ST Momentum Module

USER MANUAL

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Author: Kevin MOROT

I. Purpose of the document

This document aims at presenting the Momentum module and the associated flow. It gives also some user guidelines.

Keysight Momentum is a planar 3D electromagnetic simulator dedicated to RF design. The solver is based on the Method Of Moments. For a detailed Momentum user manual, see Keysight documentation.

II. Module presentation

The **Momentum Module** is a technology kit which provides all the technology data and options to run within the GoldenGate (GG) RF environment electromagnetic simulations of RF designs for a given technology. It integrates Keysight/ST specific skill functions to process the layout modification and simplification required before simulation.

The Module contains:

- Momentum technology files describing the technology back-end stack for various process corner conditions (NOMINAL, RCMIN and RCMAX). Additional techfiles are provided for NOMINAL corner in PWELL or VVLARGE configurations. Each of them includes temperature coefficient (TC) values for temperature dependency assessment of metal layers sheet resistance.
- Derived layers for Alucap conformal modeling (if the technology has an Alucap layer), MIM capacitance modeling (if available), and Via Contact management.
- Pre-computed substrate database corresponding to the technology files and containing the Green functions for capacitance extraction.
- Skill functions required for stack definition and setup.
- A setup file for loading automatically the correct settings related to technology file (expansion UP/DOWN per layer, 2D or 3D current, recommended options, etc...).
- Documentation.

The Momentum Module is aligned on a given Design Kit. This means that it is aligned on the StarRC itf files used for parasitic extraction (PLS/PEX). The Green functions have been computed with a given version of Keysight ADS. All information needed (ADS version, Design Kit version…) are given in the Release Notes document.

Warning: Bias effect on metal conductivity described in the StarRC itf files is not included in this module. For each metal layer, conductivity is aligned on the value given for the largest metal width in the itf.

Warning: The technology files provided with this Momentum module are making the assumption that your design includes a BFMOAT layer preventing to have any PWell doping in the substrate. This does not mean that you have to put any BFMOAT shape in your momentum view but only that there is no PWell below STI taken into account during Momentum extraction.
If you want to evaluate with Momentum the impact of PWell on your passive design please select the stack that takes into account the presence of PWell implantation in silicon substrate (see in section V).

III. Momentum flow

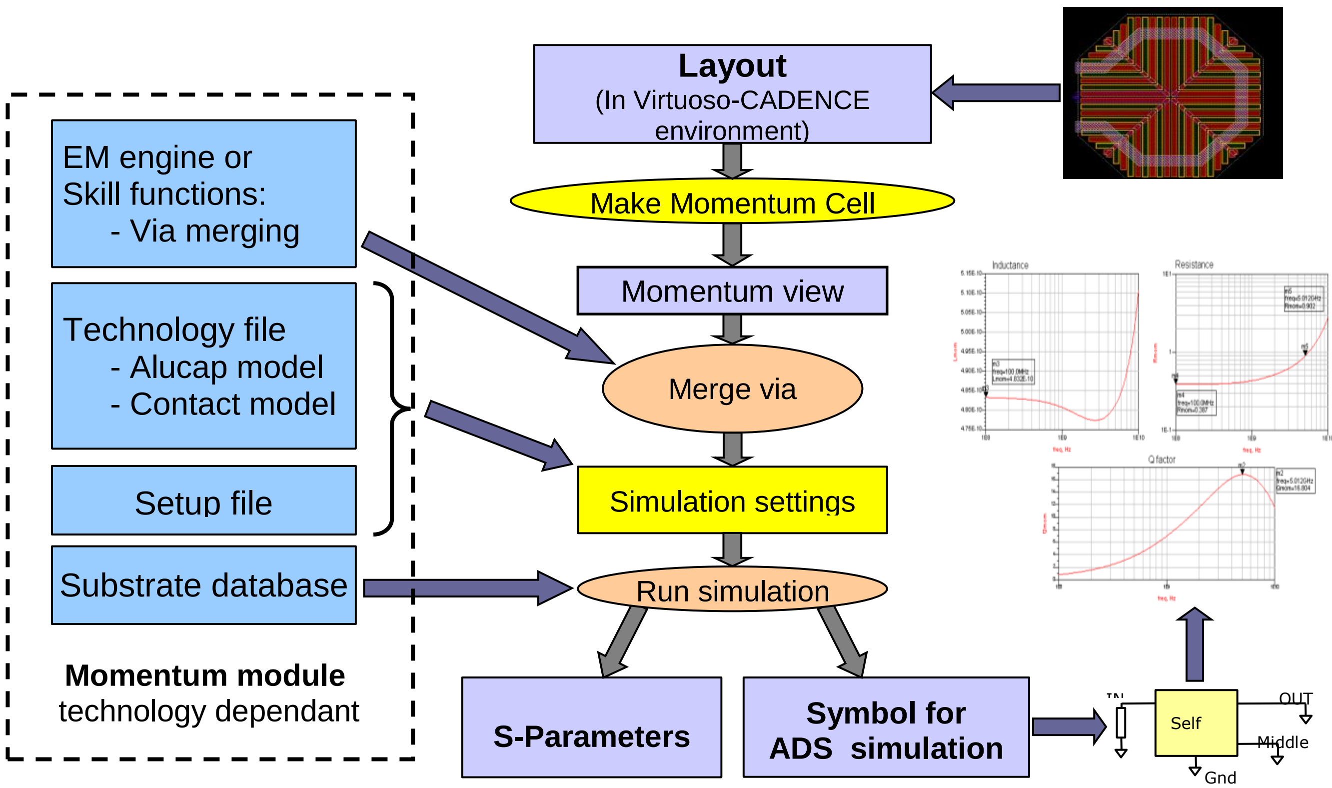


Fig.1. Schematic of Momentum Flow

IV. Technology files and topology optimization

A technology file describes the back-end dielectric stack and is layout independent. The stacks provided with a module correspond to a selection of technology process corners (one technology file per corner). The process data for each corner are derived with an in-house tool from the technology files delivered in a given Design Kit for PEX with StarRC.

