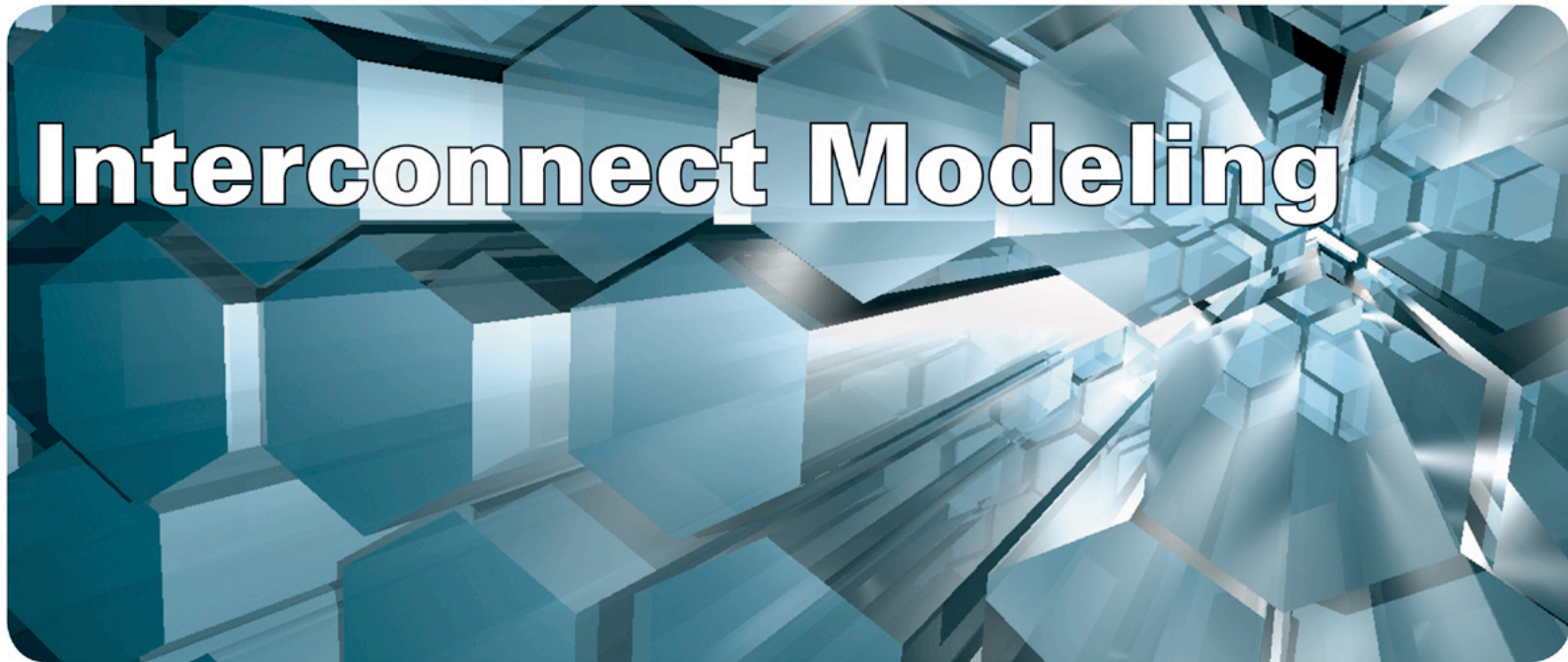


EXACT Interconnect Parasitic Characterization



Application Examples



SIMUCAD

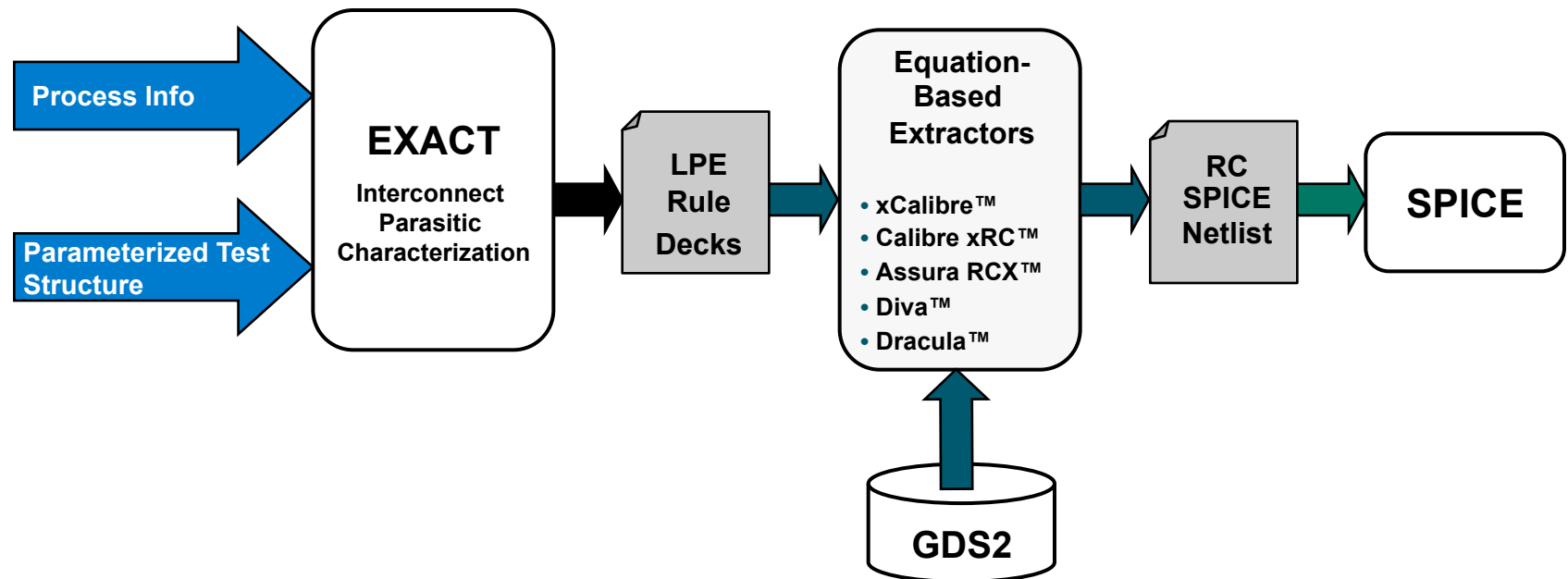


Introduction

- EXACT delivers the most accurate interconnect models for nanometer semiconductor processes and generates layout parameter extraction (LPE) rule files for leading full chip extraction tools
- EXACT's powerful 3D field solvers support xCalibre, Calibre xRC, Diva, Assura RCX, and Dracula LPE

Introduction: Exact Flow

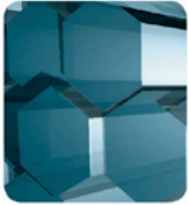
- EXACT takes process information and produces LPE rule decks





Introduction: Key Benefits

- Powerful 3D solver supports non-planar semiconductor profiles and dummies
- 3D field solver calculates interconnect capacitance models
- Intuitive and user-friendly graphical interface for process layer description and test structure definition
- Standard mode of operation handles most conventional processes
- Integrated scripting language provides custom LPE rule files for other extraction tools
- Powerful statistical analysis module option available to calculate variations of capacitance



