

EMX Virtuoso interface tutorial

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Integrand Software, Inc.

Introduction

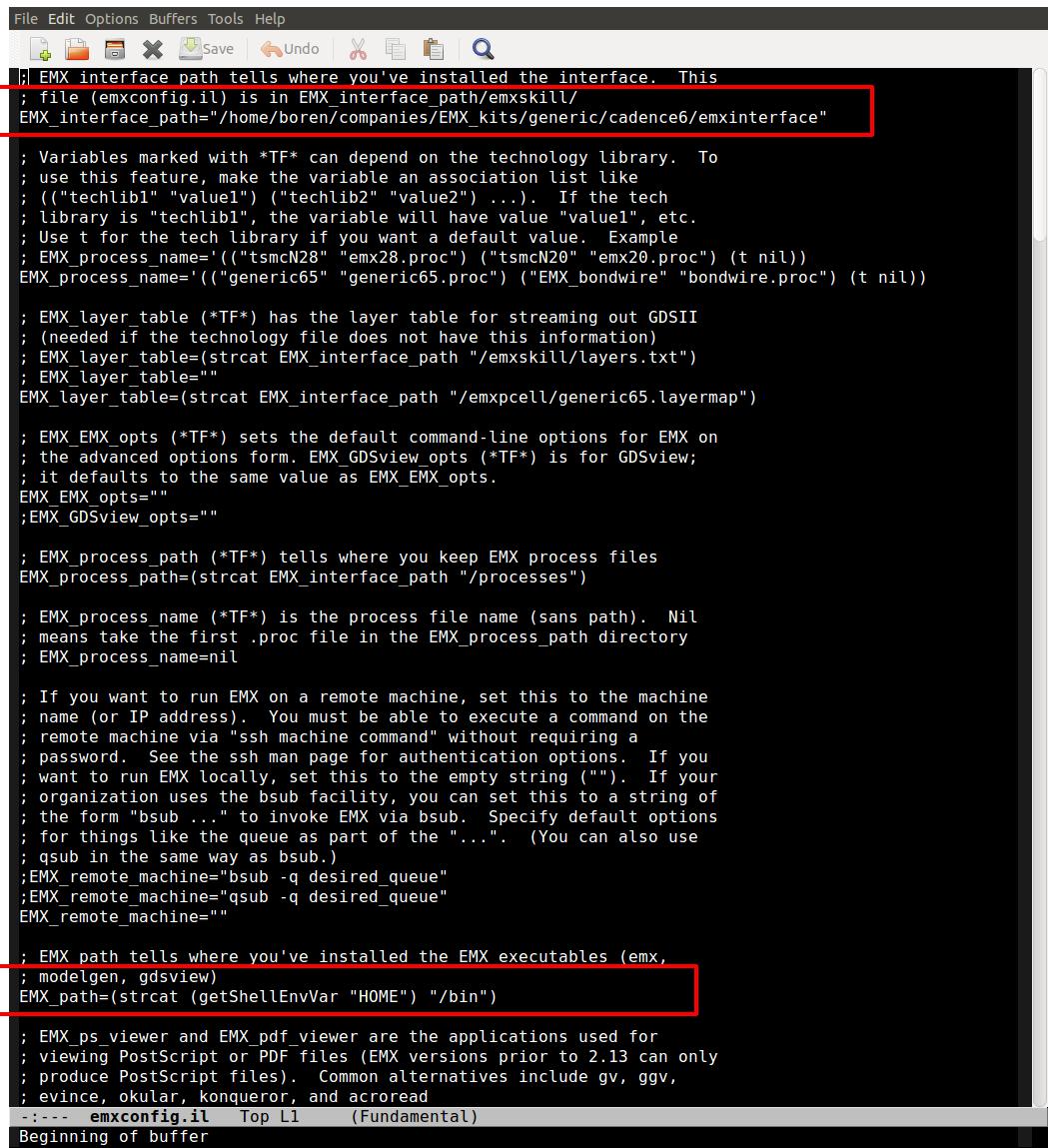
- The Cadence Virtuoso interface is provided along with EMX for users who want the convenience of Virtuoso as the GUI for EMX.
- Several features have been added to allow EMX simulations and Modelgen models to be directly incorporated into a design flow with Cadence.
- The interface supports most of 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 postscript 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”)



```

File Edit Options Buffers Tools Help
Save Undo Cut Copy Paste Find Replace
; EMX interface path tells where you've installed the interface. This
; file (emxconfig.il) is in EMX interface path/emxskill/
EMX_interface_path="/home/boren/companies/EMX_kits/generic/cadence6/emxinterface"

; Variables marked with *TF* can depend on the technology library. To
; use this feature, make the variable an association list like
; ("techlib1" "value1") ("techlib2" "value2") .... If the tech
; library is "techlib1", the variable will have value "value1", etc.
; Use t for the tech library if you want a default value. Example
; EMX_process_name='(("tsmcN28" "emx28.proc") ("tsmcN20" "emx20.proc") (t nil))
EMX_process_name='(("generic65" "generic65.proc") ("EMX_bondwire" "bondwire.proc") (t nil))

; EMX_layer_table (*TF*) has the layer table for streaming out GDSII
; (needed if the technology file does not have this information)
; EMX_layer_table=(strcat EMX_interface_path "/emxskill/layers.txt")
; EMX_layer_table=""
EMX_layer_table=(strcat EMX_interface_path "/emxpcell/generic65.layermap")

; EMX_EMX_opts (*TF*) sets the default command-line options for EMX on
; the advanced options form. EMX_GDSview_opts (*TF*) is for GDSview;
; it defaults to the same value as EMX_EMX_opts.
EMX_EMX_opts=""
;EMX_GDSview_opts=""

; EMX_process_path (*TF*) tells where you keep EMX process files
EMX_process_path=(strcat EMX_interface_path "/processes")

; EMX_process_name (*TF*) is the process file name (sans path). Nil
; means take the first .proc file in the EMX_process_path directory
; EMX_process_name=nil

; If you want to run EMX on a remote machine, set this to the machine
; name (or IP address). You must be able to execute a command on the
; remote machine via "ssh machine command" without requiring a
; password. See the ssh man page for authentication options. If you
; want to run EMX locally, set this to the empty string (""). If your
; organization uses the bsub facility, you can set this to a string of
; the form "bsub ..." to invoke EMX via bsub. Specify default options
; for things like the queue as part of the "...". (You can also use
; qsub in the same way as bsub.)
;EMX_remote_machine="bsub -q desired_queue"
;EMX_remote_machine="qsub -q desired_queue"
EMX_remote_machine=""

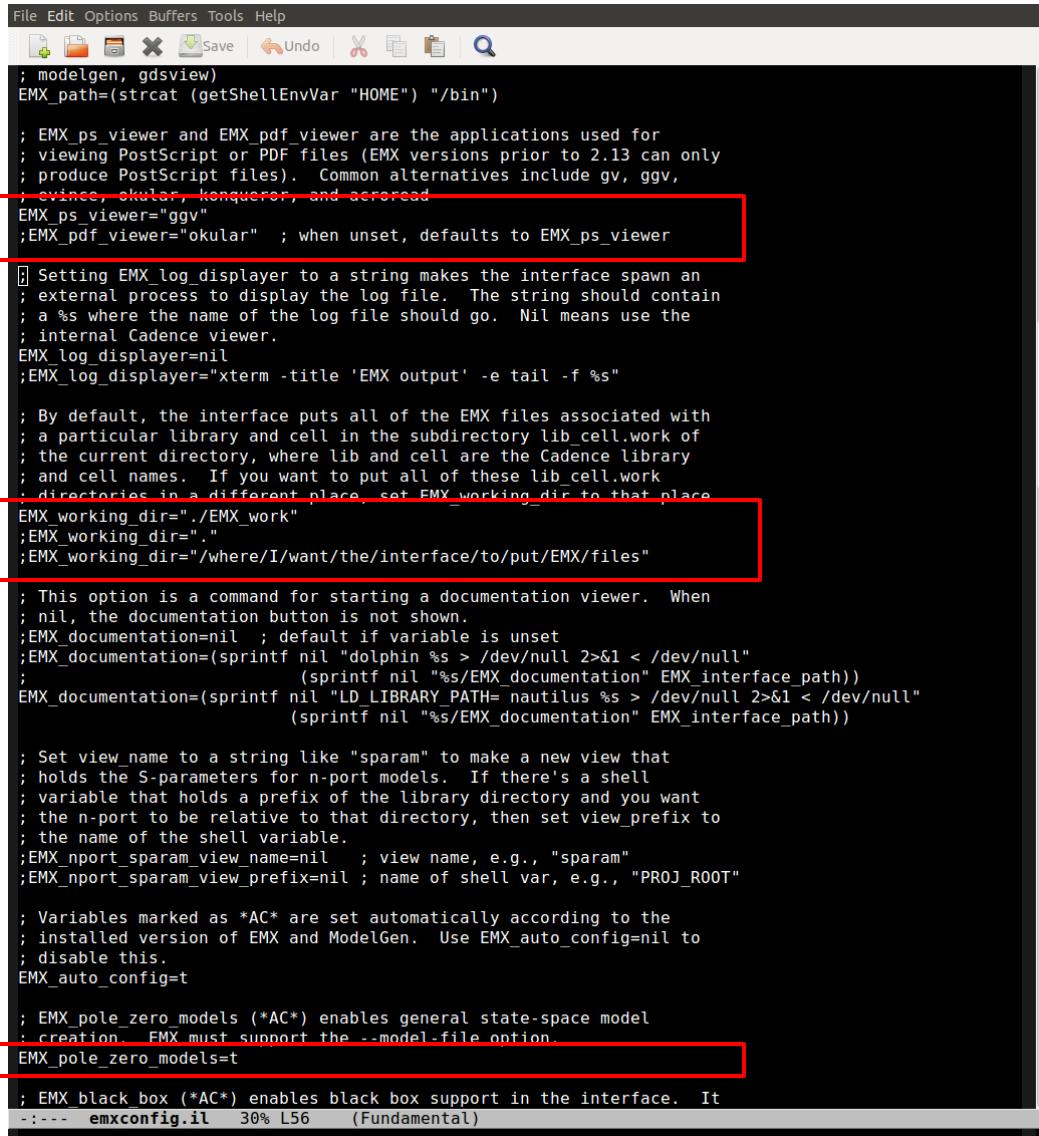
; EMX path tells where you've installed the EMX executables (emx,
; modelgen, gdsview)
EMX_path=(strcat (getShellEnvVar "HOME") "/bin")

; EMX_ps_viewer and EMX_pdf_viewer are the applications used for
; viewing PostScript or PDF files (EMX versions prior to 2.13 can only
; produce PostScript files). Common alternatives include gv, ggv,
; evince, okular, konqueror, and acroread
----- emxconfig.il Top L1 (Fundamental)
Beginning of buffer

```

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



```

File Edit Options Buffers Tools Help
; modelgen, gdsview)
EMX_path=(strcat (getShellEnvVar "HOME") "/bin")

; EMX_ps_viewer and EMX_pdf_viewer are the applications used for
; viewing PostScript or PDF files (EMX versions prior to 2.13 can only
; produce PostScript files). Common alternatives include gv, ggv,
; evince, okular, konqueror, and acroread
EMX_ps_viewer="gv"
;EMX_pdf_viewer="okular" ; when unset, defaults to EMX_ps_viewer

; Setting EMX_log_displayer to a string makes the interface spawn an
; external process to display the log file. The string should contain
; a %s where the name of the log file should go. Nil means use the
; internal Cadence viewer.
EMX_log_displayer=nil
;EMX_log_displayer="xterm -title 'EMX output' -e tail -f %s"

; By default, the interface puts all of the EMX files associated with
; a particular library and cell in the subdirectory lib.cell.work of
; the current directory, where lib and cell are the Cadence library
; and cell names. If you want to put all of these lib.cell.work
; directories in a different place, set EMX_working_dir to that place
EMX_working_dir="./EMX_work"
;EMX_working_dir=""
;EMX_working_dir="/where/I/want/the/interface/to/put/EMX/files"

; This option is a command for starting a documentation viewer. When
; nil, the documentation button is not shown.
;EMX_documentation=nil ; default if variable is unset
;EMX_documentation=(sprintf nil "dolphin %s > /dev/null 2>&1 < /dev/null"
;                   (sprintf nil "%s/EMX_documentation" EMX_interface_path))
;EMX_documentation=(sprintf nil "LD_LIBRARY_PATH=nautilus %s > /dev/null 2>&1 < /dev/null"
;                   (sprintf nil "%s/EMX_documentation" EMX_interface_path))

; Set view name to a string like "sparam" to make a new view that
; holds the S-parameters for n-port models. If there's a shell
; variable that holds a prefix of the library directory and you want
; the n-port to be relative to that directory, then set view_prefix to
; the name of the shell variable.
;EMX_nport_sparam_view_name=nil ; view name, e.g., "sparam"
;EMX_nport_sparam_view_prefix=nil ; name of shell var, e.g., "PROJ_ROOT"

; Variables marked as *AC* are set automatically according to the
; installed version of EMX and ModelGen. Use EMX_auto_config=nil to
; disable this.
EMX_auto_config=t

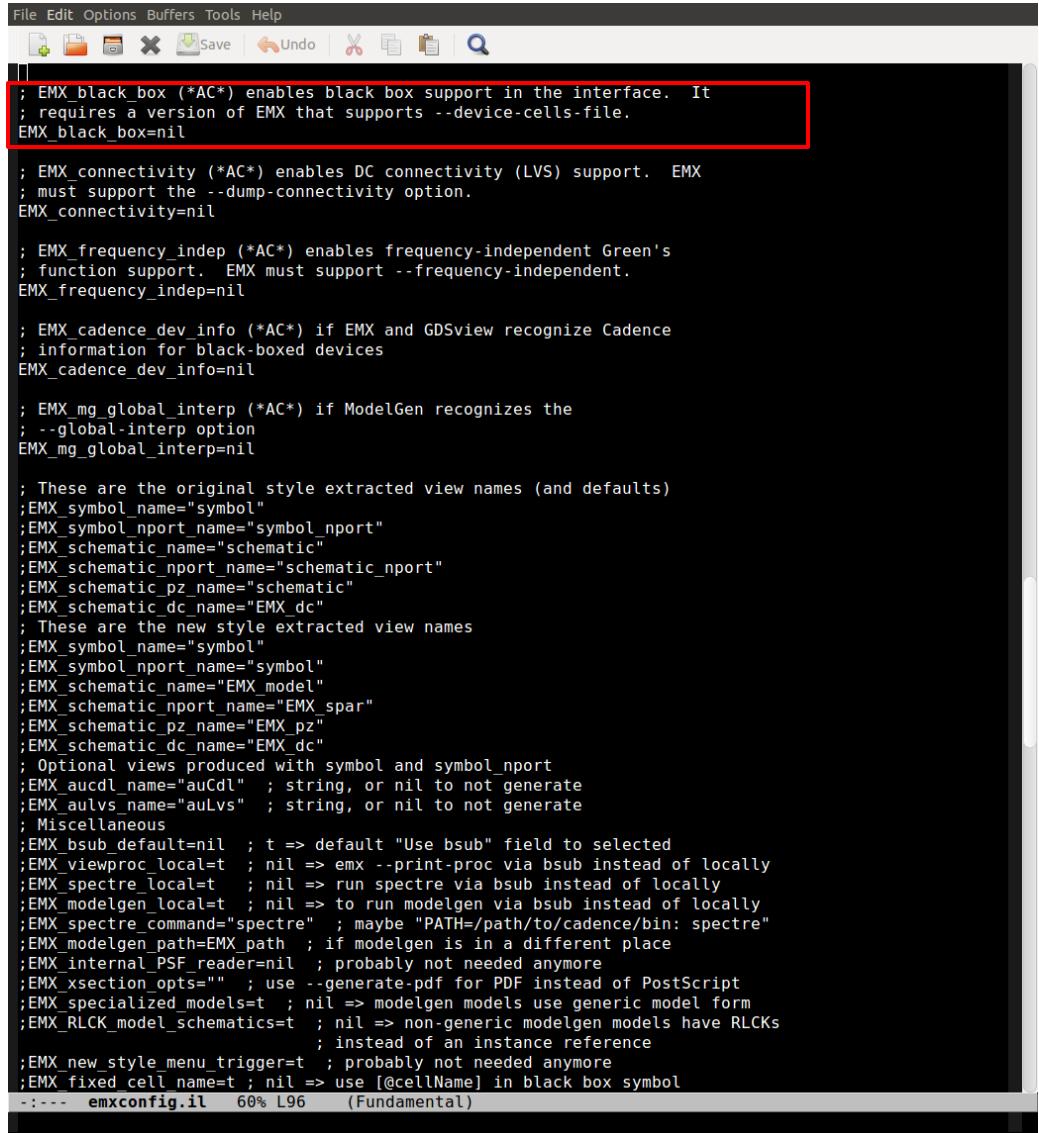
; EMX_pole_zero_models (*AC*) enables general state-space model
; creation. EMX must support the --model-file option.
EMX_pole_zero_models=t

; EMX black box (*AC*) enables black box support in the interface. It
; --- emxconfig.il 30% L56 (Fundamental)

```

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.



```

File Edit Options Buffers Tools Help
Save Undo Cut Copy Paste Find Replace
; EMX black box (*AC*) enables black box support in the interface. It
; requires a version of EMX that supports --device-cells-file.
EMX_black_box=nil

; EMX_connectivity (*AC*) enables DC connectivity (LVS) support. EMX
; must support the --dump-connectivity option.
EMX_connectivity=nil

; EMX_frequency_indep (*AC*) enables frequency-independent Green's
; function support. EMX must support --frequency-independent.
EMX_frequency_indep=nil

; EMX_cadence_dev_info (*AC*) if EMX and GDSview recognize Cadence
; information for black-boxed devices
EMX_cadence_dev_info=nil

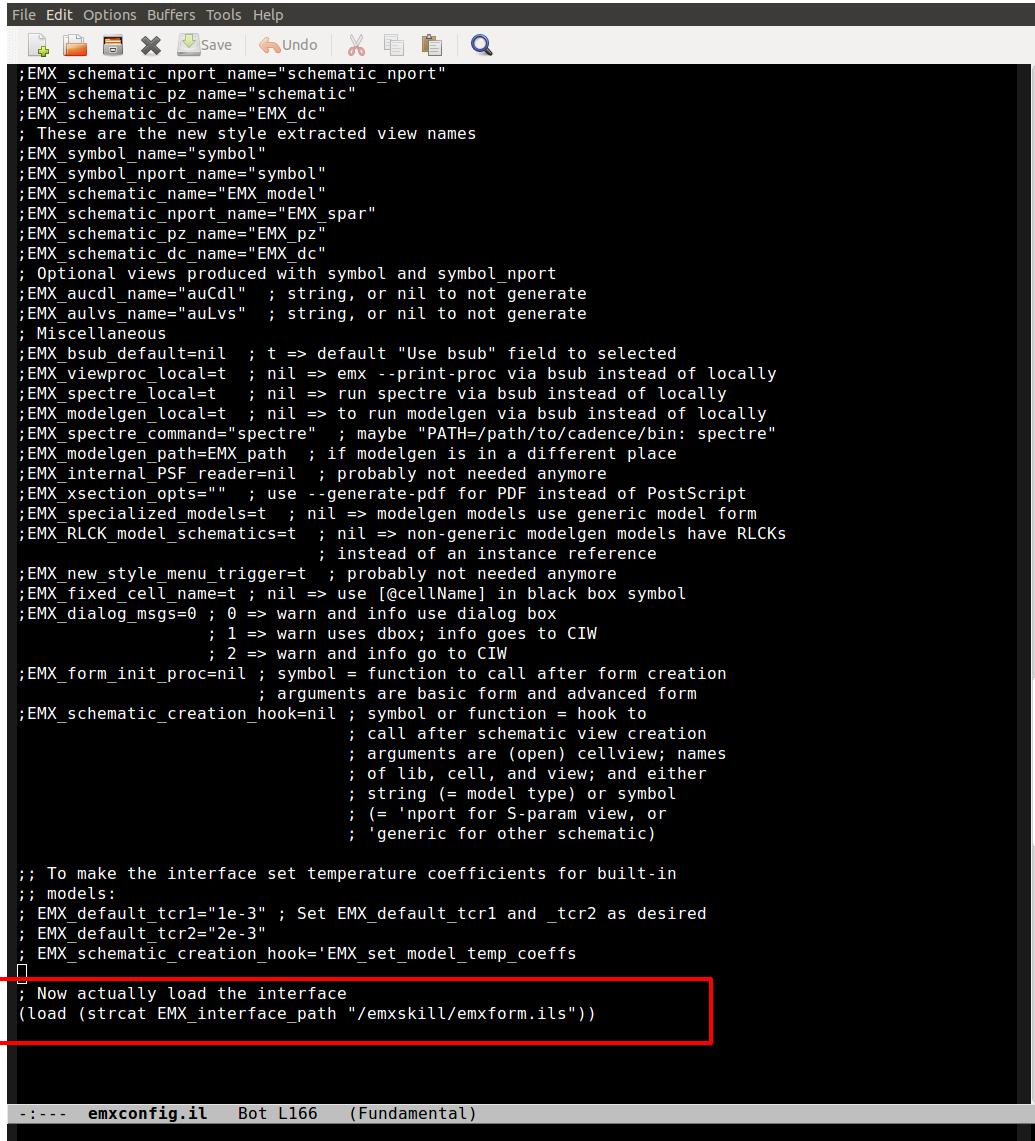
; EMX_mg_global_interp (*AC*) if ModelGen recognizes the
; --global-interp option
EMX_mg_global_interp=nil

; These are the original style extracted view names (and defaults)
;EMX_symbol_name="symbol"
;EMX_symbol_nport_name="symbol_nport"
;EMX_schematic_name="schematic"
;EMX_schematic_nport_name="schematic_nport"
;EMX_schematic_pz_name="schematic"
;EMX_schematic_dc_name="EMX_dc"
; These are the new style extracted view names
;EMX_symbol_name="symbol"
;EMX_symbol_nport_name="symbol"
;EMX_schematic_name="EMX_model"
;EMX_schematic_nport_name="EMX_spar"
;EMX_schematic_pz_name="EMX_pz"
;EMX_schematic_dc_name="EMX_dc"
; Optional views produced with symbol and symbol_nport
;EMX_audl_name="auCdl" ; string, or nil to not generate
;EMX_auvls_name="auLvs" ; string, or nil to not generate
; Miscellaneous
;EMX_bsub_default=nil ; t => default "Use bsub" field to selected
;EMX_viewproc_local=t ; nil => emx -print-proc via bsub instead of locally
;EMX_spectre_local=t ; nil => run spectre via bsub instead of locally
;EMX_modelgen_local=t ; nil => to run modelgen via bsub instead of locally
;EMX_spectre_command="spectre" ; maybe "PATH=/path/to/cadence/bin: spectre"
;EMX_modelgen_path=EMX_path ; if modelgen is in a different place
;EMX_internal_PSF_reader=nil ; probably not needed anymore
;EMX_xsection_opts="" ; use --generate-pdf for PDF instead of PostScript
;EMX_specialized_models=t ; nil => modelgen models use generic model form
;EMX_RLCK_model_schematics=t ; nil => non-generic modelgen models have RLCKs
; instead of an instance reference
;EMX_new_style_menu_trigger=t ; probably not needed anymore
;EMX_fixed_cell_name=t ; nil => use [@cellName] in black box symbol
----- emxconfig.il 60% L96 (Fundamental)

```

Interface setup (continued)

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



The screenshot shows a text editor window with a menu bar (File, Edit, Options, Buffers, Tools, Help) and a toolbar with icons for file operations. The main area contains a configuration file named emxform.ils. A red box highlights the final line of the file:

```

; Now actually load the interface
(load (strcat EMX_interface_path "/emxskill/emxform.ils"))

---- emxconfig.il Bot L166 (Fundamental)

```

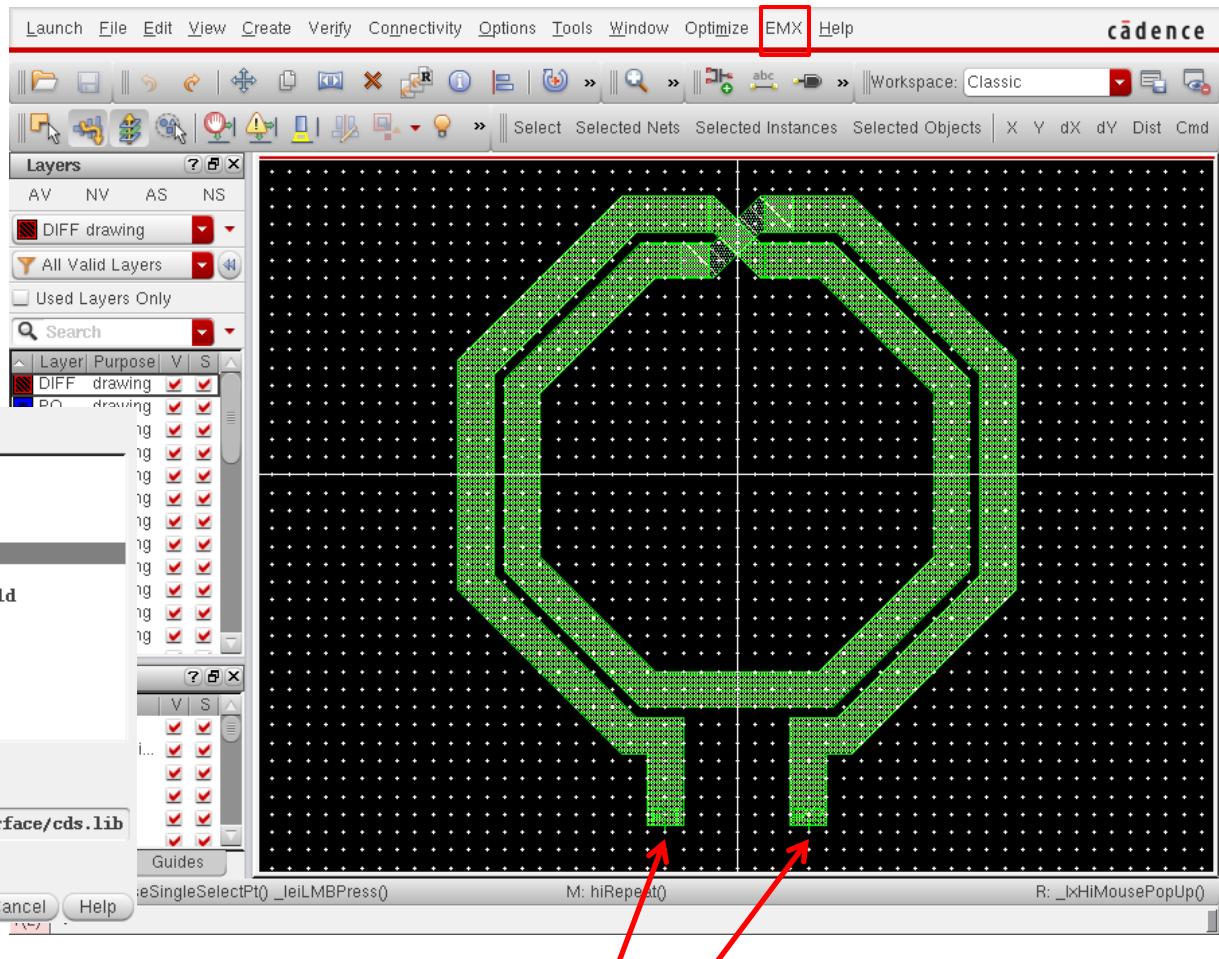
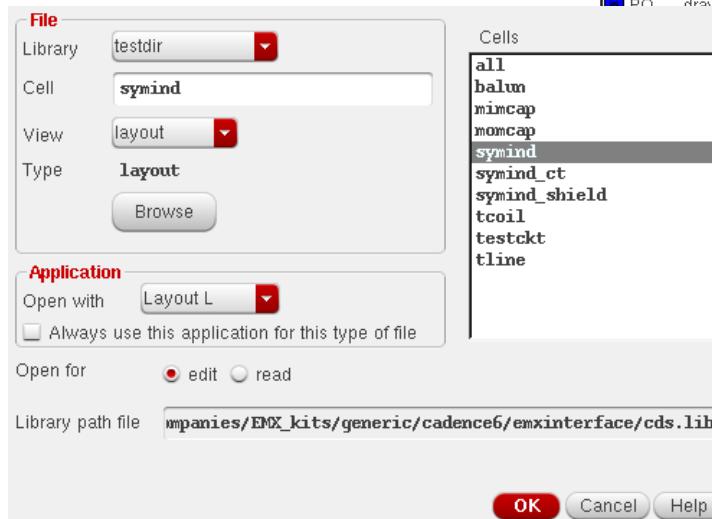
Using the Interface (overview)

Tutorial material

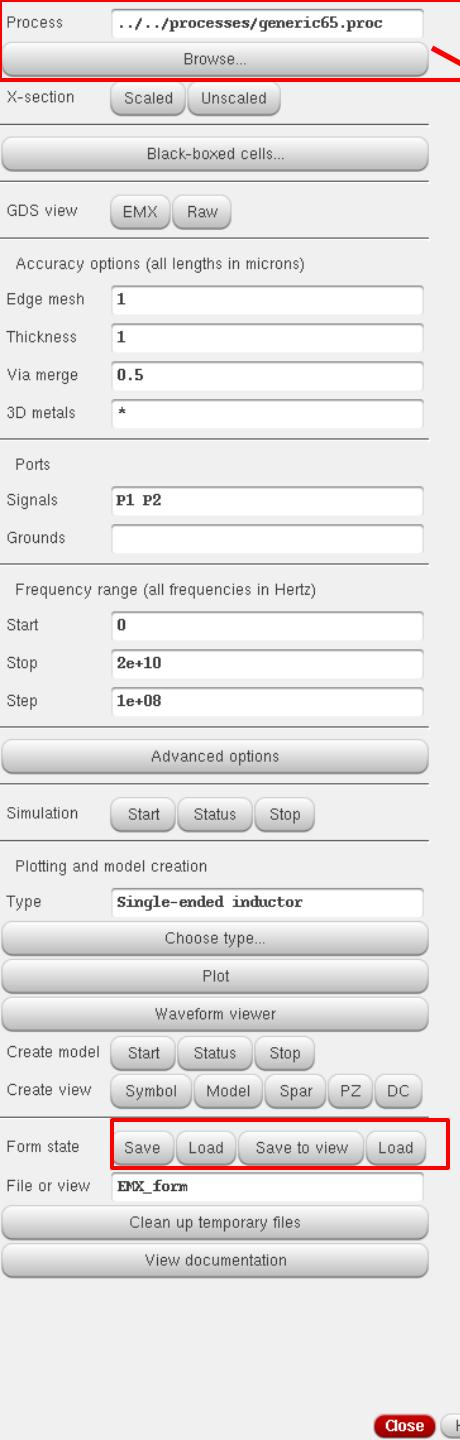
- Several examples have been set up for this tutorial.
- These examples can be used to learn about the various features of the Cadence interface.
- Examples include
 - symind (symmetric inductor)
 - symind_ct (center tapped inductor)
 - symind with shield
 - balun
 - momcap
 - mimcap
 - tcoil
 - transmission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



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 <http://.../processes/generic65.proc>

Browse...