IV.1 Dielectric stack simplification

In most cases Momentum techfiles cannot describe actual stacks and simplifications have to be performed. This is e.g. the case to handle 3D metal layers in a multi-layers dielectric (see manual for explanations on 3D metal expansion). The simplification methodology employed in the Momentum Module allows preserving as much as possible the lateral and vertical capacitances. This simplified description leads to a reasonable stack complexity for the Momentum volume mesher. In order to optimize the number of layers, the kind of expansion (up or down) is defined per layer (generally all metal layers are specified DOWN and Alucap related layers are UP).

IV.2 Conformal Alucap modeling

In case of a technology with an Alucap layer, if a planer layer is used instead of a conformal one, either the sheet resistance or the topology is erroneous, decreasing the accuracy on R or C.

VVBar configuration

Momentum is a 2.5D EM simulator and then do not support conformal layers. But they can be approximated by using derived layers.

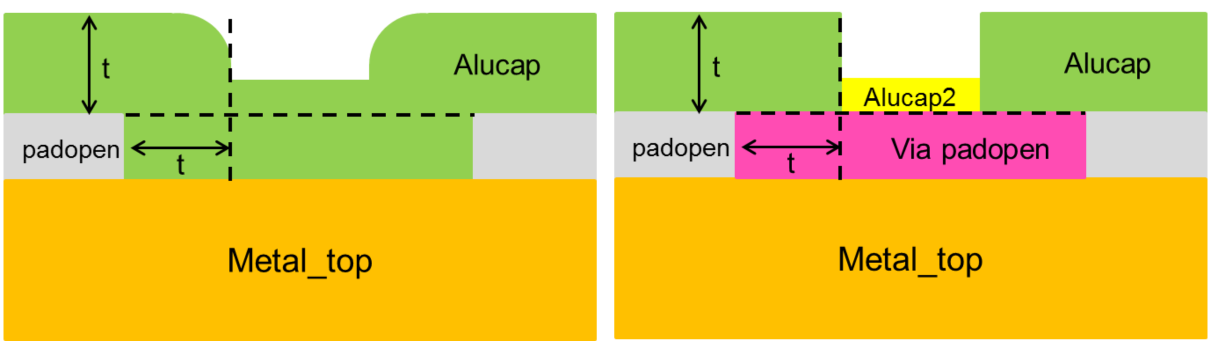


Fig. 2a: Conformal Alucap modeling (VVbar configuration)

The derived layers are generated at Momentum startup and can be seen with the 3D layout viewer (not in the momentum view). This description applies in the case of NOMINAL, RCMIN, RCMAX or NOMINAL_PWELL techfiles.

Large VV configuration

With VV opening larger than the standard VV (>3 µm) the LB deposition is more conformal and the total thickness in VV becomes equal to LB one. To emulate this topology, please select the *NOMINAL_VVLARGE techfile.

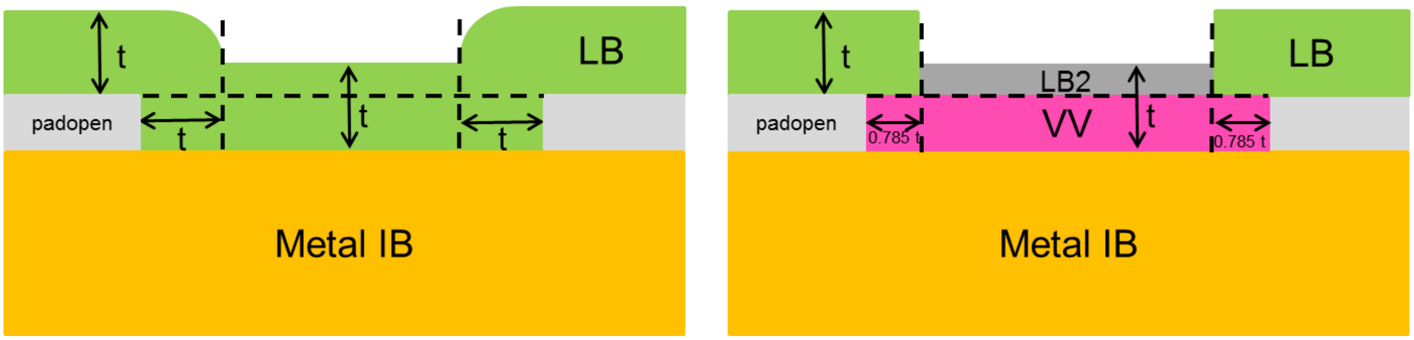


Fig. 2b: Conformal Alucap modeling (Large VV configuration)

IV.3 Support of MIM capacitances

The Momentum module supports MIM capacitance using derived layers for via definition. The MIM capacitance is considered in a homogeneous dielectric material (ε_r) and the distance between the two plates is adapted to obtain the good capacitance.

