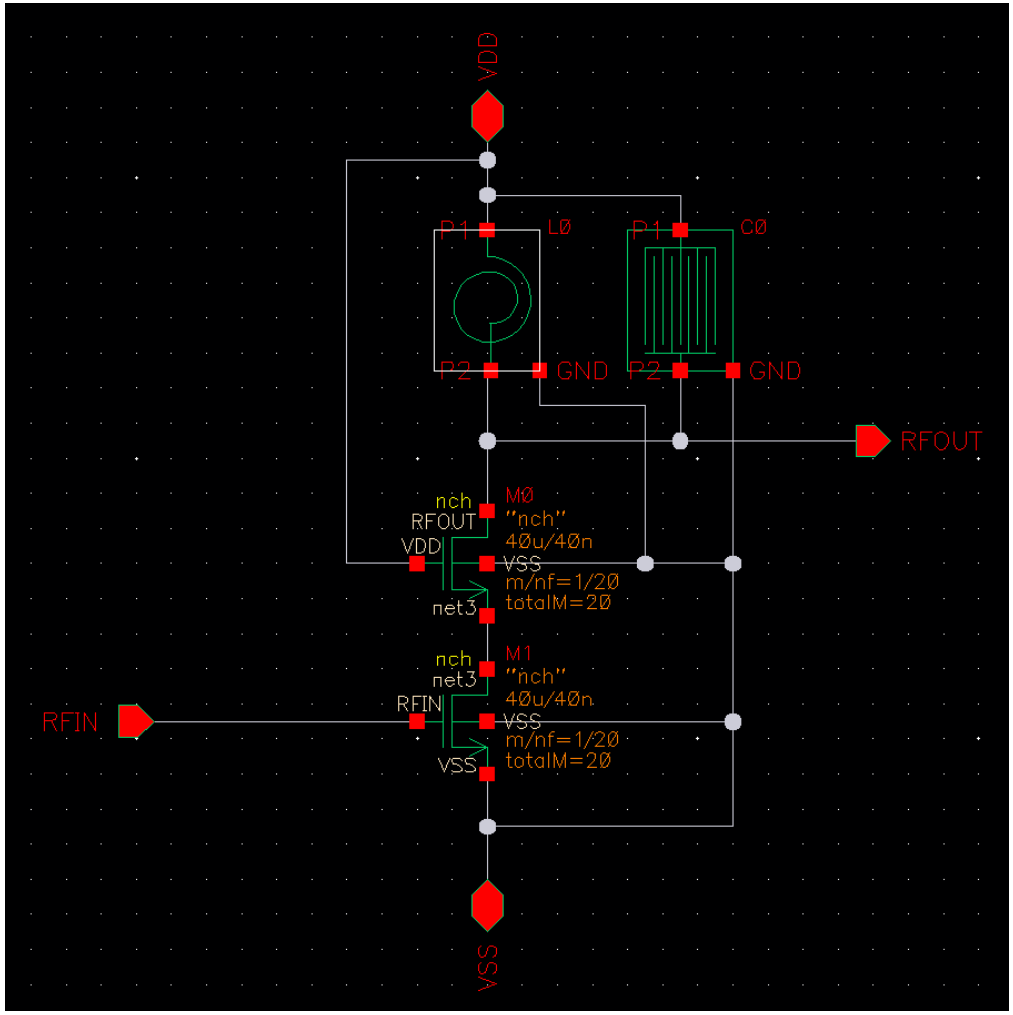
```
$ emx --version
EMX version 3.8+blackbox preview
Copyright (c) 2003 - 2014 Integrand Software, Inc.
Please report bugs to support@integrandsoftware.com
$ cat emxskill/emxconfig.il
...
; This option enables general state-space model creation.  It requires
; one of the later versions of EMX (one that supports the --model-file
; option).  Otherwise, model creation is only supported for certain
; types of devices.
EMX_pole_zero_models=t

; This option enables black box support in the interface.  It requires
; a version of EMX that supports the --device-cells-file option.
EMX_black_box=t

; Miscellaneous
EMX_symbol_name="symbol"
EMX_symbol_nport_name="symbol"
EMX_schematic_name="EMX_model"
EMX_schematic_pz_name="EMX_pz"
EMX_schematic_nport_name="EMX_spar"
...
$
```

- The black box flow needs to be enabled in “emxconfig.il”
- EMX 4.2 or later needs to be used
- Separate view names need to be provided

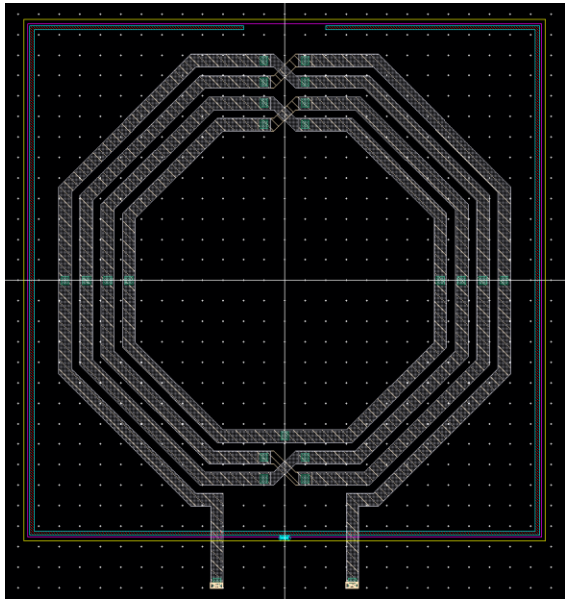
Example of amplifier design

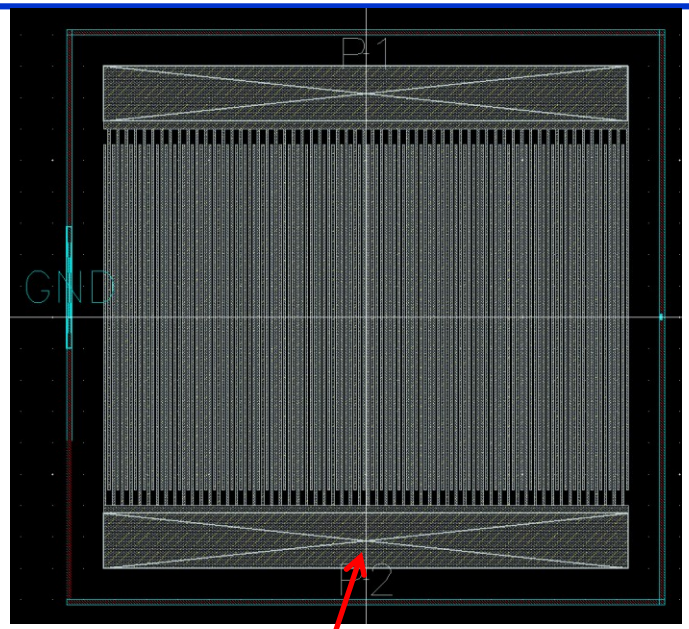


amp2

- A simple amplifier is used to illustrate the flow
- It contains an inductor, a MOM capacitor and transistors