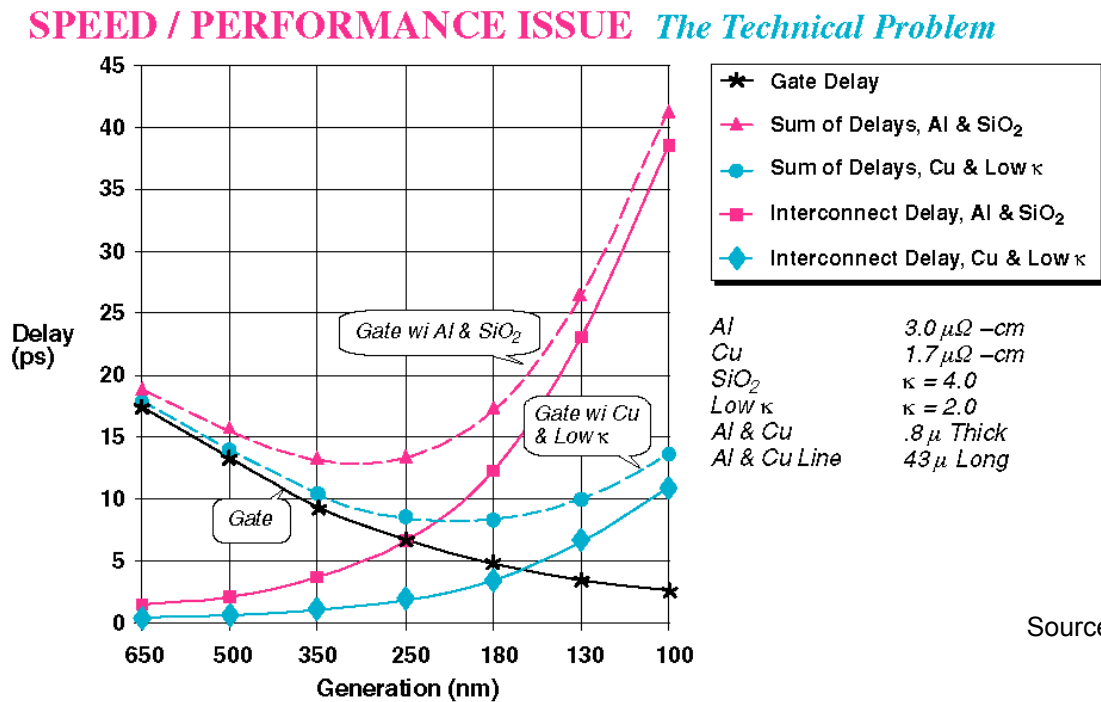
Introduction: Ease of Use and Adoption

- Easy to use, menu-driven graphical interface for process layer definition
- Menu-driven parameterized layout generator for test structure and pattern generation
- Easy LPE rule generation with LISA™ scripting language
- Flexible architecture for fitting raw parasitic data into a wide range of custom equations for xCalibre/Calibre xRC, and Assura-RCX/Diva/Dracula LPE
- Easy to understand extracted capacitance tables that facilitate the analysis of effects on interconnect due to various process change or experiment
- Automatic mesh and deck generation and submission to 3D field solver



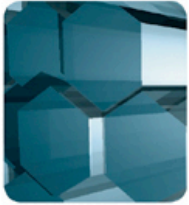
Introduction: Importance of Accurate Parasitic Extraction

- Parasitics now dominate circuit timing



Source: SIA Roadmap 1997

Figure 1.



Introduction: Data Required for Deep Sub-Micron Designs

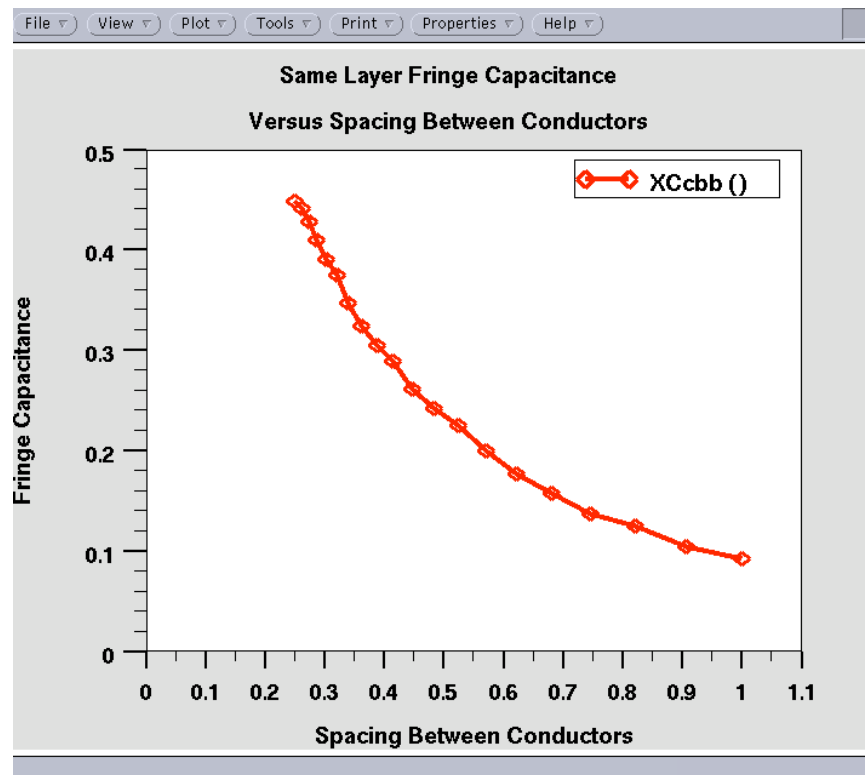
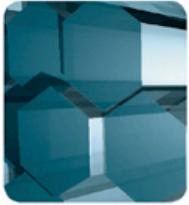


Figure 2.

- Lateral capacitance plot versus spacing between two conducting lines
- The figure shows that in this simple case, the capacitance can vary by a factor of 4 between minimum spacing and only 1 micron away.
- Typical foundry data above would only provide the first point on this graph



Introduction: Data Required for Deep Sub-Micron Designs (con't)

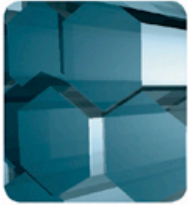
- What should the LPE Tool do if only the minimum spacing coefficient data are provided... Guess? Ignore? Use the value for minimum spacing?
- None of the above options are acceptable for deep sub-micron technologies . An accurate value must be known for all geometries
- Different widths of conductor and other geometries require different capacitance coefficients

E.g., A line over a line will result in a significantly different coefficient value compared to a line over a ground plane.



Introduction: Data Required for Deep Sub-Micron Designs (con't)

- Other typical configurations
 - 1/ Co-incident edges
 - 2/ Cross overs
 - 3/ Corners
 - 4/ Proximity effects
- EXACT can generate coefficients for ANY structure