The derived layers for via definition are generated at Momentum startup and can be seen with the 3D layout viewer (not in the momentum view).

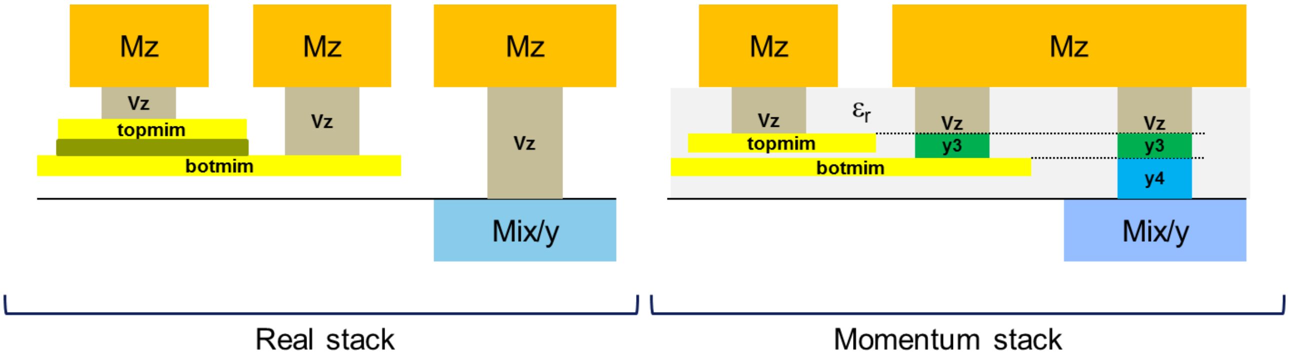


Fig. 3: MIM capacitance modeling

IV.4 Contact management

The Momentum module introduces derived layers for the contact definition.

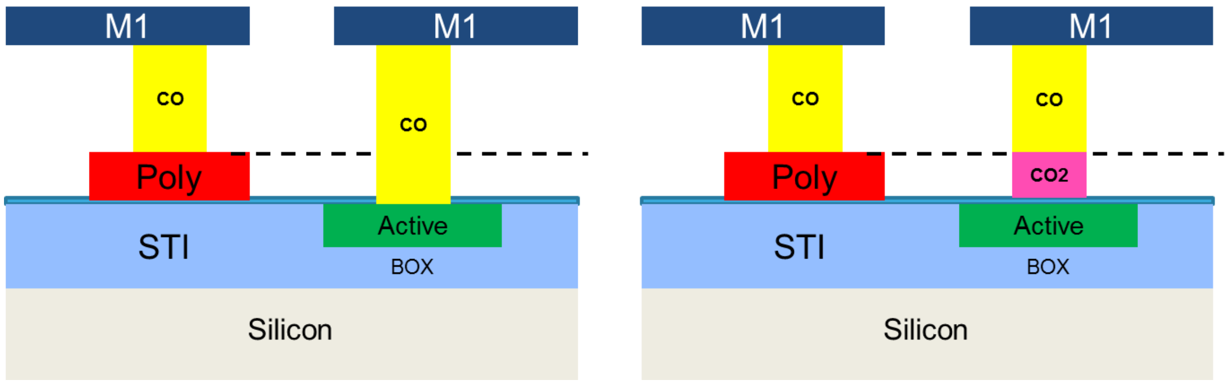


Fig. 4: Contact management

The derived layers for contact definition are generated at Momentum startup and can be seen with the 3D layout viewer (not in the momentum view).

V. Substrate database

From a Momentum point of view, the substrate database is the dielectric-stack database pre-computed from the process technology file. This database contains Green functions used for capacitance extraction and is called by the solver during each electromagnetic simulation. This database is layout independent. For a given frequency range, this database is computed only once per technology file. The module is provided with pre-computed databases for the all process corners selected for the module.

These pre-computed databases are provided in the Module for designer time saving. Depending on the dielectric stack complexity, the computation time for Green function can take from few hours up to two or three days…

Warning:

The pre-computed substrate database is valid only for the simulation options set by default by the Momentum Module. If a simulation option (such as the kind of expansion) is modified, the database will be re-computed by the tool. It will also be recomputed if the technology file from the Module is modified by user or if the user selects a frequency outside the validity domain.

The green functions are computed in Microwave mode. The RF mode is also valid and it can be used for simulation without any database re-computation. For the frequency range, please see the

Release Notes.

Dielectric stacks available

<u>VVbar and BFMOAT configuration</u>

28LP_6U1X_2T8X_LB_FDSOI_NOMINAL.ltd (default stack)
28LP_6U1X_2T8X_LB_FDSOI_FUNCRCMIN.ltd
28LP_6U1X_2T8X_LB_FDSOI_FUNCRCMAX.ltd

<u>VVbar and PWell configuration</u>

28LP_6U1X_2T8X_LB_FDSOI_NOMINAL_PWELL.ltd **(Microwave mode mandatory)**

<u>Large VV and BFMOAT configuration</u>

28LP_6U1X_2T8X_LB_FDSOI_NOMINAL_VVLARGE.ltd

VI. Using Momentum in GoldenGate environment with the Momentum Module

VI.1 Product loading

Two solutions exist for the Momentum Modules:

1) Developed as stand-alone product. In this case you have to declare the product in a local ucdprod and in your .ucdprod together with the good ADS version.
2) Integrated into the design kit. In this case you have nothing special to do. Do not forget to add the good ADS version to your product list (.ucdprod)

VI.2 Momentum view generation

The layout modifications functions available with the Momentum Module are done in the Momentum view. To make a Momentum view from the layout view:

1. From the layout view, the user launches Momentum from the Tools menu → Momentum.
2. The menu Momentum-virtuoso appears in the layout window.
3. Select “Make a Momentum Cell” in this new menu to generate the Momentum view.