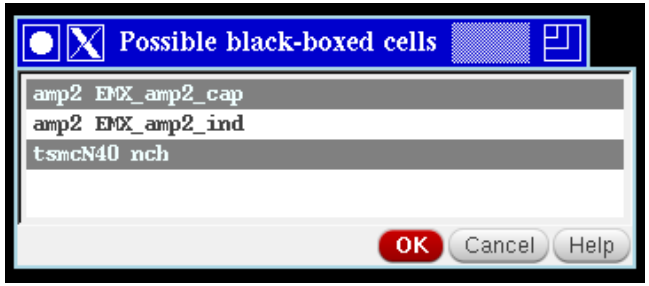
Inductor and MOM cap layout



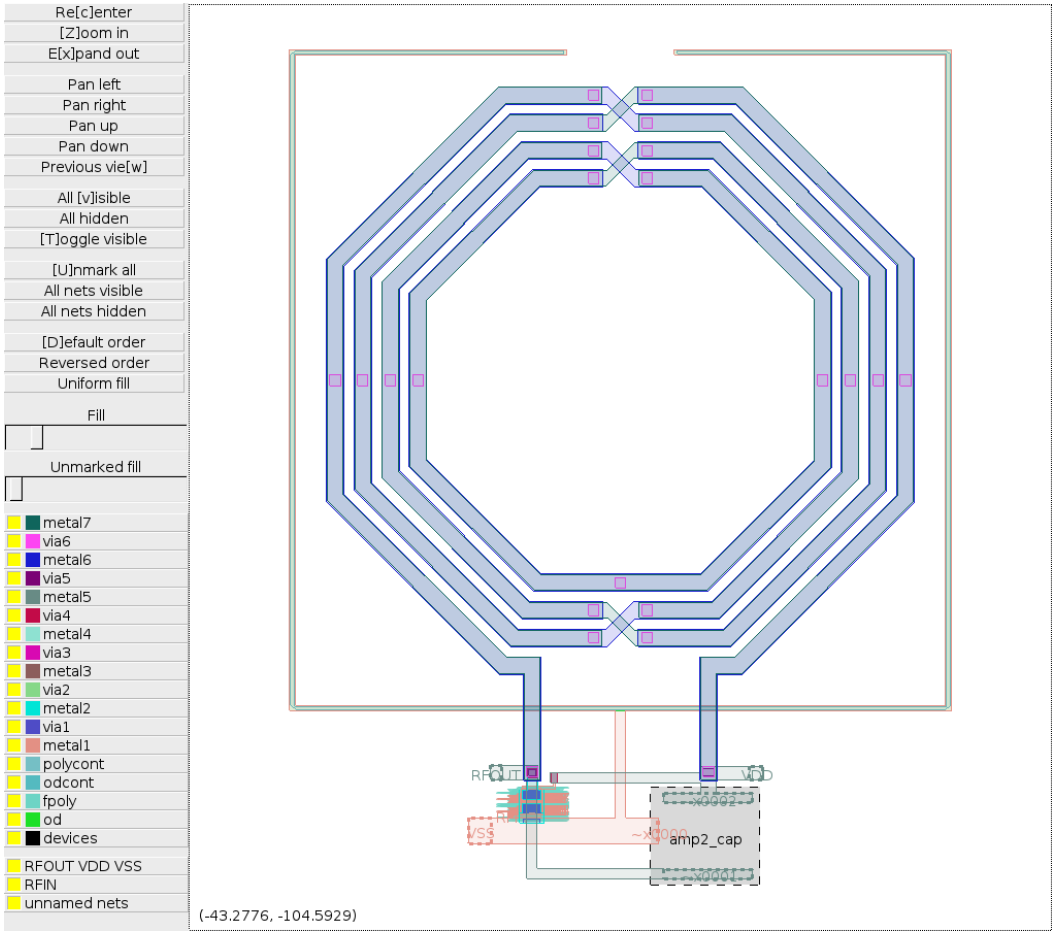


- Inductor and capacitor layout
- Cadence pins need to be used for the ports (in this case internal ports)
- Cadence pins are always at the 0^{th} level of the hierarchy.

Selecting only caps and transistors as bboxes



- Now EMX will be used to simulate the inductor and all the interconnect excluding the capacitor and transistors



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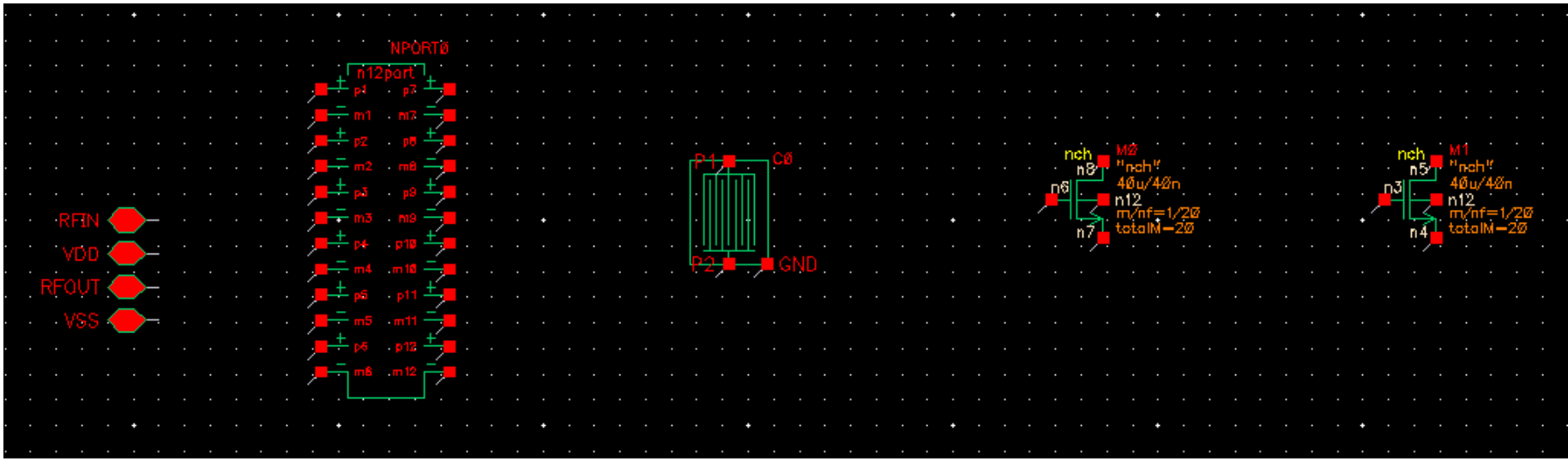
S-parameter view



- EMX S-parameter view (includes inductor)
- The N-port block is a pointer to the S-parameters
- Only the caps and transistors come from the foundry models

Temperature

- Option 1: Use the TCR coefficients in the Spectre model to get temperature effects
- Option2: Run EMX at a particular temperature
- Running EMX at a certain temperature may be slightly more accurate since it can account for different temperature coefficients for different metals.