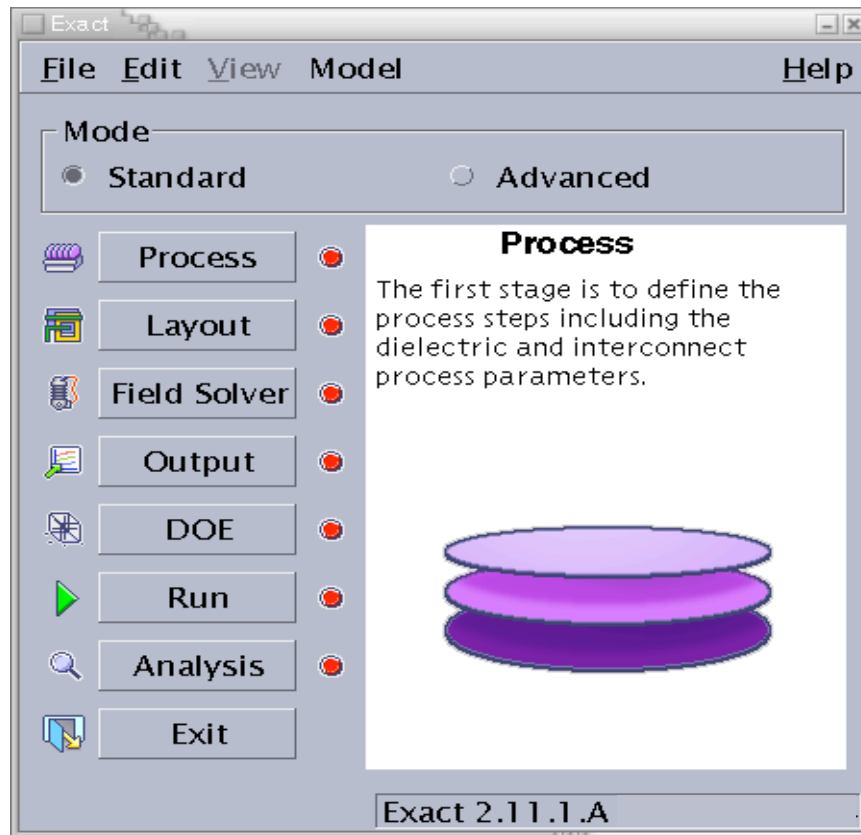


Workshop Summary

- Getting started
- Defining a process flow
 - (i) Simple processing using the Interactive Tool
 - (ii) Advanced process flow
- Defining and editing layout
- Test structures
- Defining the “Design of Experiments” (DOE)
- Executing the experiments
- Processing the data

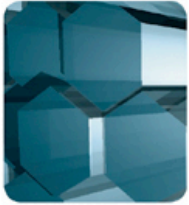


EXACT GUI



- Type “EXACT” in a shell window to display this EXACT G.U.I., (Figure 3)

Figure 3.



5 Stages of EXACT

- EXACT takes you through the 5 stages sequentially:
 - STAGE 1 Process Stage: Define the process
 - STAGE 2 Layout Stage: Define or load the test structure mask layouts
 - STAGE 3 Design of Experiments Stage: Select which experiments
 - STAGE 4 Run Stage: Run the experiments using the 3D process simulator and field solver
 - STAGE 5 Analysis Stage: Write or import a script to process all the data

Define the Process Flow: Standard Mode

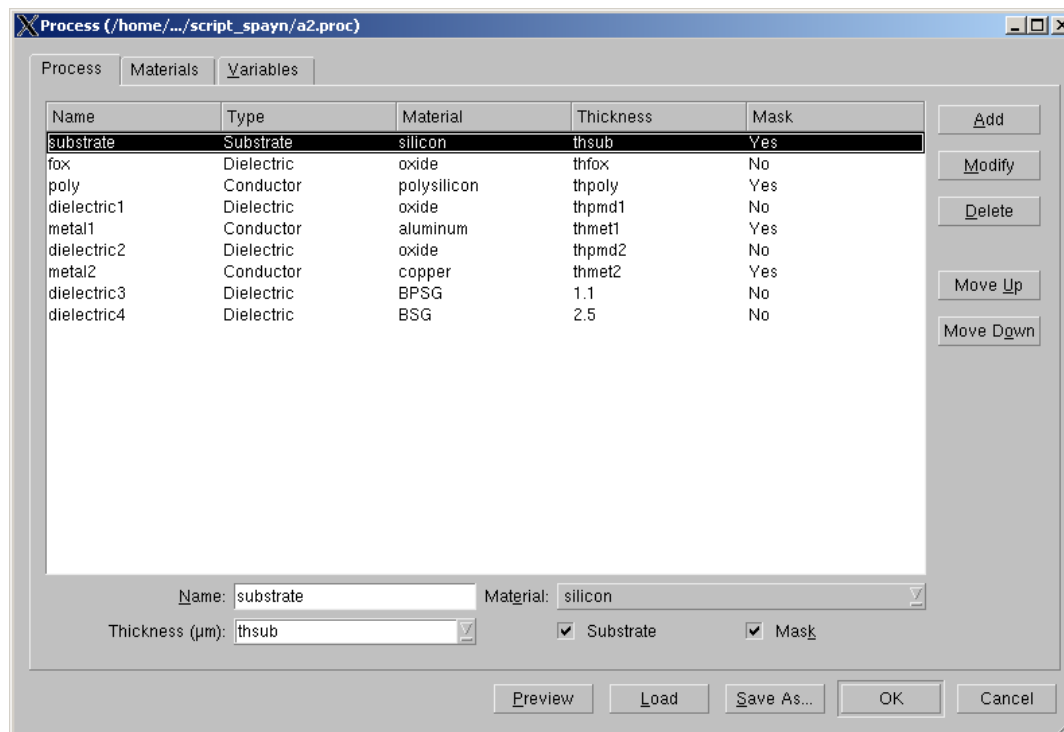
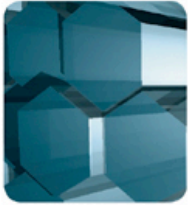


Figure 4.

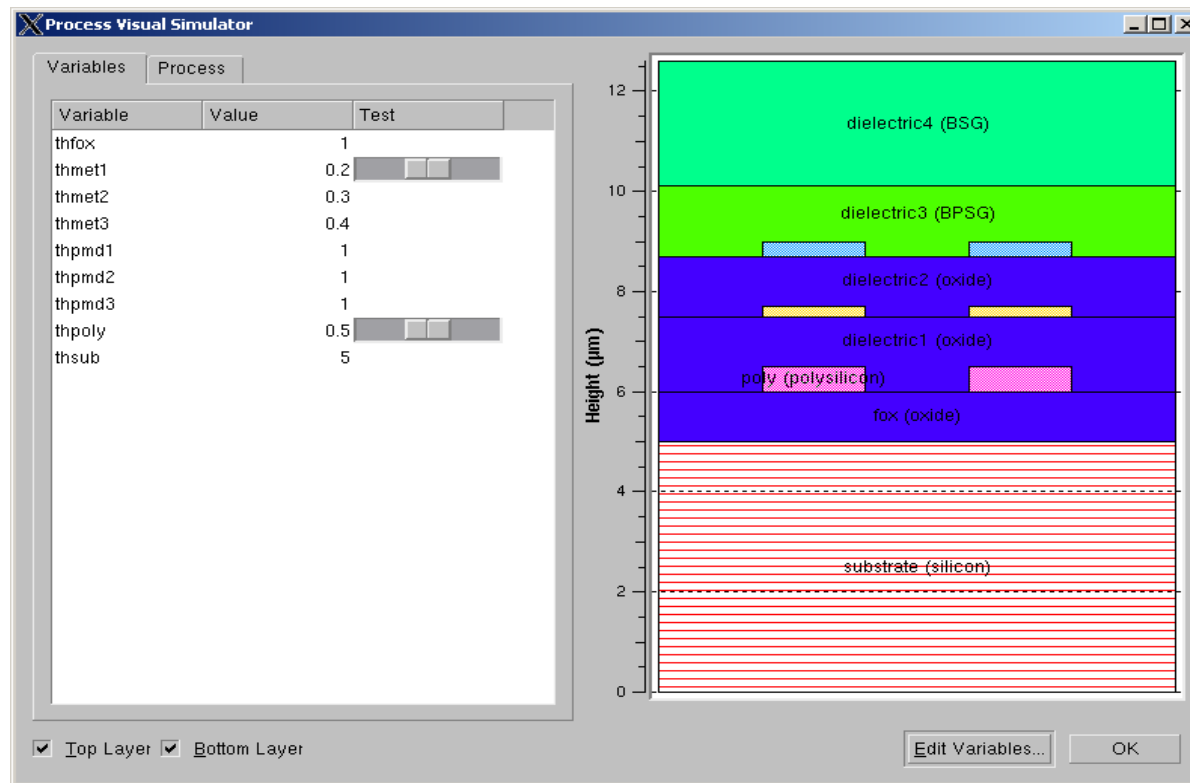
- The Standard Mode option allows quick “interactive” creation of a simple process flow
- This creates simple “planar” structures
- Click “OK” when finished