VI.3 Automated via simplification

Simulating via arrays in detail requires significant simulation resources. For typical RFIC designs, accurate results can obtained much faster by merging them upfront. The underlying assumption is that the impedance presented by the via array is low and has little effect on the device performance. The merge of rectangular via shapes occurs during the layout preprocessing step of an EM simulation.

Two simplification modes are supported:

1) Simplification is made by the Momentum engine (called 'Simplification by EM Engines'). All simplifications are made at Momentum startup and can be seem with the 3D layout viewer. **This new mode is the default one at Momentum startup and is highly recommended due to the extensive usage of derived layers** (MIM, contact…) and for the support of local via arrays on diagonal lines.
2) Simplification at the layout level through embedded skill pre-processing. The result of the simplification is visible in the momentum view. This mode is called 'Simplification by user'. This is the mode used in momentum modules before ADS 2016.01.

VI.4.1 Interfaces

<u>Simplification by EM Engines</u>: To use this mode select the menu item **"*Layout / Set Via simplification options***.

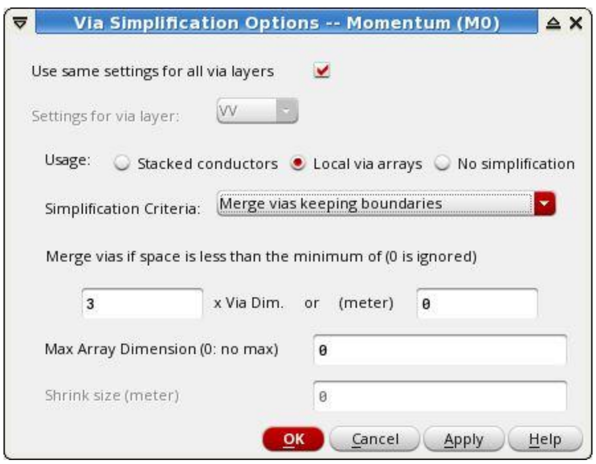


Fig. 5: Via simplification interface (EM engine)

<u>Simplification at layout level</u>: To use this mode select first the menu item **"*Layout*" / *Switch to simplification by User***. And then select the menu item **"*Layout / Perform Via simplification***.

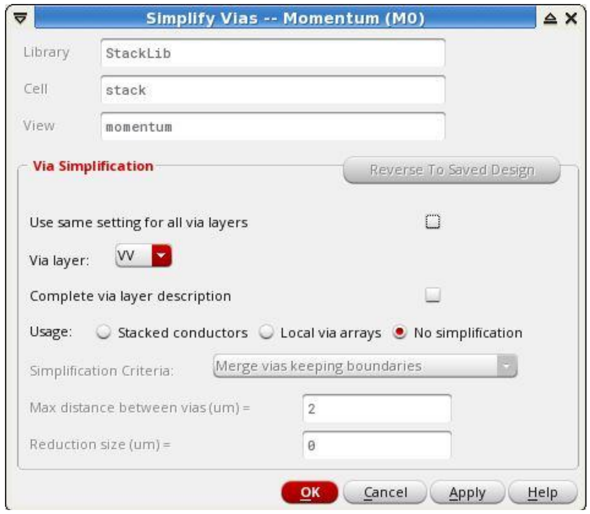


Fig. 6: Via simplification interface (User mode)

VI.4.2 Simplification criteria with EM Engine mode

Two distinct types of via clustering are provided: Local via arrays (recommended) and Stacked conductors.

<u>Local Via Arrays</u>

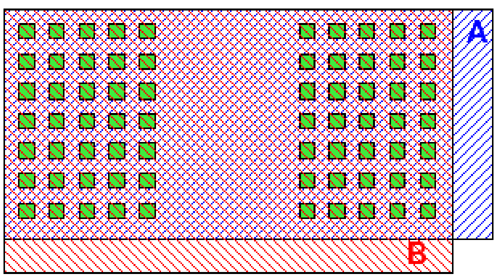
Only axis aligned or 45 degree turned rectangles are being considered. The other shapes are left unchanged. First the shapes are grouped per contiguous area where the top and bottom via cover presence are the same (present or absent). Shapes having their center exactly on a boundary between areas are left unchanged. In each such group, the algorithm looks for arrays of exactly identically sized rectangles. The arrays can be axis aligned or 45 degree turned. The spacing between the cuts across the array axes does not need to be uniform. However, if VAS_MAX_STEP_RATIO is strictly positive (default 0), non-uniformities of the array step size in the same dimension cannot exceed VAS_MAX_STEP_RATIO when dividing the larger by the smaller step. (e.g. 1.1 will allow 10% step difference). The combination of axis aligned rectangles and 45 degree arrays (or 45 degree rectangles and axis aligned arrays) is only detected as an array if the rectangles are square.