Temperature coefficients

- The EMX .proc file can contains the temperature coefficients of the metals

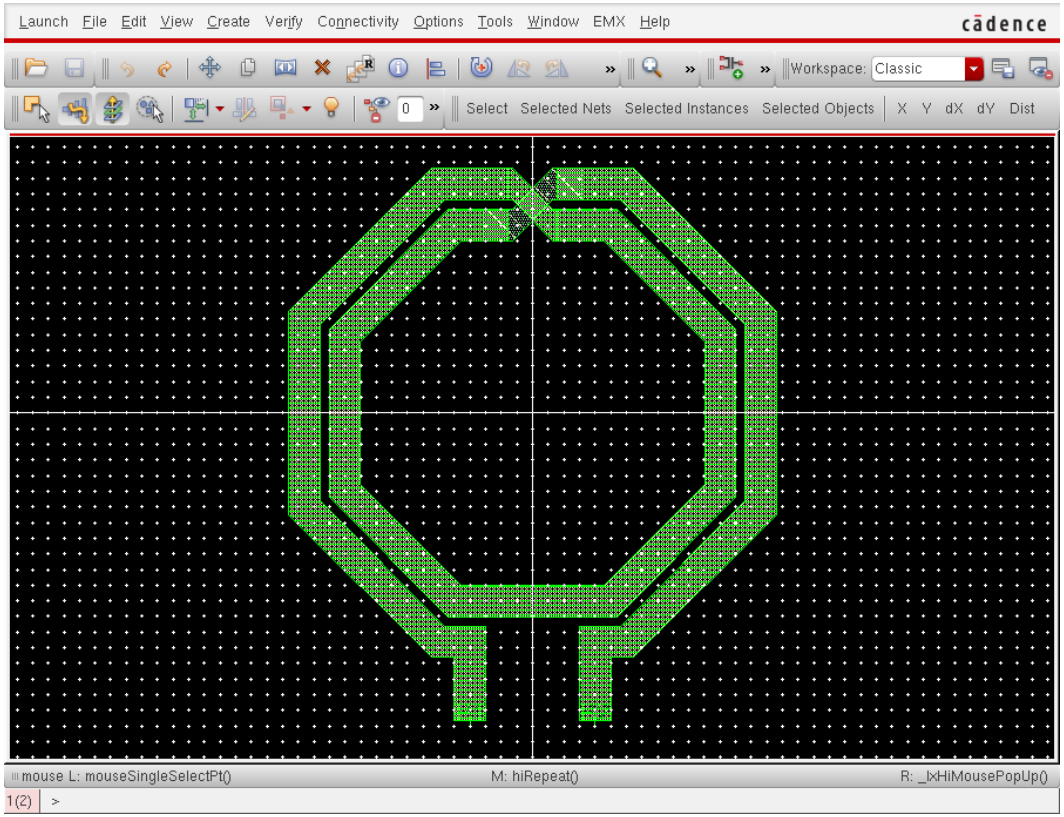
```
layer 0.03 4.5 # IMD1a
layer 0.13 3.0 # IMD1b
layer 0.05 5 # IMD1c
position -0.18
conductor 0.18 m1res*(1+0.00265*dtemp) -/+ 0.0001*shvar metal1
  bias m1bias
layer 0.03 4.0 # IMD1d
layer 0.1 3.0 # IMD2a
layer 0.25 3.0 # IMD2b
conductor 0.25 m27res*(1+0.003*dtemp) -/+ 0.0001*shvar metal2
  bias m2bias
layer 0.05 5 # IMD2c
layer 0.03 4.0 # IMD2d
layer 0.1 3.0 # IMD3a
layer 0.25 3.0 # IMD3b
conductor 0.25 m27res*(1+0.003*dtemp) -/+ 0.0001*shvar metal3
  bias m2bias
layer 0.05 5 # IMD3c
layer 0.03 4.0 # IMD3d
layer 0.1 3.0 # IMD4a
layer 0.25 3.0 # IMD4b
conductor 0.25 m27res*(1+0.003*dtemp) -/+ 0.0001*shvar metal4
  bias m2bias
layer 0.05 5 # IMD4c
layer 0.03 4.0 # IMD4d
layer 0.1 3.0 # IMD5a
layer 0.25 3.0 # IMD5b
```

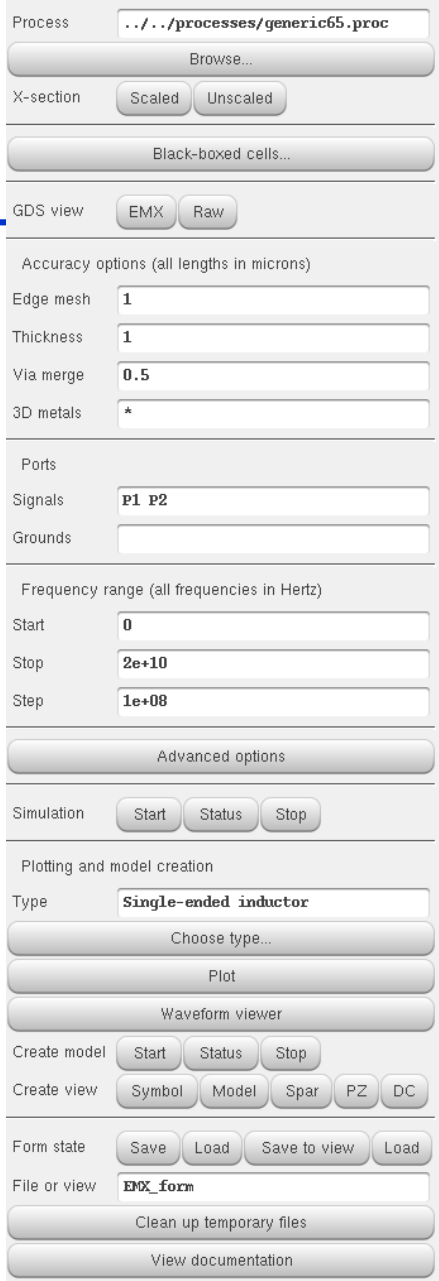
tcr1=0.003

The temperature coefficients may be different for different metals

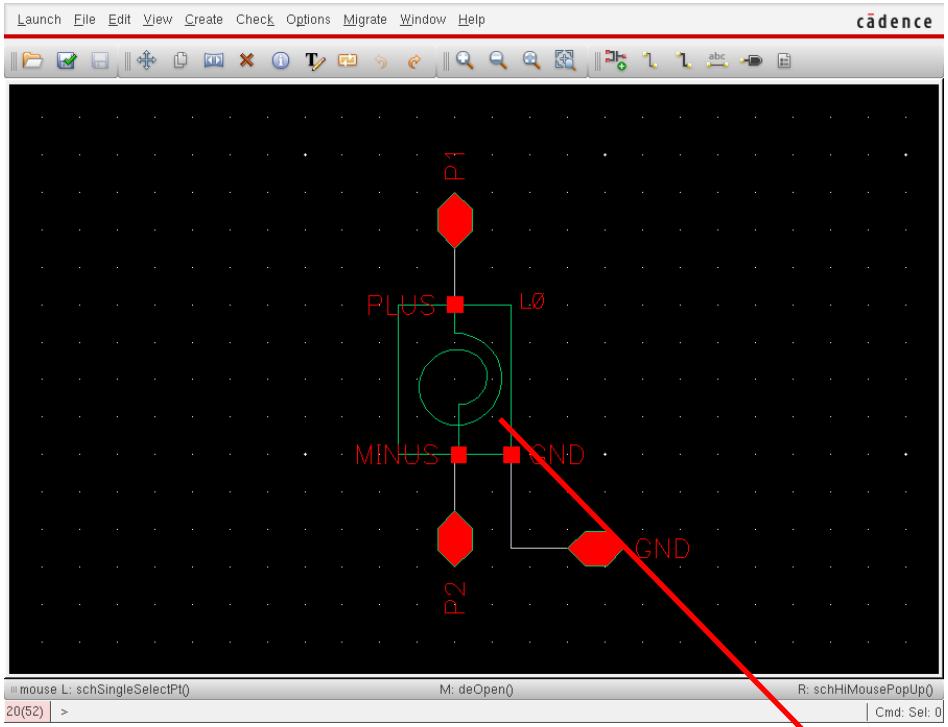
OPTION 1

Run EMX, create model, create symbol schematic





OPTION1



Setup tcr1 to 0.003 in emxskill/emxconfig.il

Browse | Reset Instance Labels Display

Property	Value	Display
Library Name	EMX_models	off
Cell Name	EMX_inductor	off
View Name	symbol	off
Instance Name	L0	off

