What makes the difference?
On model quality assurance
Jörg Berkner, Klaus-Willi Pieper
What makes the difference?

Introduction

- We use several circuit simulators, because each one offers specific advantages.
- That is why we have to deliver model parameter sets in different “flavours”.
- A model quality assurance (QA) is mandatory with respect to:
  1. ICCAP+Spectre vs. ICCAP+ADS
  2. Spectre under ICCAP vs. Spectre under Virtuoso
  3. Old vs. new model version
- These checks, however, deliver often different results. Why?
The reasons for deviations in simulation results are (at least) three fold:

1. Simulation condition reasons
2. Circuit related reasons
3. Model implementation reasons

The last point brings up the following question: How to detect model implementation changes?
What makes the difference?

Agenda

1. Simulation condition reasons
2. Circuit related reasons
3. Model implementation reasons
4. How to detect model implementation changes?
What makes the difference?
Simulation problem: TNOM and TEMP

- A simulation using TEMP=27 and TNOM=25 will create of course differences
- But, simulation with TEMP=TNOM may create deviations too!
  - Note: ADS default is TEMP=25, TNOM=25
  - Note: Cadence default is TEMP=27, TNOM=27

**Conclusion:** define the same TNOM in each model card, do not use defaults
What makes the difference?
Simulation problem: Gmin

- Circuit simulator tolerance parameters affect the simulation result, e.g. Vrelto, Vabstol, Ireltol, Iabstol, Gmin

- Especially different default values for Gmin will result in different currents for low Vbe

- Conclusion: define the same Gmin in the ICCAP circuit and for the verification in the design environment
What makes the difference?

Agenda

1. Simulation condition reasons
2. Circuit related reasons
3. Model implementation reasons
4. How to detect model implementation changes?
What makes the difference?
Simulation circuit reasons

- It’s simple: If the simulation circuits for extraction and verification are different, the results *must* be different.
  - $I_{c@V_{ce}} = \text{const.} \neq I_{c@V_{bc}} = \text{const.}$
  - If you use in ICCAP a DUT circuit (e.g. for a Bias T), but in the verification not, the simulation results must be different.
  - If one extracted model parameter is missing in the ICCAP circuit: ICCAP reads the mps file *without error notice*, and uses then the default, instead of the extracted value.

- Conclusion: Use absolute identical circuits, define ALL mp’s in ICCAP!
What makes the difference? Simulation circuit reasons

- Special case: Lateral pnp simulation in Cadence ADS Virtuoso environment
  - Problem: inherit GND connection
  - You have to connect the circuit ground with general node VSS! and connect VSS! to 0V
  - If you use GND only, deviations compared to ICCAP simulation will appear in the high current range
  - Conclusion: Define the inherit ground connection properly!
What makes the difference?

Agenda

1. Simulation condition reasons
2. Circuit related reasons
3. Model implementation reasons
4. How detect model implementation changes?
What makes the difference?
Model implementation reasons

Here are a number of examples for model implementation problems, founding during the last years:

1. Unknown parameters. Example: HFE, HJEI, TSF unknown in Spectre 4.4.3 implementation of HICUM 2.1

2. Different model parameter names: Cbeo in ADS and Cbe0 in Spectre. Creating an ADS-net-file using an Spectre-scs-file using the ADS-netlister resulted in zero oxid-capacitances and, consequently, in different ft-curves.

3. Wrong pin order: HICUM 2.1 (2001) in ADS 1.5, the pin order was BCHEST instead of CBEST.

4. Missing equations: No collector current temperature dependence of HICUM 2.1 in ADS 1.5
What makes the difference?

Agenda

1. Simulation condition reasons
2. Circuit related reasons
3. Model implementation reasons
4. How detect model implementation changes?
What makes the difference?
QA of model implementations

Question: What does a modeling engineer fear most?

Answer: A new simulator version is implemented in the Design Flow and suddenly simulation results with the same model parameters are different compared those of the old simulator version.

Why:
- It can be killing for the product.
- The route cause is hard to detect.
- It means in general new parameter extraction.
What makes the difference?

QA of model implementations

- A *fast test is needed* to check model implementations in different simulator versions against each other.

- Sensitivity analysis delivers *sensitivities with respect to all model parameters*.

- If sensitivities of different simulator versions are different, the *model equations have been changed*.

- That’s the idea of the *Sensitivity-Disaster-Check*.
QA of model implementations in different Simulator versions

- DCOp and AC (100kHz) analysis
- sens analysis with respect to DCOp and AC
- high temperature (150 deg C)
- 1 current I(Vprobe:p)
What makes the difference? QA of model implementations

DC sensitivity analysis for `dcOp':

OutputVariable  Sensitivity  DesignParameter  Value

Vbase:p  -6.4785e+09  npn:is  2.61e-16
Vcoll:p  -4.51642e+11  npn:is  2.61e-16
Vbase:p  3.7813e-05  npn:mcf  1.005
Vcoll:p  0.00263612  npn:mcf  1.005
Vbase:p  0  npn:mcr  1
Vcoll:p  0  npn:mcr  1
Vbase:p  -1.87884e-08  npn:vef  36
Vcoll:p  -1.30972e-06  npn:vef  36