You can optionally limit the distance between cuts where arrays are detected by setting **Max Space**, either in absolute terms (in **meter**) or as a multiple of the cut size (**x Via Dim**) along the direction of the array (i.e. for 45 degree array of axis aligned squares, the diagonal is taken into account). Specify a strictly positive value to turn this on. 0 will turn it off.

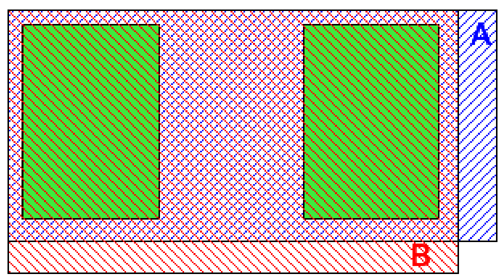
The shapes of arrays with only one cut are left unchanged. Otherwise, the algorithm looks at the array as a bitmap of cuts. For each bitmap, a hull around the cuts is constructed and limited to fit inside the contiguous top/bottom area. The resulting shapes become "cluster shapes". The bitmap can be modified before cluster shape construction occurs. You can optionally divide an array into smaller arrays not larger than not larger than a specific dimension by specifying a strictly positive **Max Array Dimension (0: no max)**. Arrays will not be larger than this amount of pixels in either dimension. This allows to find a middle ground between all original cuts and merging everything.

In the second stage, final shapes are generated from cluster shapes according to the selected clustering **Simplification Criteria**:

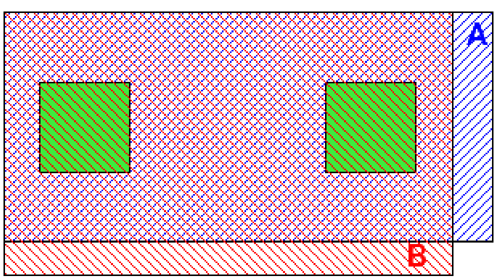
- **Merge vias keeping boundary**: returns the cluster shapes as-is.
- **Merge vias keeping area**: shrinks the cluster shapes until they have the same area as the original via cuts they are replacing
- **Merge vias keeping area and boundaries**: constructs donut shapes with the same outer boundary as keep boundary and the same area as keep area.
- **Merge vias increment/clip to lid boundary**: extends the cluster shape bitmap horizontally, vertically and diagonally by 1 pixel. The cut distance applied to the extension is the average cut distance in that dimension (or in the other dimension if the array is 1D). This allows you to make arrays that almost fill the top/bottom conductor they are in to fill the conductor surface up to the boundary.



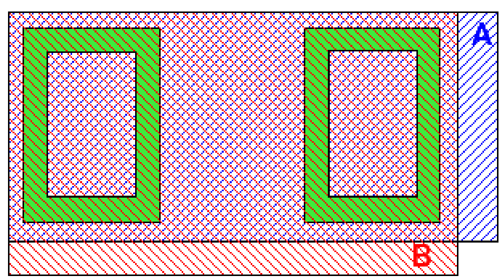
Original via array



Local via arrays
Merge Vias keeping boundaries



Local via arrays
Merge Vias keeping area



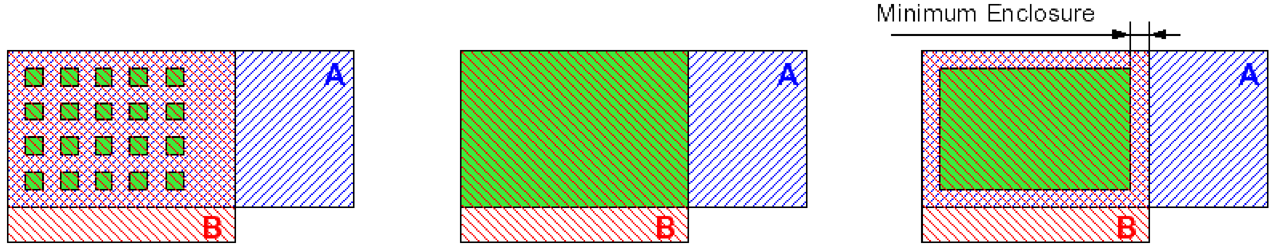
Local via arrays
Merge Vias keeping area and boundaries

<u>Stacked Conductors</u>

In the first stage, each contiguous intersection area of interface layer masks present at both the top and bottom via interfaces becomes a cluster shape, provided there is at least one via shape present in the intersection. Sections of via shapes where there are no shapes on both top and bottom interface masks are discarded.

In the second stage, final shapes are generated from cluster shapes according to the selected clustering Method:

- **<upper> AND <lower>**: returns the cluster shapes as-is.
- **shrink <upper> AND <lower>**: shrinks the cluster shapes with the distance amount specified by Shrink Size.



Original via array | **Stacked Conductors** A and B | **Stacked Conductors** A and B resized by MinEnclosure

VI.4.3 Simplification criteria with User simplification mode (old mode)

<u>Stacked conductors</u>**:** The group of via connecting layers A and B are merged in a single shape corresponding to the overlap of the 2 layers A and B (equivalent to Boolean operation A AND B).

You can then choose between two options:

- **"*[Upper metal level] AND [Lower metal level]*":** the resulting via edges will coincide with layer A and B edges.
- **"*[Upper metal level] AND [Lower metal level] reduced by size*"**: the resulting via shape will be downsized by the reduction size specified by user (in um).