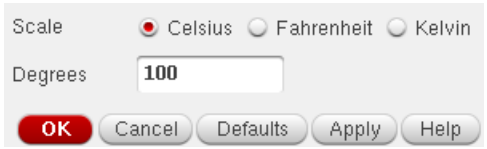
Add | Delete | Modify

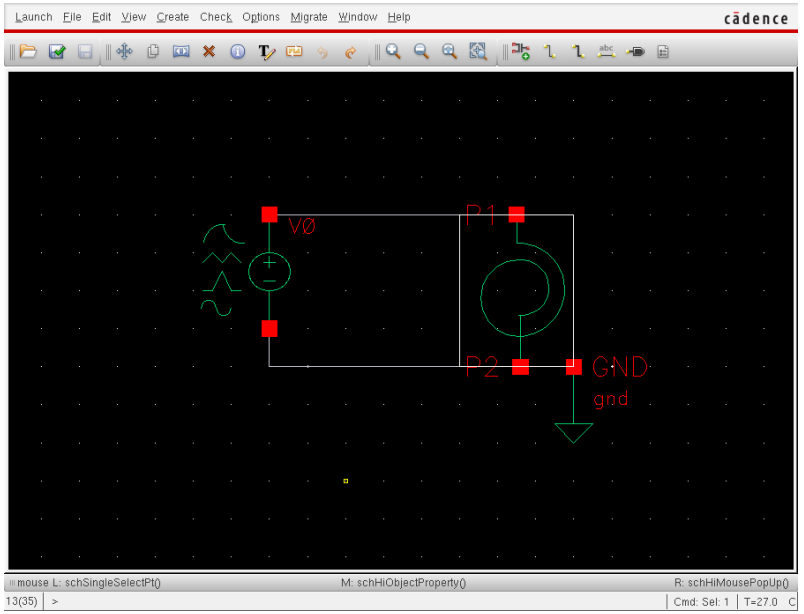
User Property	Master Value	Local Value	Display
interfaceLastCh..	2 14:07:56 2011		off

CDF Parameter	Value	Display
cs	5.03459f F	off
rs1_1	260.025m Ohms	off
ls1_1	394.37p H	off
rs2_1	260.025m Ohms	off
ls2_1	394.37p H	off
rs1_2	34.3559 Ohms	off
ls1_2	2.3274n H	off
k1	259.035m	off
k2	259.035m	off
c_1_sub	42.4115f F	off
rs_1_sub	4.99279K Ohms	off
cs_1_sub	23.6355f F	off
c_2_sub	43.7028f F	off
rs_2_sub	802.447 Ohms	off
cs_2_sub	17.7629f F	off
c_3_sub	32.2717f F	off
rs_3_sub	488.508 Ohms	off
cs_3_sub	8.63894f F	off
rx_1_2_sub	1M Ohms	off
cx_1_2_sub	6.10937f F	off
rx_1_3_sub	10m Ohms	off
cx_1_3_sub	1n F	off
rx_2_3_sub	1M Ohms	off
cx_2_3_sub	10.2251a F	off
tcr1	3e-3	off
tcr2	0.0	off