X-section [Scaled](#) [Uncalced](#) (highlighted)

[Black-boxed cells...](#)

GDS view [EMX](#) [Raw](#)

Accuracy options (all lengths in microns)

Edge mesh

Thickness

Via merge

3D metals

Ports

Signals

Grounds

Frequency range (all frequencies in Hertz)

Start

Stop

Step

[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](#)

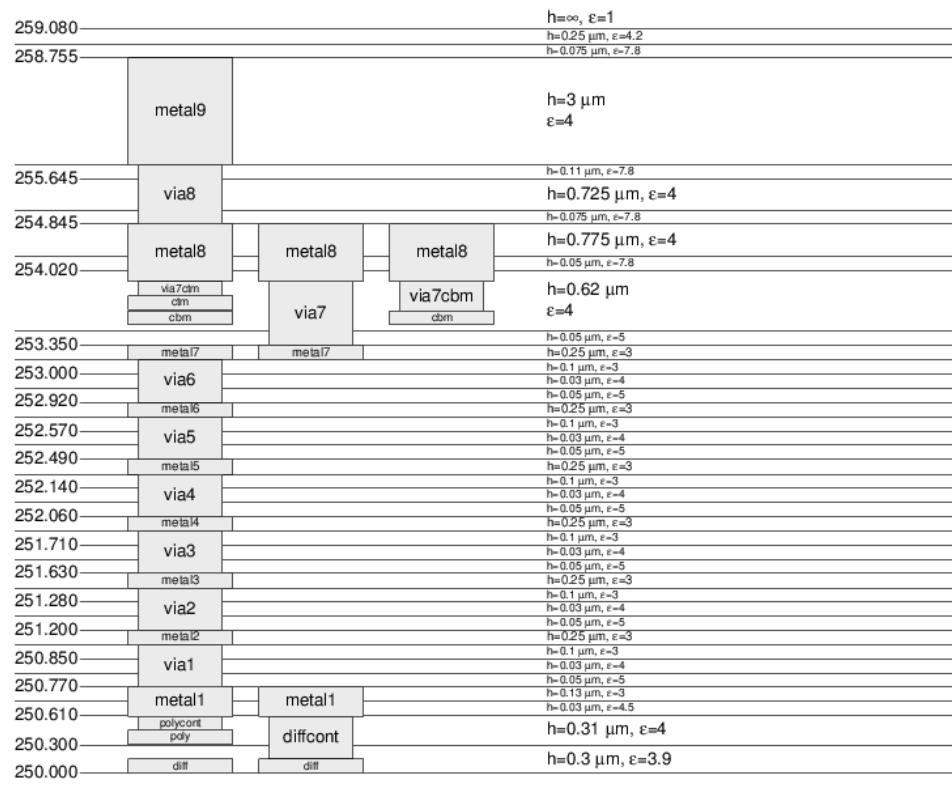
Form state [Save](#) [Load](#) [Save to view](#) [Load](#)

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.



0.000

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

h=250 μm
 ε=11.9
 12.5 Ω·cm
 8 S/m

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

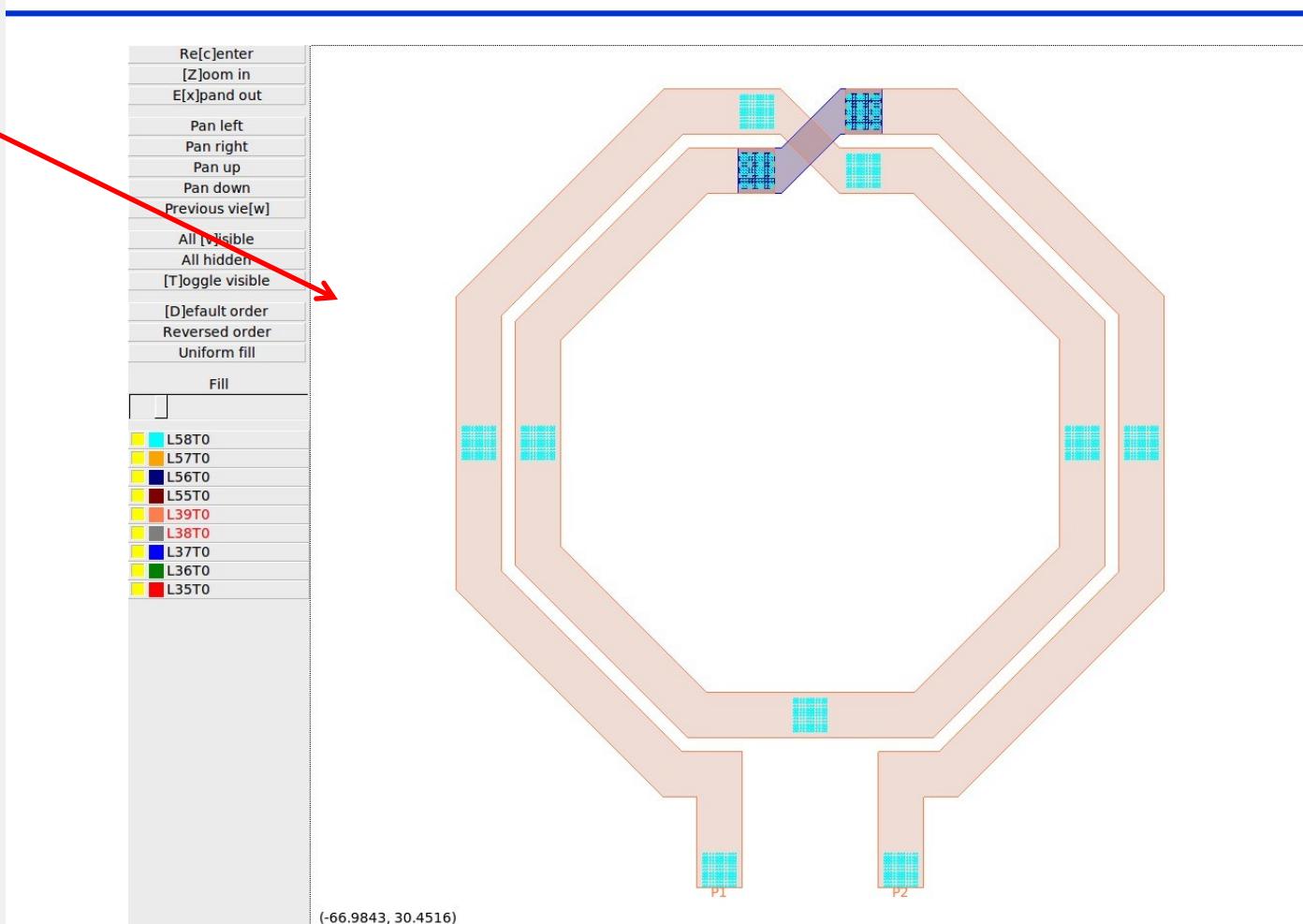
Form state Save Load Save to view Load

File or view EMX_form

[Clean up temporary files](#)

[View documentation](#)

[Close](#) [Help](#)



View the raw .gds

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

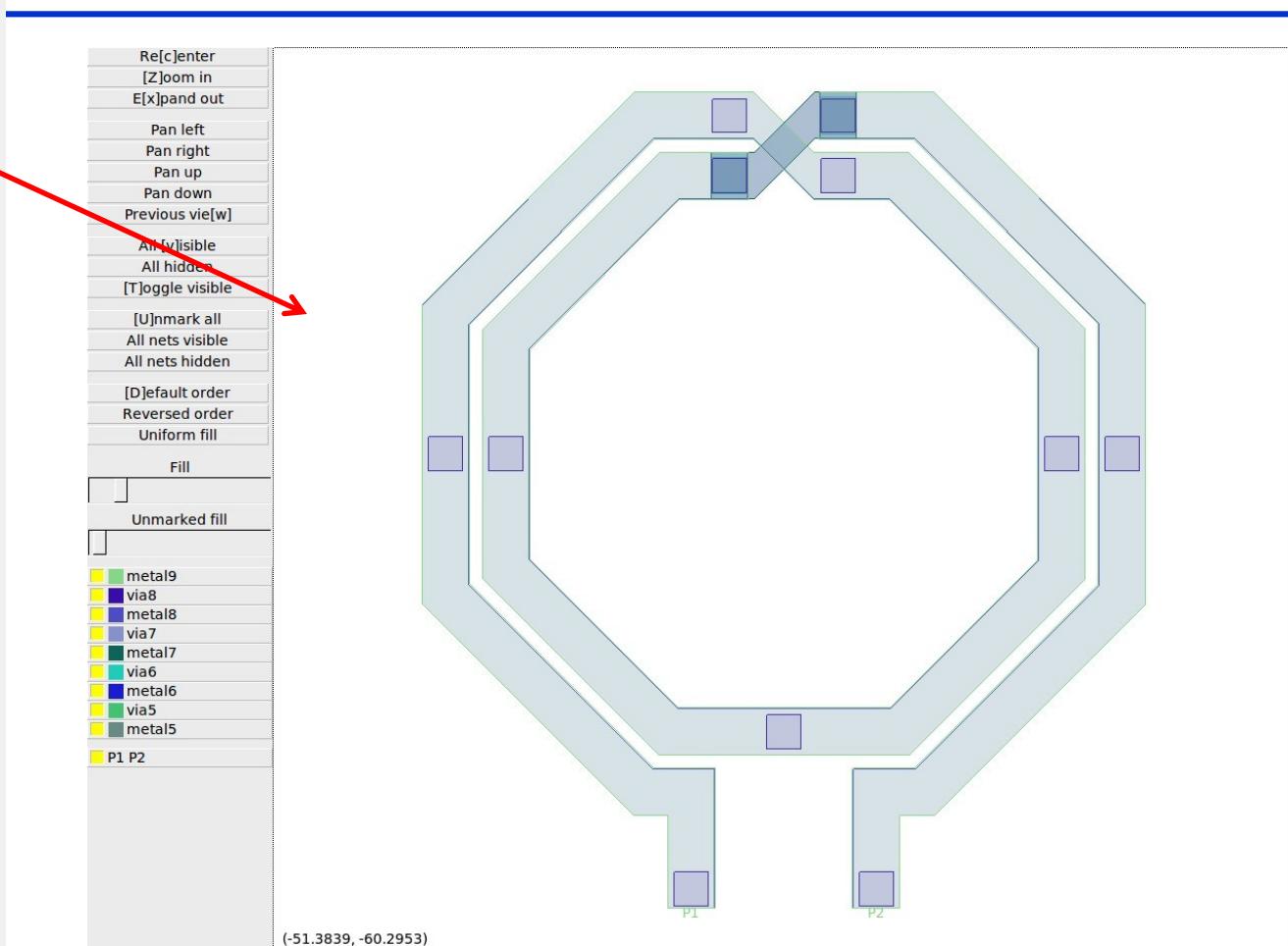
Form state Save Load Save to view Load

File or view EMX_form

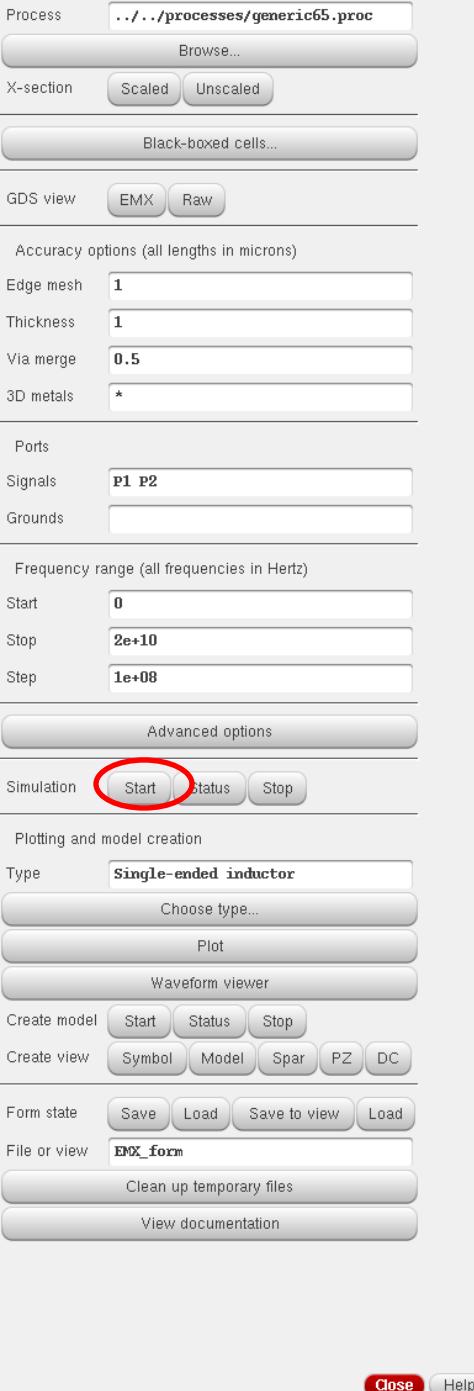
Clean up temporary files

View documentation

Close Help



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



Run on multi-CPU machine

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 P001 --sweep 1e+08
2e+10 --sweep-stepsize 1e+08 --verbose=3 --print-command-line -l 2 --quasistatic
--dump-connectivity --parallel=5 --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

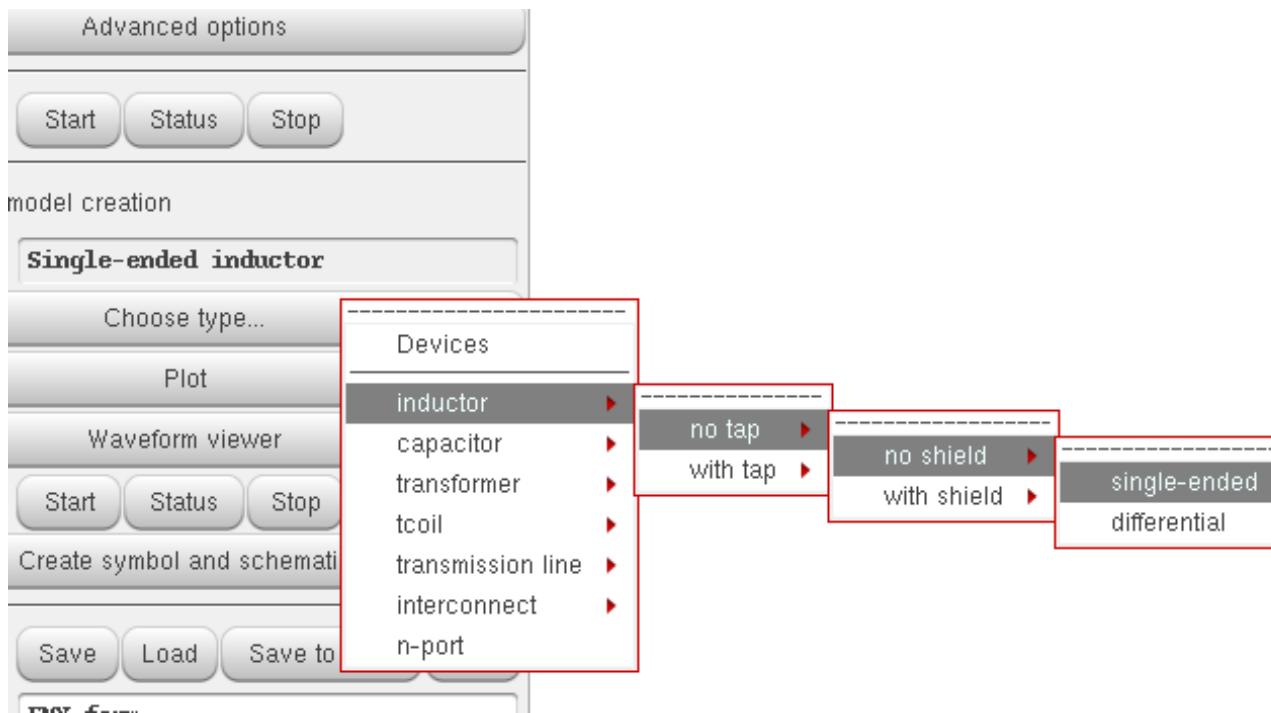
Simulating at frequency 1.000000e+08...

Simulating at frequency 2.000000e+10...

Ports: P000 P001 @ 1.000000e+08 [0]

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

X-section

GDS view

Accuracy options (all lengths in microns)

Edge mesh	1
Thickness	1
Via merge	0.5
3D metals	*

Ports

Signals

Grounds

Frequency range (all frequencies in Hertz)

Start	0
Stop	2e+10
Step	1e+08

Simulation

Plotting and model creation

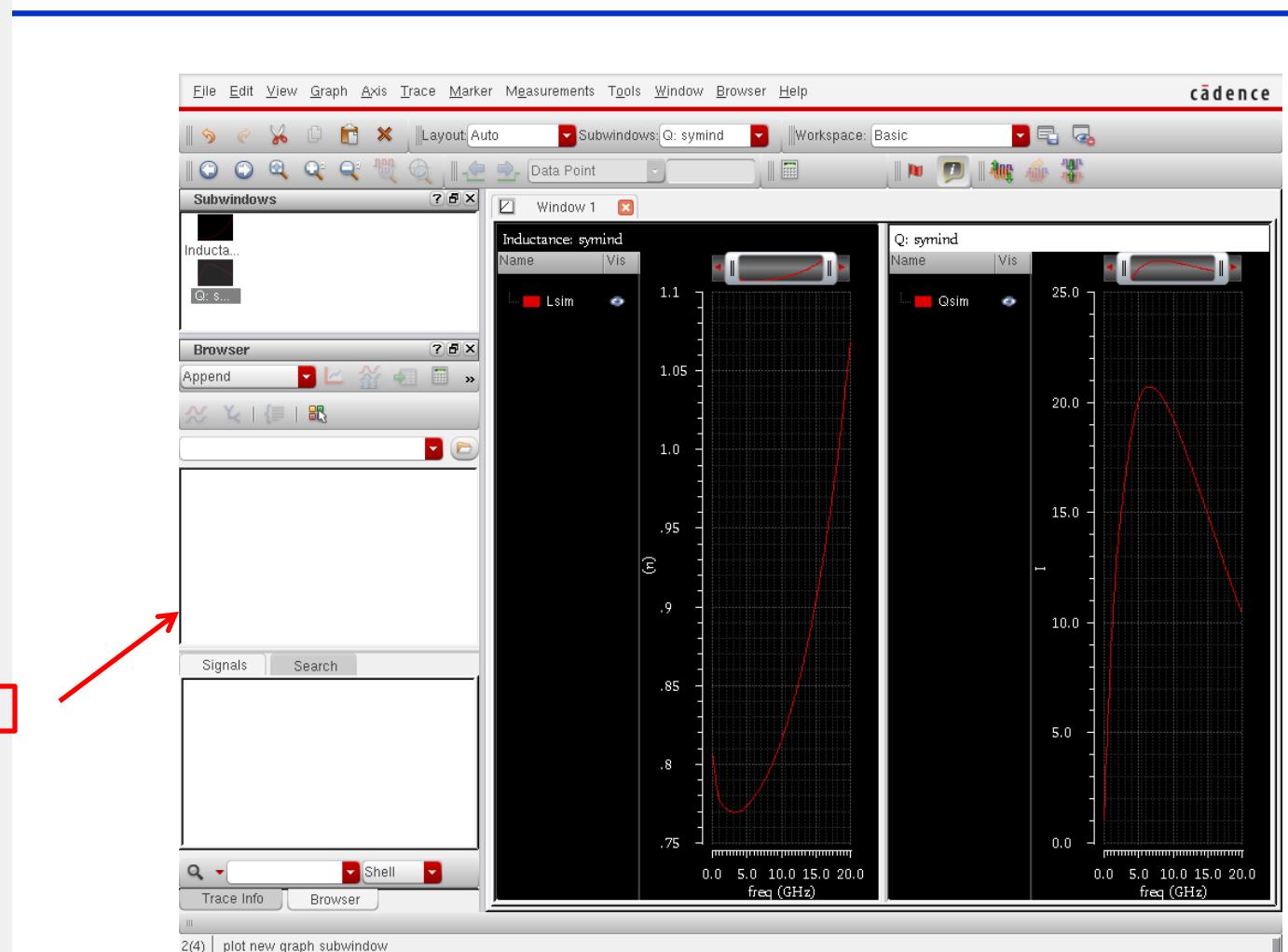
Type

Create model

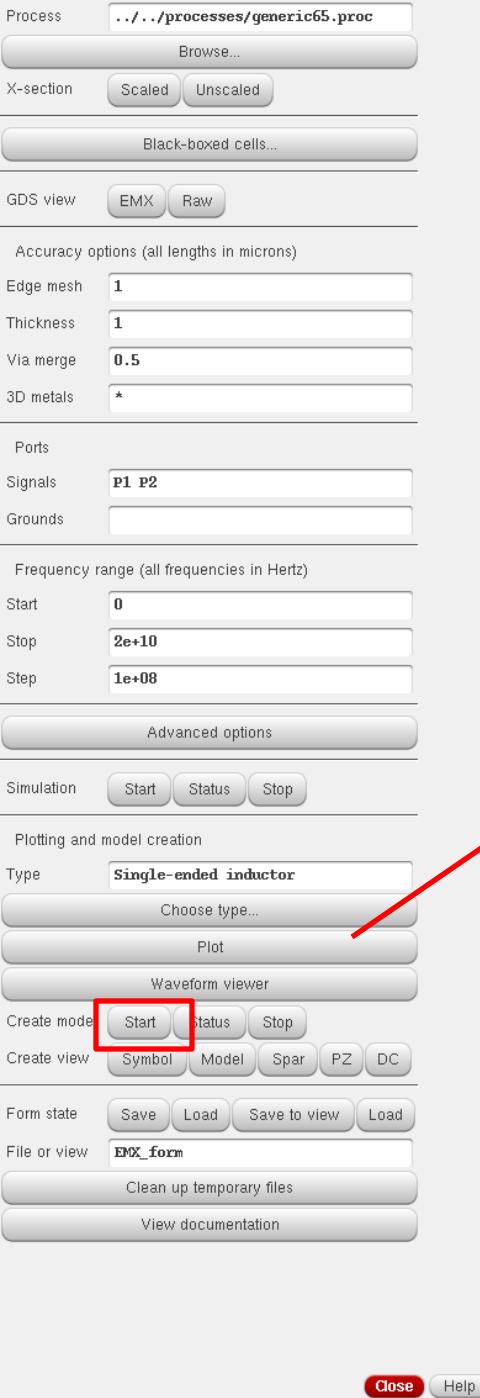
Create view

Form state

File or view



View the L and Q results in single-ended mode

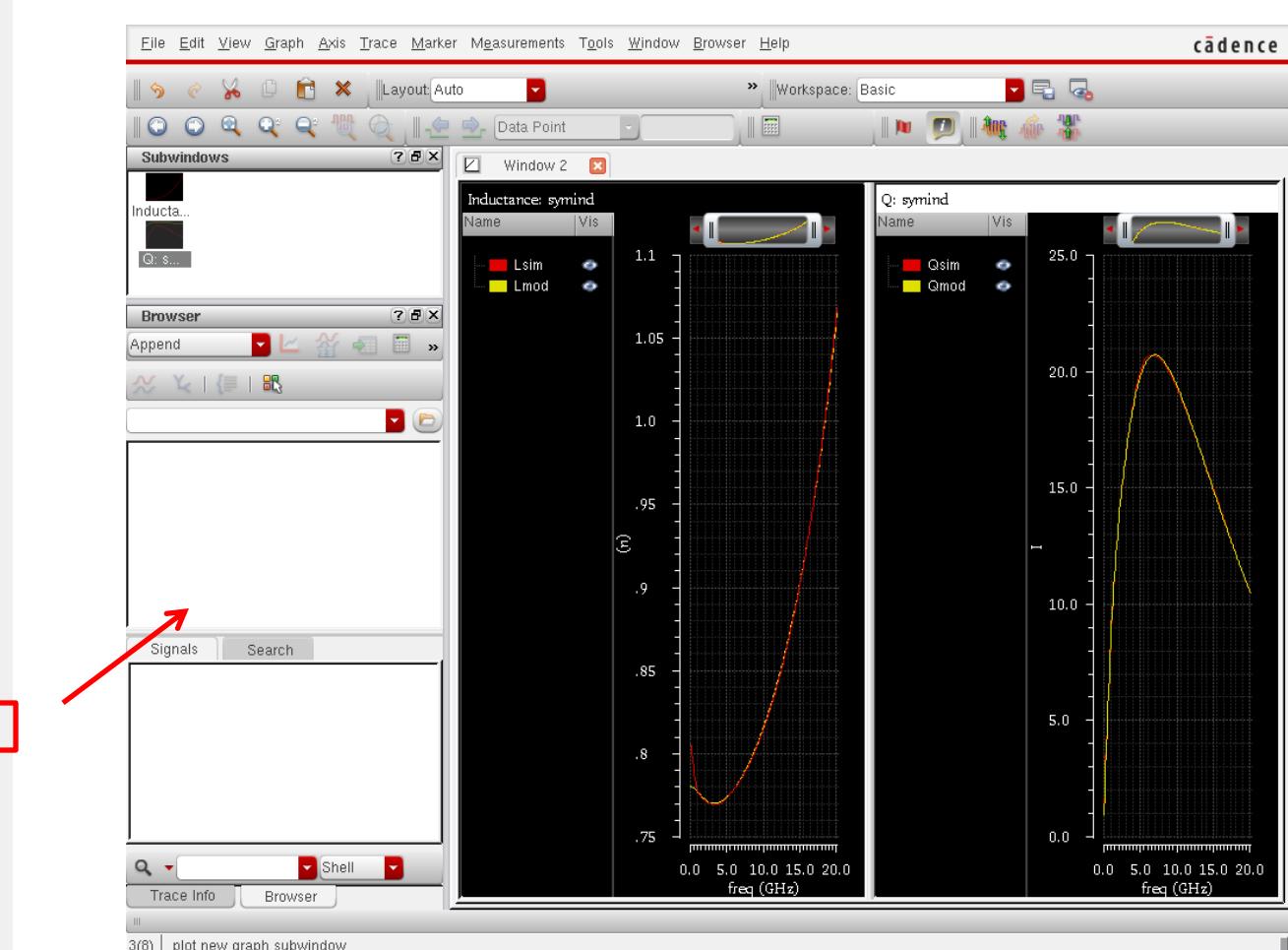
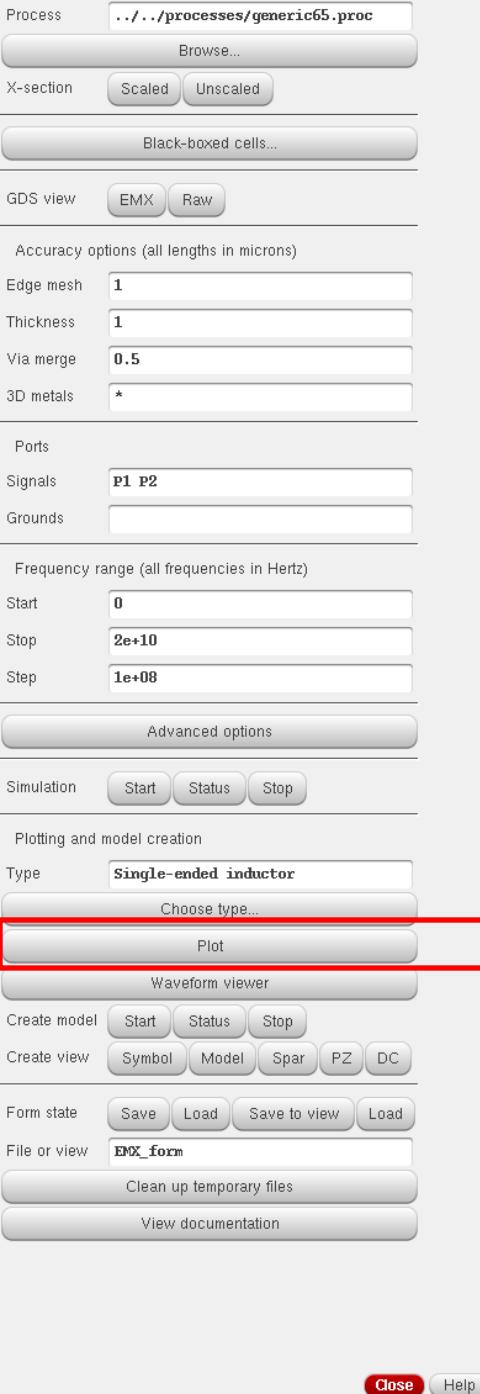


File Help **cadence**

```
err 7.941824e-02
Iteration 2...>|
Iteration 3...>|
err 6.012002e-02
Iteration 4...>|
Iteration 5...>|
err 5.995217e-02
Iteration 6...>|
err 5.934570e-02
Iteration 7...>|
Iteration 8...>|
Iteration 9...>|
Iteration 10...>|
Iteration 11...>|
err 5.933056e-02
Iteration 12...>|
Iteration 13...>|
Iteration 14...>|
Iteration 15...>|
Iteration 16...>|
Iteration 17...>|
Iteration 18...>|
Iteration 19...>|
Iteration 20...>|
Iteration 21...>|
Iteration 22...>|
Iteration 23...>|
Iteration 24...>|
Iteration 25...>|
Iteration 26...>|
Iteration 27...>|
Iteration 28...>|
Iteration 29...>|
Iteration 30...>|
Iteration 31...>|
Process exited normally
```

10

Generate circuit model



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

Process

Browse...

X-section

Black-boxed cells...