<u>Local via arrays</u>**:** each via matrix will be merged in a simple shape. Vias are merged in the same shape if the distance between them is < to **"*Max distance between vias [um]*".**

- **"*Merge vias keeping boundaries*"** → the resulting via shape will have the same perimeter than the initial via matrix.
- **"*Merge vias keeping area*"** → the resulting via shape will have the same area than the initial via matrix. This criterion allows a better accuracy on via resistance.
- **"*Merge vias keeping area and boundaries*"** → the resulting via shape will have the same perimeter and area than the initial via matrix. This criterion is the most accurate but it is

very difficult to handle for the meshing process for a gain in accuracy usually not significant.

VI.4.3 Per layer simplification

To use the same criteria for all via layers, select **“*Global via simplification*”**.

Usually, users select a different simplification criterion for each kind of via: Unselect “*Global via simplification*” → Select the via layer → Select the criterion (with **“*Usage*”** and **“*Simplification criteria*”**) → Select the next via to be simplified and so on → Select “*Apply*” or *OK* to see the simplification on the Momentum view.

For the simplification of via contacts on pattern shields, the criterion “stacked conductors” without resizing is deeply recommended. *It creates chevron patterns for via contacts that are easier to mesh for Momentum because their edges coincide with the edges of Metal1 and Poly or Active layer.*

VI.5 Running simulation

VI.5.1 Simulation options: everything is automatically loaded.

When using the Momentum Module, ***simulation options*****, in line with the technology file, are automatically loaded.** So the default settings using the Momentum Module are different that the default settings defined initially by Keysight Momentum.

The default ***simulation mode*** is *RF* which has proven to be accurate enough the majority of cases. This mode is less CPU time consuming than the Microwave mode which is only recommended for large problems.

The ***current model types*** are automatically defined per layer, in order to optimize accuracy vs. mesh complexity. The automatic settings are the following:

Conductors & vias:

- ***No Edge Mesh*** Not required when using 3D currents
- ***3D-distributed*** for all conductors
- ***2D-distributed*** for standard via
- ***3D-distributed*** for via padopen => 3D is mandatory to accurately model transverse currents

Mesh:

- ***50 cells per wavelength*** (can be reduced but must be greater than 20)
- ***Reduce mesh*** option selected
- ***Include Thin Layer Overlap*** option selected

The ***expansion type*** that is directly linked to the technology file description is automatically defined for each metal level. So, when using the Module and its technology file, the expansion type cannot be modified.

<u>Warning: </u>the technology files have been validated for default settings defined in Momentum Module. If the simulation options are changed (Current model type, via model...), the accuracy has not been validated.

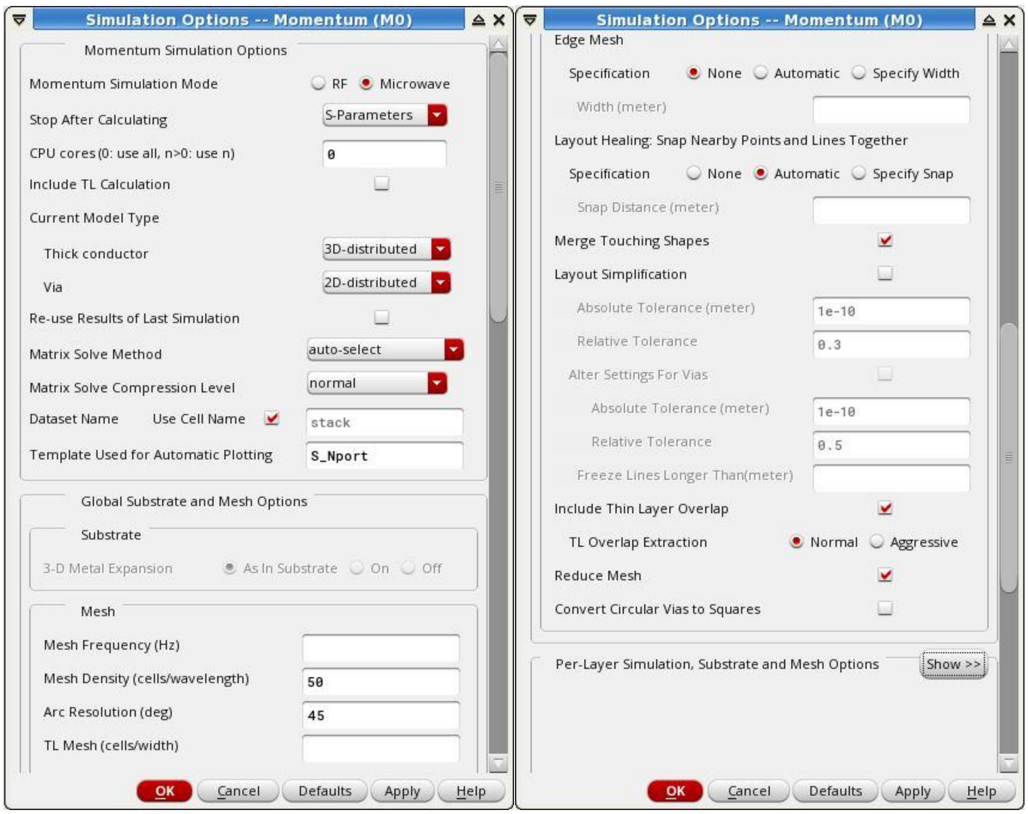


Fig. 9: Simulation options window

VI.5.2 Ports, Frequency plan and process corner definition

At this level only few operations remain to be performed:

<u>a) Ports:</u> ***Ports Menu → auto-generate***

The ports can then be re-combined or re-defined (see Keysight Momentum documentation for more details). For typical microstrip or inductors, Keysight recommend to use ‘Edge ports’. This is also true for ports to reconnect devices. The ‘Point ports’ are more dedicated to ports on pads to emulate the current behavior in measurement.