OK | Cancel | Apply | Defaults | Previous | Next | Help

OPTION1





Create a testbench

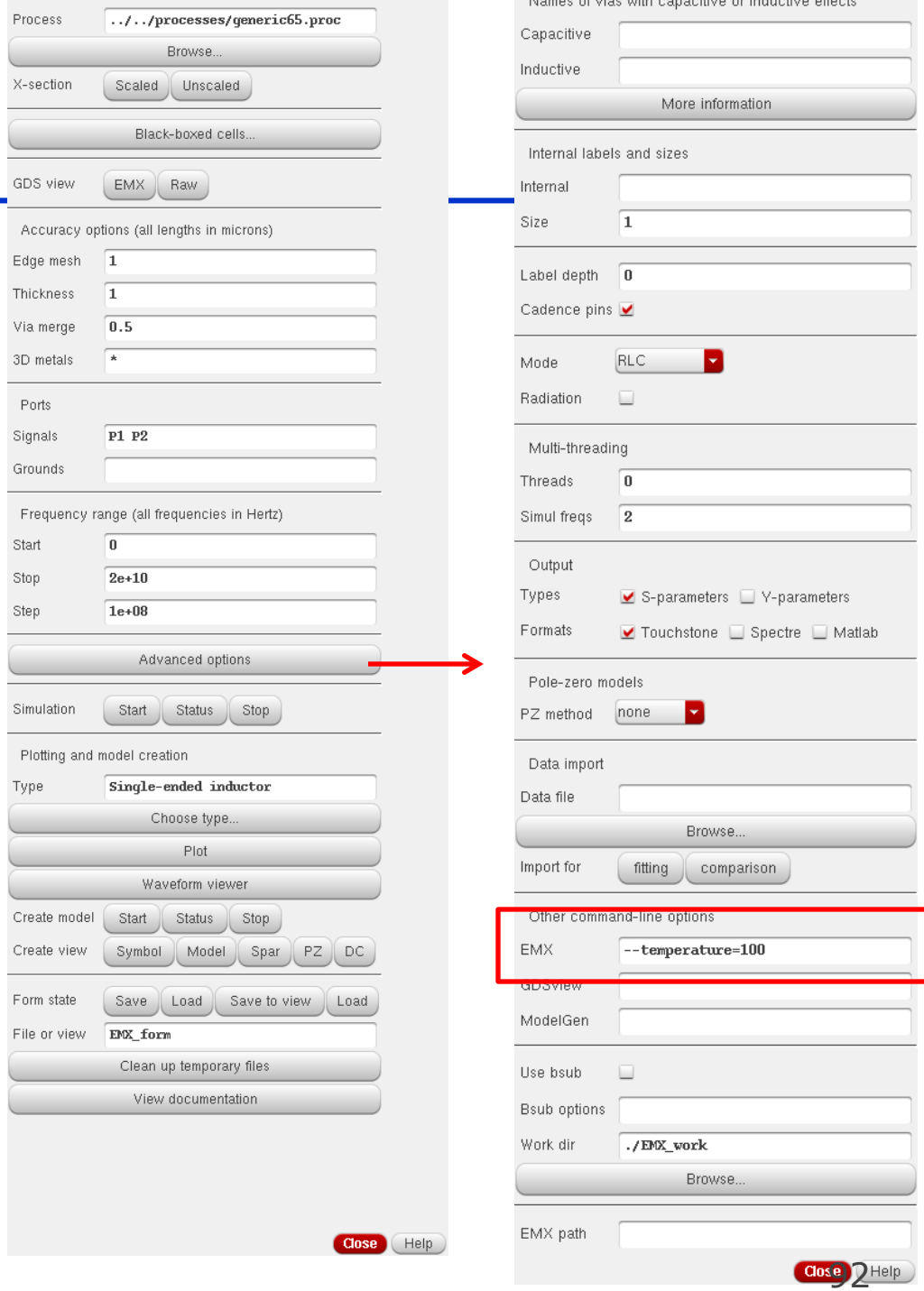
Change the temperature in ADE

Run the simulation

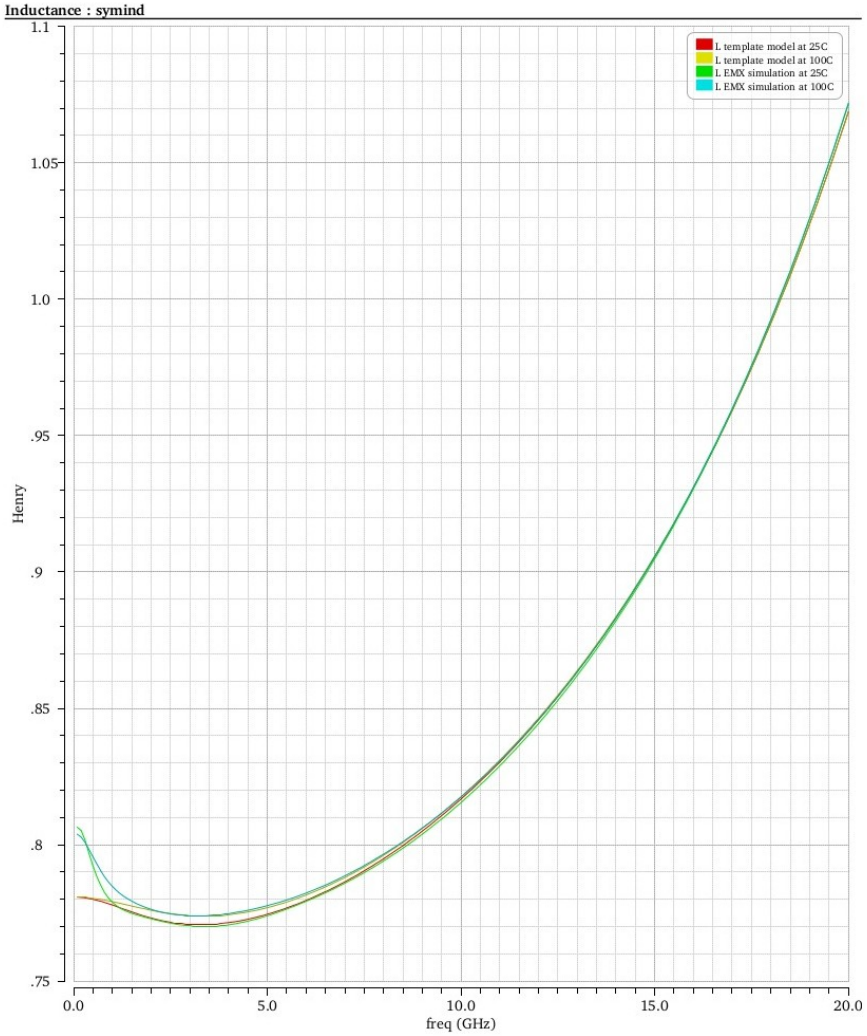
OPTION2

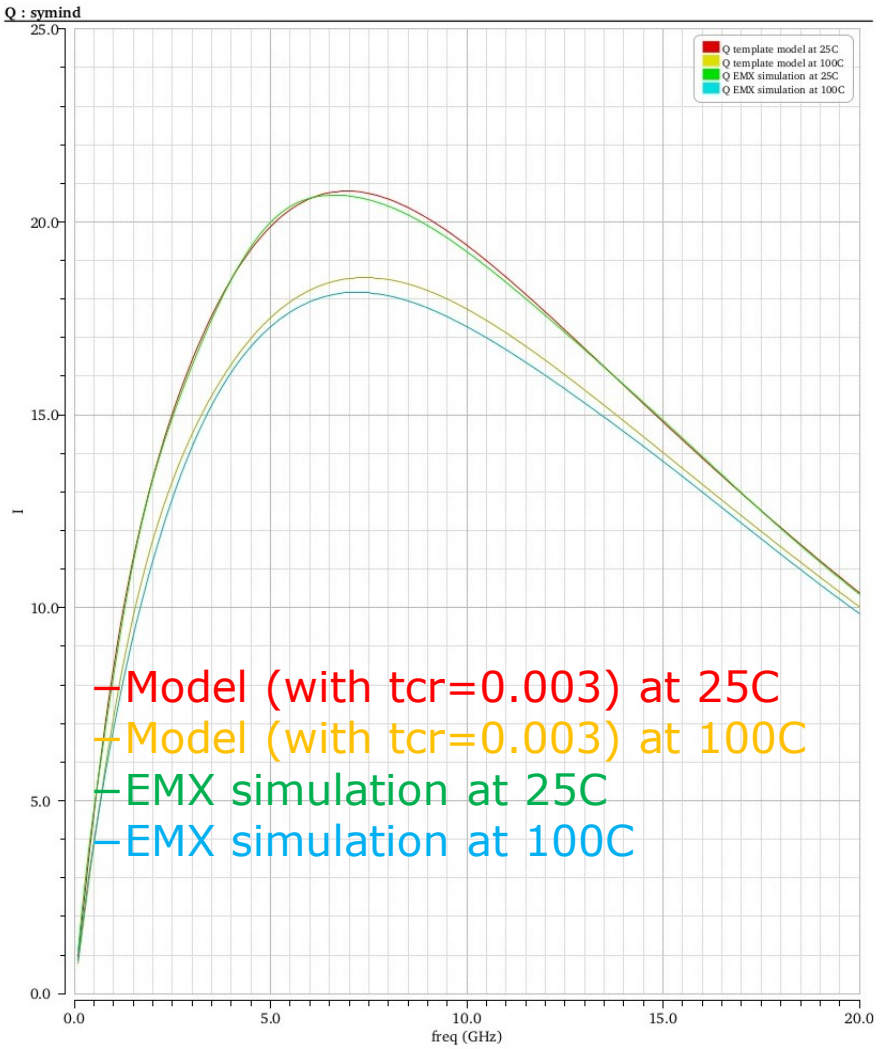
Run EMX at a different temperature

Create symbol and schematic and export to a different symbol with temperature encoded



Comparison of OPTION1 and OPTION2

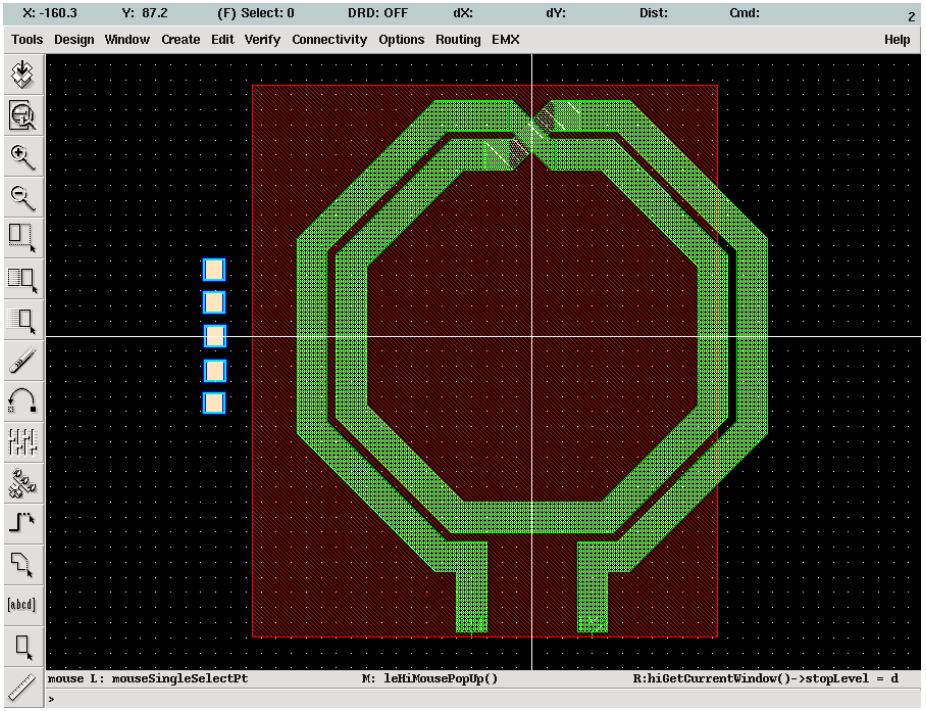


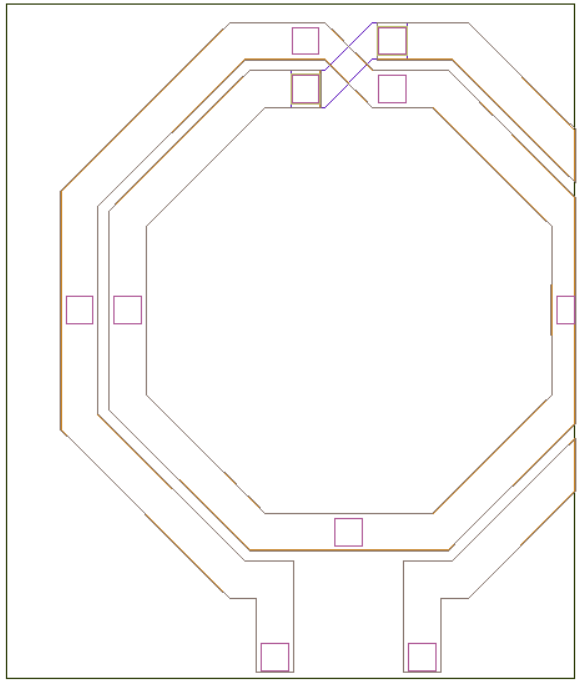


For this case, both approaches give roughly the same result.