Define the Process Flow: Advanced Mode

- The Advanced Mode option allows the use of realistic photolithography, deposition or etching to create the test structures:
- In the Advanced mode users can:
 - (i) create their own process flow
 - (ii) edit a previous process flow from the interactive (from the Standard Mode) builder
 - (iii) edit a CLEVER input deck
- We shall only deal with the Standard Mode option in this workshop

Process Preview with the Internal Viewer of EXACT



- Having entered the process via the Standard Mode, the process verification is made possible using the “process preview” button in the process GUI, (Figure 5)

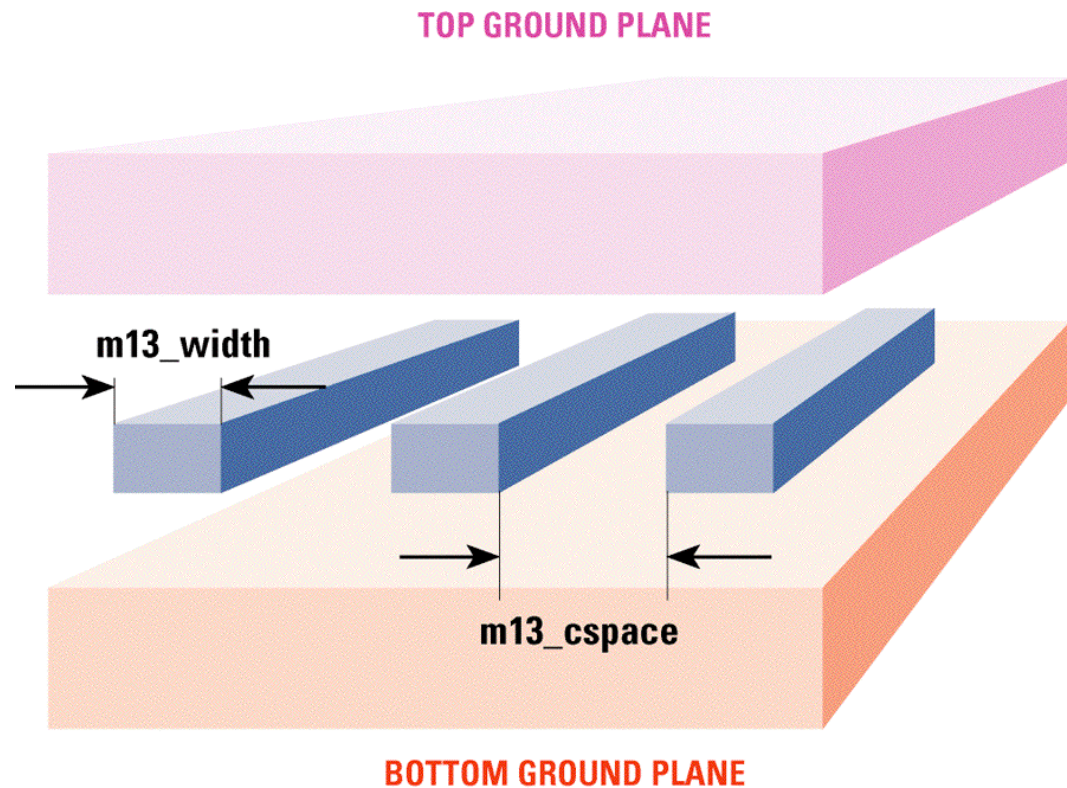
Figure 5.



Layout Stage

- After having entered the process the test structure specific to which required capacitance coefficient are then loaded into EXACT
 - Standard generic test structures will be provided for various Extraction (LPE) Tools
 - Load test structures using the layout GUI
 - The layout GUI also allows user to create their own test structures using the “more options” mode of EXACT layout GUI

Example of a Layout Test Structure



- An example of a layout test structure is shown in Figure 6
- From the test structure capacitances such as near body capacitance (the capacitance between two wires of the same process layer) are easily obtained

Figure 6.

Loading a Layout

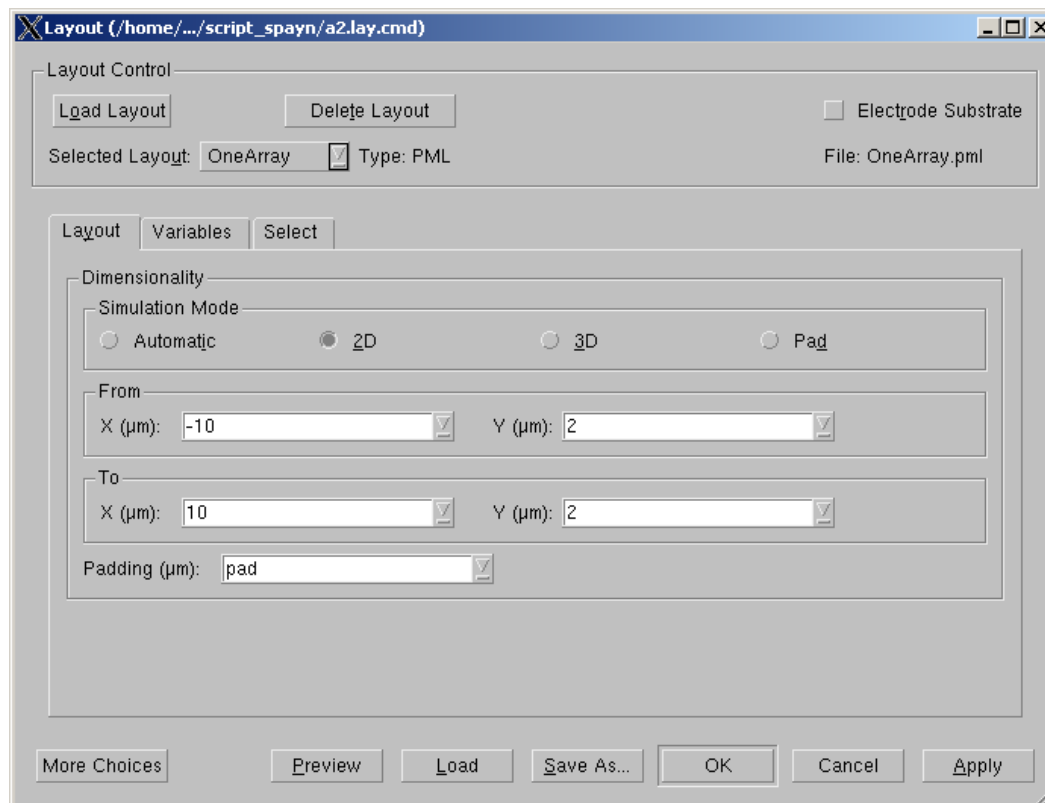
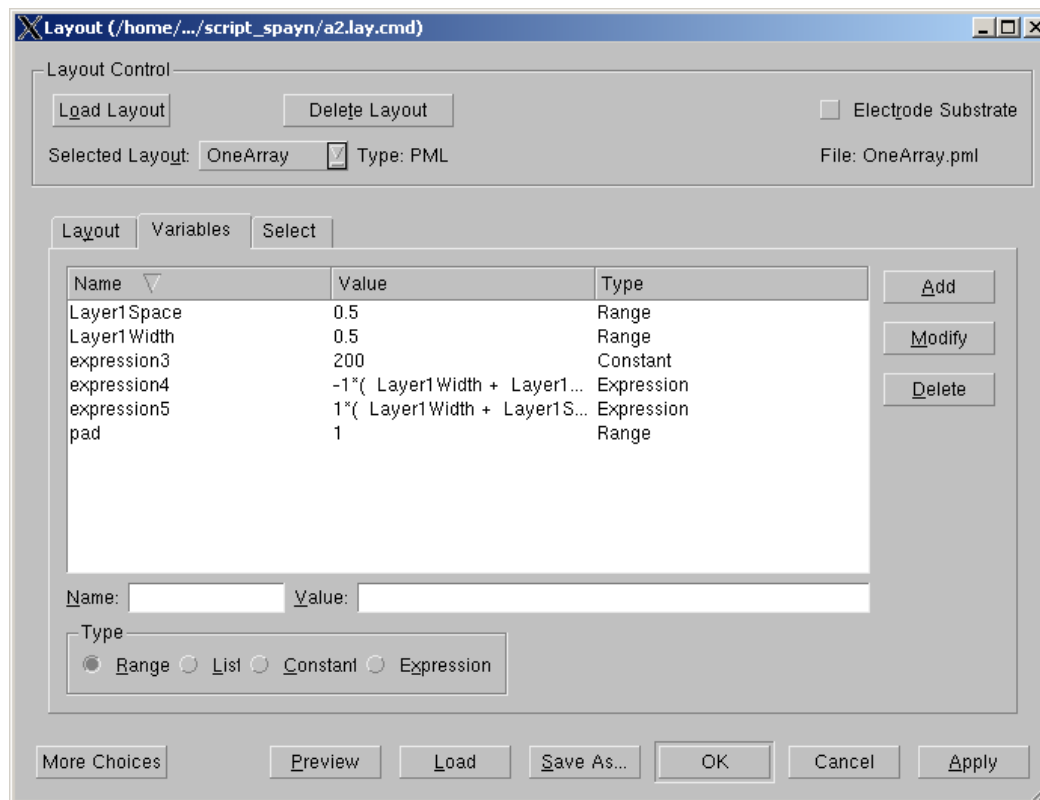