<u>b) Frequency range:</u> ***Frequencies Menu → Add***

The **Adaptive mode** is recommended to reduce the computation time.

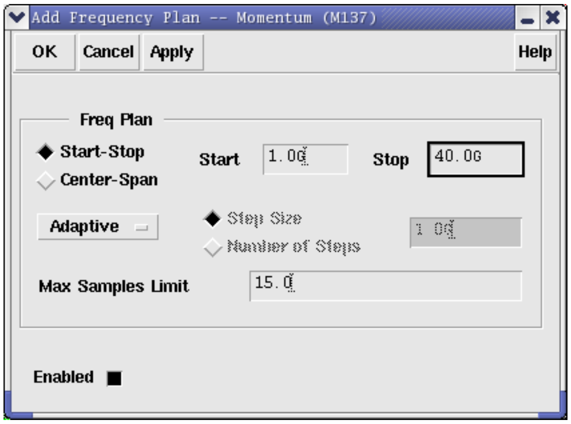


Fig.10: Selection of frequency plan

For frequencies out of the frequency range used for Green function computation, the substrate database will require additional computations.

c) Process corner:

By default the module selects the technology file relative to typical process corner conditions and automatically loads the corresponding substrate database. This technology file is located in the *MomentumSDB* directory which is in the module installation root directory. The pre-computed databases are located in the *MomentumSDB/substrate* directory.

To select another process corner condition, the user has to load another technology file. By selecting the menu ***Setup/Substrate*** a popup window appears. Then selecting the option ***“Use Alternate Substrate File”*** and clicking on the ***“Browse…”*** button, a browsing window appears, allowing to select another technology file among those available in the *MomentumSDB* directory.

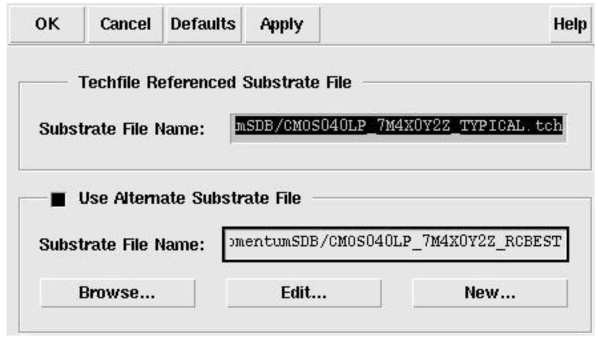


Fig.11: Selection of process corner

VII. Additional user guidelines

In this part we give additional guidelines to designers which are “non-expert” with Momentum. This part is not specific to the Momentum Module.

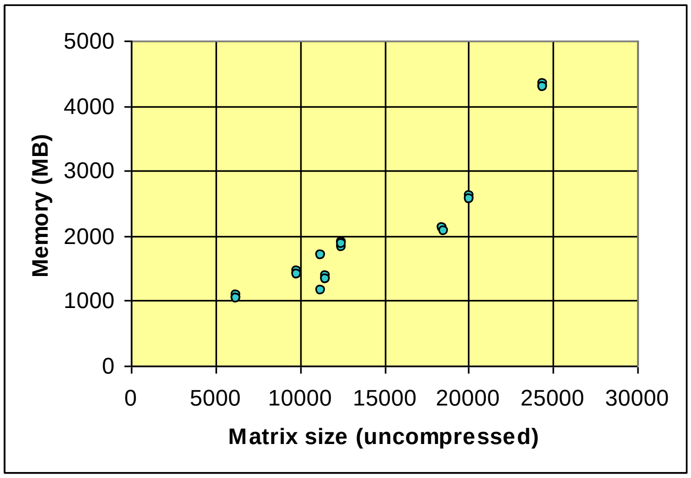
VII.1 Simulation flow and memory resource issues

1) <u>Checking mesh characteristics before simulation</u>

For the first extraction of a new cell, it may be useful to check the mesh complexity before running the whole simulation:

1) Select in simulation option ***“ Stop after calculating: Mesh”***
2) Launch the simulation: the mesh generation is a fast process that can be run on any machine.
3) Then check in ***Result*** menu → ***mesh report/statistic*** to see any error message during meshing and to estimate the memory required from the matrix size (or the number of cell).

Figure below shows typical memory requirements experienced with RFDE/Momentum on several technologies.



2) Run the S-Parameters simulation

Then select ***"Stop after calculating: S-Parameters"*** and re-run the simulation (on a machine in line with the required memory resource).

A simulation computed in adaptive mode computes S-parameters at only few points in the frequency range. To analyze the S-parameters results on a detailed and accurate curve, the user can create a symbol and then re-simulate the system with more sample points:

- Use the ***Tools*** menu→ ***Auto-create circuit simulator view***.
- In Library Manager, new cell views are now available including the ads view and the symbol view.
- In a new schematic view, instance this symbol view, add "*Terms*" from the adsLib and *"gnd"* from the analog lib and run an S-parameter simulation with the number of frequency points required.

This solution is very fast when compared to a Momentum simulation for same number of frequencies.