GDS view

Accuracy options (all lengths in microns)

Edge mesh

Thickness

Via merge

3D metals

Ports

Signals

Grounds

Frequency range (all frequencies in Hertz)

Start

Stop

Step

Advanced options

Simulation

Plotting and model creation

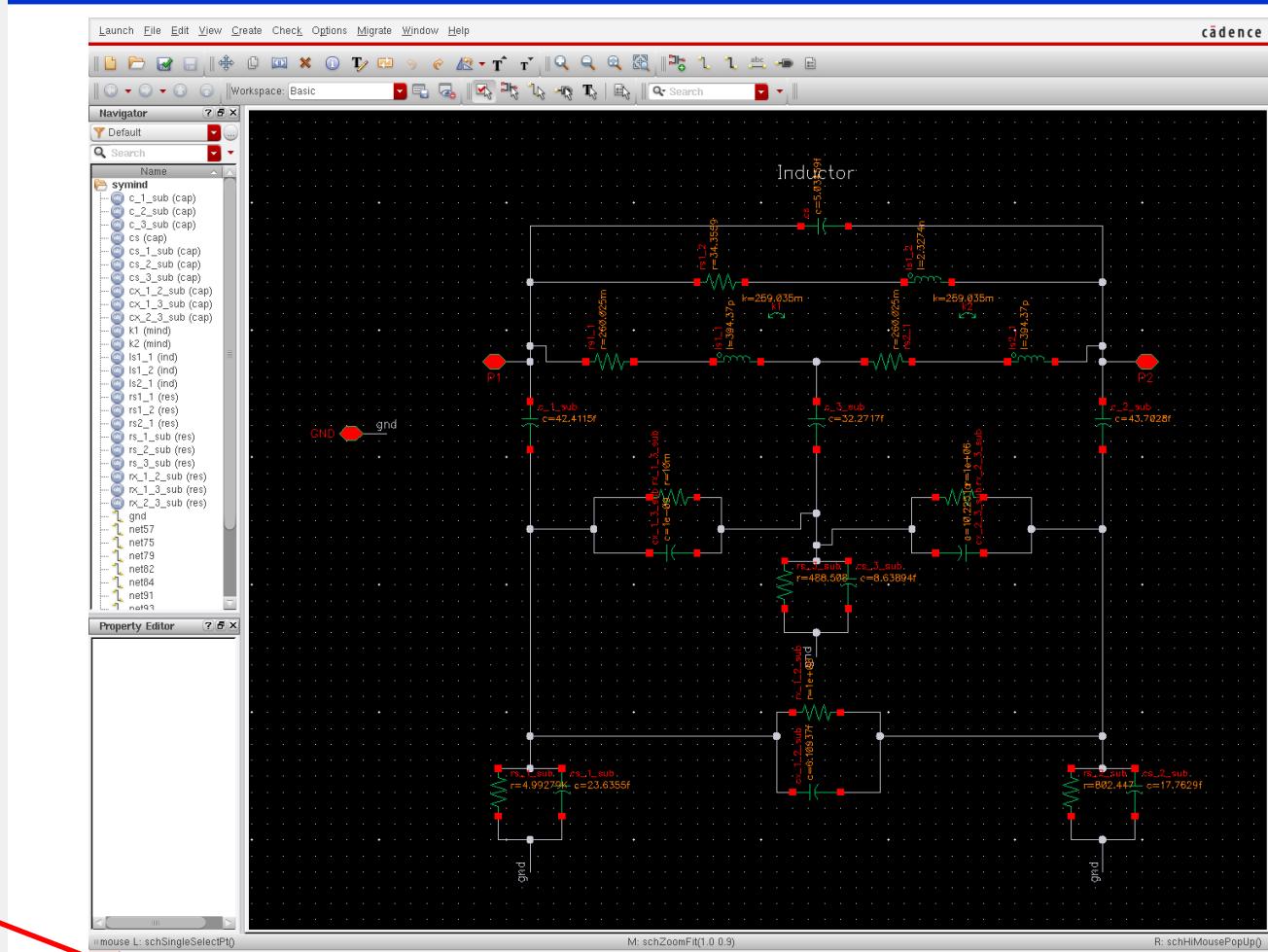
Type

Create model

Create view

Form state

File or view



Generate Schematic

Schematic with temp coefficients

File Edit Options Buffers Tools Help

Launch File Edit View Create Check Options Migrate Window Help

Cadence

The screenshot shows the Cadence schematic editor interface. On the left is a code editor window displaying an EMX configuration file. A red box highlights the section where default temperature coefficients are set. A red arrow points from this section to the right-hand property editor window, which shows the 'Property Editor' for a selected component. The 'Property Editor' window displays various parameters for a resistor, including 'Resistance' (262.57m Ohms), 'Temperature coefficient 1' (3e-3), and 'Temperature coefficient 2' (0.0). The 'Property Editor' also includes tabs for 'Library Name' (analogLib), 'Cell Name' (res), 'View Name' (symbol), and 'Instance Name' (rsl_1).

```

;EMX_schematic_dc_name="EMX_dc"
; These are the new style extracted view names
;EMX_symbol_name="symbol"
;EMX_symbol_nport_name="symbol"
;EMX_schematic_name="EMX_model"
;EMX_schematic_nport_name="EMX_spar"
;EMX_schematic_pz_name="EMX_pz"
;EMX_schematic_dc_name="EMX_dc"
; Optional views produced with symbol and symbol nport
;EMX_audcl_name="audCl"
;EMX_aulvs_name="aulVs"
;Miscellaneous
;EMX_bsbus_default=nil ; t => default "Use bsbus" field to selected
;EMX_viewproc_local=t ; nil => emx --print-proc via bsbus instead of local
;EMX_spectre_local=t ; nil => run spectre via bsbus instead of locally
;EMX_modelgen_local=t ; nil => to run modelgen via bsbus instead of local
;EMX_spectre_Command="spectre" ; maybe "PATH=/path/to/cadence/bin: sp"
;EMX_modelgen_path=EMX_path ; if modelgen is in a different place
;EMX_internal_PSF_reader=nil ; probably not needed anymore
;EMX_xsection_opts="" ; use --generate-pdf for PDF instead of PostScript
;EMX_specialized_models=t ; nil => modelgen models use generic model for
;EMX_RLCK_model_schematics=nil ; nil => non-generic modelgen models have
; instead of an instance reference
;EMX_new_style_menu_trigger=t ; probably not needed anymore
;EMX_fixed_cell_name=t ; nil => use [ocellName] in black box symbol
;EMX_dialog_msgs=0 ; 0 => warn and info use dialog box
; 1 => warn uses dbox; info goes to CIW
; 2 => warn and info go to CIW
;EMX_form_init_proc=nil ; symbol = function to call after form creation
; arguments are basic form and advanced form
;EMX_schematic_creation_hook=nil ; symbol or function = hook to
; call after schematic view creation
; arguments are (open) celview; names
; of lib, cell, and view; and either
; string (= model type) or symbol
; (= nport for S-param view, or
; 'generic for other schematic)

; To make the interface set temperature coefficients for built-in
; models:
; EMX_default_tcr1="1e-3" ; Set EMX_default_tcr1 and _tcr2 as desired
; EMX_default_tcr2="2e-3"
; EMX_schematic_creation_hook='EMX_set_model_temp_coeffs'

EMX_default_tcr1="3e-3" ; Set EMX_default_tcr1 and _tcr2 as desired
EMX_default_tcr2="0"
EMX_schematic_creation_hook='EMX_set_model_temp_coeffs'

; Now actually load the interface
(load (strcat EMX_interface_path "/emxskill/emxconfig.ils"))

---- emxconfig.ils Bot L167 (Fundamental)

```

Navigator

Search

Inductor

Property Editor

Apply To: only current instance

Show: system user CDF

Browse Reset Instance Labels Display

Property

Library Name: analogLib

Cell Name: res

View Name: symbol

Instance Name: rsl_1

Add Delete Modify

CDF Parameter

Model name: 262.57m Ohms

Resistance: 262.57m Ohms

Length:

Width:

Multiplier:

Scale factor:

Temp rise from ambient:

Temperature coefficient 1: 3e-3

Temperature coefficient 2: 0.0

Resistance Form:

Generate noise?:

Capacitance:

Alias for Lin. temp. co.:

Alias for Quad temp. co.:

Lin temp co of lin cap:

Quad temp co of lin cap:

Resistance Scaling Factor:

Capacitance Scaling Factor:

AC resistance:

Temperature difference:

OK Cancel Apply Defaults Previous Next Help

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

Process [.../processes/generic65.proc](#)

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](#)

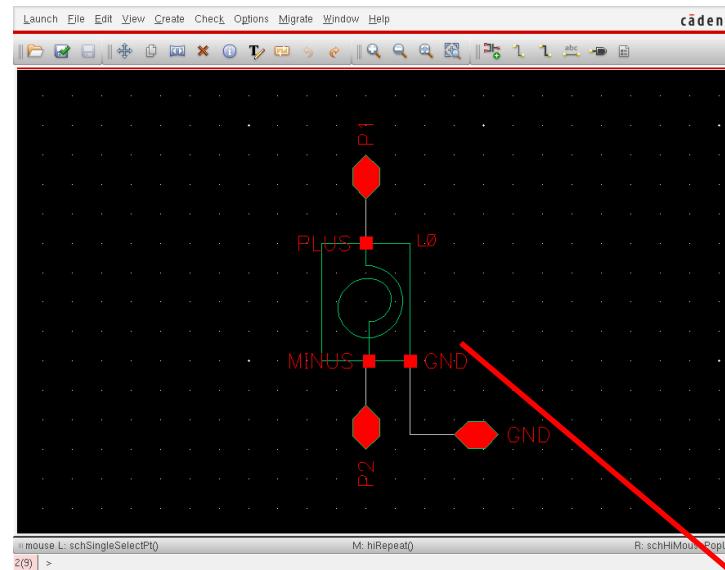
File or view [EMX_form](#)

Clean up temporary files

View documentation

[Close](#) [Help](#)

Using symbol/cdf instead of schematic



Apply To [only current](#) [instance](#)

Show system user CDF

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. [16 11:18:02 2009](#) off

CDF Parameter Value Display

cs	4.343311f F	off
rs1_1	893.7064m Ohms	off
ls1_1	379.7006p H	off
rs2_1	893.7064m Ohms	off
ls2_1	379.7006p H	off
rs1_2	729.0552m Ohms	off
ls1_2	834.9946p H	off
k1	6.387893e-01	off
k2	6.387893e-01	off
c_1_sub	44.09232f F	off
c_1_sub	780.4411 Ohms	off
cs_1_sub	18.37848f F	off
c_2_sub	44.55012f F	off
rs_2_sub	17.97133K Ohms	off
cs_2_sub	31.88267f F	off
c_3_sub	28.88187f F	off
rs_3_sub	457.6598 Ohms	off
cs_3_sub	3.05494e-22 f	off
rx_1_2_sub	67.683K Ohms	off
cx_1_2_sub	8.143328f F	off
rx_1_3_sub	90.69914K Ohms	off
cx_1_3_sub	6.56153e-21 f	off
rx_2_3_sub	12.99991u Ohms	off
cx_2_3_sub	229.7179p F	off
tcr1	0	off
tcr2	0	off

OK Cancel Apply Defaults Previous Next 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

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

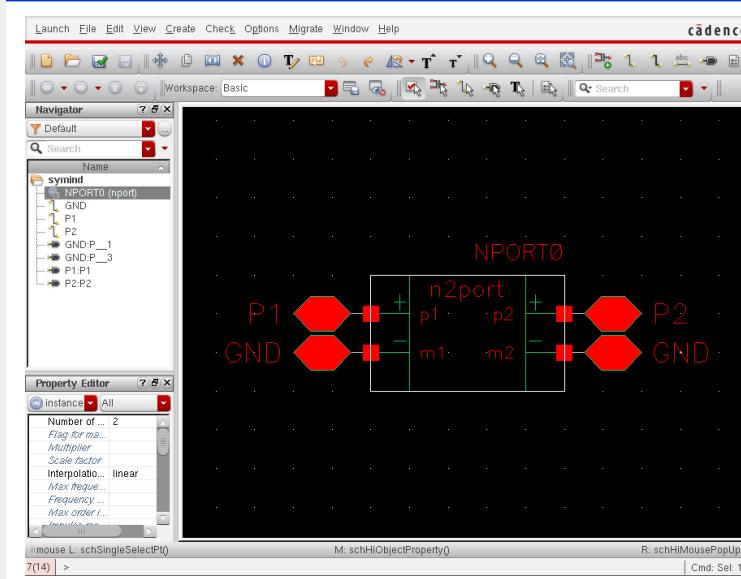
Form state Save Load Save to view Load

File or view EMX_form

Clean up temporary files

View documentation

Close Help



Apply To only current instance

Show system user CDF

Browse Reset Instance Labels Display

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

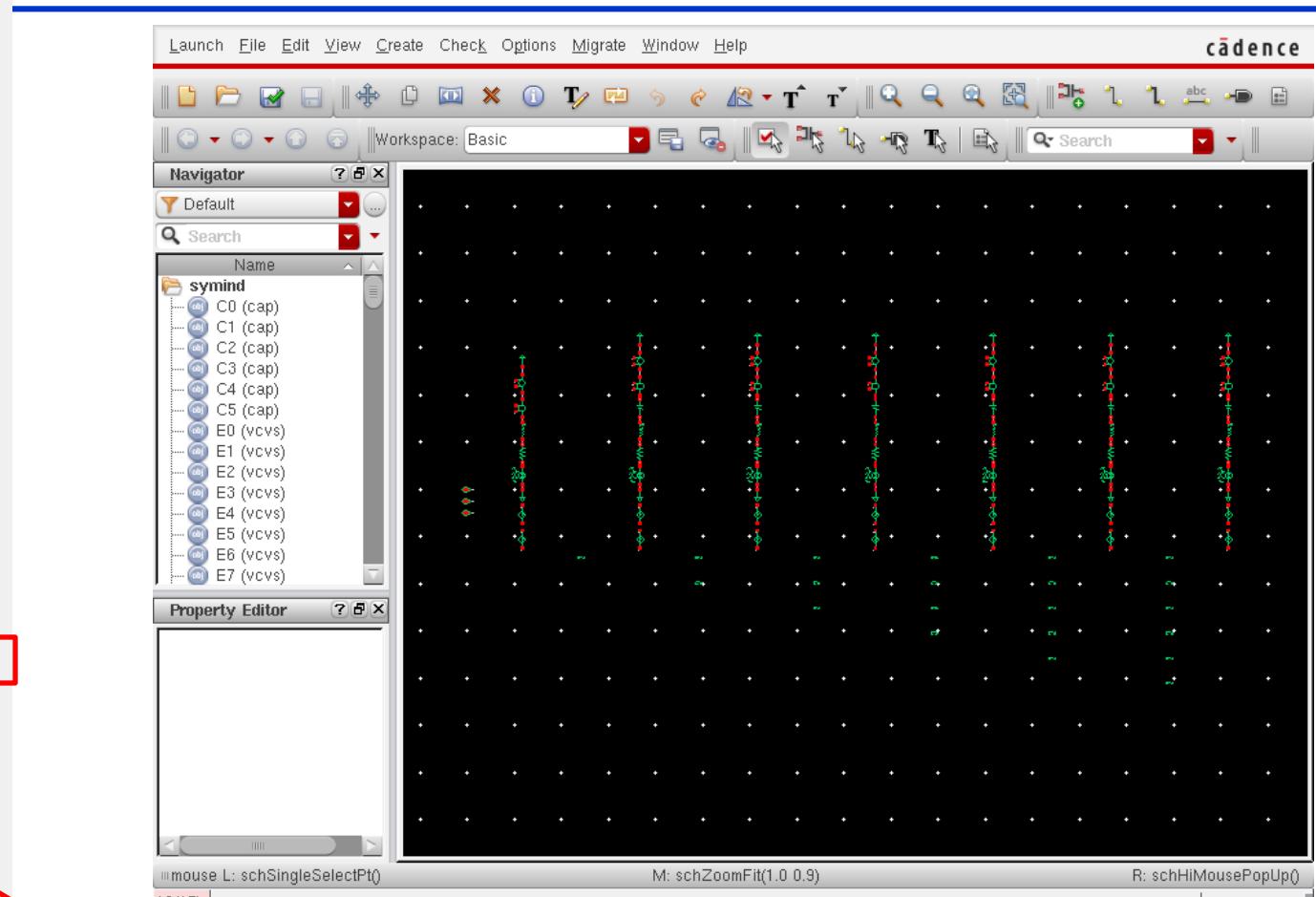
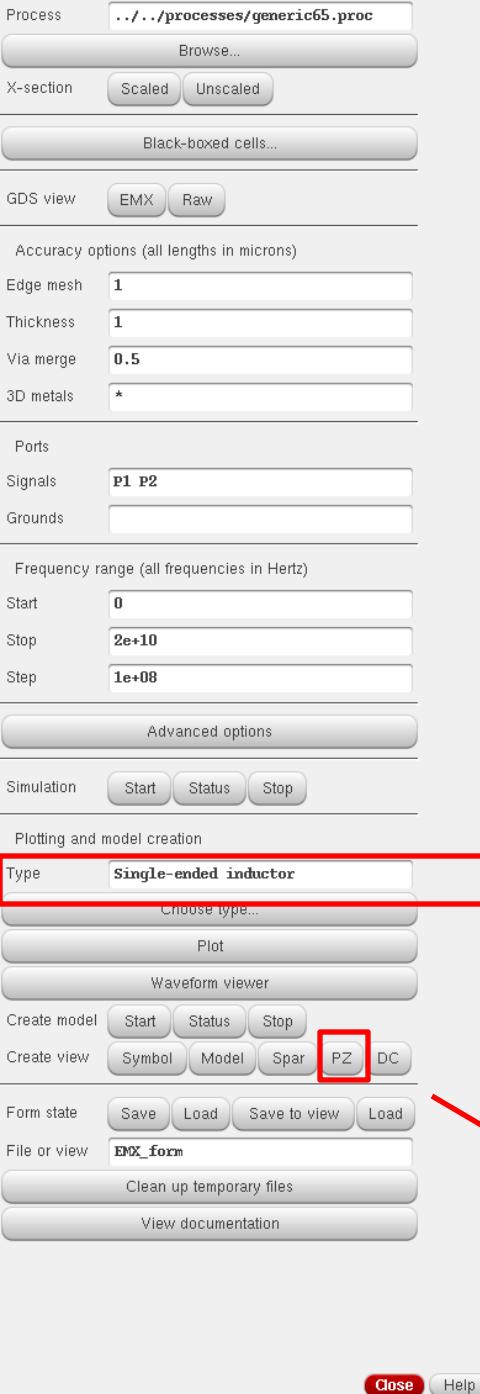
Add Delete Modify

CDF Parameter Value Display

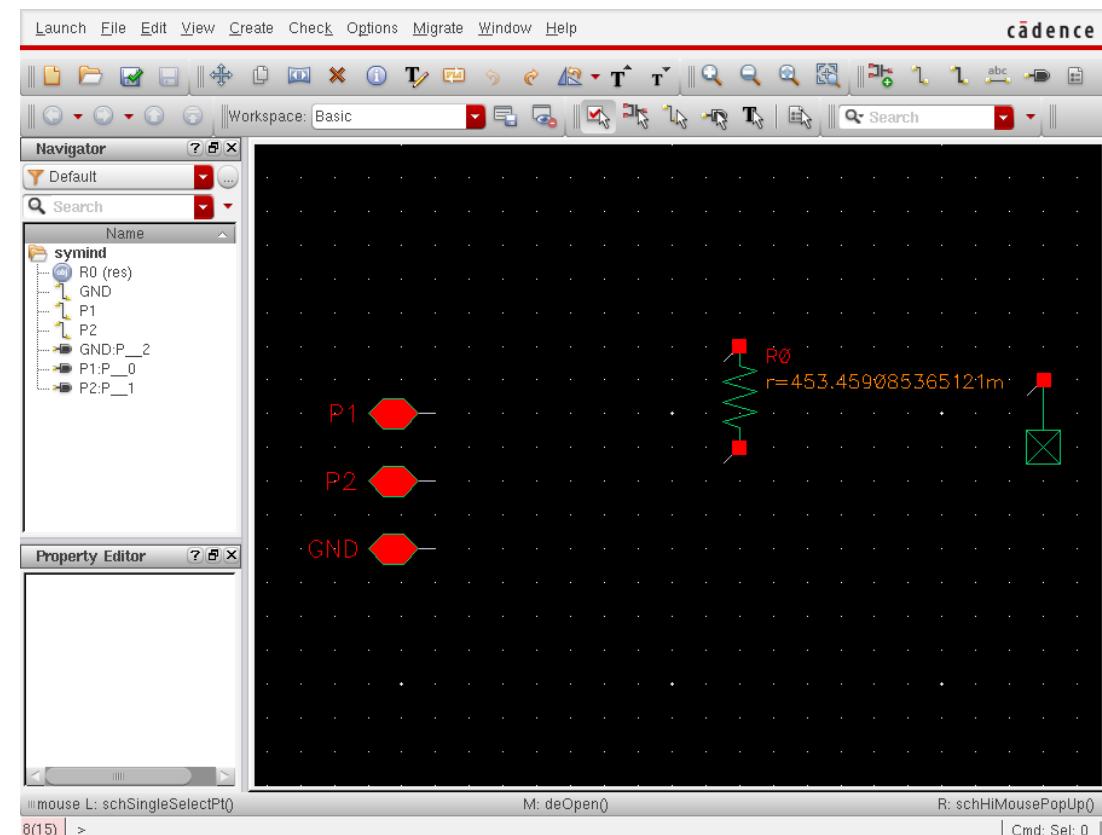
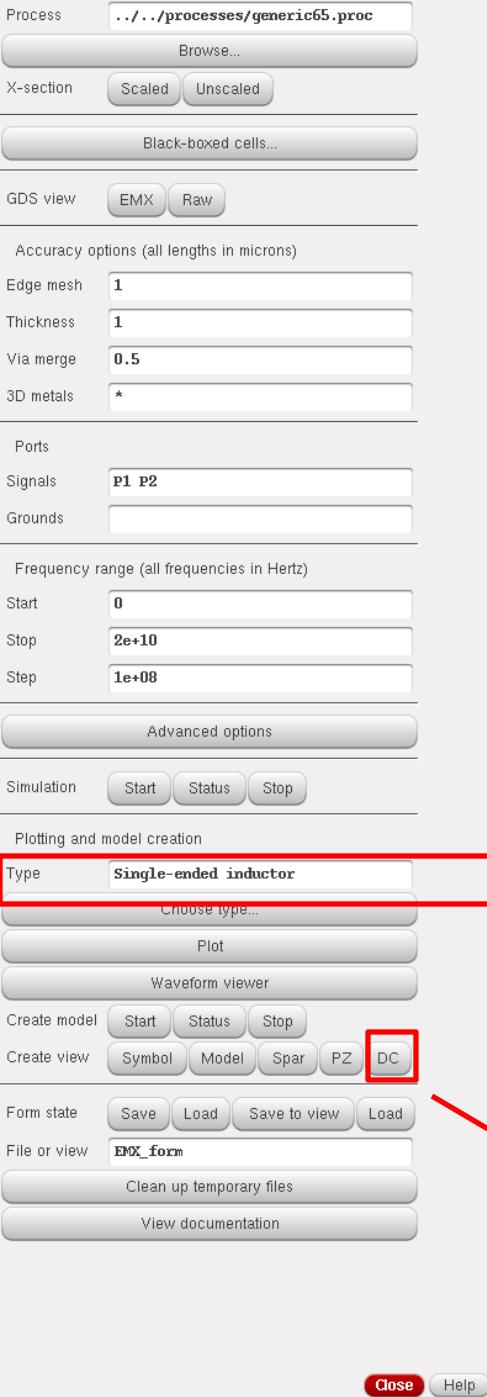
Number of Ports	2	Value off
Flag for matrix form input		Value off
Multiplier		Value off
Scale factor		Value off
Interpolation method	linear	Value off
Max frequency of interest		Value off
Frequency sampling interval		Value off
Max order impulse response		Value off
Impulse response trunc thresho		Value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

OK Cancel Apply Defaults Previous Next Help

Generate schematic_nport
which points to S=parameters



Generate Schematic using EMX PZ model



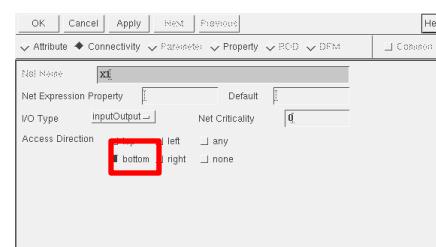
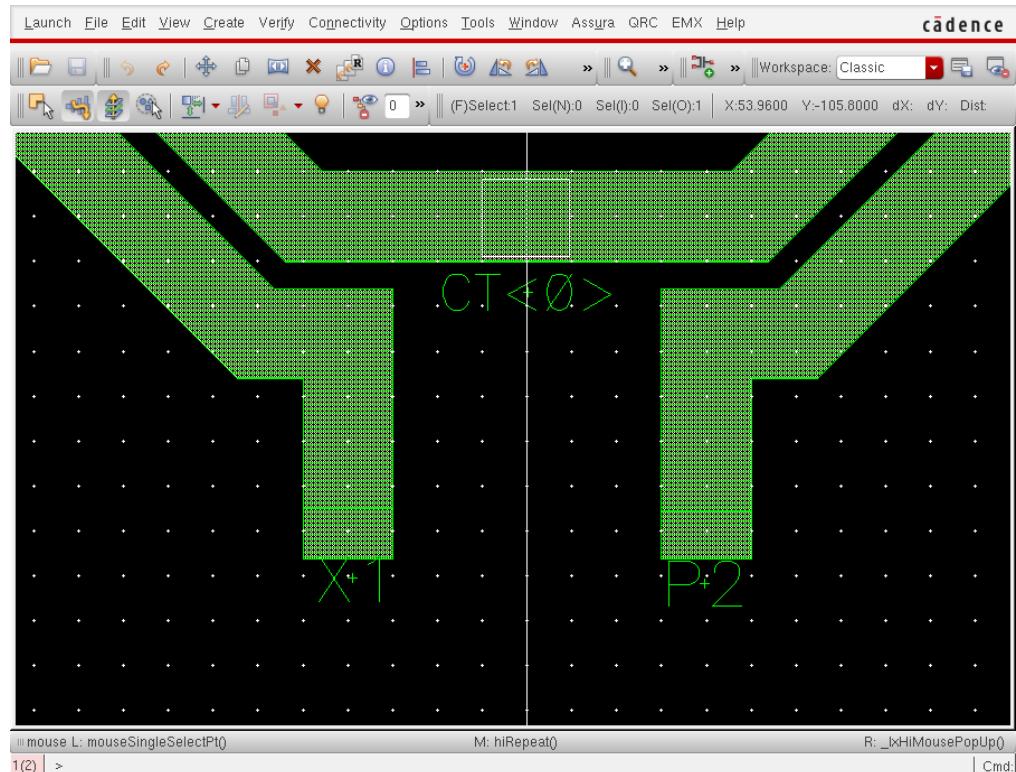
Generate schematic at DC
which can be used for LVS
purposes

Using Cadence pins (symind_ct example)

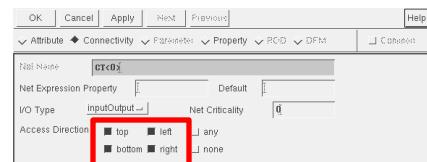
Cadence pins can be used for ports. The pin layer should be included in the process file

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

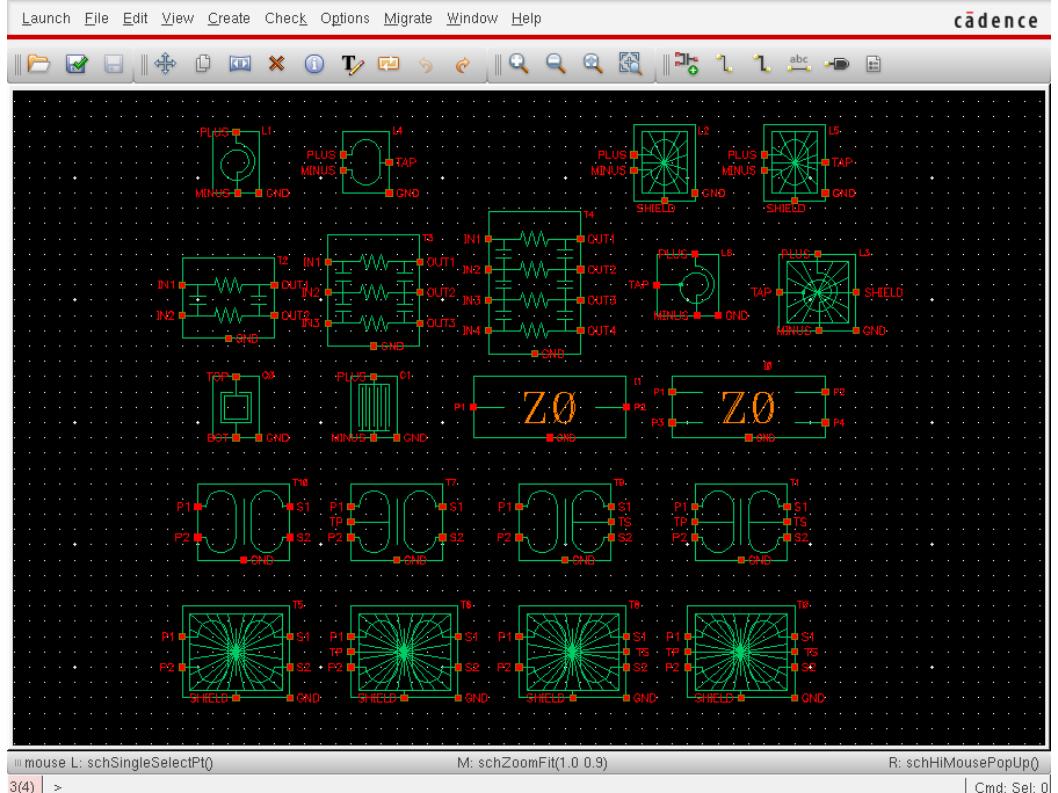
Dual tapped transformer

Shield transformer

Tapped primary shield transformer

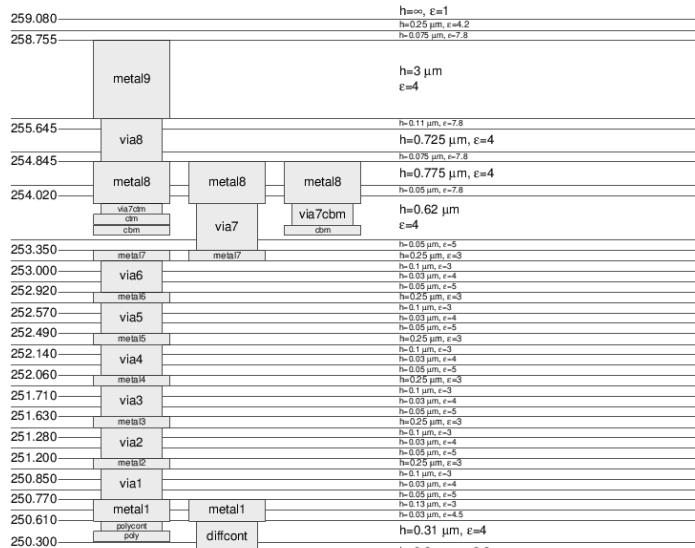
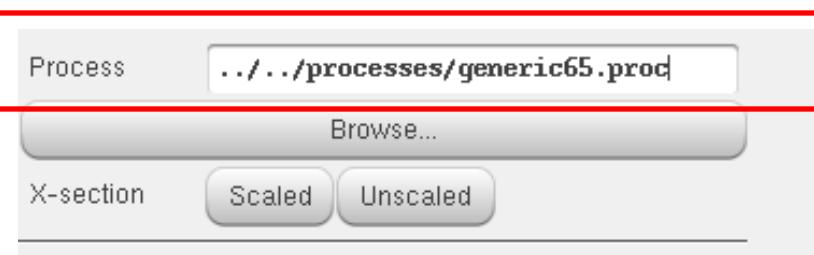
Tapped secondary shield transformer

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)



h=250 μm
ε=11.9
12.5 Ω·cm
8 S/m

metal9: h=3 μm, 6 mΩ/sq, bias 10 nm	via7ctm: h=0.0273 μm, 0.5 Ω/via
metal8: h=1 μm, 40 mΩ/sq	via7cbm: h=0.145 μm, 0.5 Ω/via
ctm: h=0.1 μm, 20 Ω/sq	via8: h=0.91 μm, 0.4 Ω/via
cbm: h=0.2 μm, 0.5 Ω/sq	via7: h=0.495 μm, 0.2 Ω/via
metal7: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via6: h=0.18 μm, 2 Ω/via
metal6: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via5: h=0.18 μm, 2 Ω/via
metal5: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via4: h=0.18 μm, 2 Ω/via
metal4: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via3: h=0.18 μm, 2 Ω/via
metal3: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via2: h=0.18 μm, 2 Ω/via
metal2: h=0.25 μm, 0.18 Ω/sq, bias 10 nm	via1: h=0.18 μm, 2 Ω/via
metal1: h=0.18 μm, 0.2 Ω/sq, bias 5 nm	polycont: h=0.17 μm, 20 Ω/via
poly: h=0.1 μm, 14.9 Ω/sq, bias -0.5 nm	diffcont: h=0.504 μm, 26 Ω/via
diff: h=0.086 μm, 16.9 Ω/sq	

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

$$\int \frac{\text{Integrand}}{\text{Software, Inc.}}$$

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

define diff = l6t0
define poly = l17t0
define metall1 = l31t0
define metall2 = l32t0
define metall3 = l33t0
define metall4 = l34t0
define metall5 = l35t0
define metall6 = l36t0
define metall7 = l37t0
define metall8 = l38t0
define metall9 = l39t0+l139t0
define cbm = l88t0
define ctm = l77t0

define diffCont = merge(l30t0, 0.22)
define polyCont = merge(l30t0, 0.22)
define vial = 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))

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
layer 0.31 4.0 # ILD
position 0.02
conductor 0.1 14.9500 poly
bias -0.0005
layer 0.03 4.5 # IMD1a
--:-- generic65.proc Top L56 (Fundamental)-----
```

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)

```

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) metall
  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

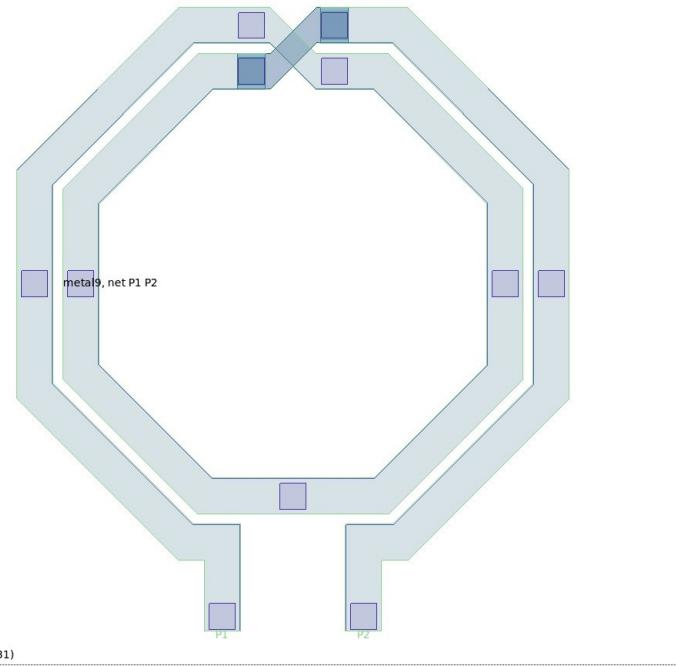
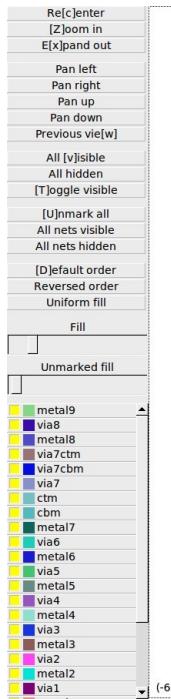
via diff metal1 26 diffCont
via poly metal1 20 polyCont
via metal1 metal2 2*(1+0.001*dtemp) via1
via metal2 metal3 2*(1+0.001*dtemp) via2
via metal3 metal4 2*(1+0.001*dtemp) via3
via metal4 metal5 2*(1+0.001*dtemp) via4
via metal5 metal6 2*(1+0.001*dtemp) via5
via metal6 metal7 2*(1+0.001*dtemp) via6
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