Figure 7.

- Click “Layout...” to bring up the Layout Editor Window
- Click on load layout to load in a layout

Loading a Layout



- Figure 8 shows the layout One Array that has been loaded into the layout GUI
- All of the layout definition is also shown in the figure

Figure 8.

Creating a Layout: More Choices



Figure 9.

- By clicking on the “more choices” button in the layout GUI users have the ability to create a layout themselves (Figure 9)
- User defined layout: “layers” and “wires” button are added to allow you to define any kind of layout

Layout: Combination Selection

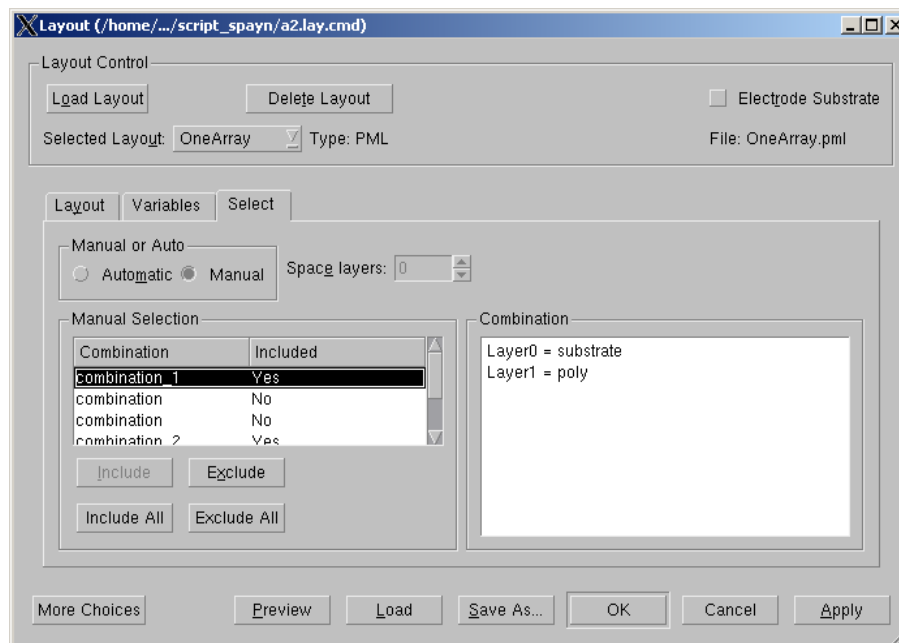


Figure 10.

- Which process layers are assigned to which layout layers is performed via the combination selection in the layout GUI (Figure 10)
- Select these by clicking on “Select”
- You may not be interested in all of them
- For example, you may not be interested in calculating the capacitance between Metal 4 and the substrate because they are very far apart
- You can select such combination individually, or use the automatic selection



Layout: Preview

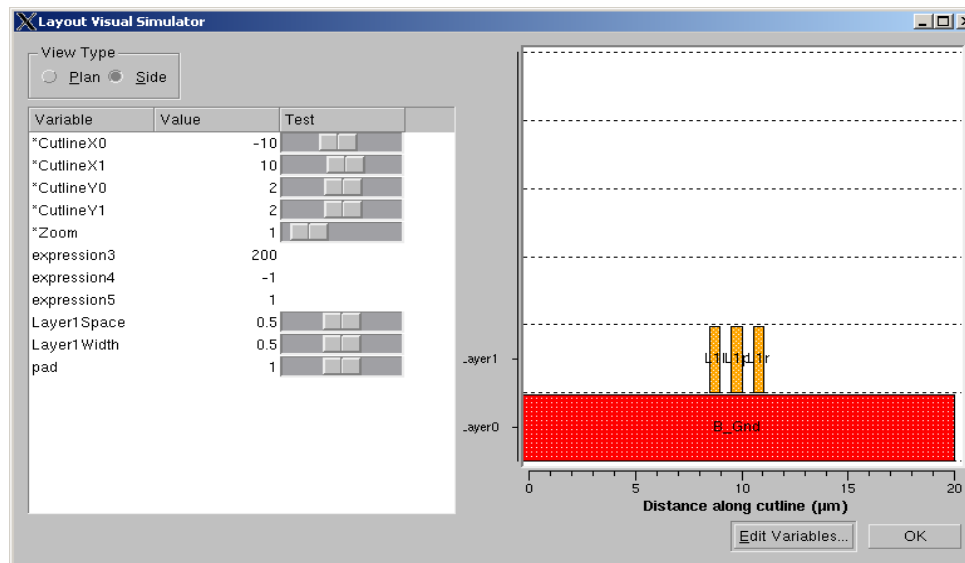
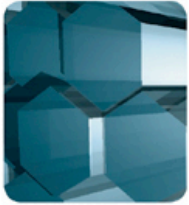


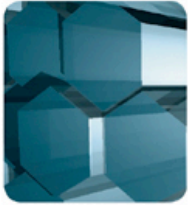
Figure 11.