Mask simplification

- The process file may have an **emxmask** statement that restricts the entire layout considered by EMX to a particular region.

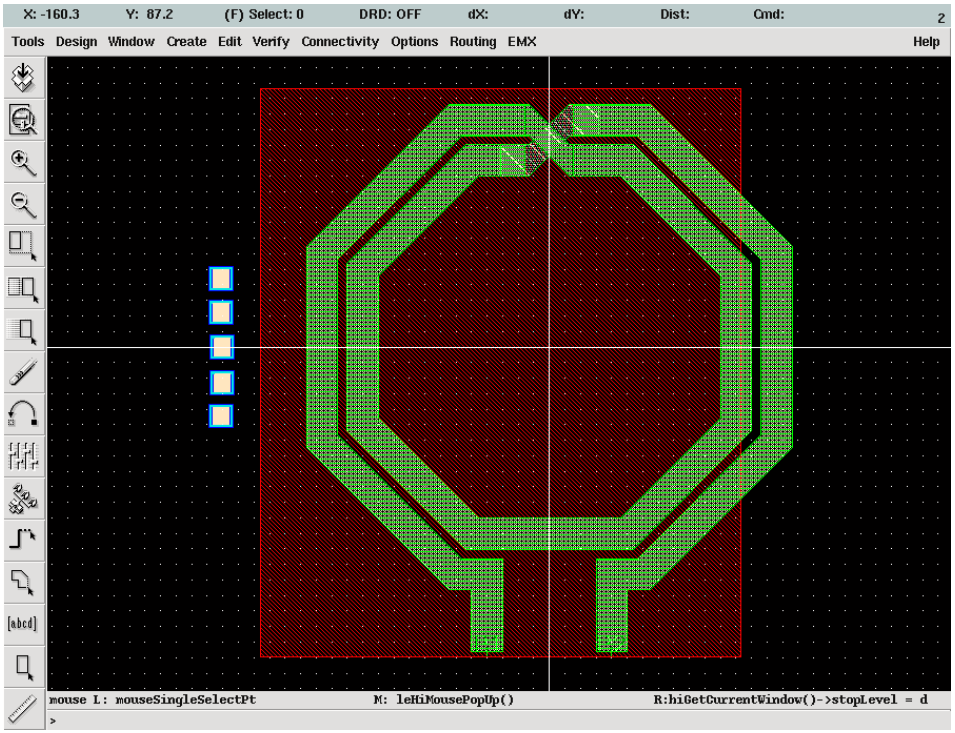


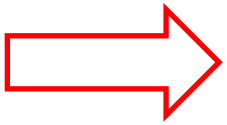


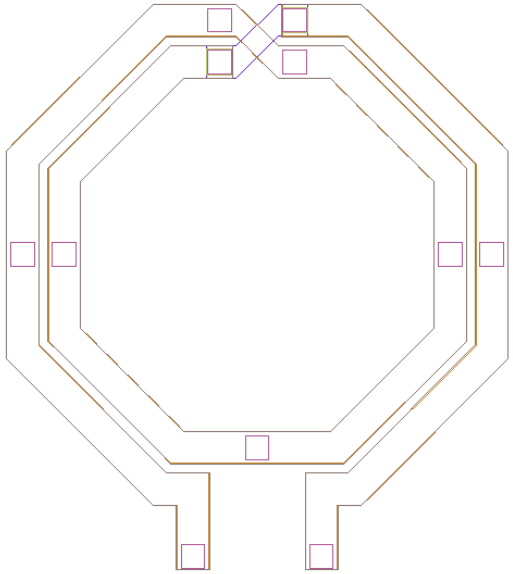
```
assume microns
assume ohms/sq
assume ohms/via

emxmask 16t0

define diff = 16t0
define poly = 117t0
define metal1 = 131t0
```

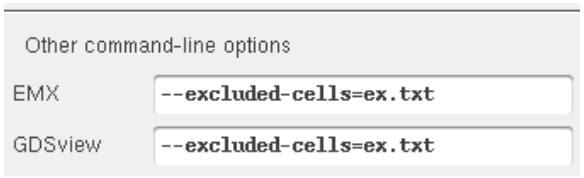
Mask simplification

- There is a **--excluded-cells-file** option that can be used to omit cells matching various regular expressions

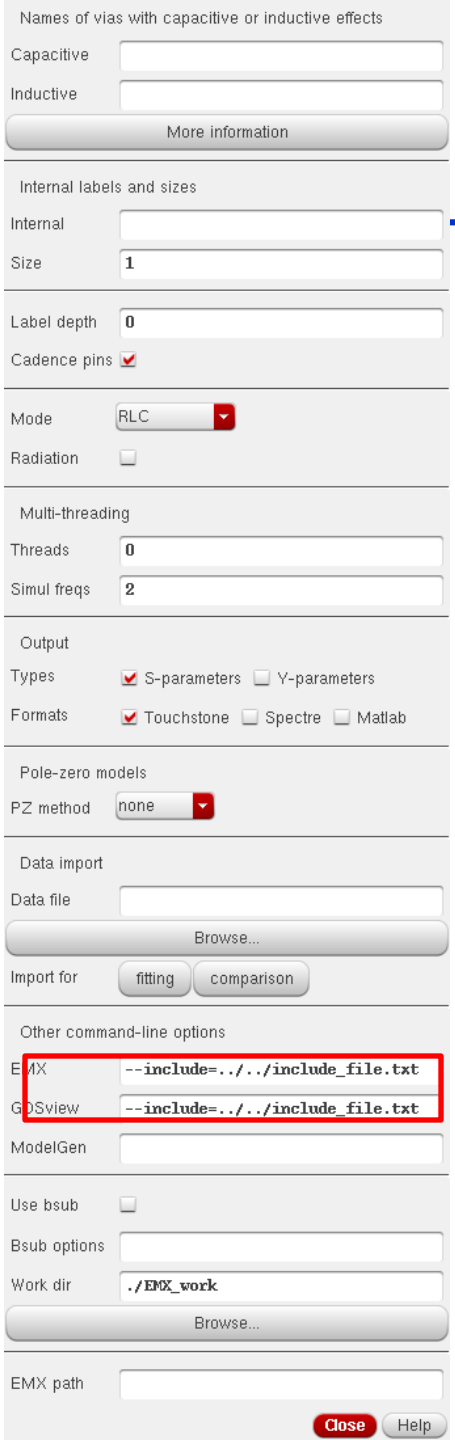






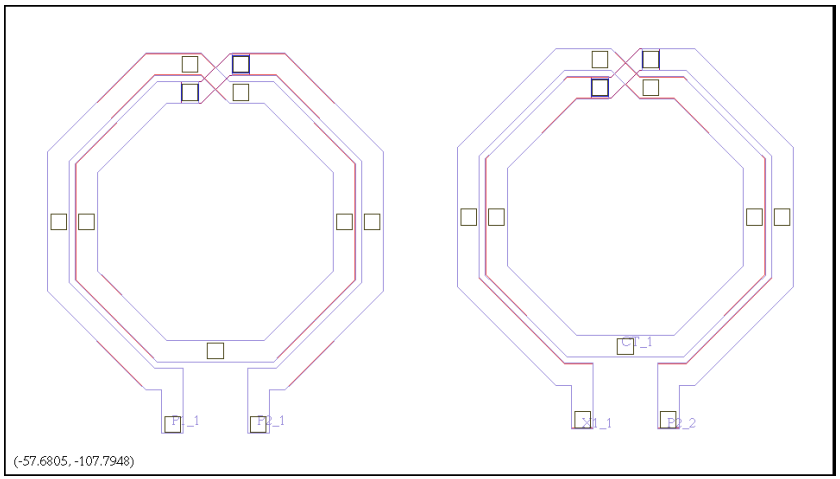


"ex.txt" contains "momcap*"



--included-cells-file

```
$
$
$
$
$
$ cat include_file.txt
symind
symind_ct
$
```



- The path to a file that contains the names of the sub cells that need to be kept will only simulate those structures. In this case the two inductors will be kept and the MOM cap will be removed.