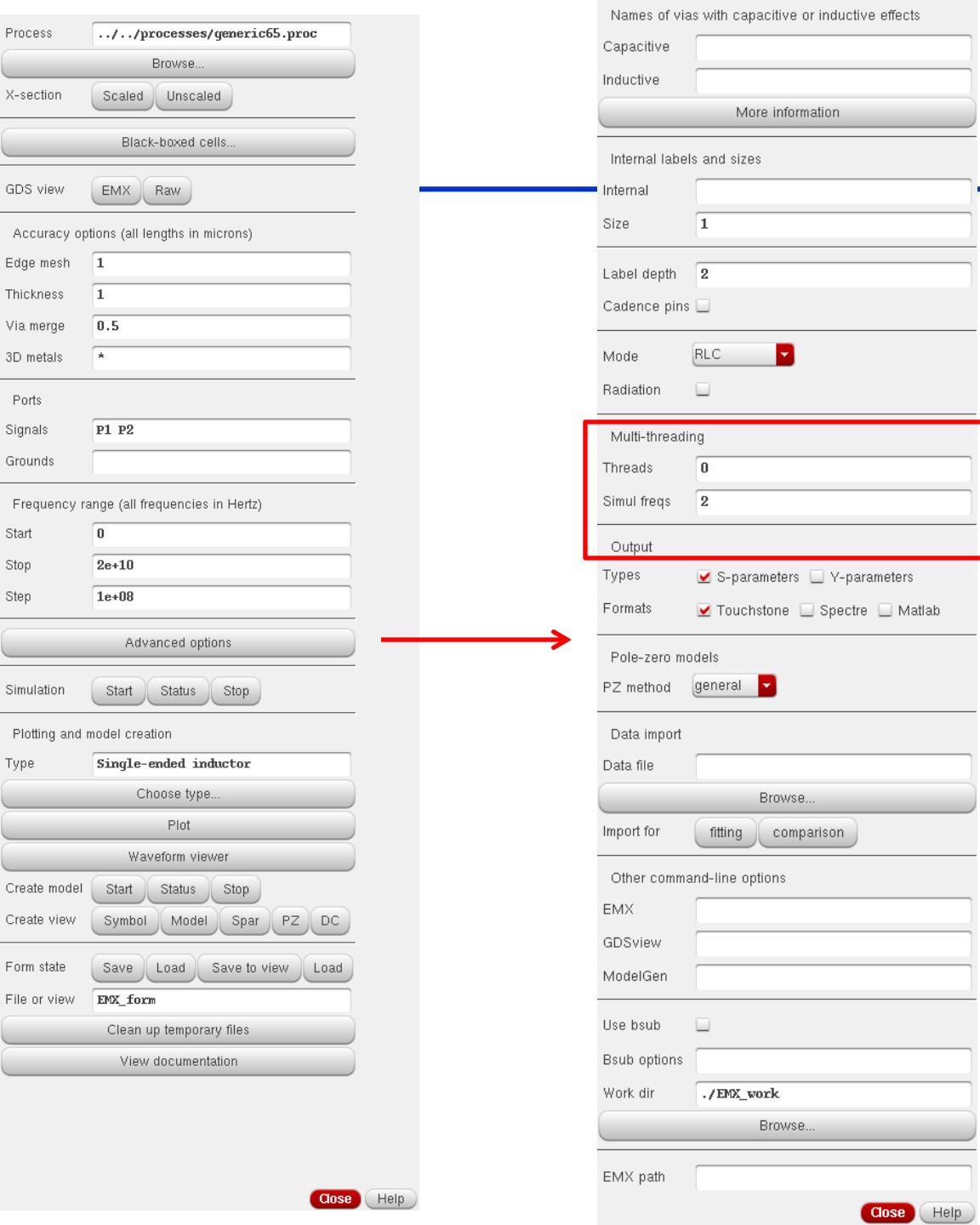


GDSview is used to see what EMX is simulating

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

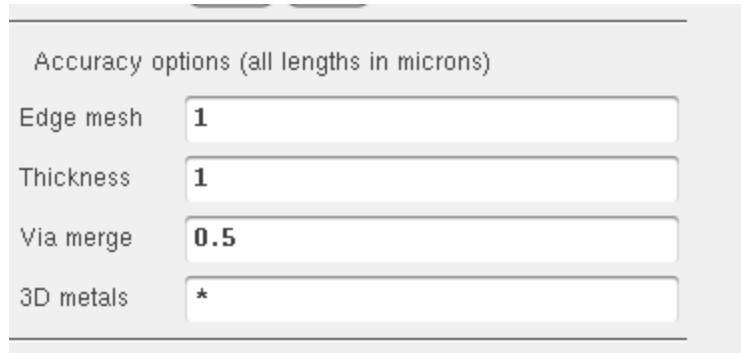
NOTE: Read the GDSview manual to learn more about this tool in detail



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.

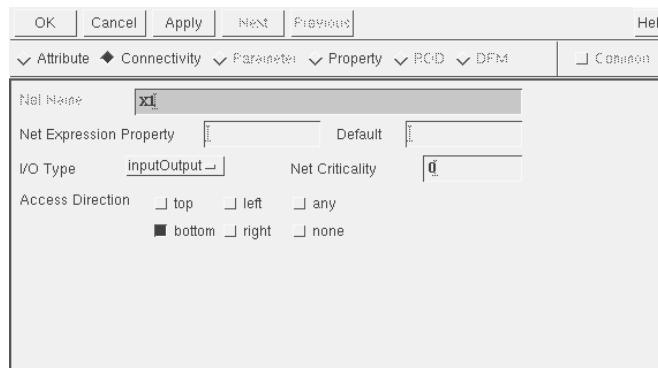
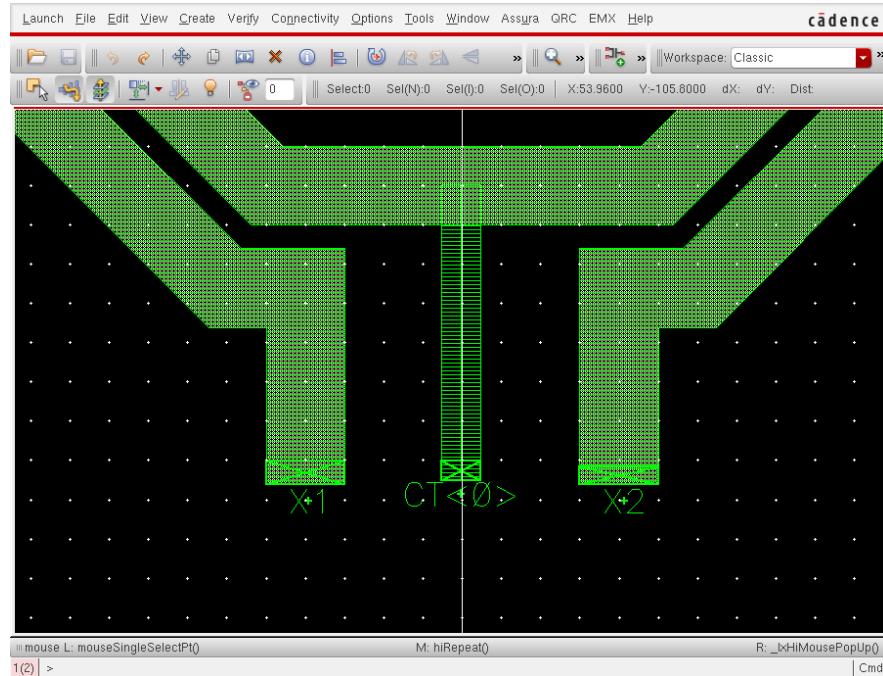
Accuracy options (Edge and thickness mesh)



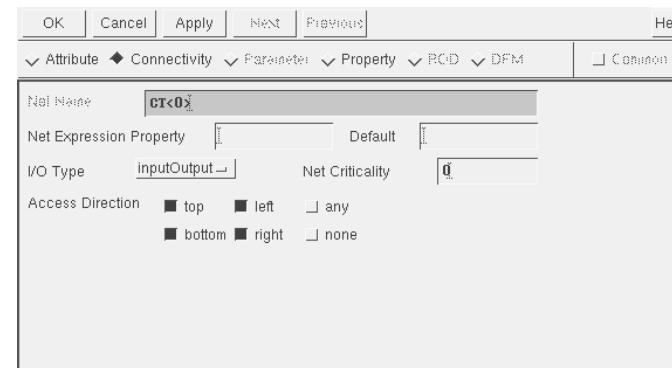
Edge mesh and thickness mesh should roughly correspond to skin depth. Setting 1um should give good accuracy with reasonable speed. Decreasing this number to 0.5 or lower will reduce the speed and increase accuracy. These settings can be used for structures like inductors, transformers where the routing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



X1: Edge port



CT<0>: Internal port

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

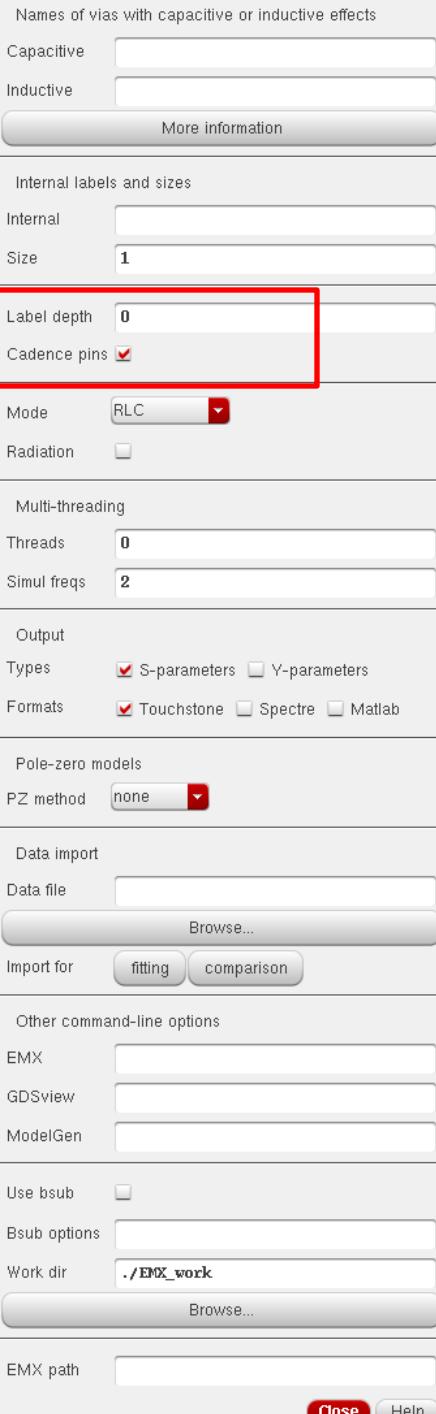
Cadence Pins

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

define diff = 16t0
define poly = 117t0
define metal1 = 131t0+1131t0
define metal2 = 132t0+1132t0
define metal3 = 133t0+1133t0
define metal4 = 134t0+1134t0
define metal5 = 135t0+1135t0
define metal6 = 136t0+1136t0
define metal7 = 137t0+1137t0
define metal8 = 138t0+1138t0
define metal9 = 139t0+1139t0
define cbm = 188t0
define ctm = 177t0
```

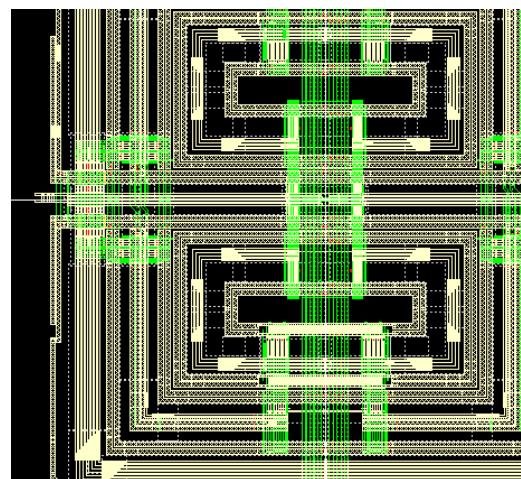
In the EMX .proc file make sure that the pin layers are Identified (metal1 drawing + metal1 pin)

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

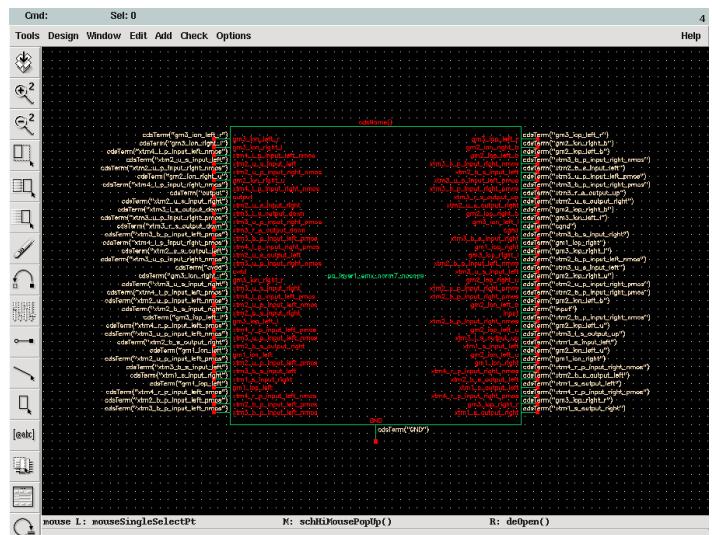


Automatic pin order

Integrand
Software, Inc.



```
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_nmios -p P025=xtm2_b_s_output_right -p P026=gml_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 le=+08 le=+10 --sweep-stepsize le=+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

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

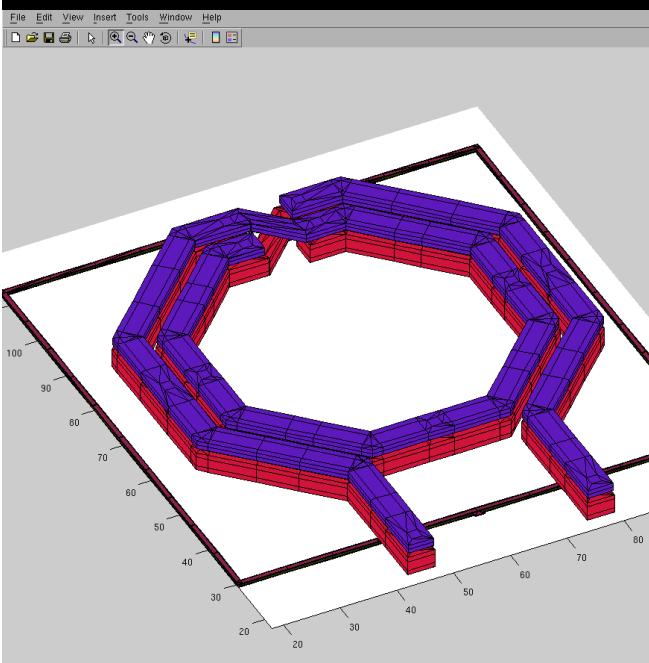
Mesh

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.

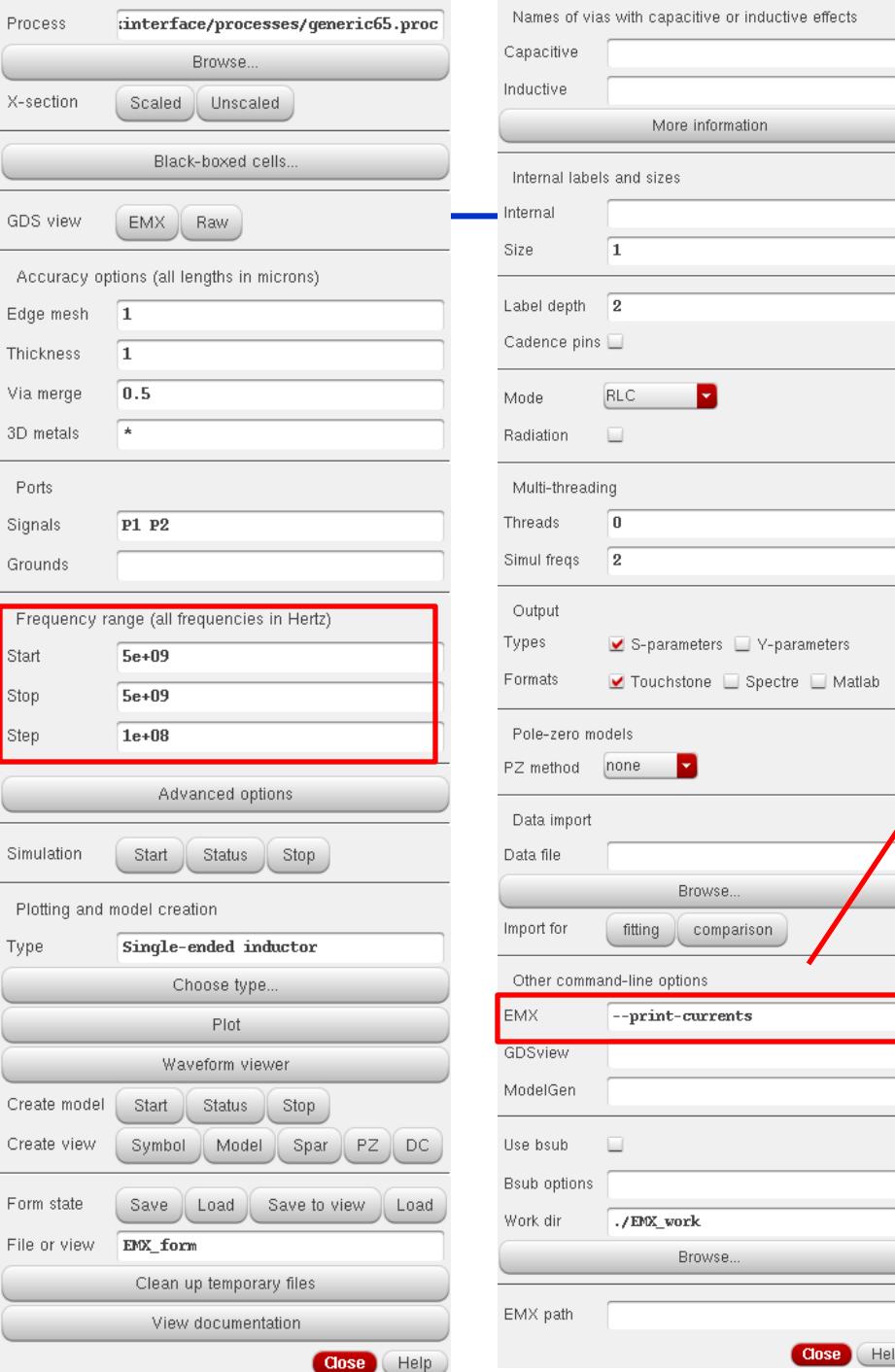
```
>> emxmesh  
emxmesh  
>> help emxmesh  
help emxmesh  
emxmesh  
Display the mesh produced by EMX.  
emxmesh('m1')  
Display the mesh for a single conductor layer.  
emxmesh({'m1', 'm2'})  
Display the mesh for the conductor layers specified in the list.
```



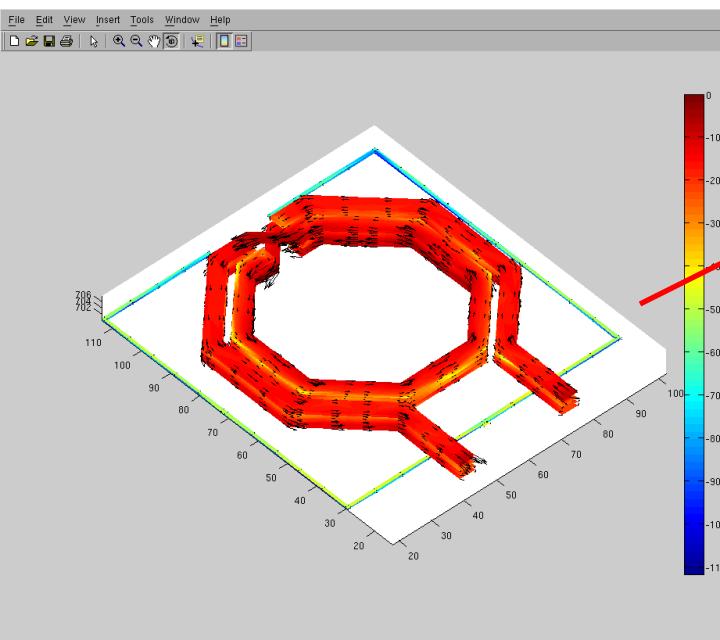
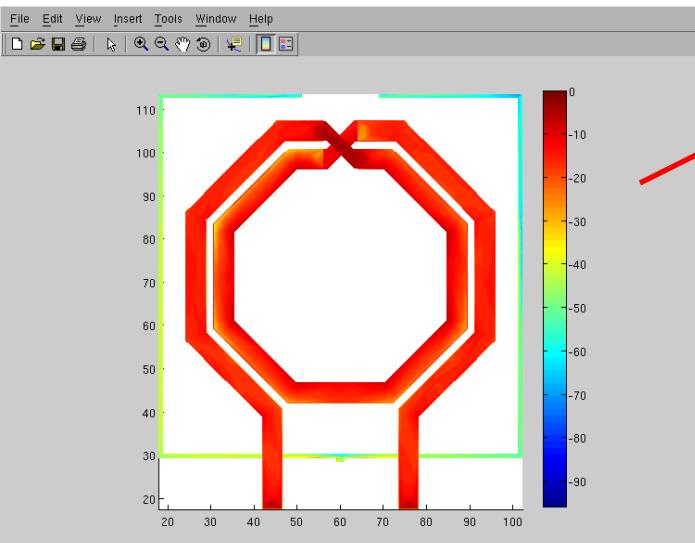
Close Help

Current plotting

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.

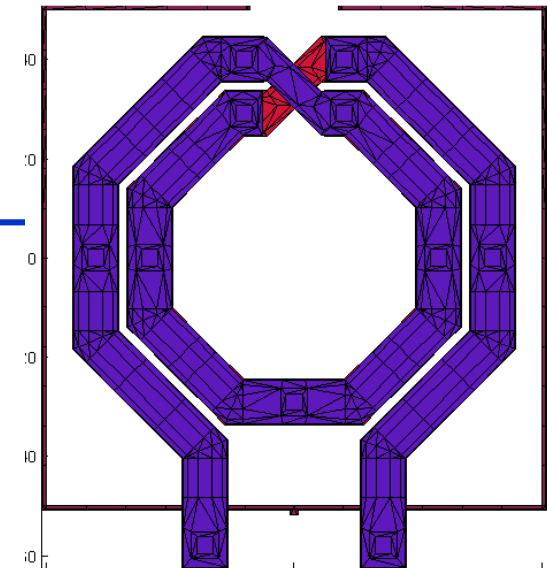
>> emxcurrent('phase', 1, 'arrows', 2)

```

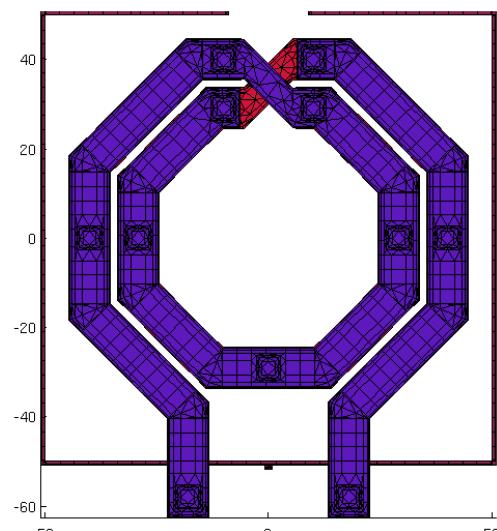
--print-currents This option makes EMX write a MATLAB-format output file `emxcurrent.m` showing the horizontal current density in the structure. The plot shows the ratio in dB of the horizontal current density to the maximum horizontal current density. Horizontal current density is calculated by integrating 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



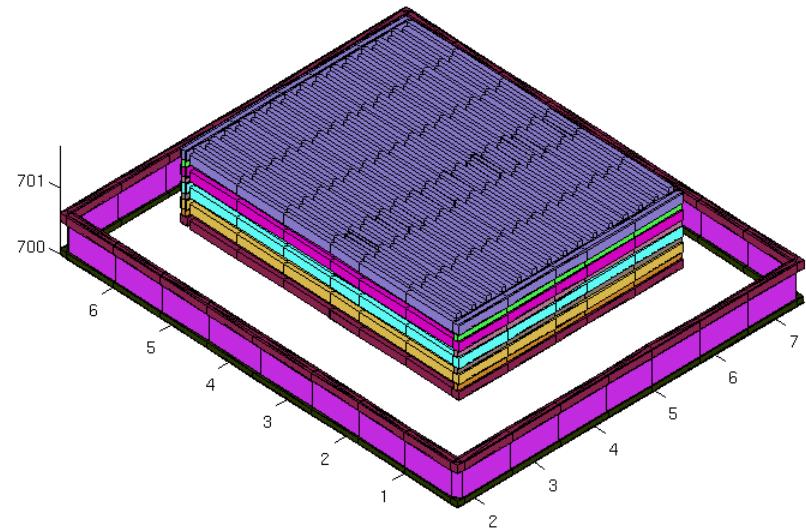
edge-mesh=1
thickness-mesh=1



edge-mesh=0.4
thickness-mesh=0.4

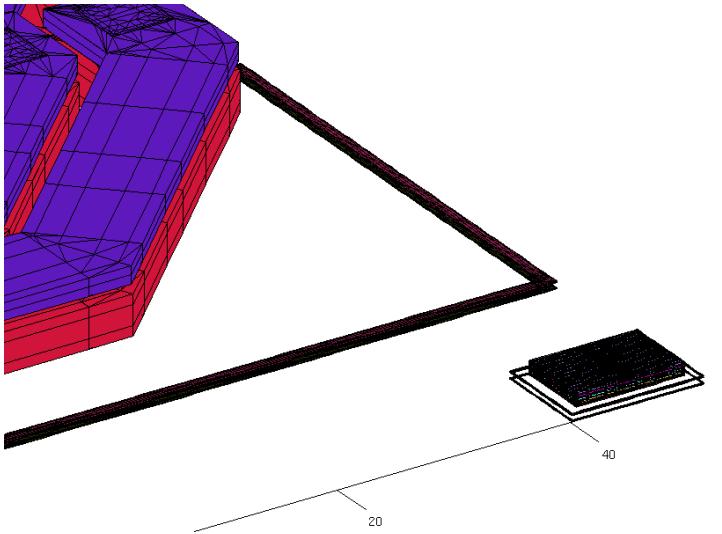
Capacitor meshing

- 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

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

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

Import for fitting comparison

Other command-line options

EMX **--edge-width=metal6,1**

GDSview

ModelGen

Use bsub

Bsub options

Work dir **./EMX_work**

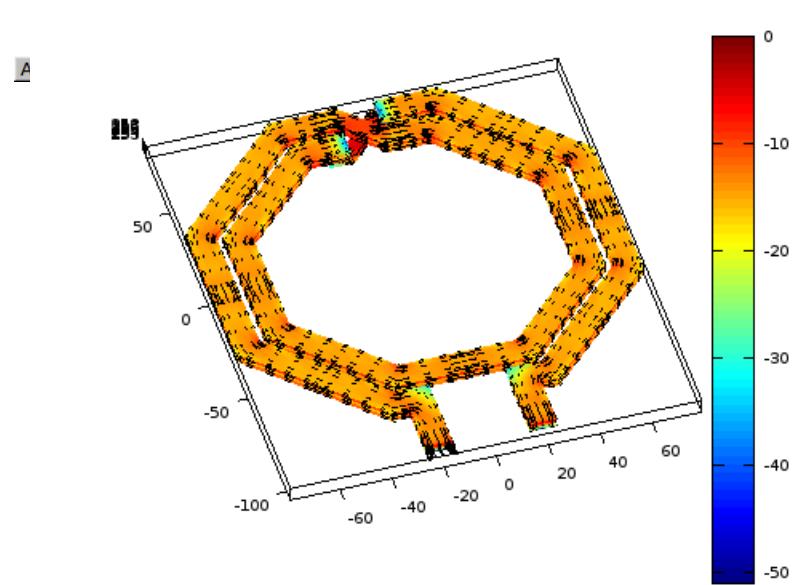
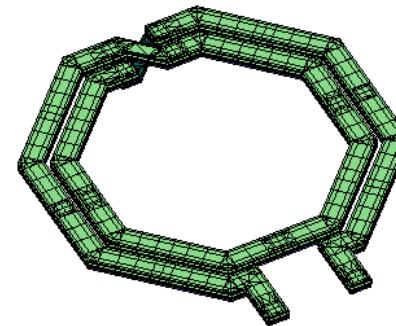
EMX path

Close Help

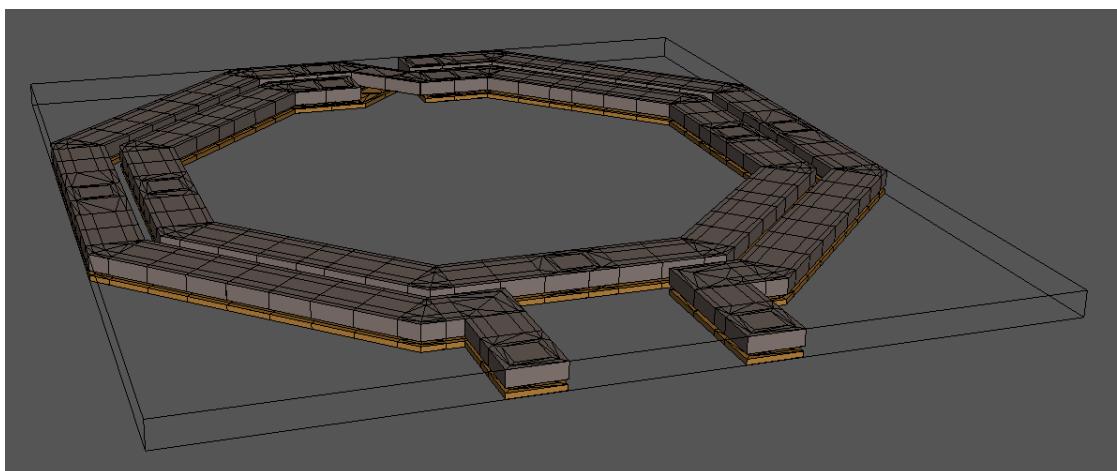
47 Close Help

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



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/>

Names of vias with capacitive or inductive effects

Capacitive

Inductive

More information

Internal labels and sizes

Internal

Size

Label depth

Cadence pins

Mode

Radiation

Multi-threading

Threads

Simul freqs

Output

Types S-parameters Y-parameters

Formats Touchstone Spectre Matlab

Pole-zero models

PZ method

Data import

Data file

Browse...

Import for

Other command-line options

EMX

GDSview

ModelGen

Use bsub

Bsub options

Work dir

EMX path

Accuracy options (Via merge)

Accuracy options (all lengths in microns)

Edge mesh	1
Thickness	1
Via merge	0.5
3D metals	*

Global via merge setting

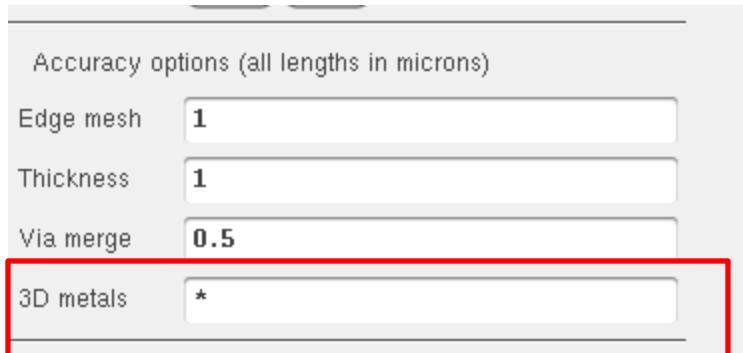
The via merge setting can be applied globally (all vias within 0.5um will be merged), or it can be controlled on a layer by layer basis within the process file. It is recommended to use the process files to control the via merging.