- Any layout loaded into the layout GUI, or created in the GUI, can be viewed together with any dynamic properties it possesses
- Test structures in EXACT are defined using an interactive menu. Slide bars allow users to observe the effects of layout changes on the parameterized structure



Layout: Preview

- To see each structure click on “preview”
- For plane view, click “plan”
- To see a cross-sectional view “side”
- This gives a cutline using the user definable co-ordinates in the 2D Cutline box
- To visualize the effect of varying the layout parameters, move sliders
- When in 2D or 3D mode use the sliders to vary the parameters



Field Solver

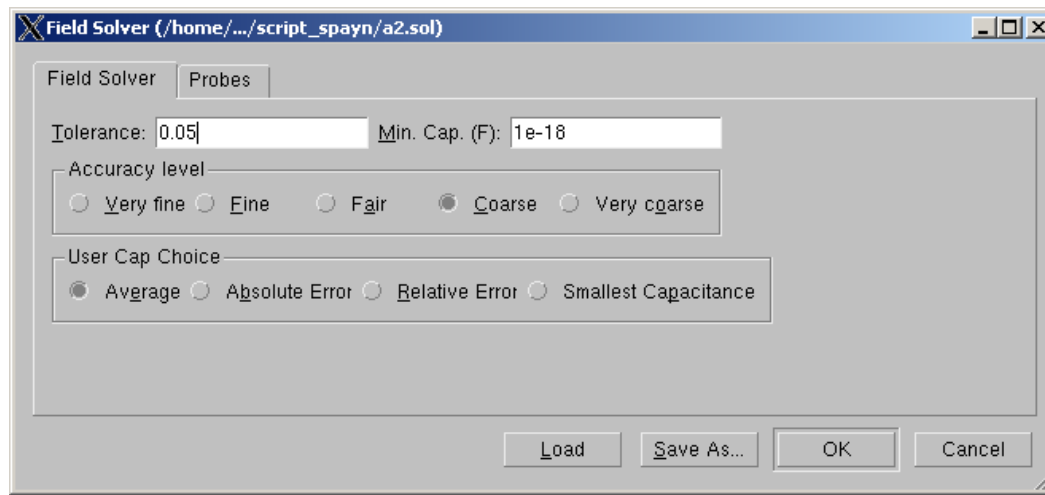
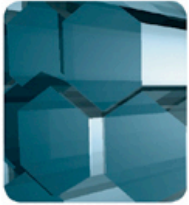


Figure 12.

- Some control of the field solver attributes is given to the user. Figure 12 shows the Field Solver GUI
- Use this window in EXACT to define the accuracy of the simulation using the “tolerance” and the “accuracy level” buttons



Output

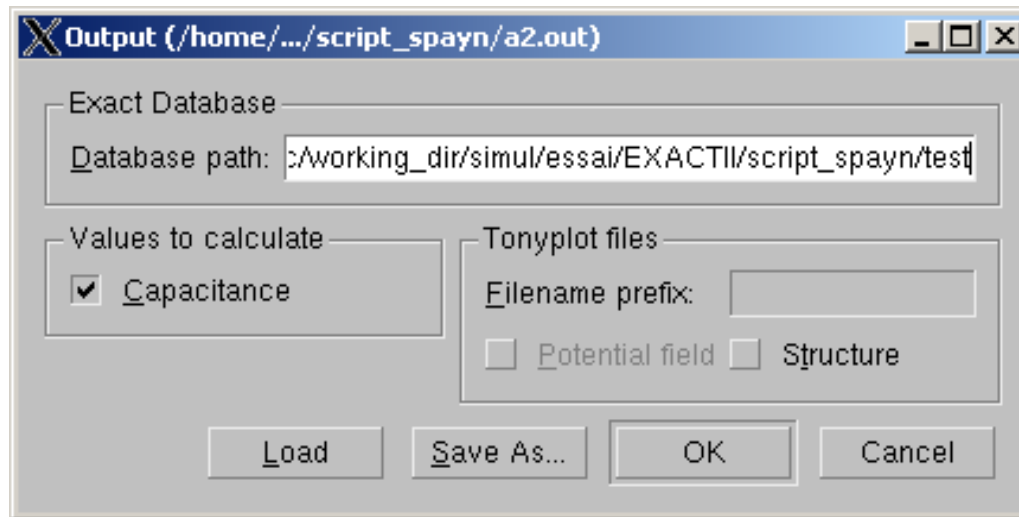
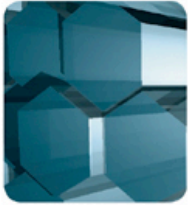


Figure 13.

- Next we must define where the data that EXACT generates is to be stored, the output GUI, Figure 13, allow this to be done
- User defined database location where all the files will be stored
- Structure files can also be saved in order to be visualized using TonyPlot



DOE

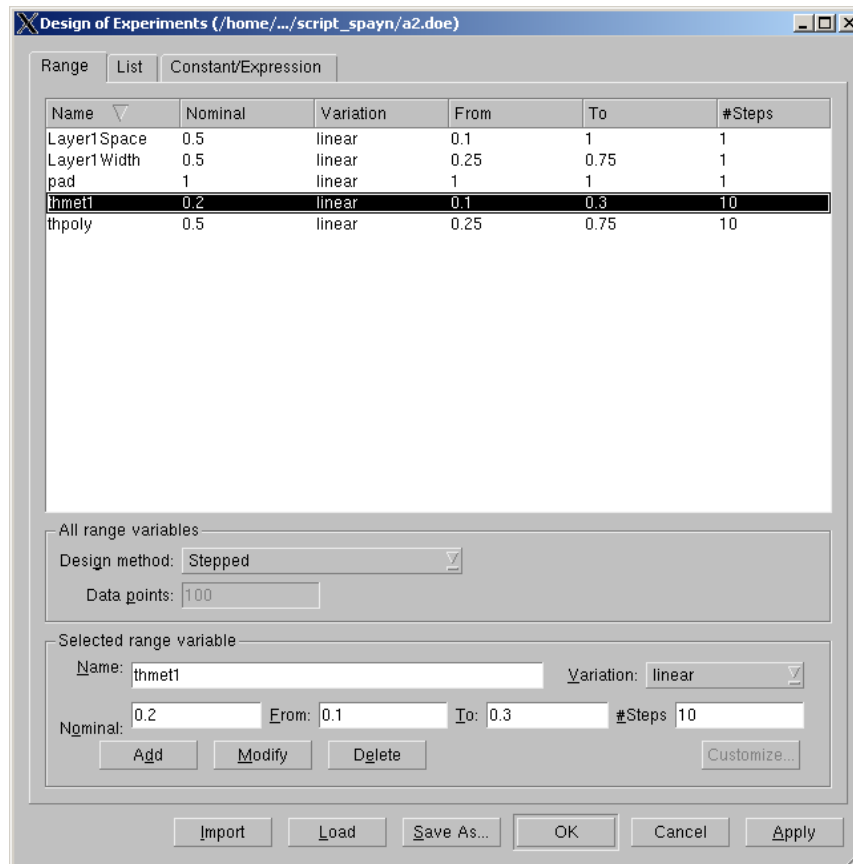


Figure 14.