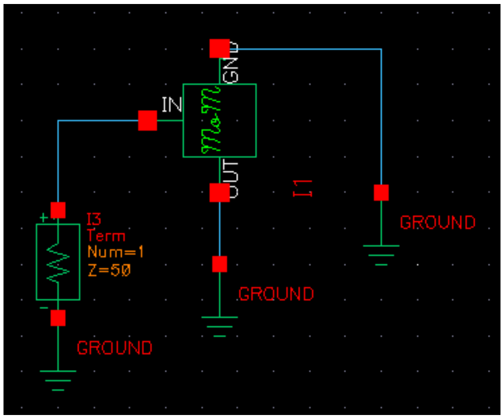


Fig.12: Momentum symbol simulation

3) <u>Check the current behavior</u>

In ***Result*** menu → ***Currents*** user can visualize the currents. Any meshing issues or wrong simulation behavior can be seen here. If the current is not distributed as expected, or trapped in a part of the structure, the user can increase the number of cells per wavelength (from 20 to 50 for instance) to increase the accuracy and solve the issue.

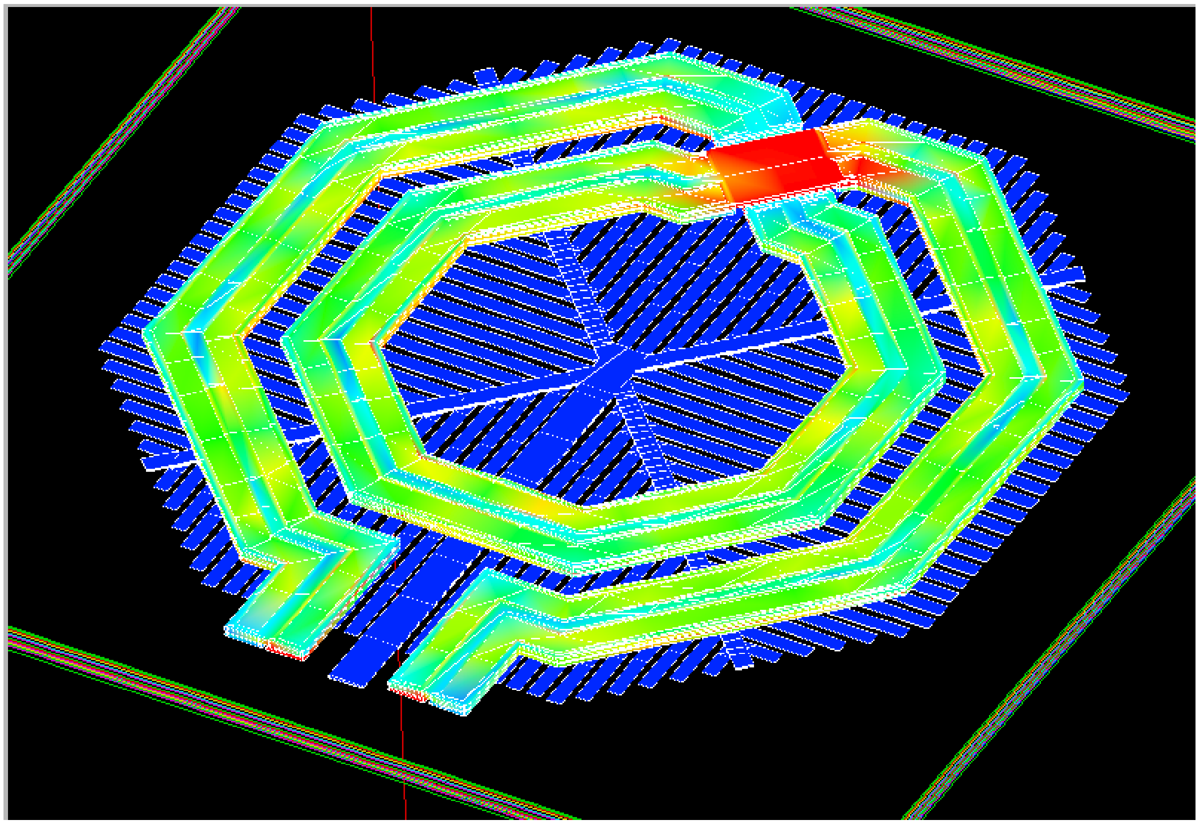


Fig.13: Current visualization

VII.2 Simulation in batch mode under LSF and CPU reservation

Launching Momentum on LSF is often mandatory for typical inductor cells.

Once the simulation is correctly set up (corners, ports, frequency range, options) then simply select the option "***Netlist"*** in the "***Simulation"*** menu of the Momentum window. This process generates all what is needed to launch the simulation in batch mode.

Then, in a LSF a window:

```
cd ./simulation/[cell]/adsMom/momentum/netlist/
```

The ***runSimulation*** file is an executable file. To launch the simulation on the LSF network (e.g. on Grenoble LSF network on the *long* queue), type:

```
bsub -R rh60 -o LSF.log – q long runSimulation
```

By default Momentum uses all CPU available. To limit the number of CPU used by momentum (e.g. 8), edit the ‘CPU cores) in the Momentum options windows.

Warning: it is to the user to reserve the number of processors for his job, as well the memory. For example, to launch the simulation and reserve 16 GB and 8 processors, type:

```
bsub -q long -R "rusage[mem=16000]" -o lsf.log –n 8 runSimulation
```