```
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))
```

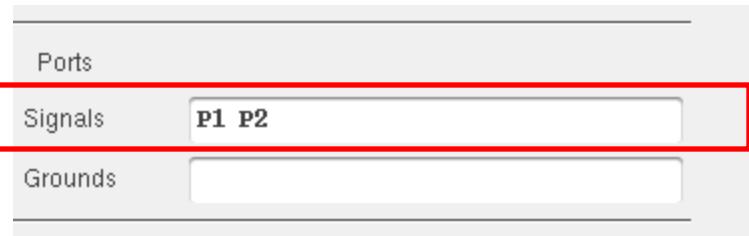
Via specific merge settings

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.

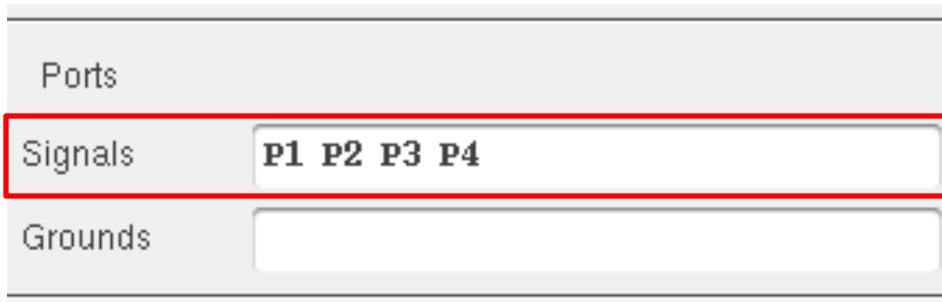
Ports



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 ordered 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.

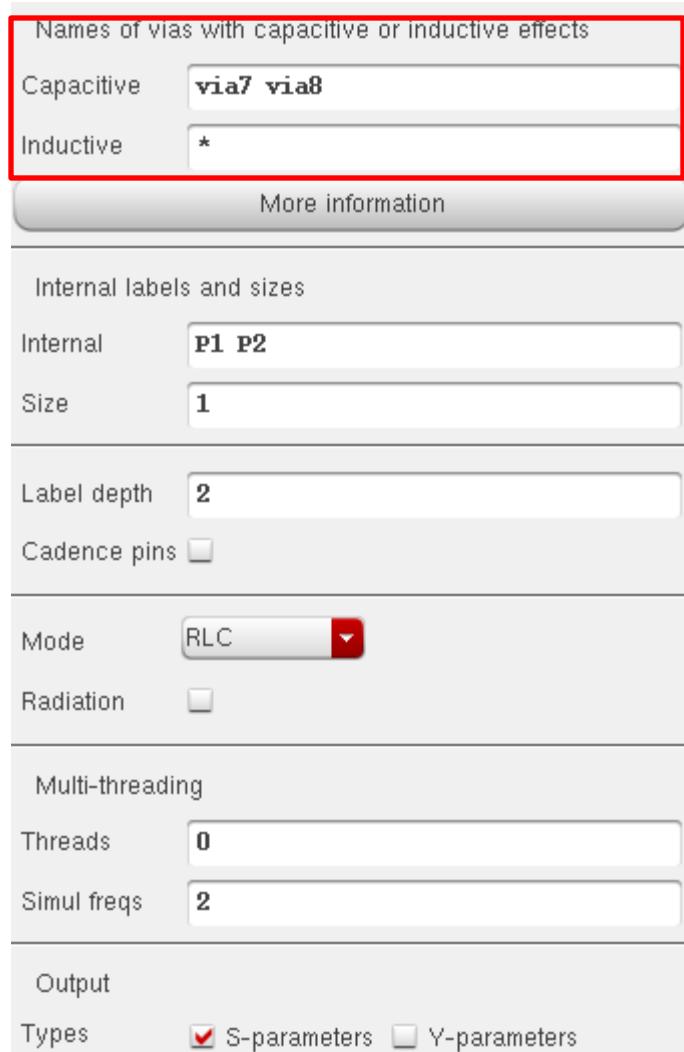
Frequencies

Frequency range (all frequencies in Hertz)

Start	<input type="text" value="1e+08"/>
Stop	<input type="text" value="2e+10"/>
Step	<input type="text" value="1e+08"/>

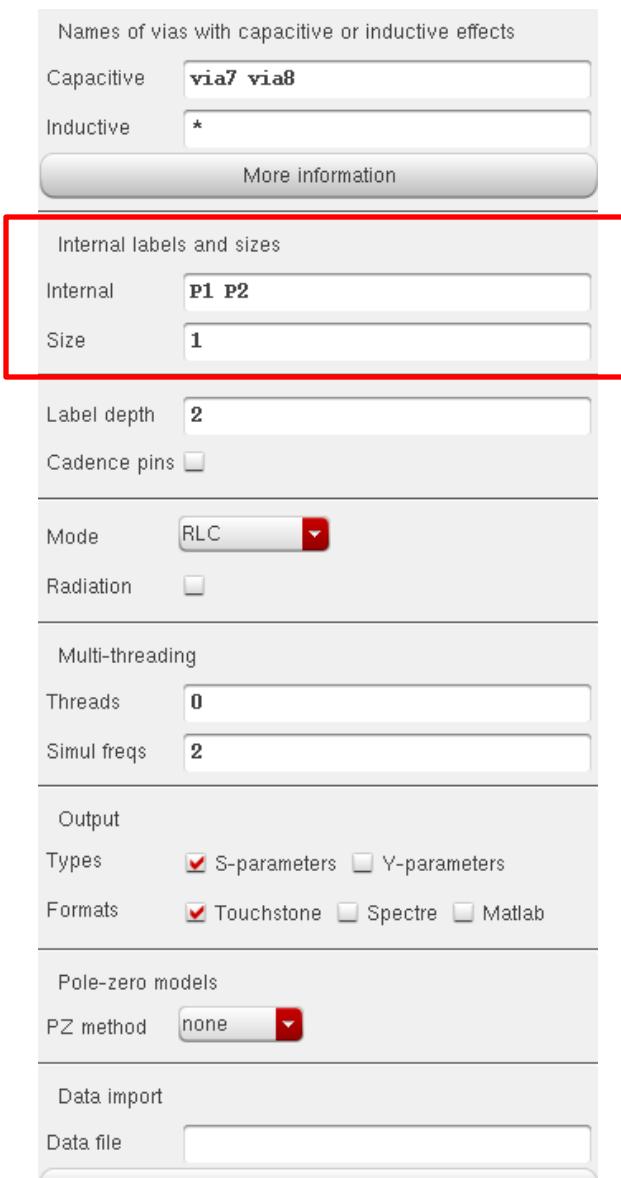
You can set the frequency range from DC (0) to any high frequency and provide the step size.
EMX is stable at DC.

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 "*".

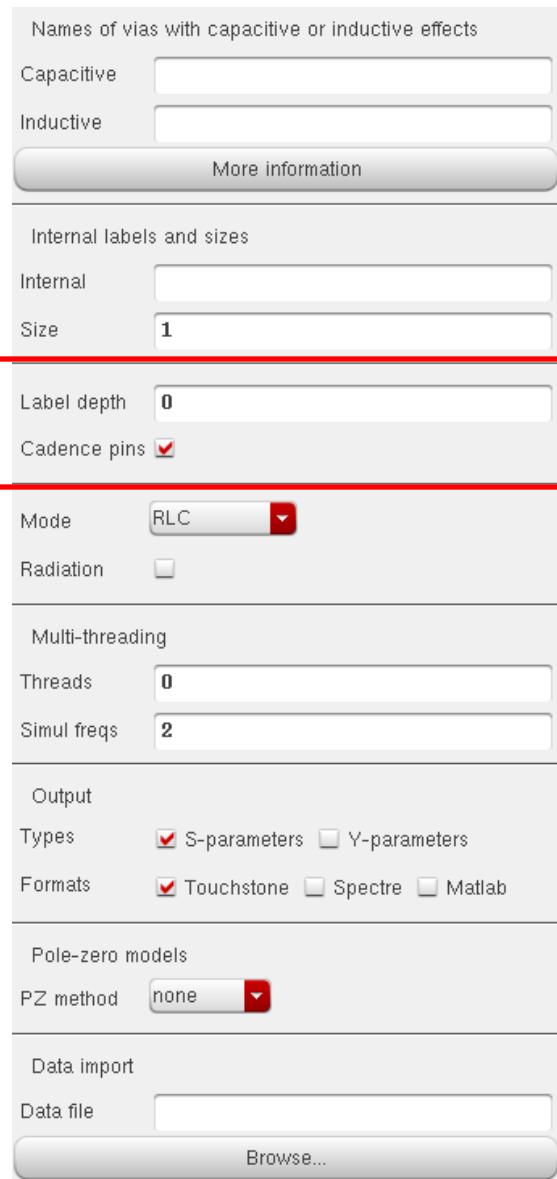
Advanced options



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

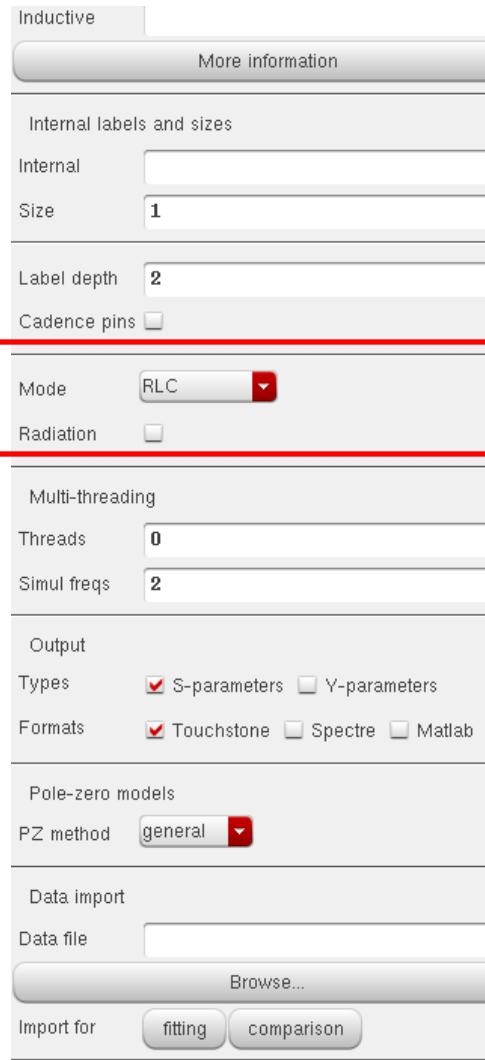
Advanced options



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.

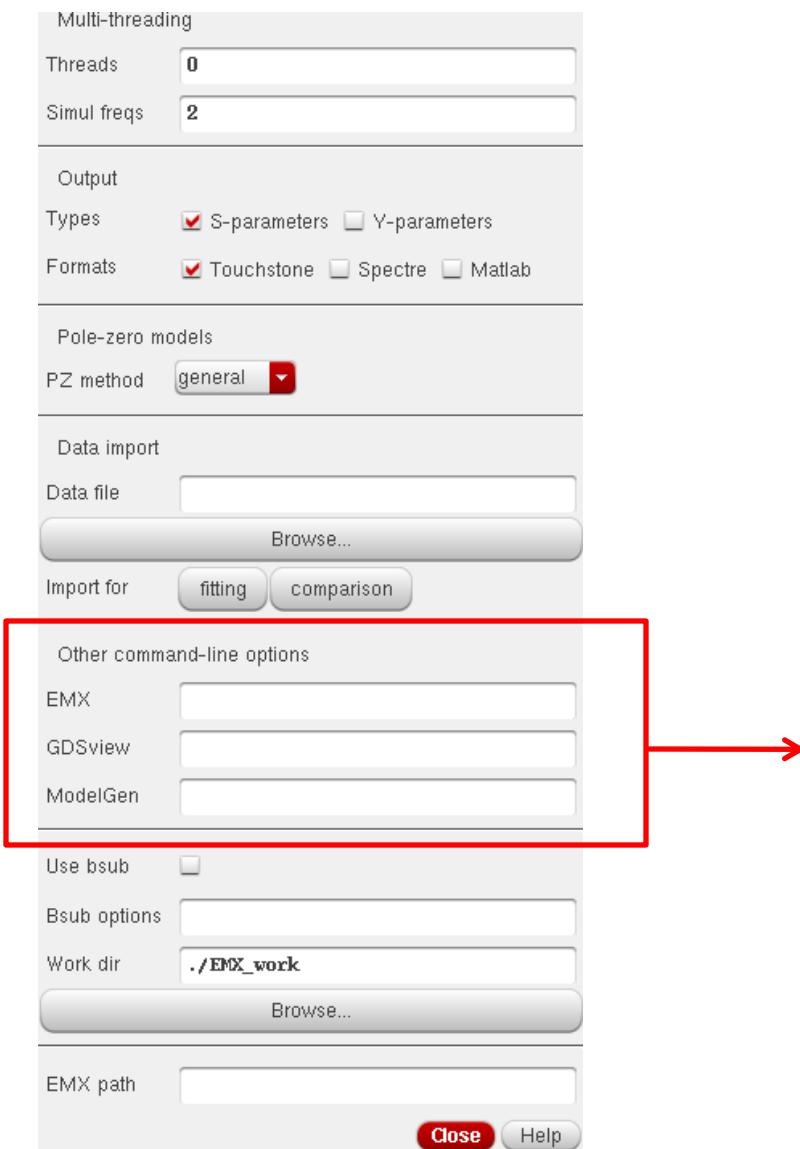
Cadence pins can be used to specify labels for ports. Needed for Black-box LVS.

Advanced options



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

Advanced options

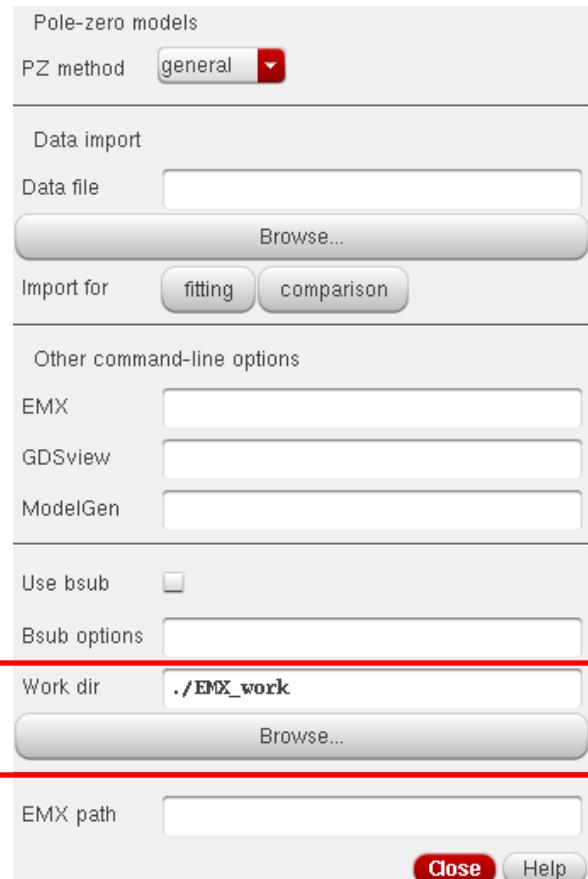


Most commands from the EMX manual or gdsview manual can be used here. Read the EMX user manual for details.

For example,

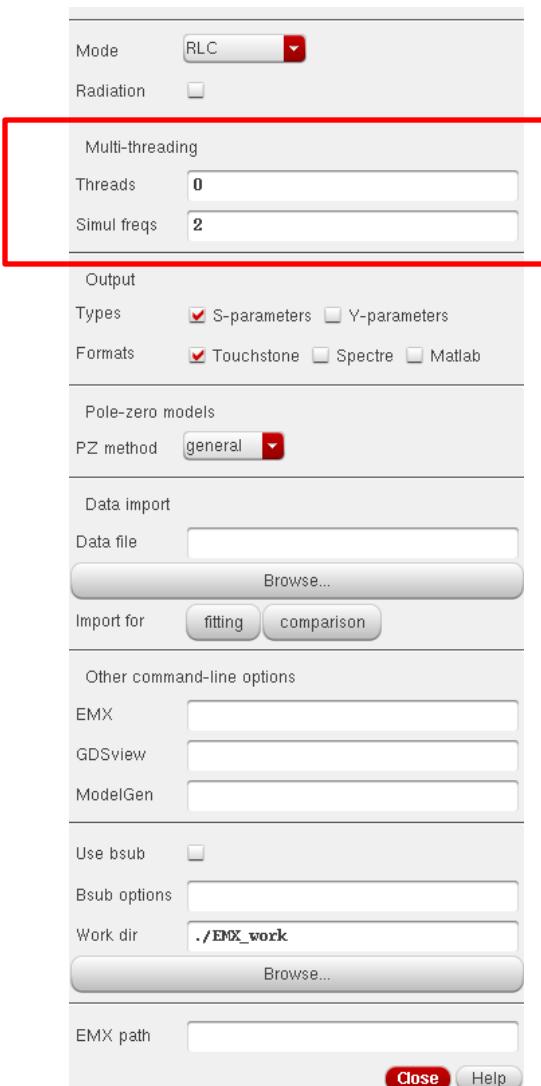
“**--matlab-mesh**” to generate a mesh
 “**--scaling=0.9**” to run EMX on a half-node.
 “**--temperature=100**” to run EMX at 100 degrees

Advanced options



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

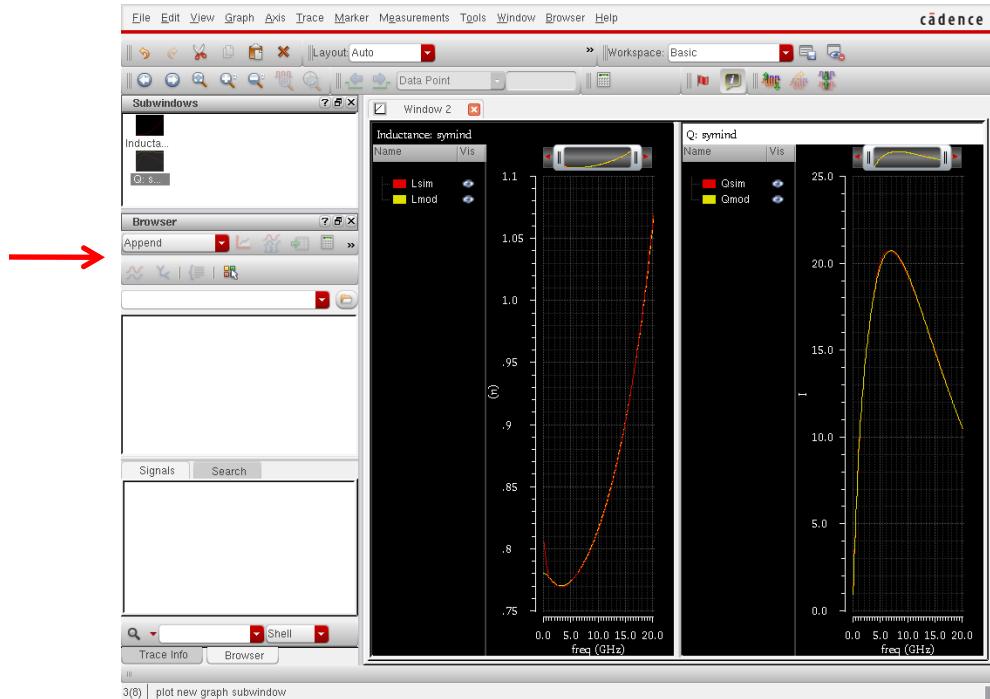
Advanced options (multi-threading)



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

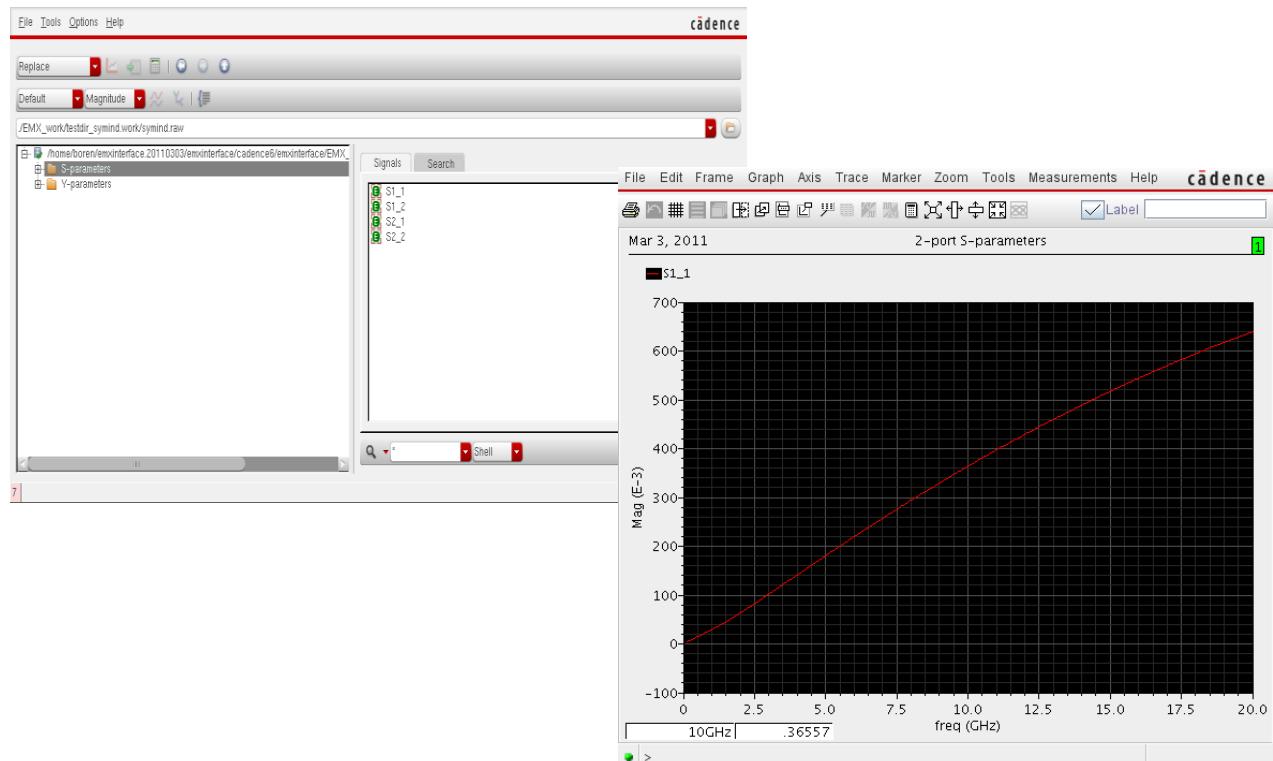
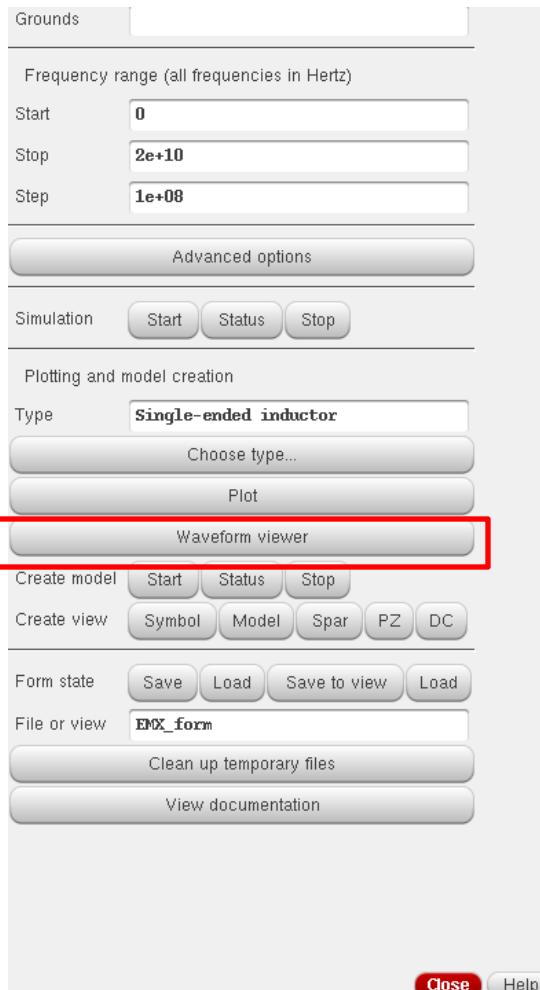
The number of threads can be specified (if you input 0) then it determines the number of CPUs on the machine. The Simul frequencies can be used to do multiple frequencies at a time. Typically you can use "Threads=0, Simul freqs=2" for optimum speed.

Fitting and comparison



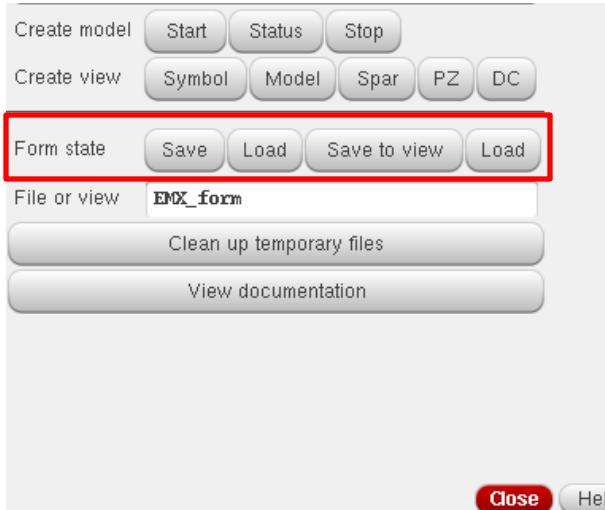
Simulations can be compared with other data files for either comparison purposes or for building a models. For example simulation can be compared to measurements.

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



```

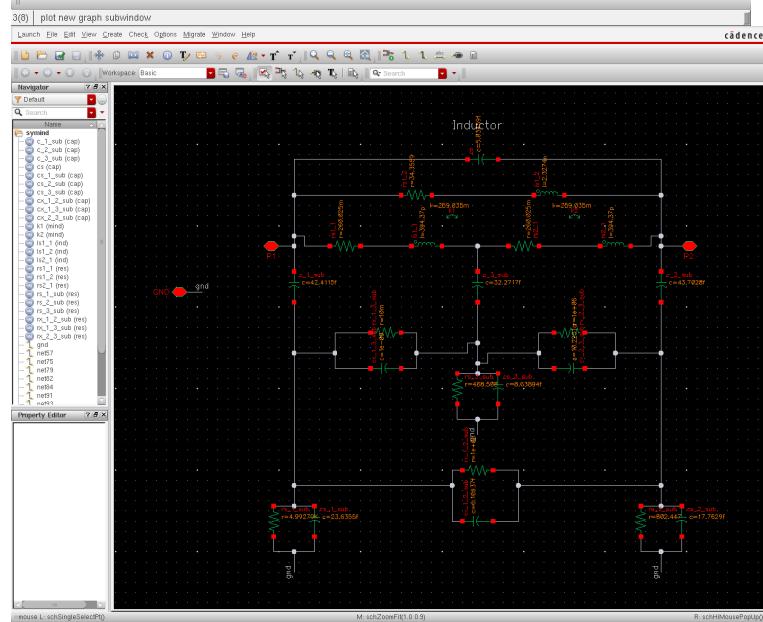
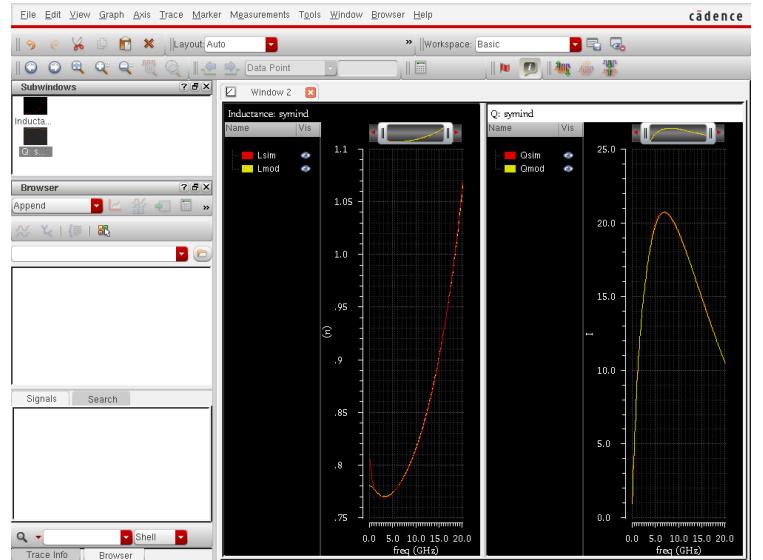
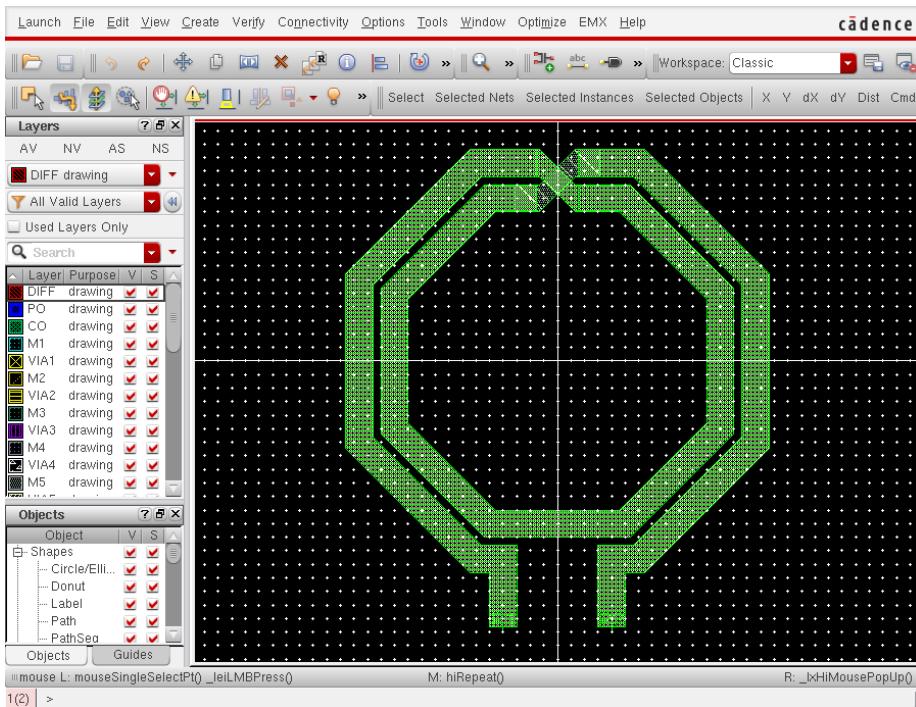
"Process" ".../..../processes/generic
"Edge_mesh" 1.0
"Thickness" 1.0
"Via_merge" 0.5
"_3D_metals" "*"
"Signals" "P1 P2"
"Grounds" ""
"Start" 1e+08
"Stop" 2e+10
"Step" 1e+08
>Type" "Differential inductor"
"State_file" "EMX_form.txt"