- The design of experiments stage is entered by clicking on the DOE button, Figure 14
- Click “DOE...” to bring up DOE window
- Use the DOE window to select the variable ranges and sample points
- Flexible design of experiment. (full factorial, stepped, ccc)
- Ability to change design parameters as well as process parameters

Running Simulations

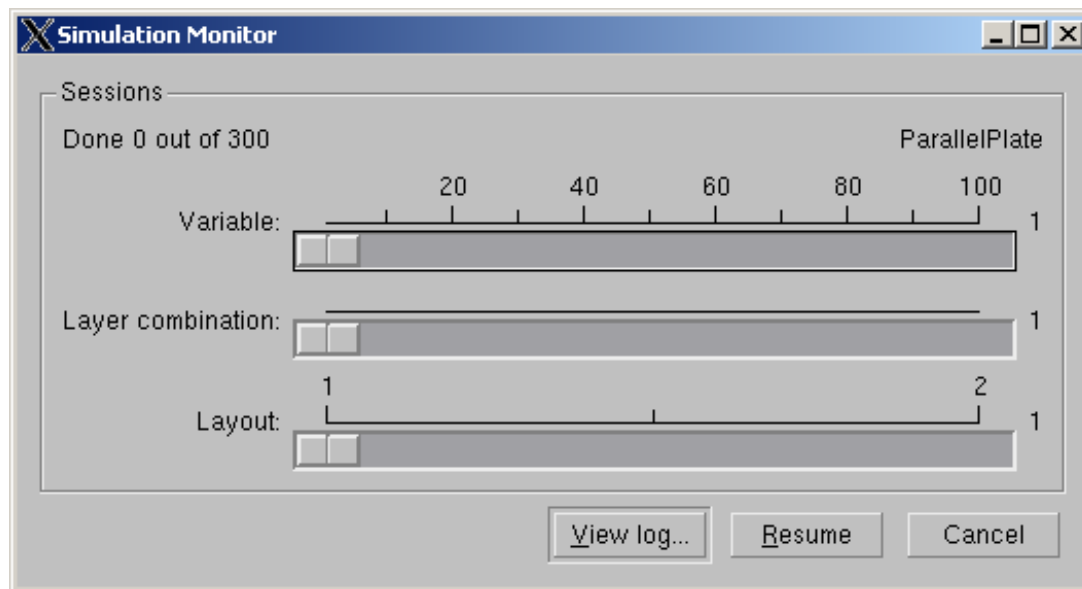
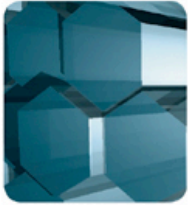


Figure 15.

- After having finished setting up the simulation experiments, we can run them by clicking on the run button. The Run GUI open up, Figure 15
- We can follow the running of the experiment
- At any stage in the execute window, click on view log shows the exact process flow being executed for that particular job, Figure 16



Run

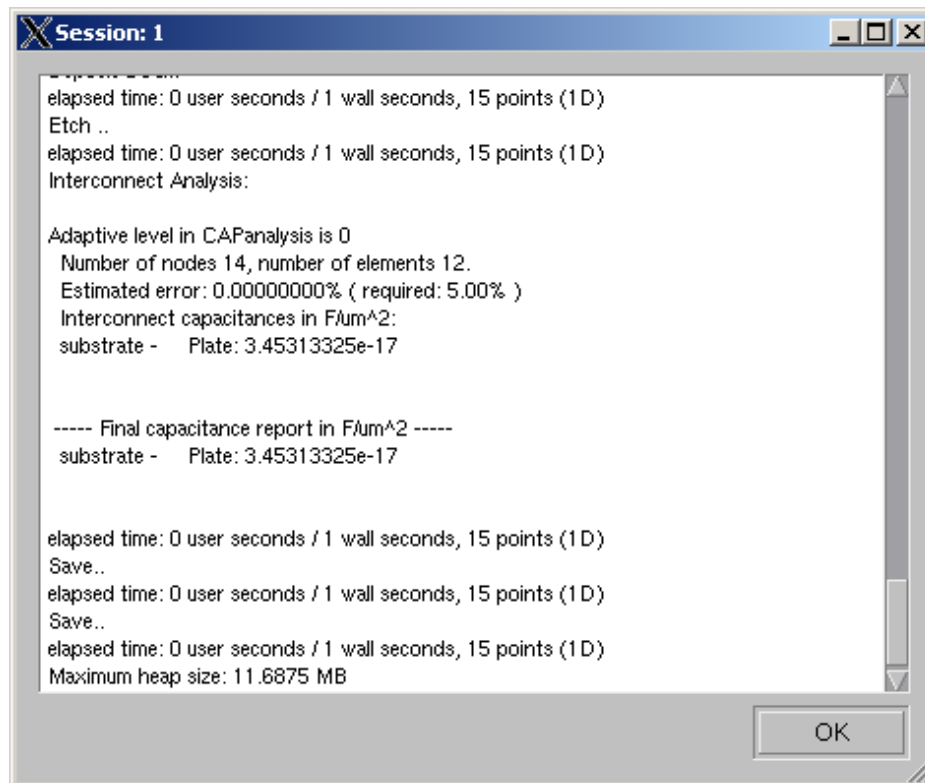
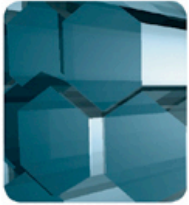


Figure 16.

- At any moment in the run window, click the View Log... button for any of the experiments to visualize the exact process flow being executed for that particular job



Analysis Stage

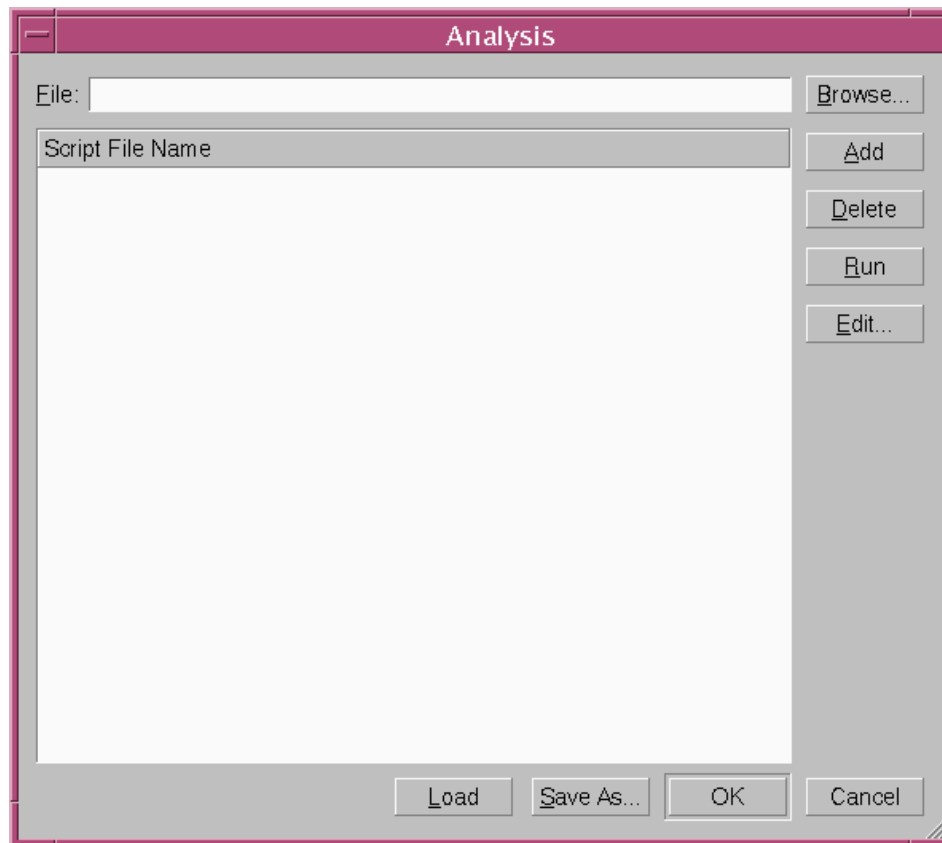
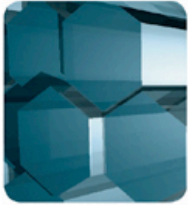


Figure 17.