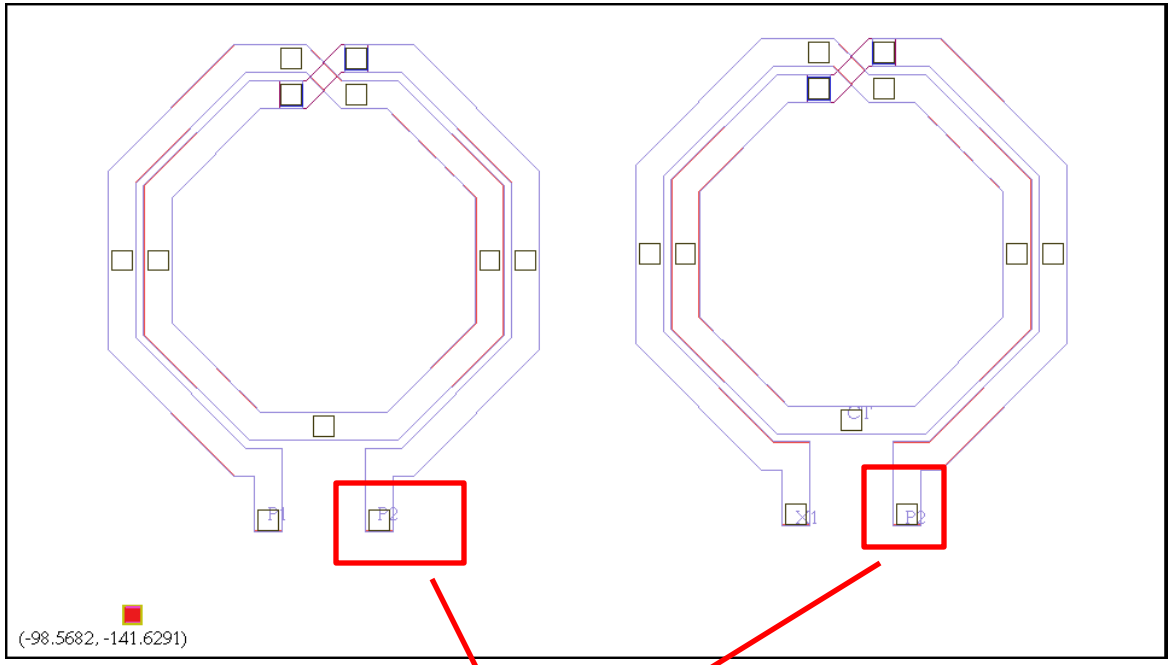
Mask simplification and hierarchy

- There is an

"--included-cells-file"

to simulate only a few of the cells in the layout

- Consider a layout composed of 3 sub cells: 2 inductors and a MOM capacitor
- The inductors have the same port name P2 in the sub cells



P2 is used in two subcells

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Unique labels

Names of vias with capacitive or inductive effects
Capacitive
Inductive
More information

Internal labels and sizes
Internal
Size 1

Label depth 0
Cadence pins

Mode RLC
Radiation

Multi-threading
Threads 0
Simul freqs 2

Output
Types S-parameters Y-parameters
Formats Touchstone Spectre Matlab

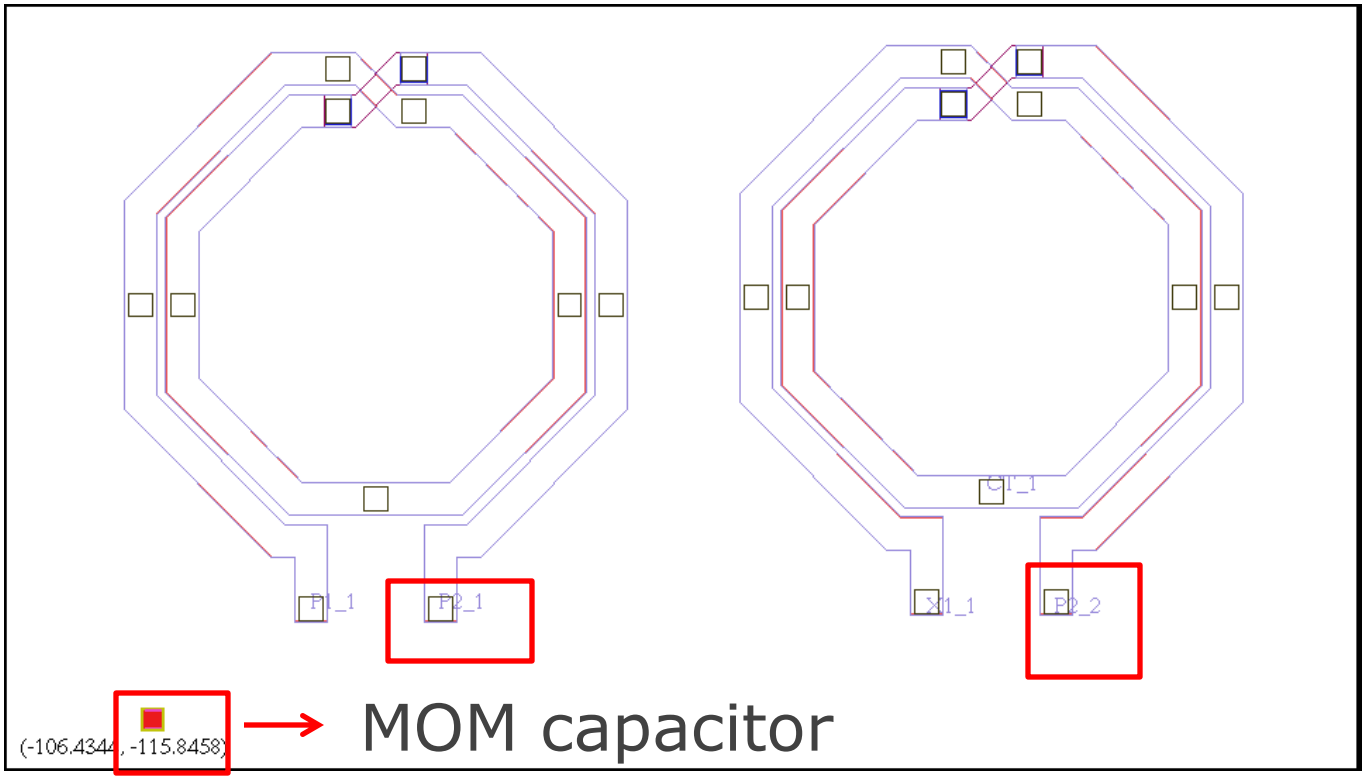
Pole-zero models
PZ method none

Data import
Data file
Browse...
Import for fitting comparison

Other command-line options
EMX --unique-labels
GDSview --unique-labels
ModelGen

Use bsub
Bsub options
Work dir ./EMX_work
Browse...

EMX path
Close Help

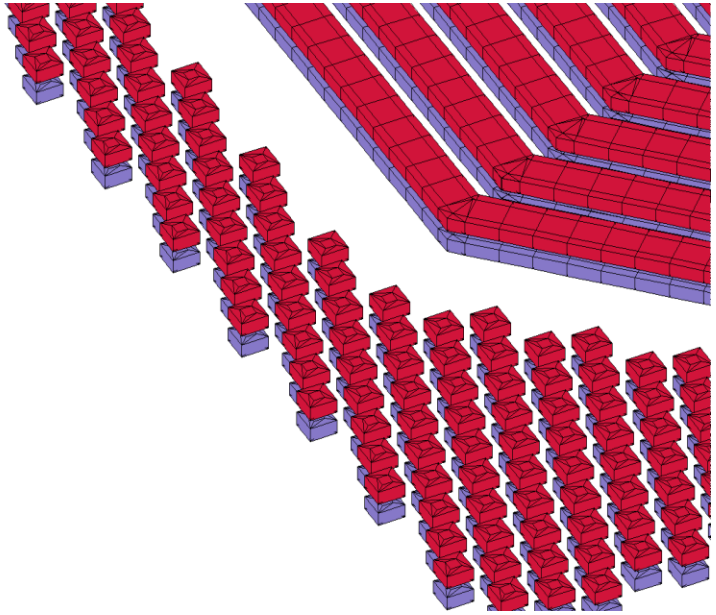


--unique labels will add suffixes to the original labels to avoid duplication. In the EMX form you will need to add the suffix in names of the ports (e.g., "P2_2") in the signals field.