"Capacitive" ""
"Inductive" ""
"Internal" ""
"Size" 1.0
"Label_depth" 2
"Label_pins" nil
"Mode" "RLC"
"Radiation" nil
"Threads" 1
"Simul_freqs" 1
"Types" (t nil)
"Formats" (t nil nil)
>Data_file" ""
"EMX" ""
"GDS_view" ""
"ModelGen" ""
"Work_dir" "./EMX_work"
"EMX_path" ""

```

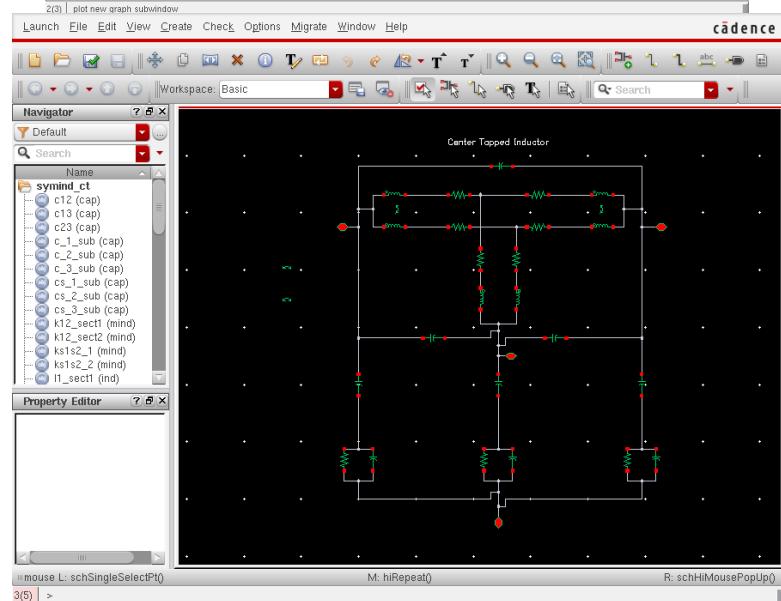
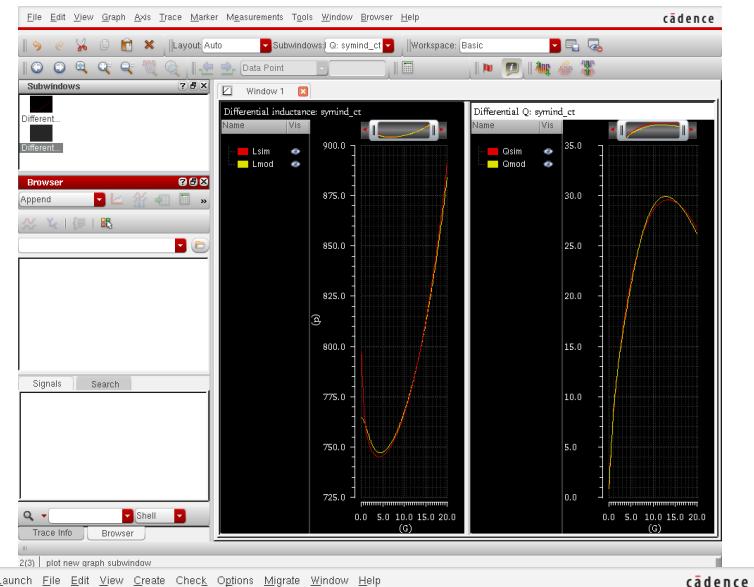
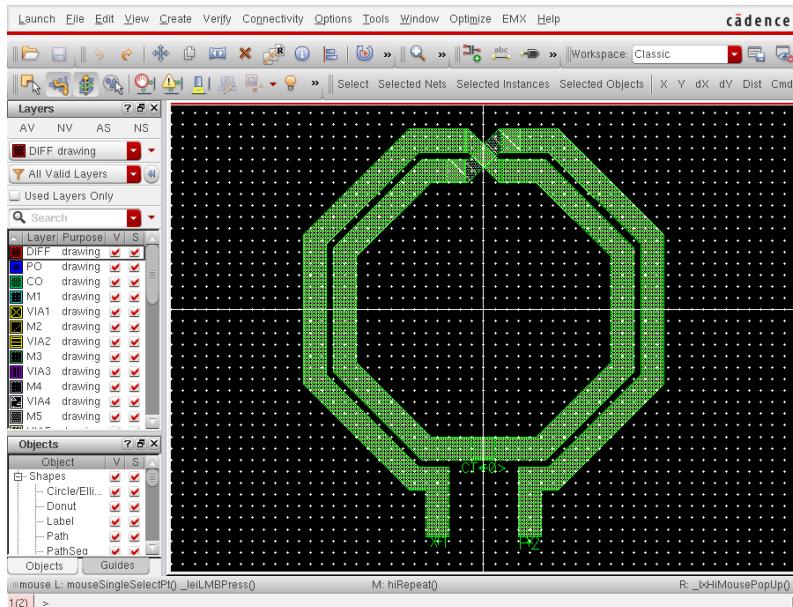
The simulation settings can be saved to a text file which can be reloaded later using load. The form states for these examples are in the directory “states” and need to be copied to the working directory. The state can be stored in the cell view.

Summary of examples



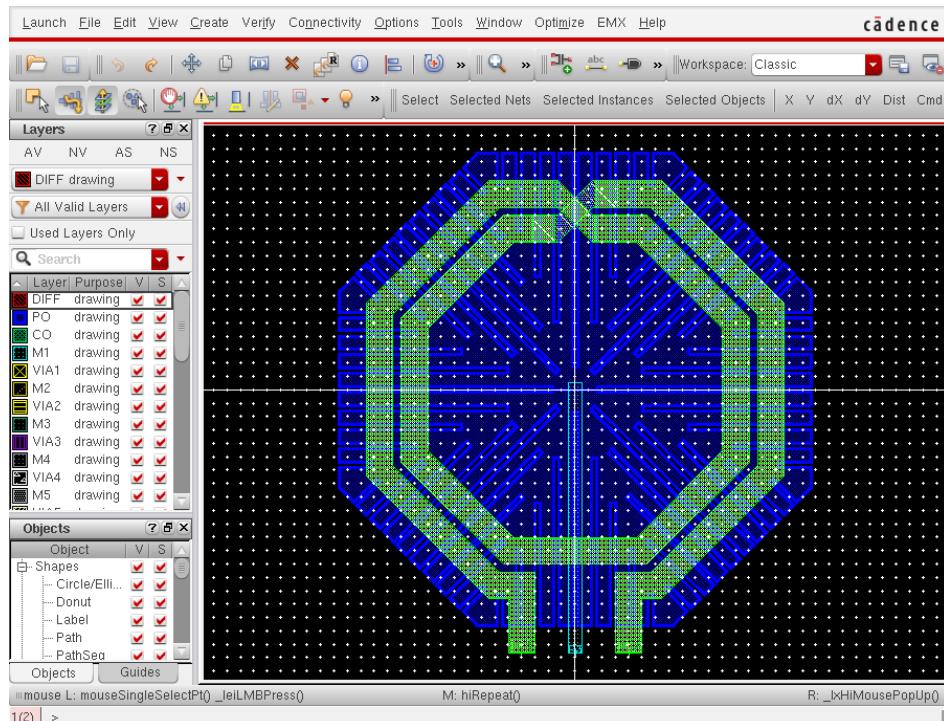
2 port inductor
(single-ended)

Summary of examples

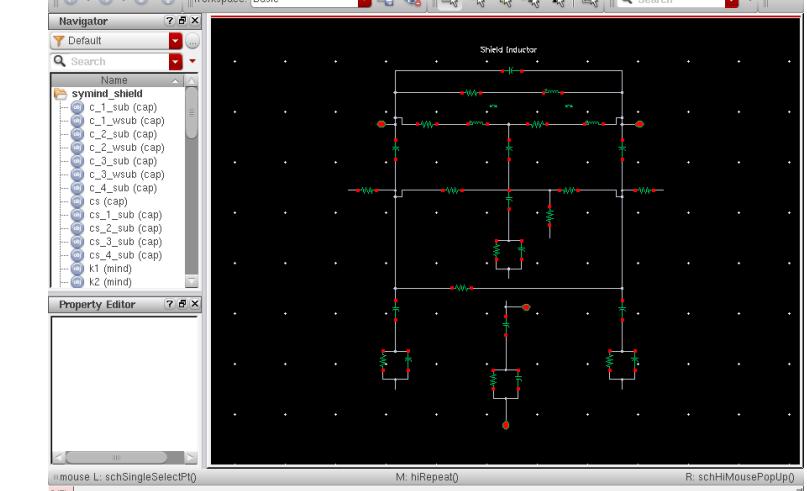
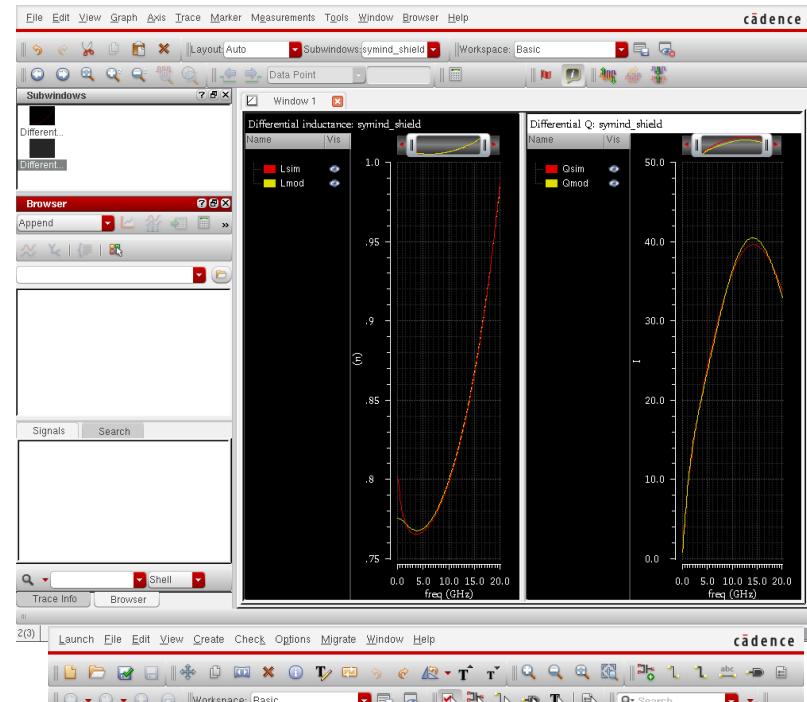


Center-tapped
inductor
(differential)

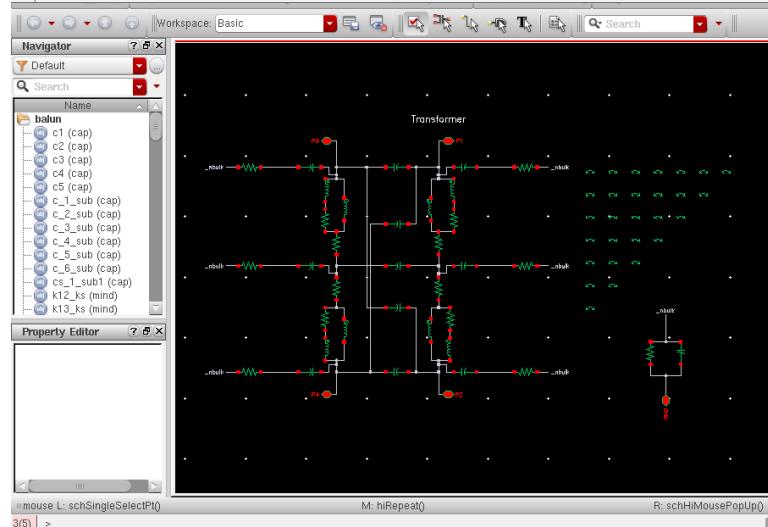
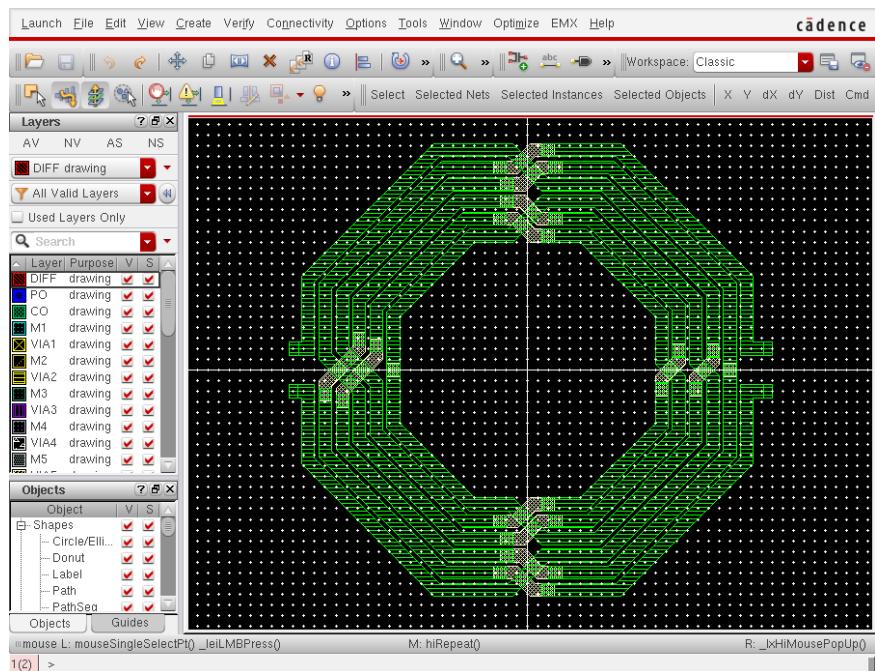
Summary of examples



Inductor with shield
(single-ended)

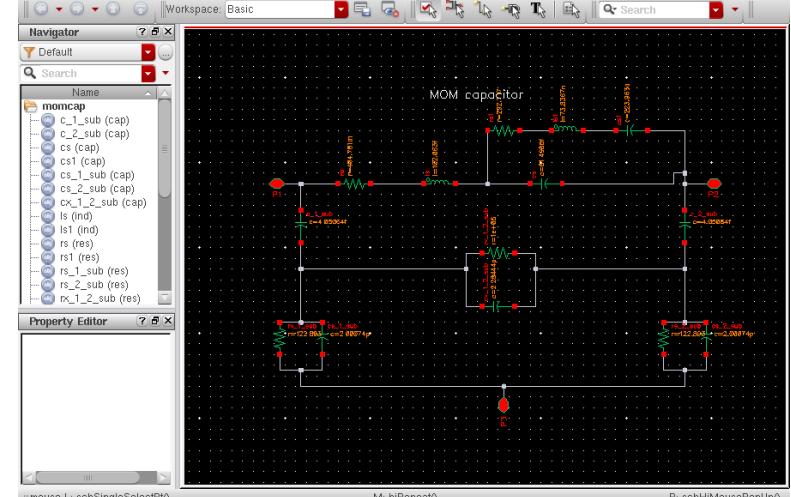
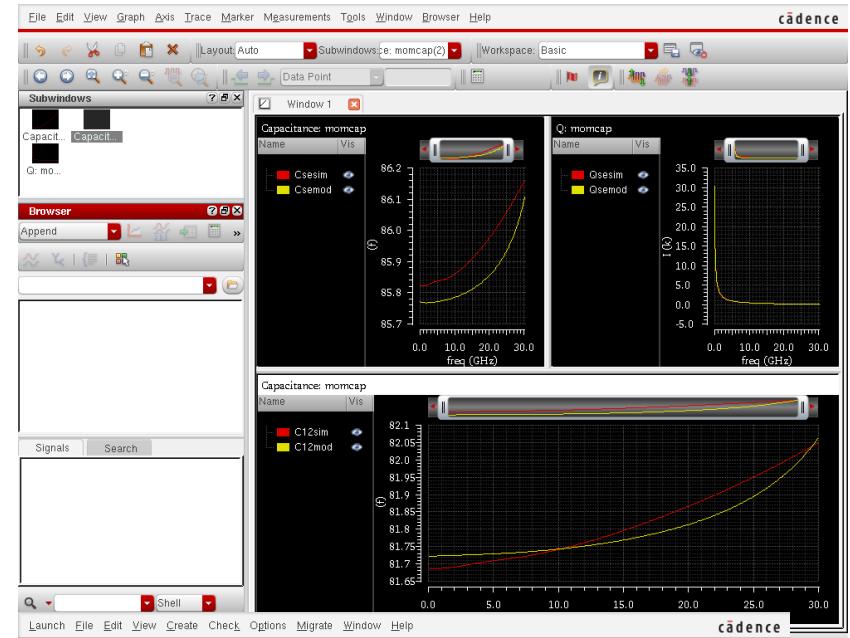
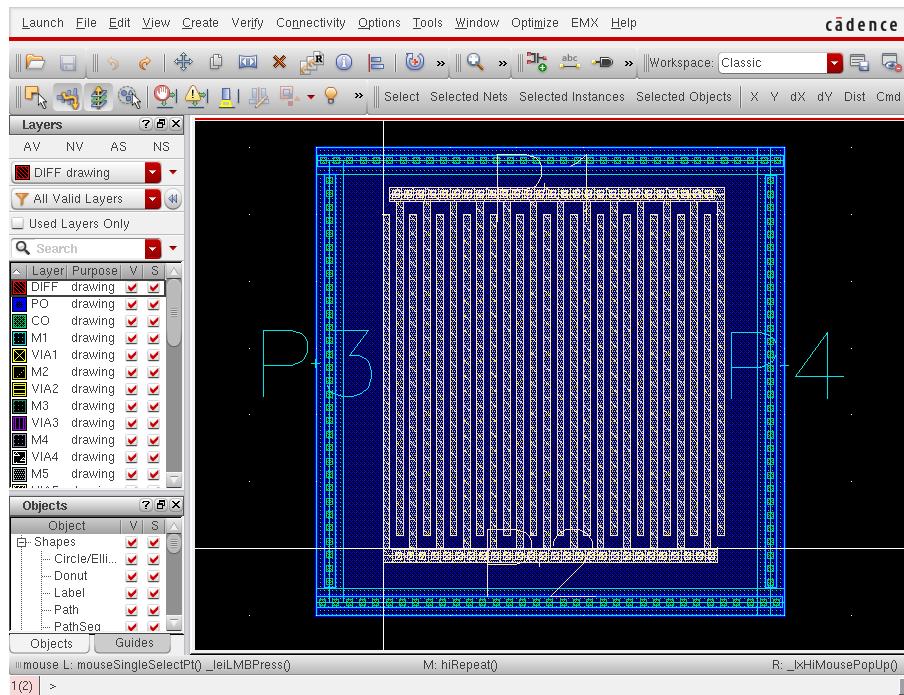


Summary of examples



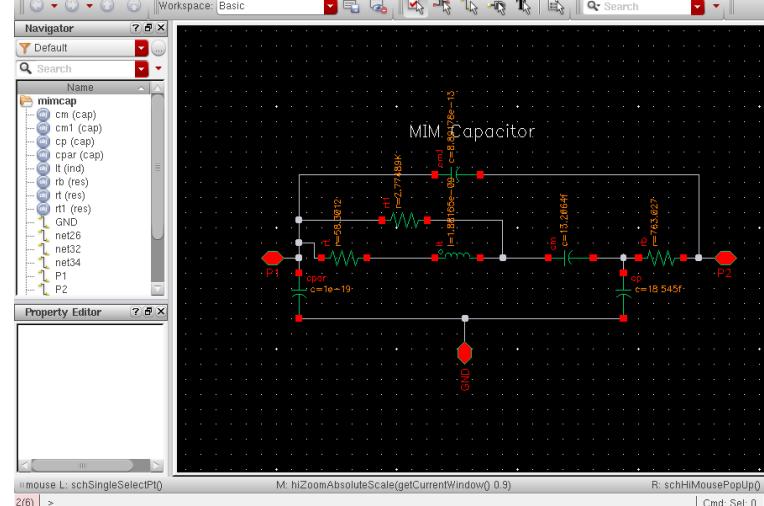
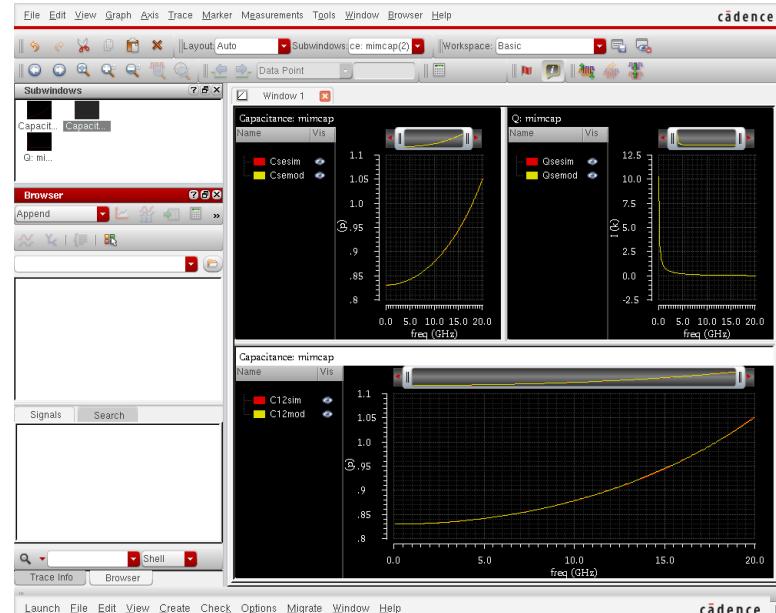
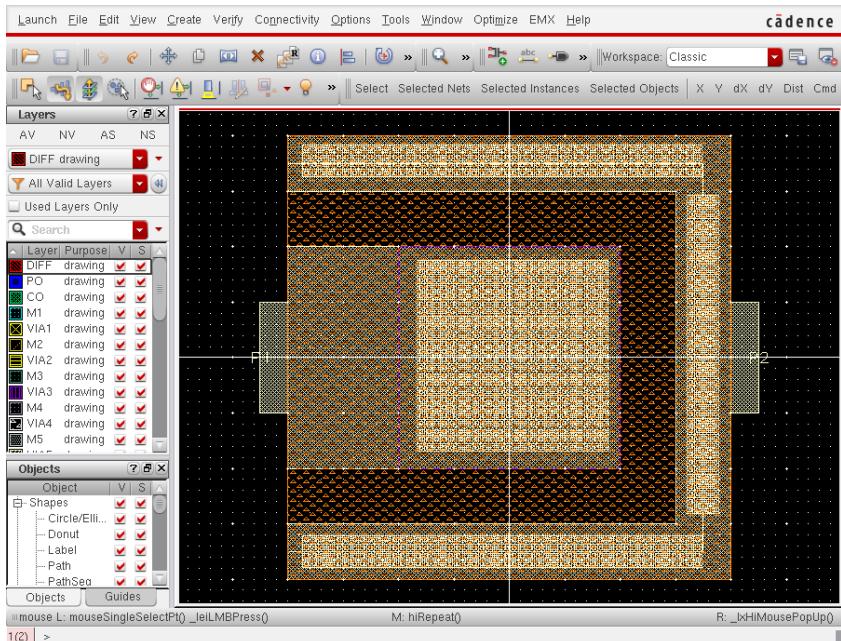
4 port transformer

Summary of examples



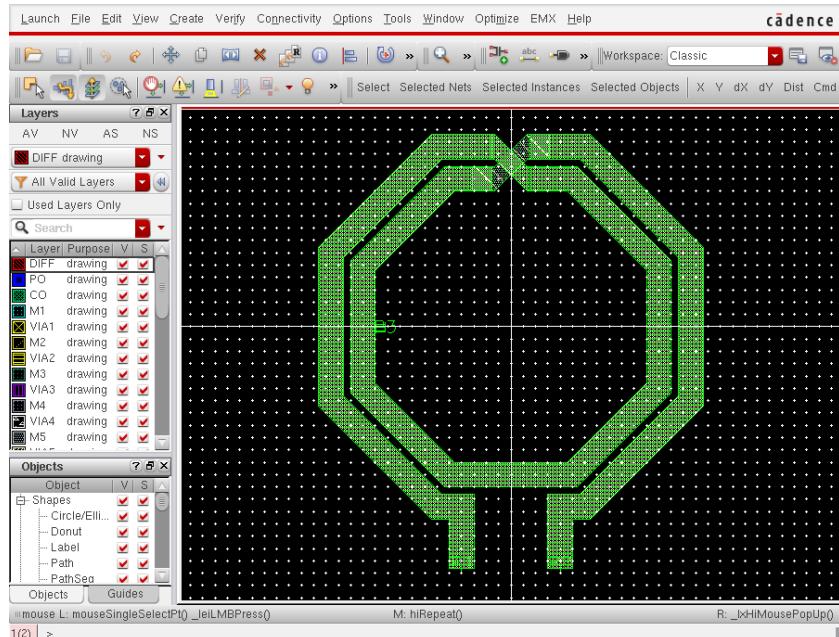
MOM capacitor

Summary of examples

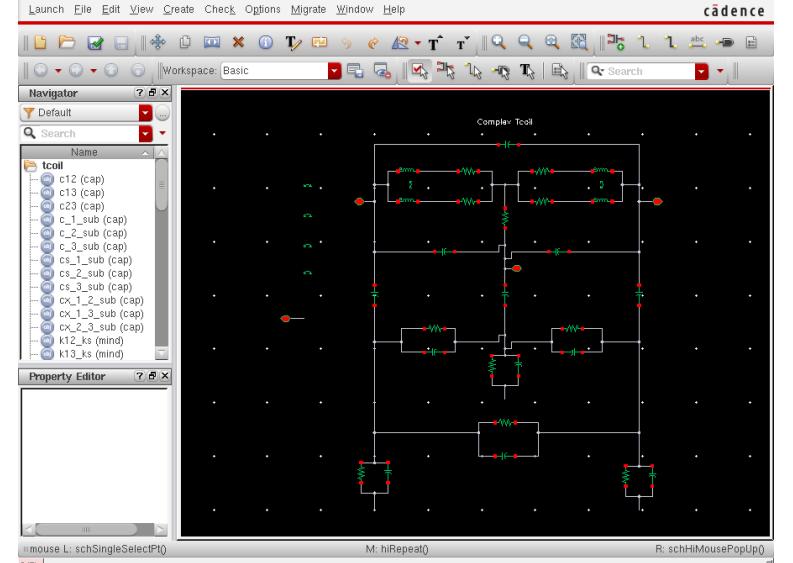
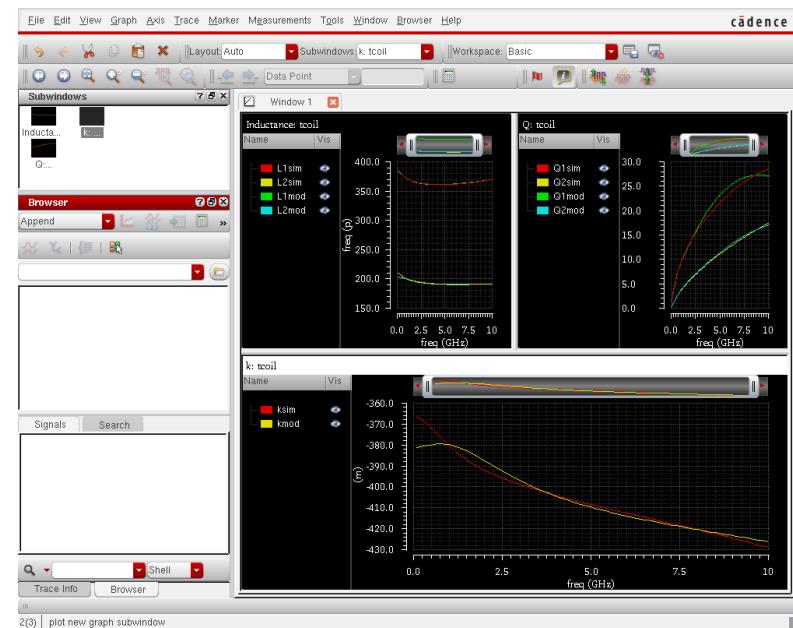


MIM capacitor

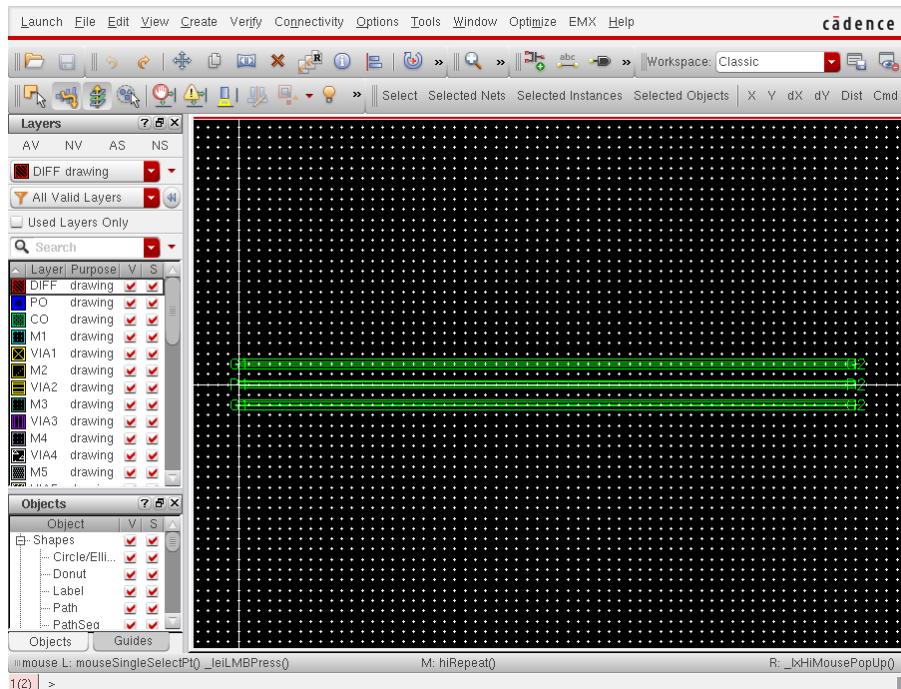
Summary of examples



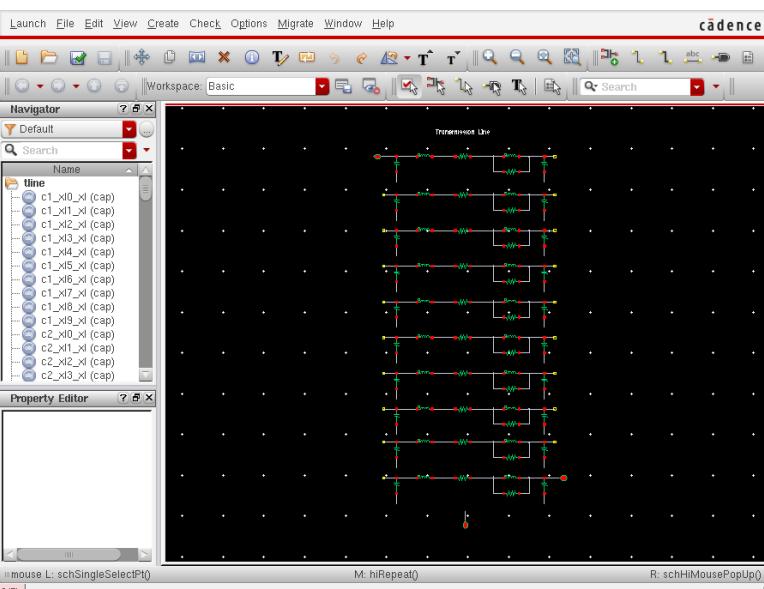
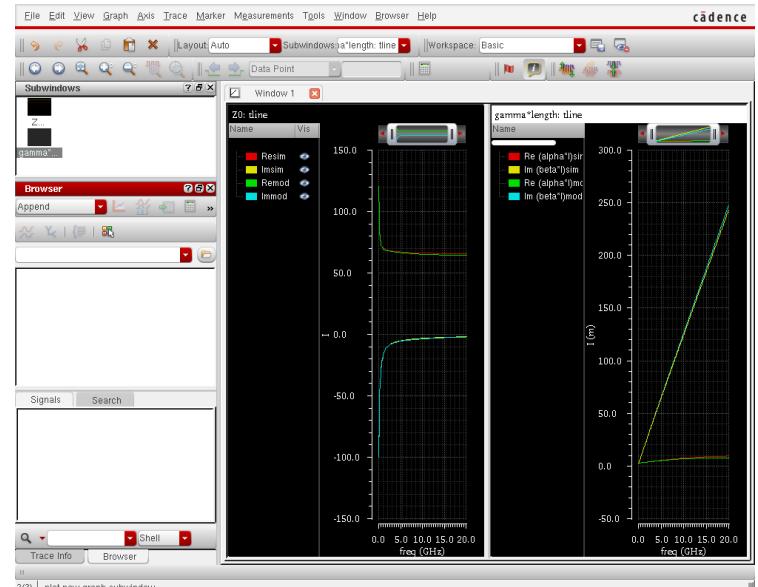
Tcoil



Summary of examples



Tline



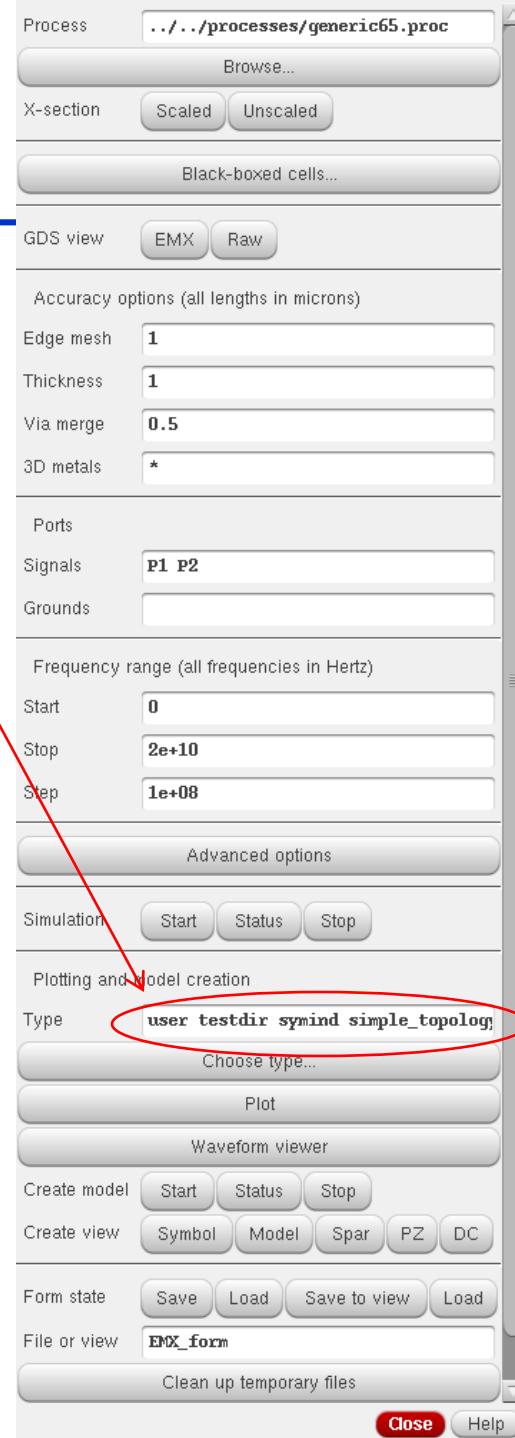
EMX Misc Features

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

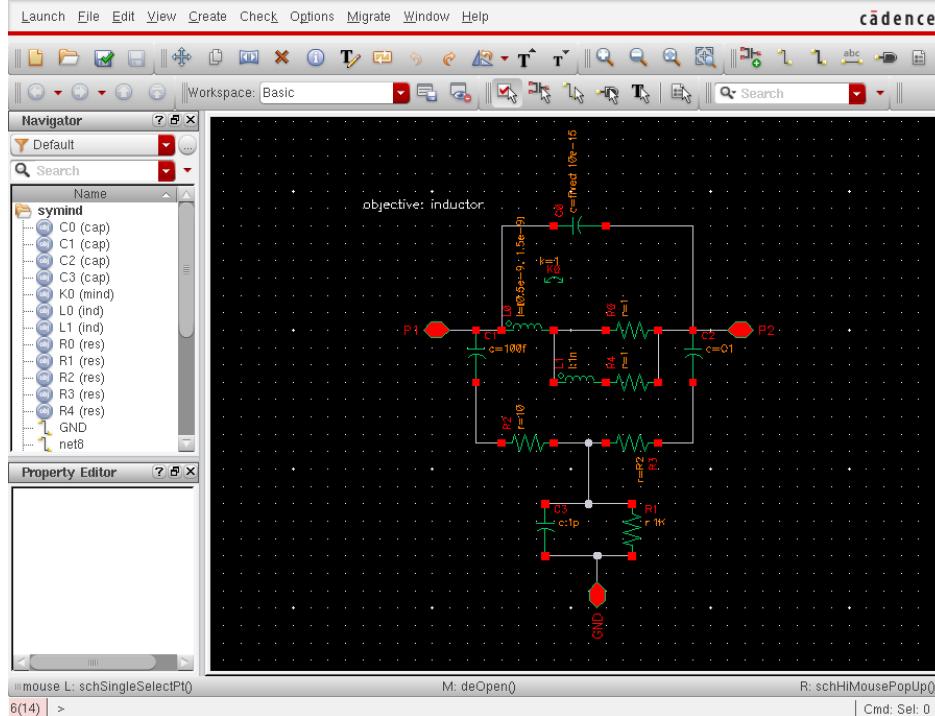
User defined model

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



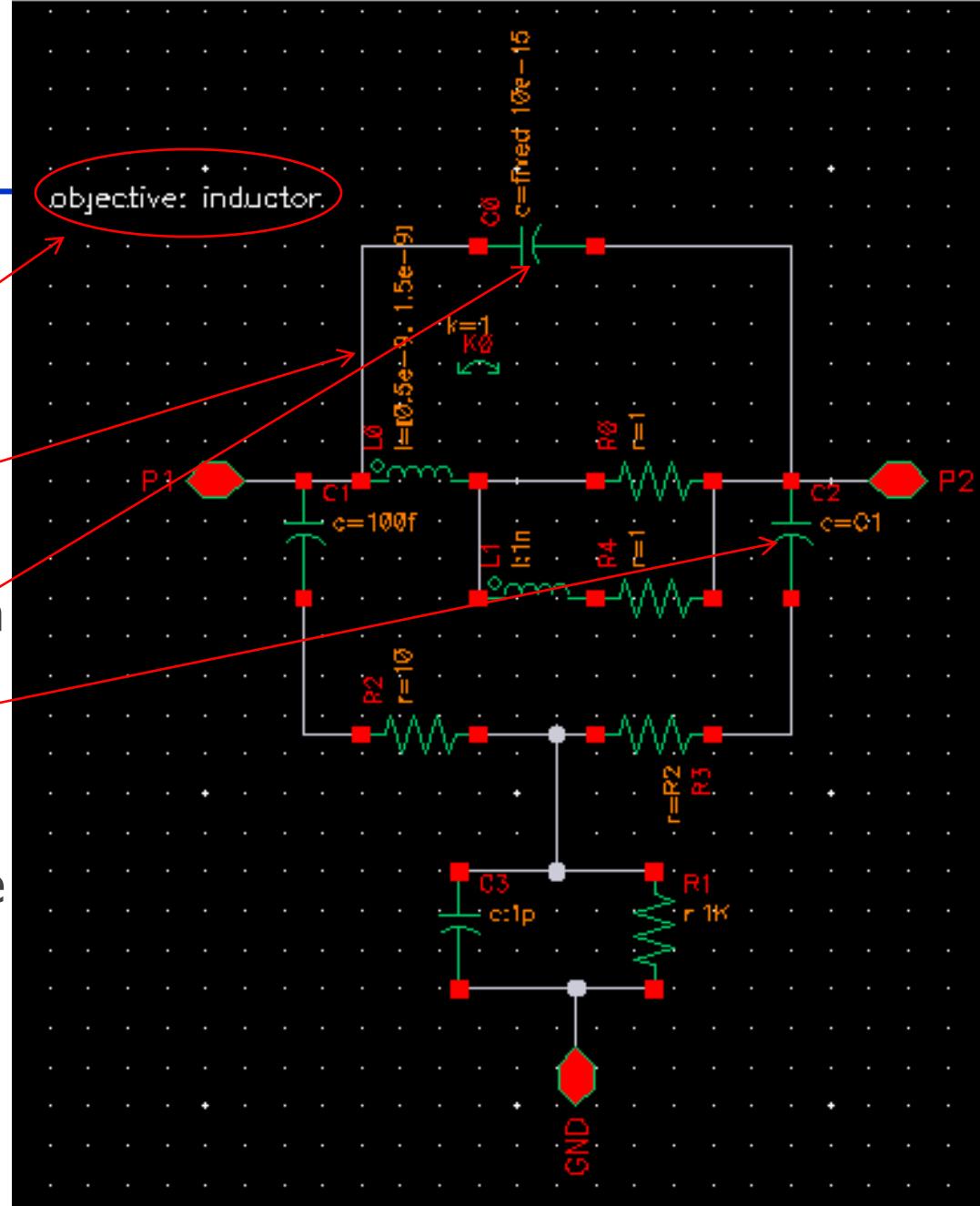
A generic schematic for a simple inductor

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



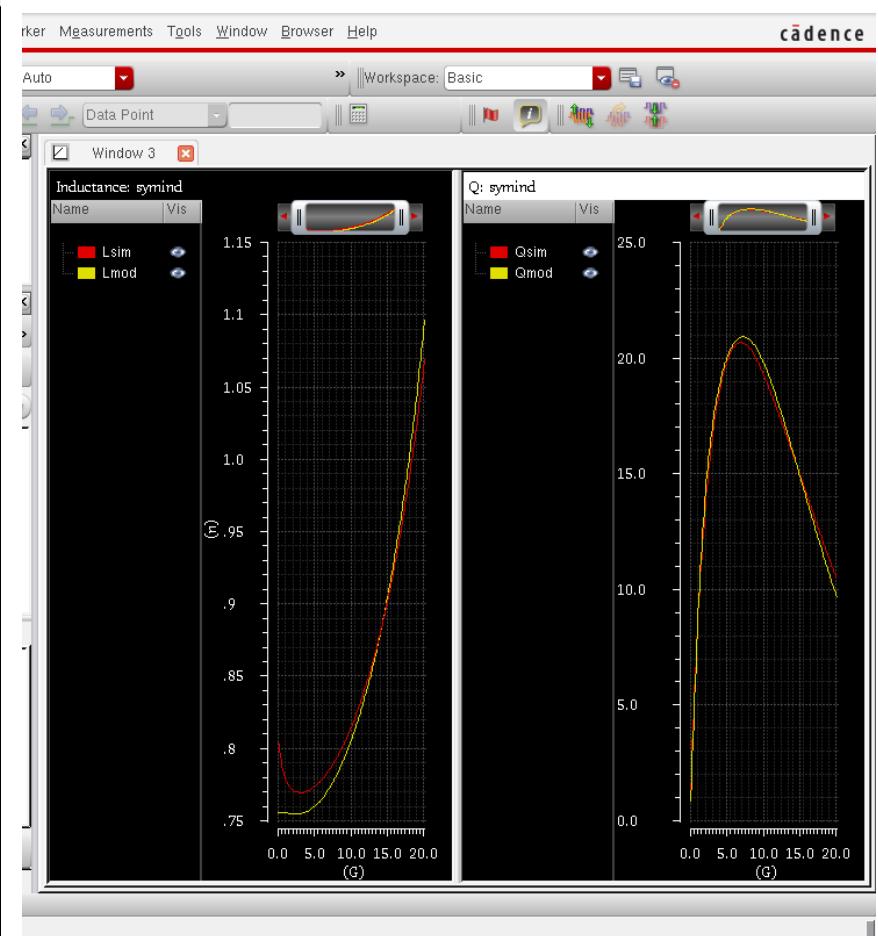
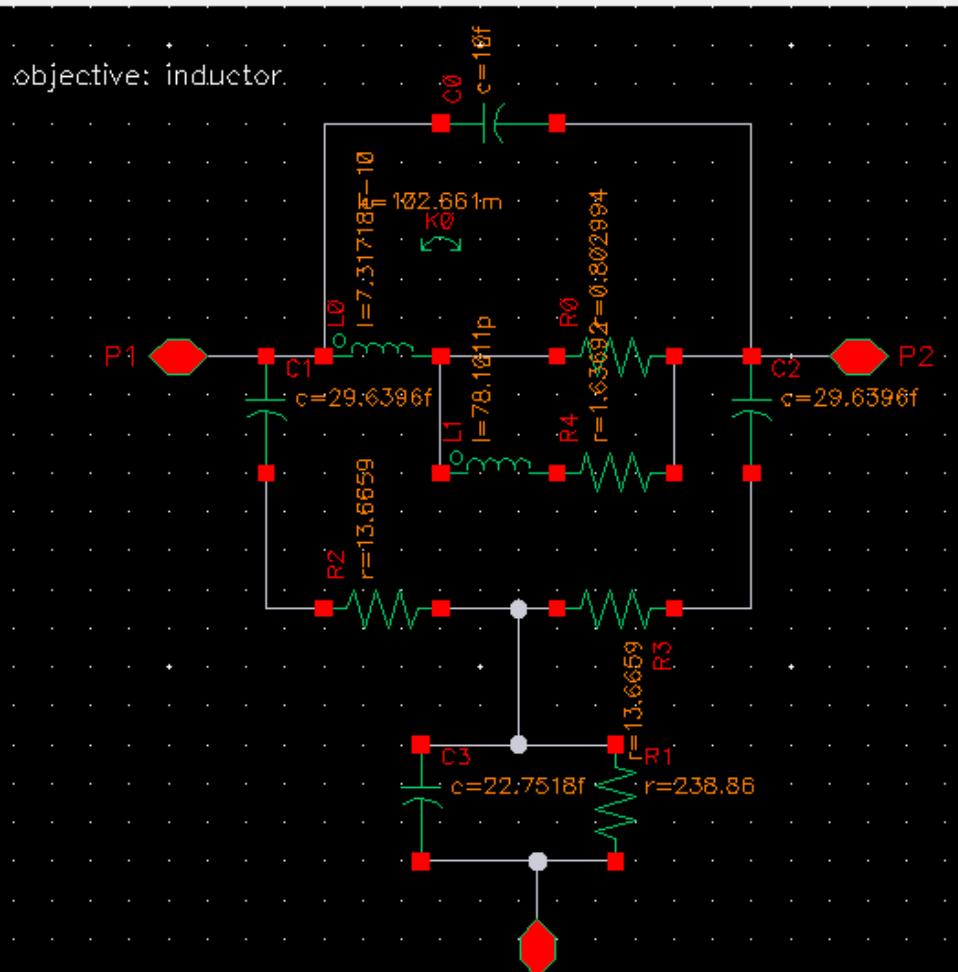
Constraints

- 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



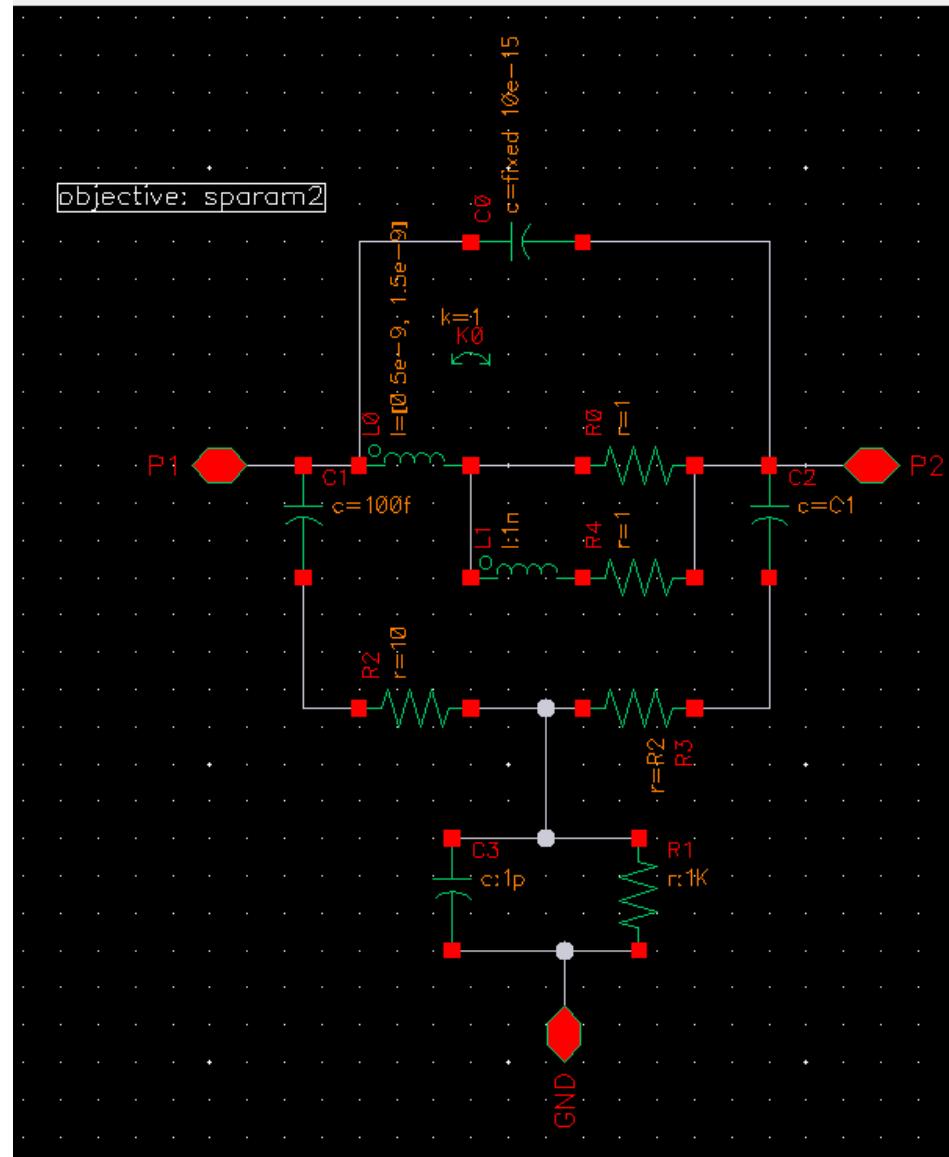
Resulting model

- The final model will be generated using the constraints



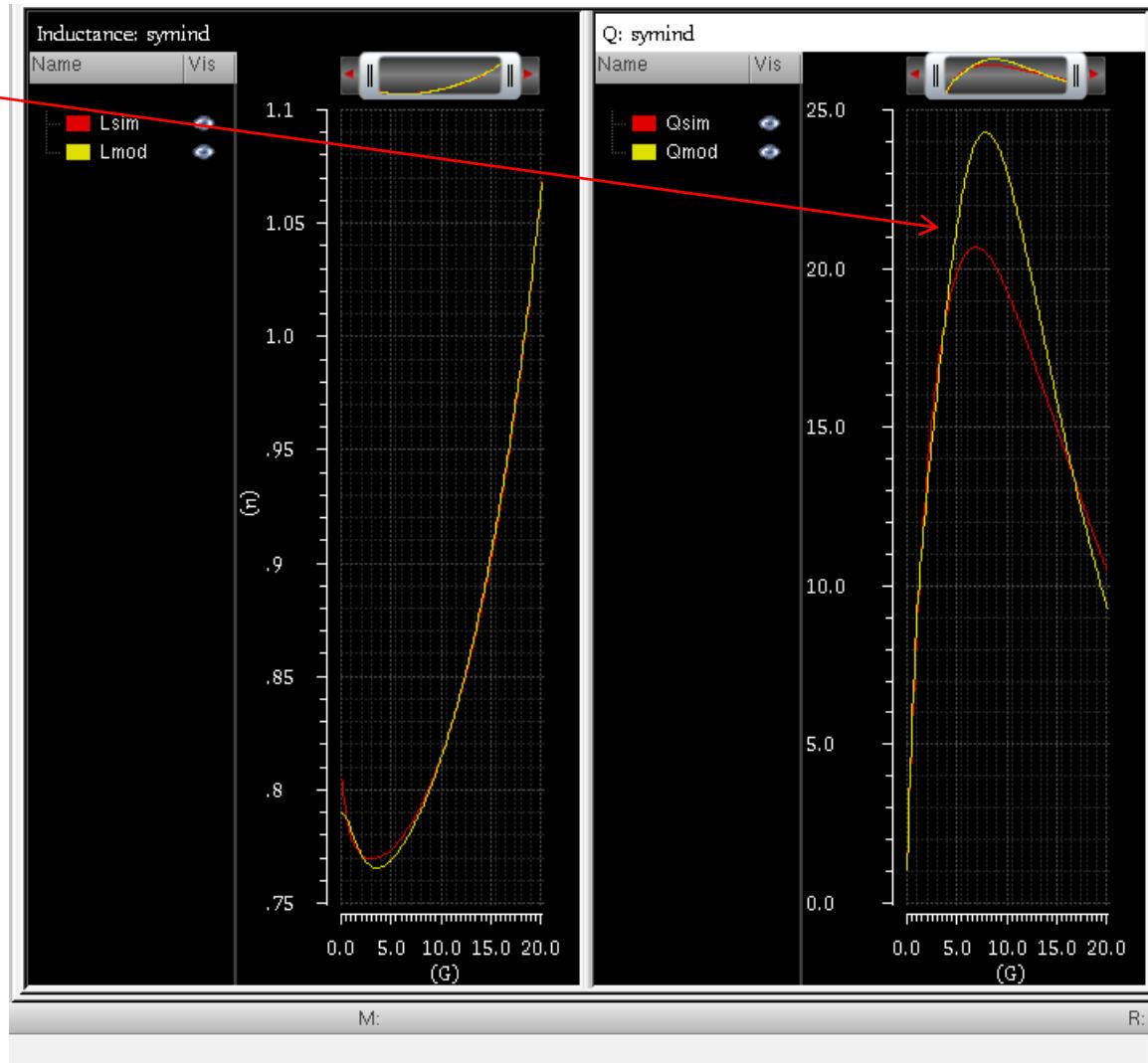
S-parameters objective function

- 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 not 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



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

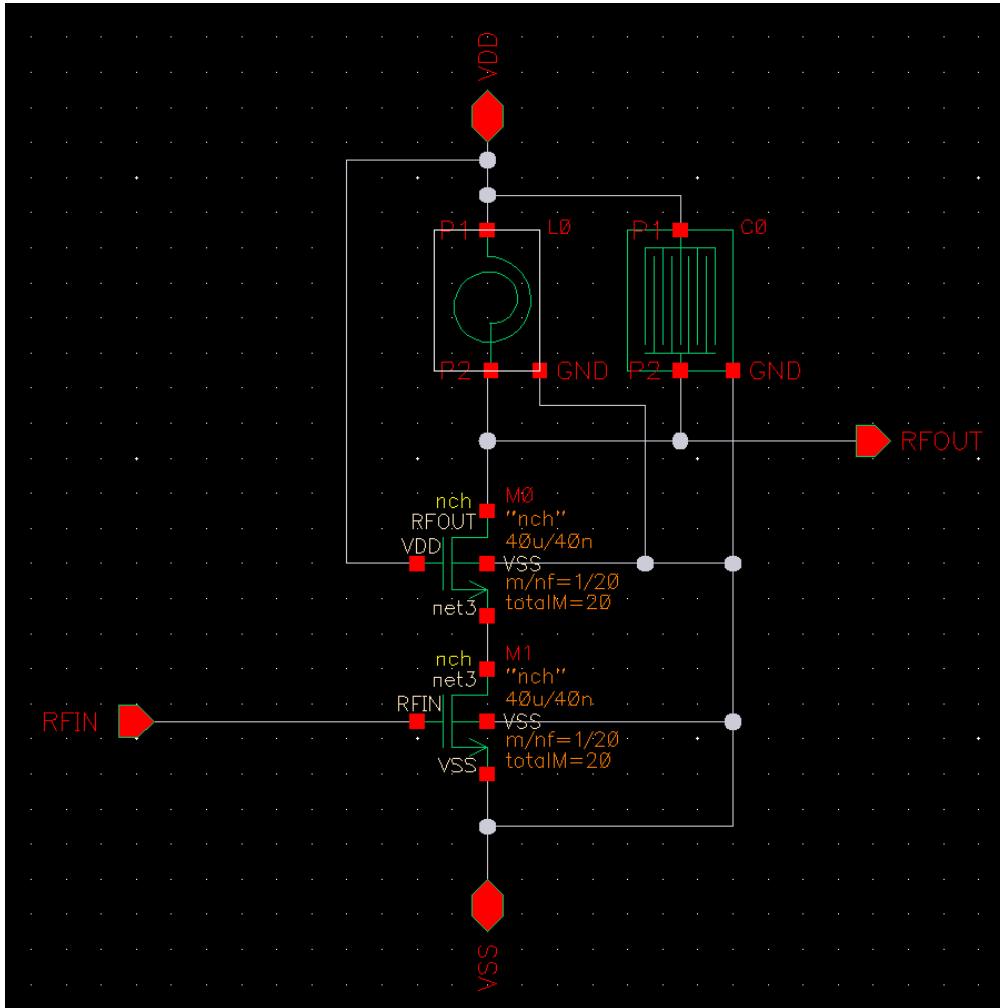
```
$ emx --version
EMX version 3.8+blackbox preview
Copyright (c) 2003 - 2014 Integrand Software, Inc.
Please report bugs to support@integrandsoftware.com
$ cat emxskill/emxconfig.il
...
; This option enables general state-space model creation. It requires
; one of the later versions of EMX (one that 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
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