- Once the experiments have been simulated, click on the analysis window
- We provide scripts to plot all the data (CSV and TonyPlot format)
- The user must now write scripts to format data to LPE tools specific format. We provide templates for Diva™, XCalibre™, and Hipex
- Direct link to SPAYN



Analysis: Script

```
! Script for model3 and model6

db = DatabaseLoad("m26");

extract_name("m3Ctotal", "m3_bgp", "m3_tgp");
extract_name("m26Ctotal", "m26_bmc", "m26_ec");

m3_combinations = {1};
m26_combinations = {1};

table_m3 = select(db, "model_3", m3_combinations, {"m3_bgpwidth", "m3_tgpwidth"}, {"m3Ctotal", "m3_bgpwidth", "m3_tgpwidth"}, {"m3Ctotal", "m3_bgpwidth", "m3_tgpwidth"}, {"m3Ctotal", "m3_bgpwidth", "m3_tgpwidth"});
column_scalar_op(table_m3, "m3Ctotal", table_m3, "m3Ctotal", "+", 1e15);
save_table(table_m3, CSV, "m3_a.csv");

table_m26= select(db, "model_26", m26_combinations, {"m26_ecwidth", "m26_cwidth", "m26_ecwidth", "m26_cwidth", "m26_ecwidth", "m26_cwidth"}, {"m26Ctotal", "m26_ecwidth", "m26_cwidth", "m26_ecwidth", "m26_cwidth"}, {"m26Ctotal", "m26_ecwidth", "m26_cwidth", "m26_ecwidth", "m26_cwidth"});
column_scalar_op(table_m26, "m26Ctotal", table_m26, "m26Ctotal", "+", 1e15);
save_table(table_m26, CSV, "m26_a.csv");

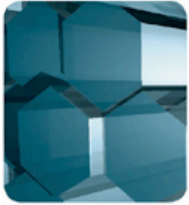
!Perform operations on table_m26 to obtain fringe up capacitance only

merge(table_m3, "m3Ctotal", table_m26);

save_table(table_m26, CSV, "m26_b.csv");
```

Figure 18.

- Load a script file (written in LISA)
- In this example a script has been loaded into the Analysis Stage, (Figure 18)



Analysis: Script Output

```
CAPACITANCE INTRINSIC FRINGE metal2
[
  PROPERTY C
  max_caldistance = 5
  max_distance = 3
  C= 0.0
  if (distance() > 0.0) {
    C =0.01001*(1.0 - exp(-1.65*(distance()+0.075)))*length()
  }
  if (distance() <= 0.0) {
    C = 0.0304042* length()
  }
]

CAPACITANCE NEARBODY poly1

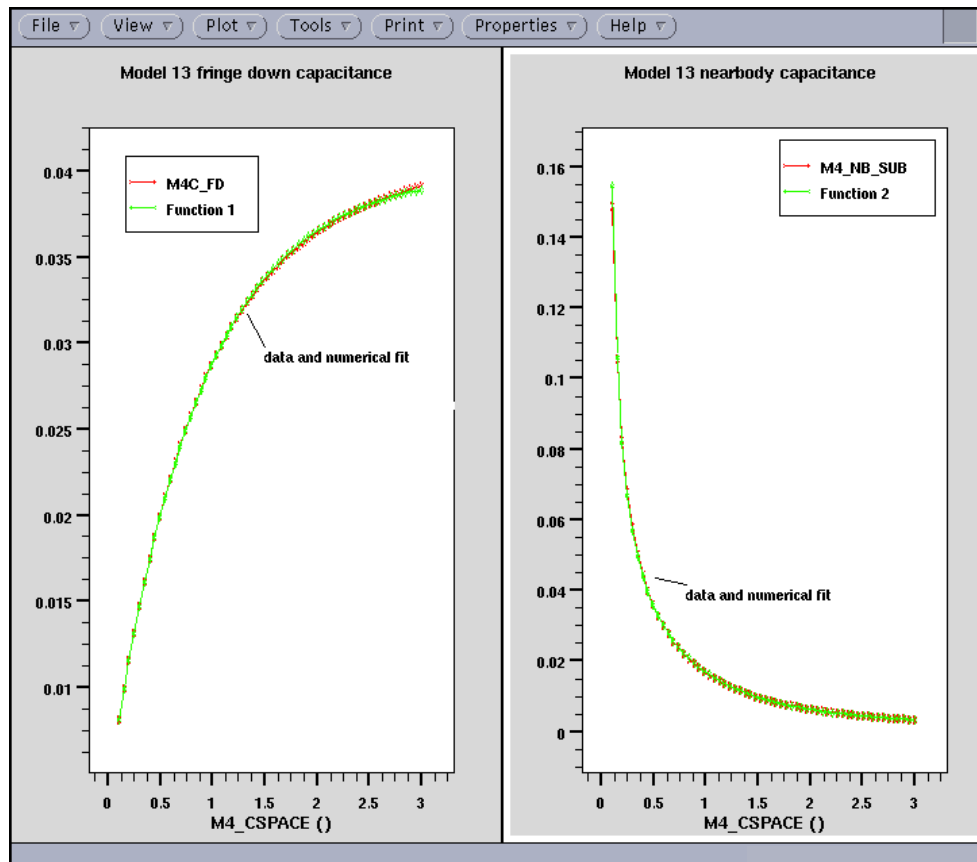
[
  PROPERTY C
  max_width = 3
  max_distance = 3
  C=0.932762*length()*pow(0.1,0.0536348)*1.0*(exp((-distance()*1.60124)-2.96352)
    +(0.00677904/pow(distance(),1.3288)))
]
```

- Mentor Graphics xCalibre™/Calibre xRC™ rule file generated by EXACT using the associated script file

Figure 19.



Filed Solver Results



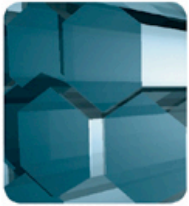
- Field solver results and fitted equation for the structure on the left

Figure 20.



Automatic Models

- Exact can automate the generation of parameters for use in Hipex
- Define a process (in either Standard or Advanced mode)
- Select the Model->Hipex menu
- Exact will load a set of pre-defined layouts that it needs, and run a series of simulations and perform equation fitting to generate the Hipex parameters, all automatically
- You can override the default for the variables used
- Exact saves a LISA file for HIPEX, and saves all of its own project files

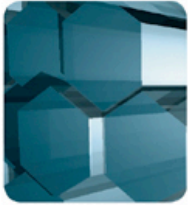


Model Hipex Output

```
Text Editor - hipex.c_cmd
File Edit Format Options Help
|*****|
| CUP_EXTRACT PROCEDURE FOR HIPEX |
|*****|
|*****|
| Coefficient in picoFarads |
|*****|
define procedure cup_extract
do begin
CUP OVERLAP
  /LAYER1 = metal1
  /LAYER2 = poly1
  /vicinity=5
  /area_coef = 3.45313e-05
  /COIND_COEF = 1.49028e-05
  /C_SIDE_DOWN_COEF = 0.02, 1.1, 0.05
  /C_SIDE_UP_COEF = 0.002,0.05,0.1;
CUP LATERAL
  /LAYER1 = metal1
  /vicinity=5
  /k_coef = 0.0011, 0.00786778, 0.00018;
end;
```

- Extract from a Hipex script generated with 'Model Hipex'

Figure 21.



Summary

- Today we have shown you how simple it is to use “EXACT”
 - To create or use existing test structures using a real process flow
 - Either realistic or simple 3D processing can be used
 - Set up and run a design of experiments using a 3D field solver
 - Process the data for LPE tools
- EXACT (will) increases the accuracy of full chip parasitic extraction
- EXACT can be used in conjunction with ANY full chip extraction tool