Meshing fill

- To account for the effect of metal loss in the fill the fill needs to be meshed into at least 3 elements

- You can exclude fill by an using the “fill” command in the .proc file

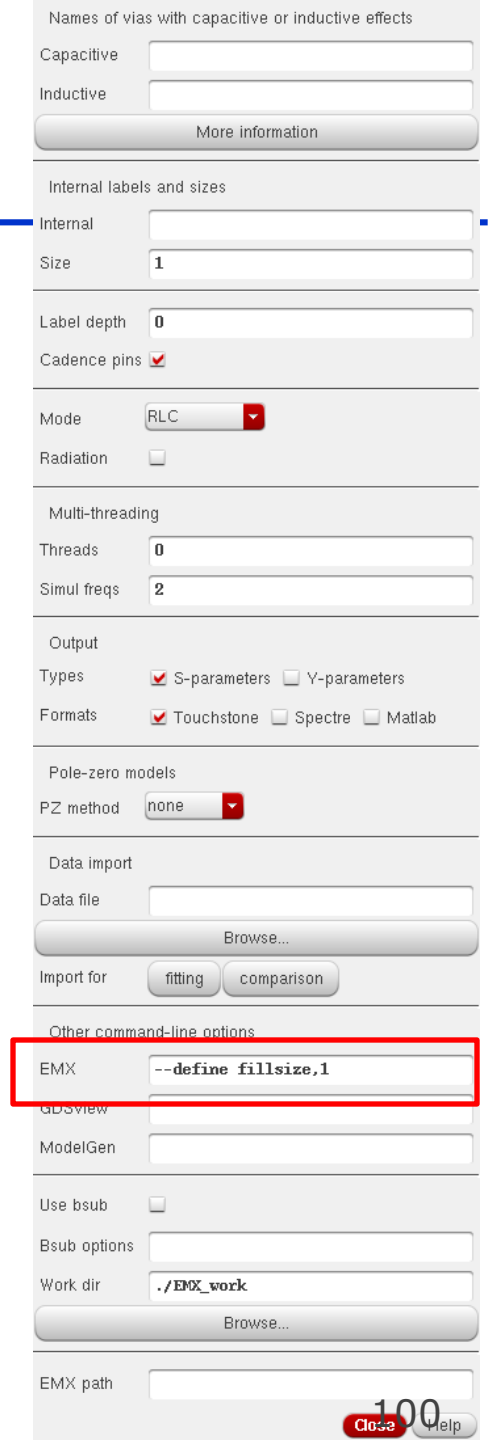


Excluding fill

```
define fillsize=0

define OD = fill(l6t0,fillsize)
define fpoly = fill(l17t0,fillsize)
define metal1 = fill(l31t0,fillsize)+l131t0
define metal2 = fill(l32t0,fillsize)+l132t0
define metal3 = fill(l33t0,fillsize)+l133t0
define metal4 = fill(l34t0,fillsize)+l134t0
define metal5 = fill(l35t0,fillsize)+l135t0
define metal6 = fill(l36t60,fillsize)+l136t0
define metal7 = fill(l74t0,fillsize)+l126t0
```

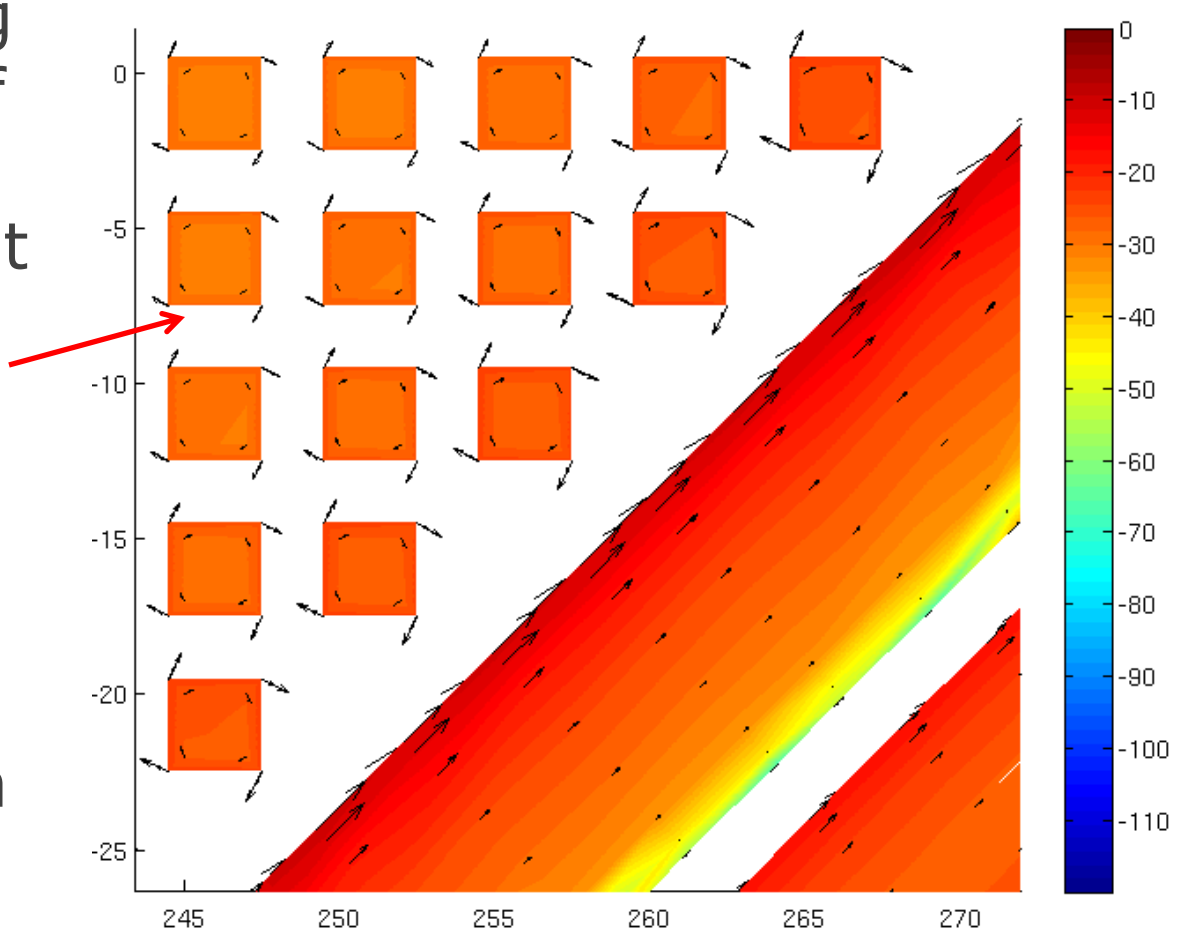
- Fill can be included or excluded from the simulation by modifying the process file
- EMX will throw out all metal shapes less than 1um in size



Zoom of fill current

There is circulating currents in the fill. If you superpose all the currents then it is causing an opposing current flow to the flow in the inductor.

This is the reason for the decrease in Q



Frequencies

DC simulation is allowed

Multiple-grids of frequencies is allowed using --multi-sweep