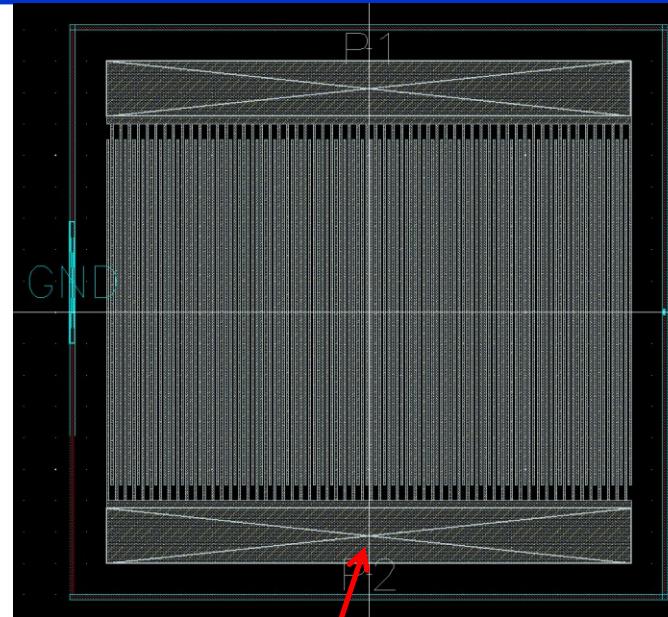
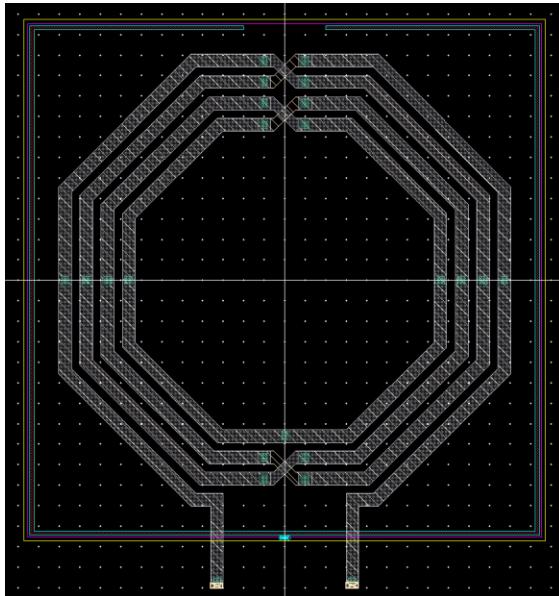
Example of amplifier design



amp2

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

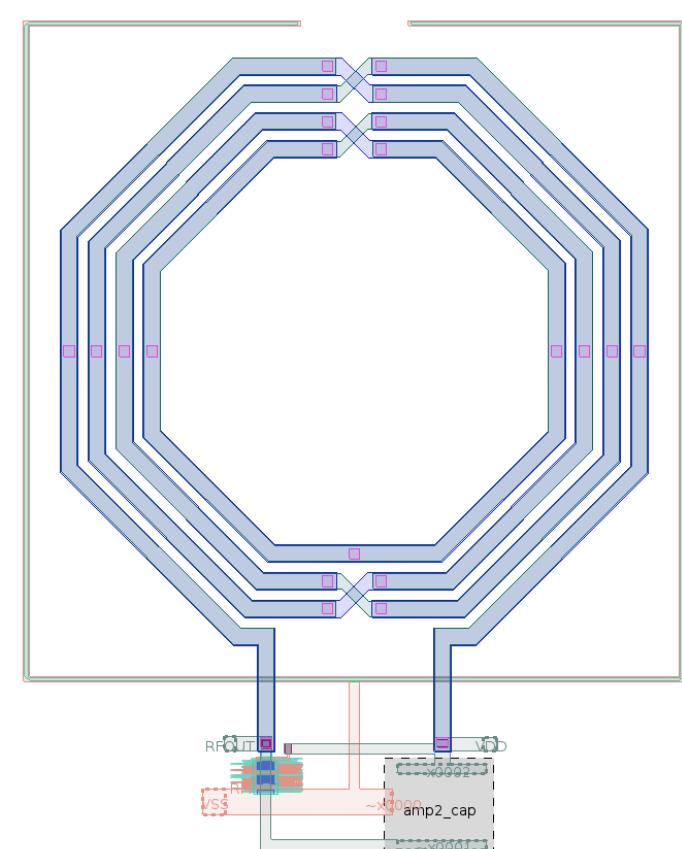
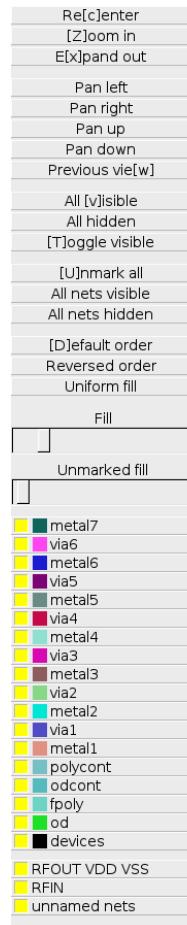
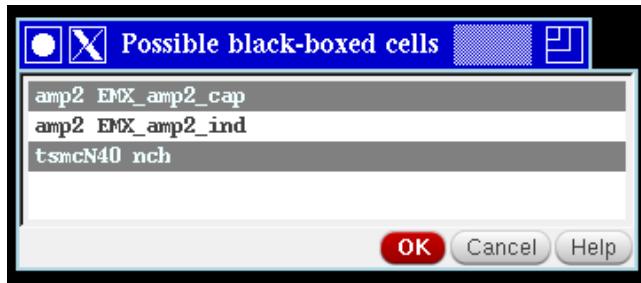
Inductor and MOM cap layout



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

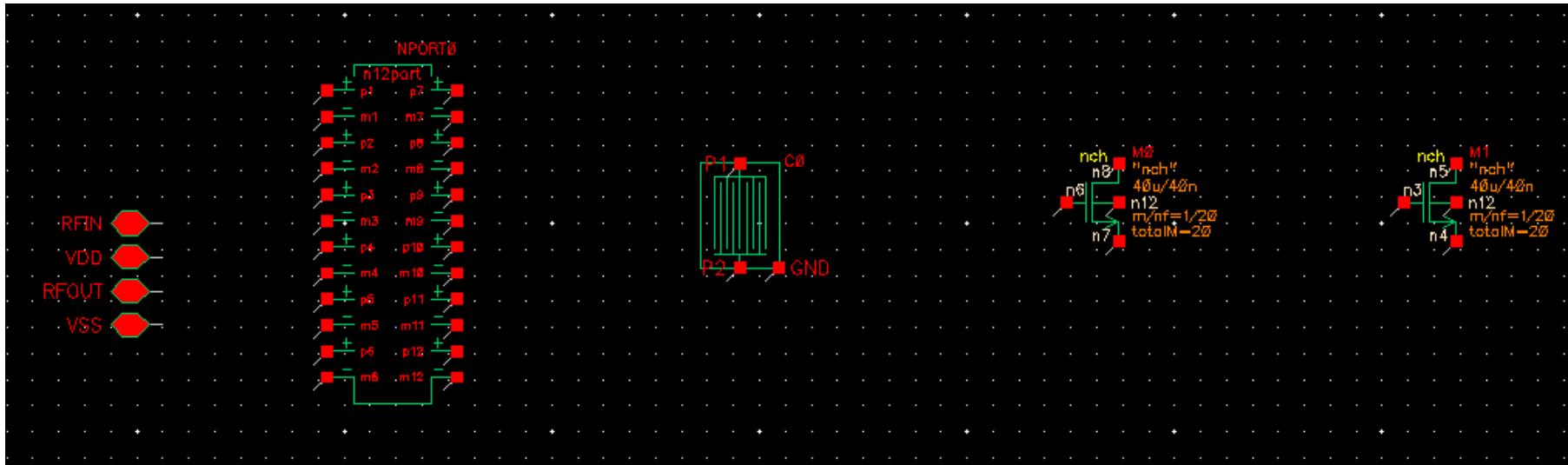
Selecting only caps and transistors as bboxes

Integrand
Software, Inc.



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

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

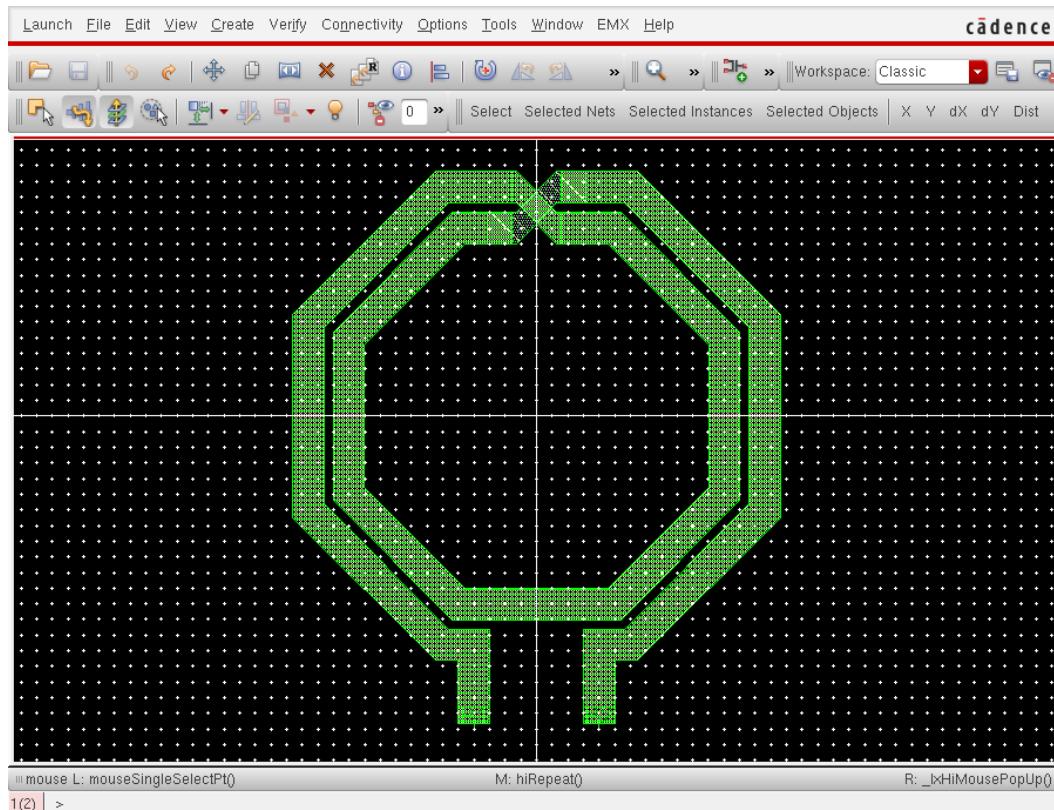
```
layer 0.03 4.5 # IMD1a
layer 0.13 3.0 # IMD1b
layer 0.05 5 # IMD1c
position -0.18
conductor 0.18 m1res*(1+0.00265*dtemp) -/+ 0.0001*shvar metal1
  bias m1bias
layer 0.03 4.0 # IMD1d
layer 0.1 3.0 # IMD2a
layer 0.25 3.0 # IMD2b
conducto 0.25 m27res*(1+0.003*dtemp) -/+ 0.0001*shvar metal2
  bias m2bias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



Process

X-section

Black-boxed cells...

GDS view

Accuracy options (all lengths in microns)

Edge mesh

Thickness

Via merge

3D metals

Ports

Signals

Grounds

Frequency range (all frequencies in Hertz)

Start

Stop

Step

Simulation

Plotting and model creation

Type

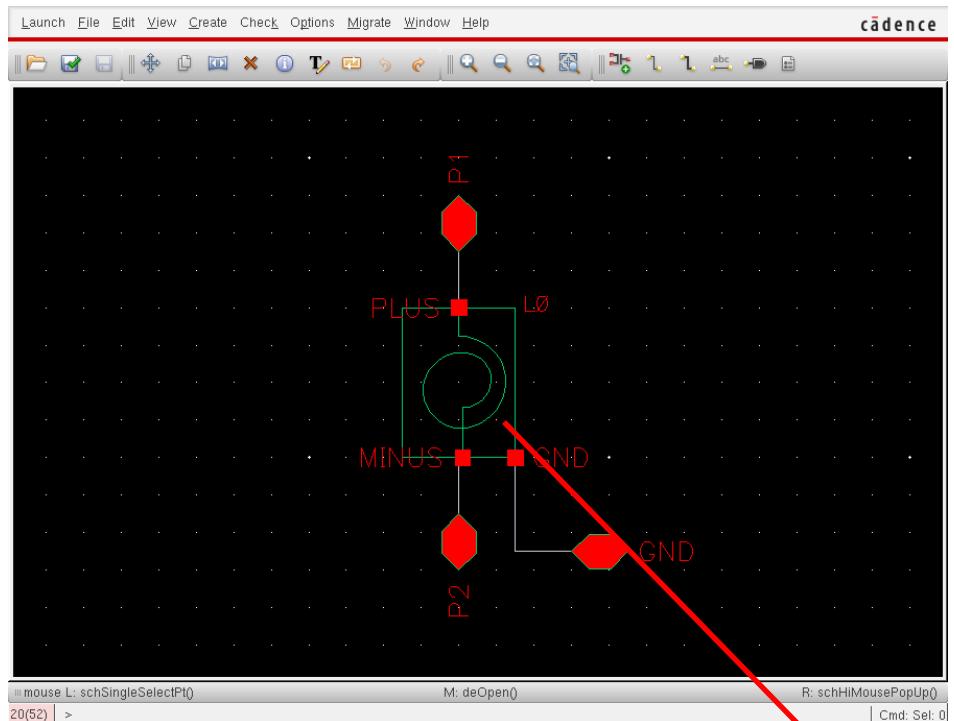
Create model

Create view

Form state

File or view

OPTION1



Setup tcr1 to 0.003 in
emxskill/emxconfig.il

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 ▾

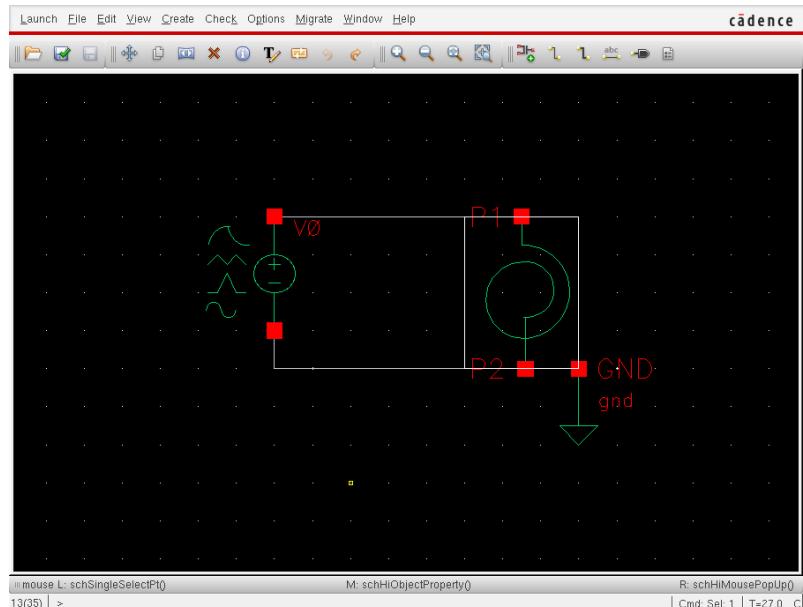
OPTION1



Create a testbench

Change the
temperature in ADE

Run the simulation



OPTION2

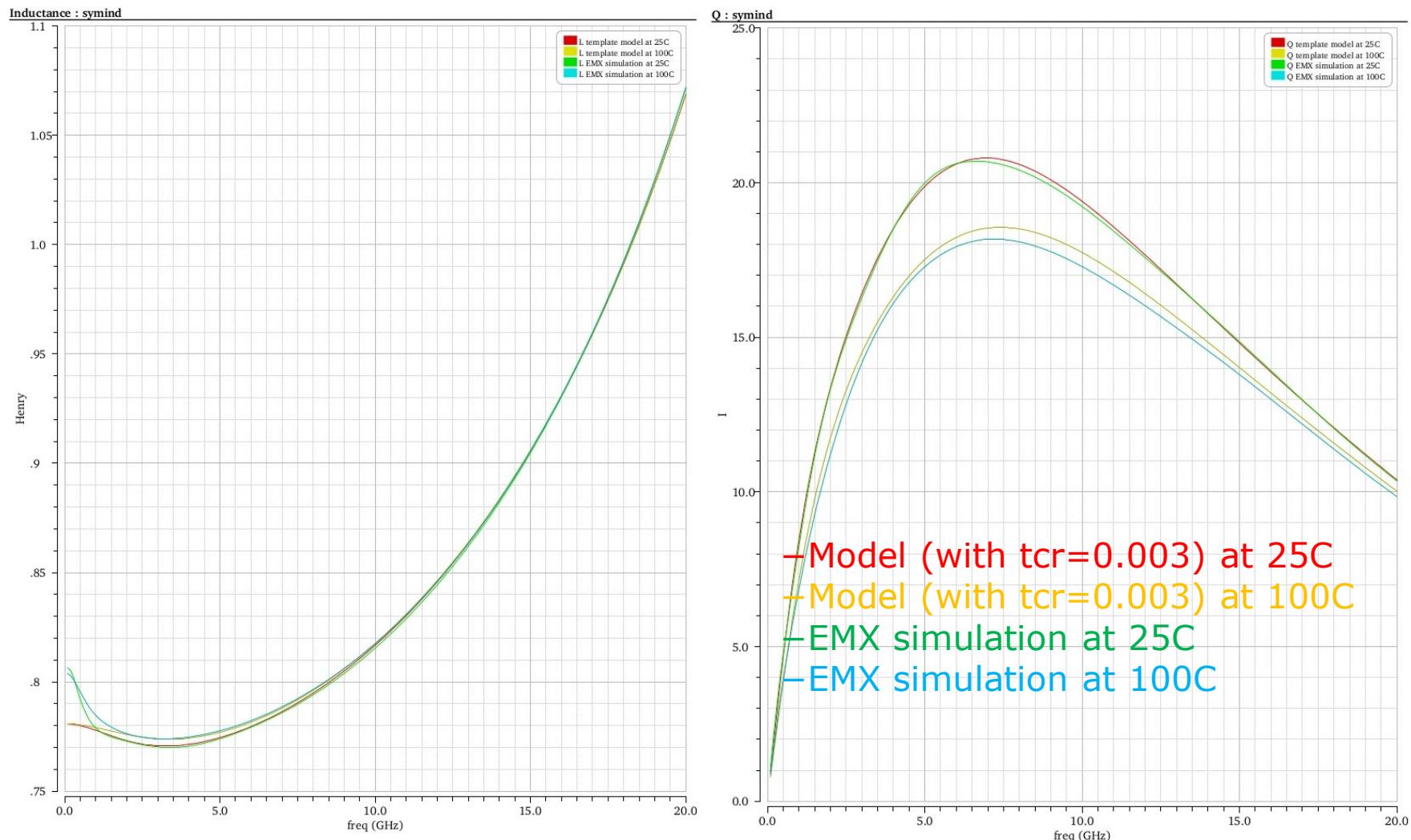
Run EMX at a different temperature

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

The screenshot shows the EMX software interface with several sections and buttons. A red arrow points from the 'Advanced options' button in the 'Frequency range' section to the 'Other command-line options' section. A red box highlights the 'EMX --temperature=100' entry in the 'Other command-line options' section.

Process: ../../processes/generic65.proc
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
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:
Import for: fitting comparison
Other command-line options
EMX --temperature=100
GDSview
ModelGen
Use bsub:
Bsub options:
Work dir: ./EMX_work
Browse...
EMX path:
Close Help

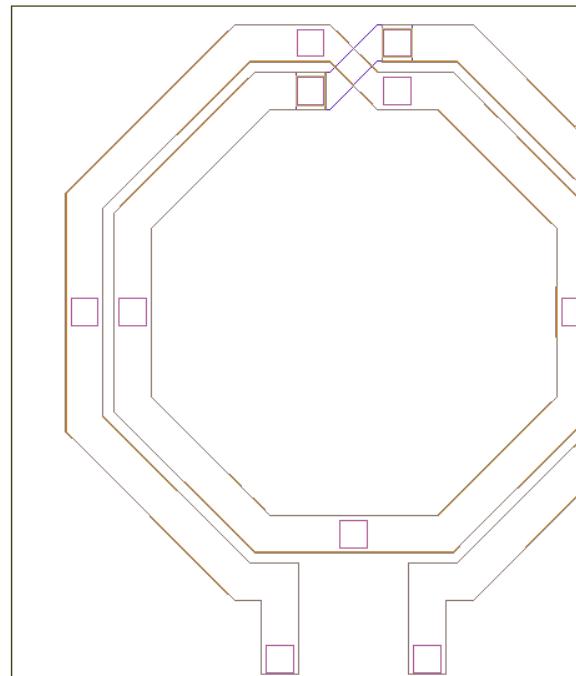
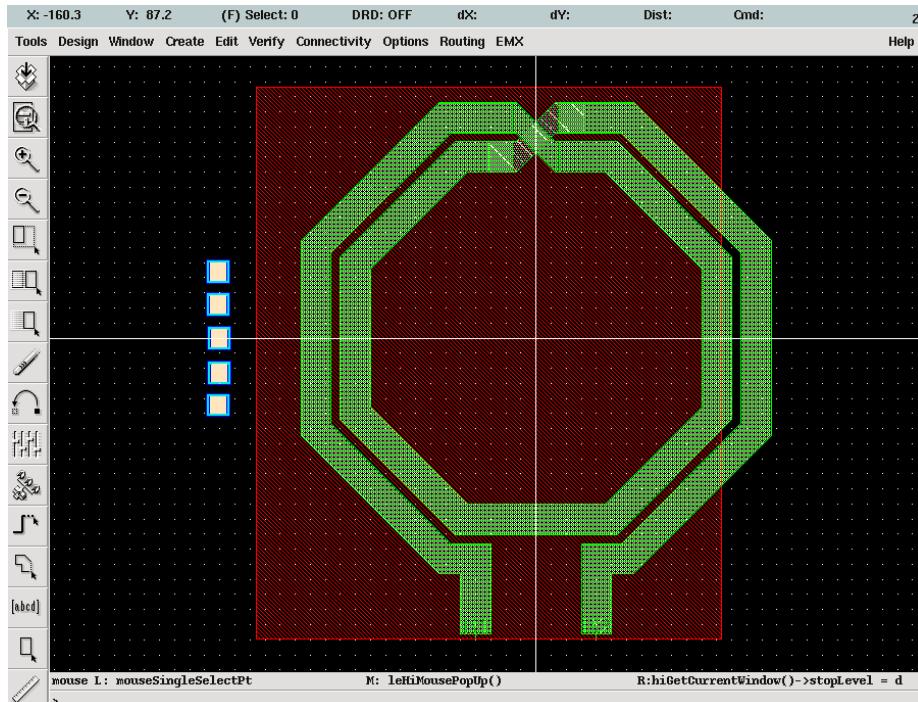
Comparison of OPTION1 and OPTION2



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

Mask simplification

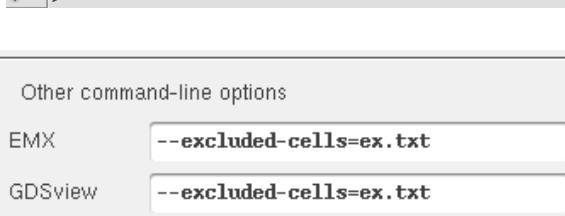
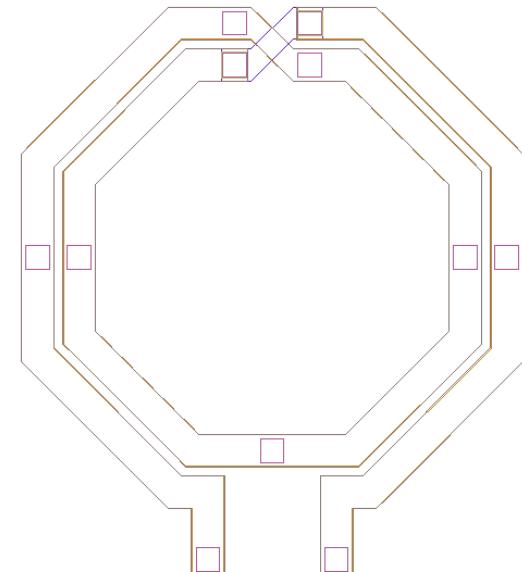
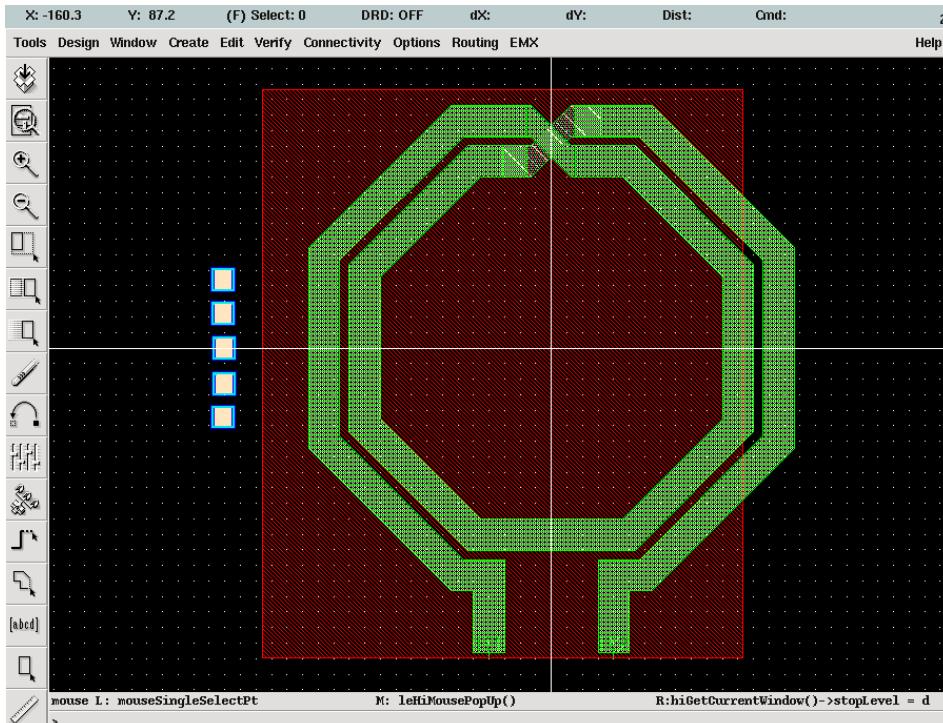
- The process file may have an **emxmask** statement that restricts the entire layout considered by EMX to a particular region.



```
assume microns
assume ohms/sq
assume ohms/via
emxmask 16t0
define diff = 16t0
define poly = 117t0
define metall = 131t0
define via = 16t0
define via1 = 16t0
```

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

Names of vias with capacitive or inductive effects

Capacitive

Inductive

[More information](#)

Internal labels and sizes

Internal

Size

Label depth

Cadence pins

Mode

Radiation

Multi-threading

Threads

Simul freqs

Output

Types S-parameters Y-parameters

Formats Touchstone Spectre Matlab

Pole-zero models

PZ method

Data import

Data file

[Browse...](#)

Import for

Other command-line options

EMX

GDSview

ModelGen

Use bsub

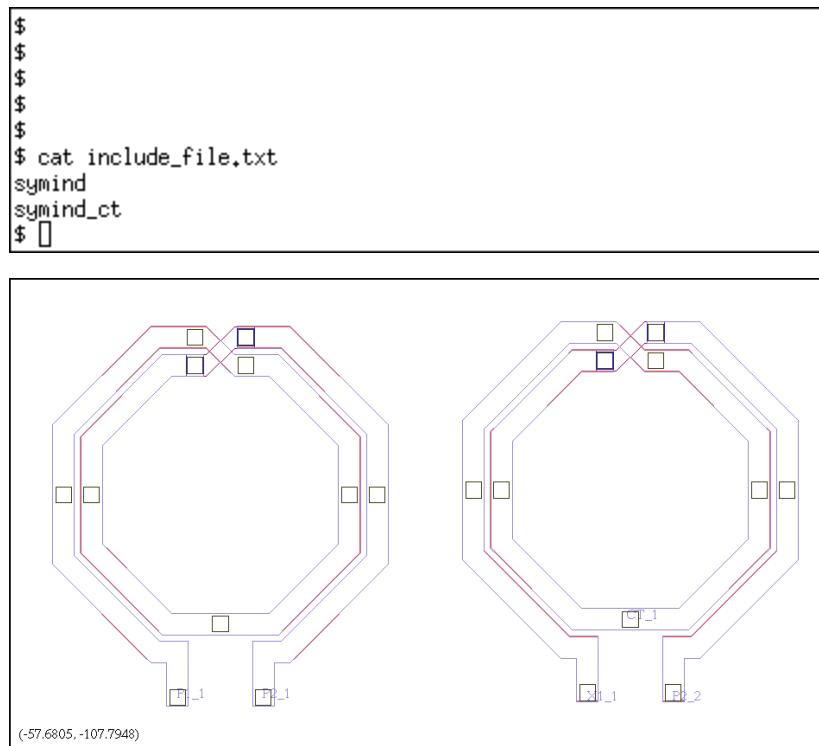
Bsub options

Work dir

[Browse...](#)

EMX path

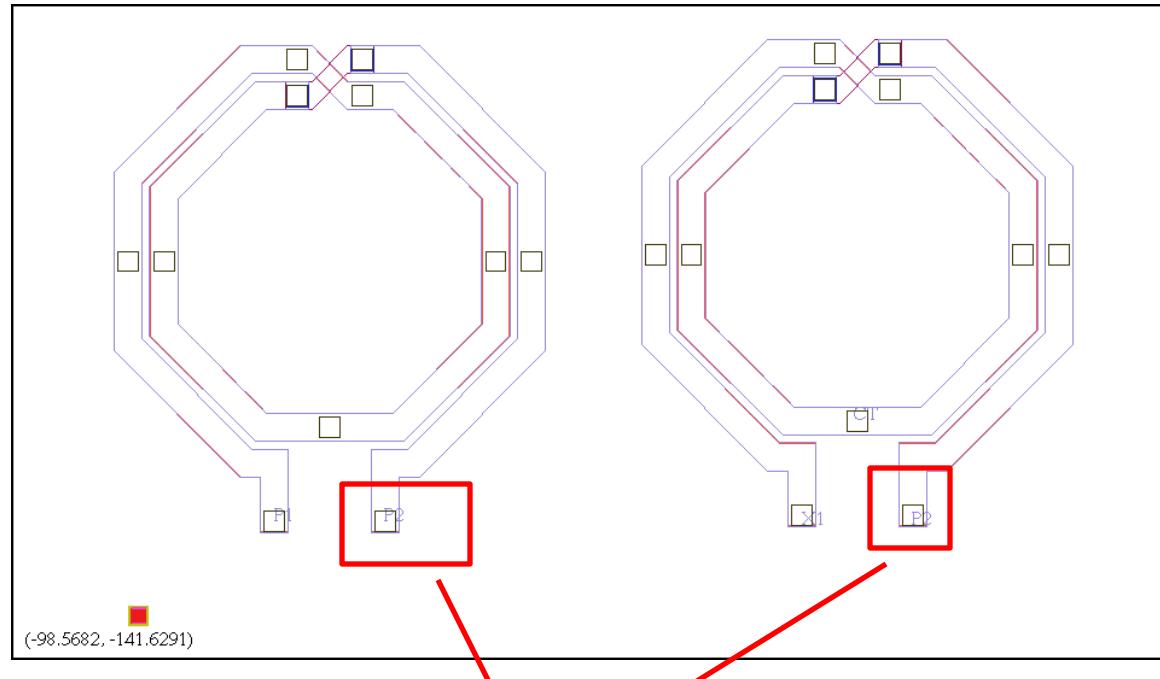
[Close](#) [Help](#)



- 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.

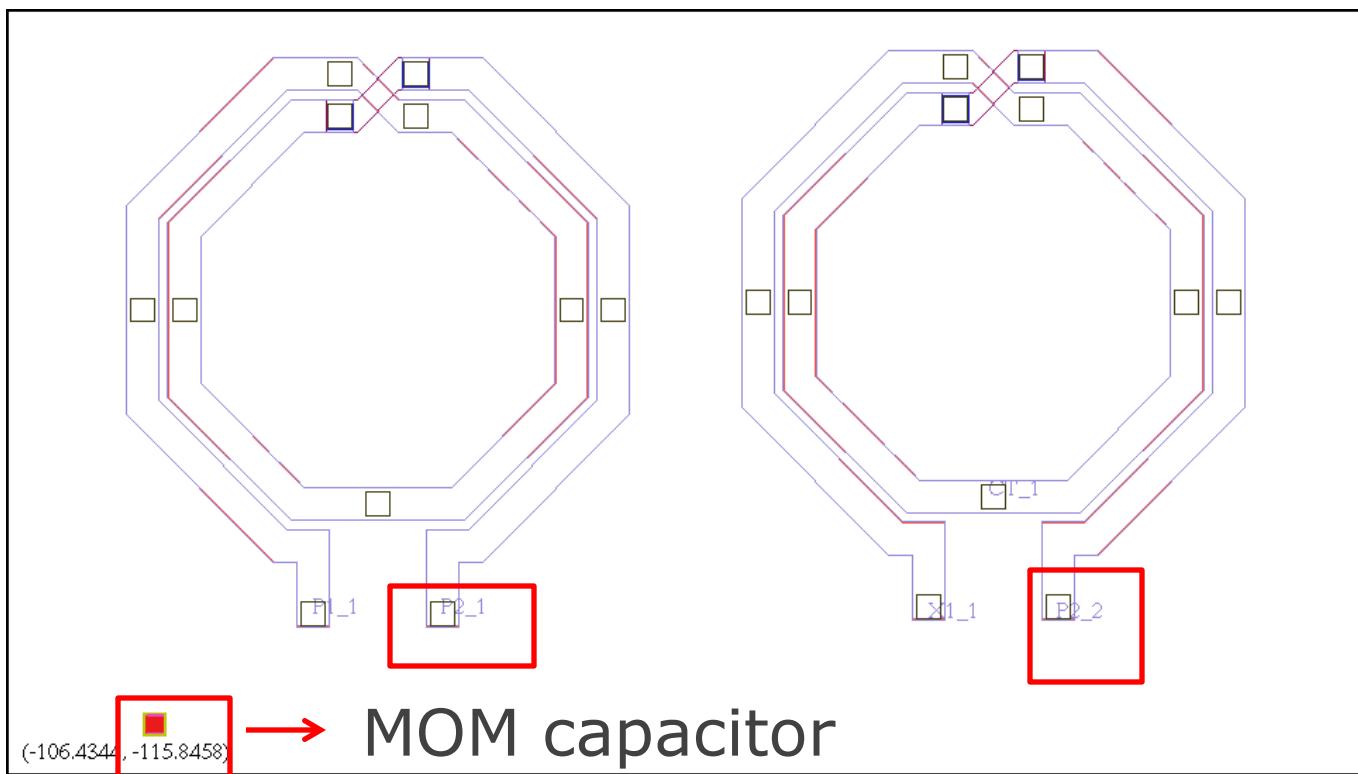
Mask simplification and hierarchy

- 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

Unique labels



--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.

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...

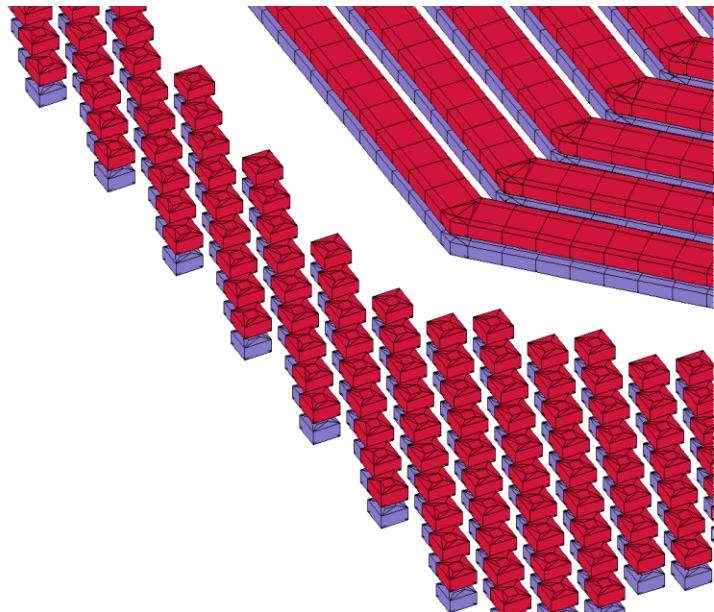
EMX path

Close

Help

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



Names of vias with capacitive or inductive effects

Capacitive

Inductive

More information

Internal labels and sizes

Internal

Size

Label depth

Cadence pins

Mode

Radiation

Multi-threading

Threads

Simul freqs

Output

Types S-parameters Y-parameters

Formats Touchstone Spectre Matlab

Pole-zero models

PZ method

Data import

Data file

Browse...

Import for

Other command-line options

EMX --define fillsize,1

GDSVIEW

ModelGen

Use bsub

Bsub options

Work dir .//EMX_work

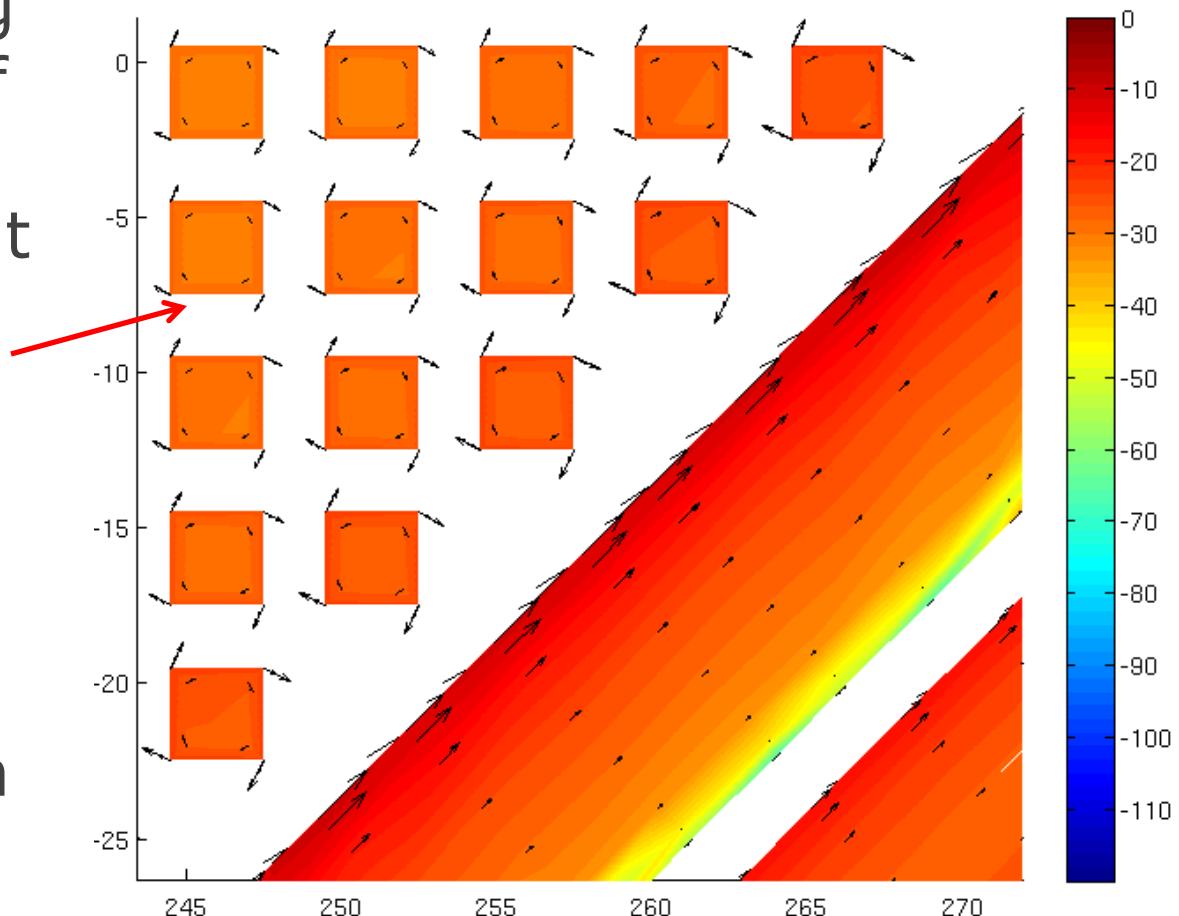
Browse...

EMX path

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