AC sensitivity analysis for `ac':

SweepParameter  SweepValue  OutputVariable  SensitivityReal  SensitivityImag  DesignParameter  Value

freq 100000  Vbase:p  1.55922e+10  6.32781e+06  npn:is  2.61e-16
freq 100000  Vcoll:p  1.26628e+12  -3.04536e+06  npn:is  2.61e-16
freq 100000  Vbase:p  -8.05606e-05  -3.29902e-08  npn:mcf  1.005
freq 100000  Vcoll:p  -0.00666218  1.67748e-08  npn:mcf  1.005
freq 100000  Vbase:p  0  0  npn:mcr  1
freq 100000  Vcoll:p  0  0  npn:mcr  1
freq 100000  Vbase:p  4.62392e-08  1.8741e-11  npn:vef  36
...
QA of model implementations in different Simulator versions

Comparison of sensitivities of HICUM Level 0 version 1.2 (DC)

<table>
<thead>
<tr>
<th>Version</th>
<th>mmsim_7.1.0.isr3</th>
<th>mmsim_7.1.0.isr3</th>
<th>mmsim_7.2.0.isr15</th>
<th>mmsim_7.2.0.isr15</th>
<th>DeltaSens</th>
<th>DeltaMPvalue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Sensitivity</td>
<td>MPvalue</td>
<td>Sensitivity</td>
<td>MPvalue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>af</td>
<td>0,000377809</td>
<td>0,5221</td>
<td>0,00039932</td>
<td>0,4791</td>
<td>1,0000000</td>
<td>-0,4791</td>
</tr>
<tr>
<td>ahc</td>
<td>0,000377809</td>
<td>0,5221</td>
<td>0,00039932</td>
<td>0,4791</td>
<td>1,0000000</td>
<td>-0,4791</td>
</tr>
<tr>
<td>ahcx</td>
<td>-3,66E-06</td>
<td>1,246</td>
<td>0,00006042</td>
<td>2,50E+00</td>
<td>1,0000000</td>
<td>-2,5</td>
</tr>
<tr>
<td>aje</td>
<td>0,000377809</td>
<td>0,5221</td>
<td>0,00039932</td>
<td>0,4791</td>
<td>1,0000000</td>
<td>-0,4791</td>
</tr>
<tr>
<td>ajedc</td>
<td>0,000377809</td>
<td>0,5221</td>
<td>0,00039932</td>
<td>0,4791</td>
<td>1,0000000</td>
<td>-0,4791</td>
</tr>
<tr>
<td>alt0</td>
<td>0,000377809</td>
<td>0,5221</td>
<td>0,00039932</td>
<td>0,4791</td>
<td>1,0000000</td>
<td>-0,4791</td>
</tr>
</tbody>
</table>

- new parameters (ahcx and ajedc) were implemented in mmsim7.2.0
- parameters ahc and aje lost sensitivity in mmsim7.2.0
## Comparison of sensitivities of HICUM Level 0 version 1.2 (AC)

<table>
<thead>
<tr>
<th>Version</th>
<th>SensReal</th>
<th>SensImag</th>
<th>SensReal</th>
<th>SensImag</th>
<th>DeltaReal</th>
<th>DeltImag</th>
</tr>
</thead>
<tbody>
<tr>
<td>mmsim_10.1.0.isr1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>mmsim_10.1.0.isr1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>mmsim_11.1.0.isr12</td>
<td>-2.05E-09</td>
<td>-4.32E-06</td>
<td>-2.06E-09</td>
<td>0.00000432</td>
<td>0.012896</td>
<td>0.0000000</td>
</tr>
<tr>
<td>mmsim_11.1.0.isr12</td>
<td>-2.06E-09</td>
<td>-4.32E-06</td>
<td>-2.06E-09</td>
<td>0.00000432</td>
<td>0.012896</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ahc</td>
<td>-2.71E-05</td>
<td>9.40E-07</td>
<td>-2.71E-05</td>
<td>0.00000094</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ahcx</td>
<td>9.40E-07</td>
<td>-2.71E-05</td>
<td>0.00000094</td>
<td>1.0000000</td>
<td>1.0000000</td>
<td></td>
</tr>
<tr>
<td>ahq</td>
<td>-2.71E-05</td>
<td>0.00000094</td>
<td>1.0000000</td>
<td>1.0000000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aje</td>
<td>-6.14E-11</td>
<td>-2.20E-07</td>
<td>-4.20E-10</td>
<td>-2.20E-07</td>
<td>0.7447450</td>
<td>0.0000000</td>
</tr>
<tr>
<td>ajedc</td>
<td>-0.00000376</td>
<td>6.68E-08</td>
<td>-3.76E-06</td>
<td>6.68E-08</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
<tr>
<td>alt0</td>
<td>-1.40E-07</td>
<td>-4.93E-04</td>
<td>-3.10E-07</td>
<td>-4.93E-04</td>
<td>0.3777778</td>
<td>0.0000000</td>
</tr>
<tr>
<td>cjci0</td>
<td>-1.09E+02</td>
<td>-4.07E+05</td>
<td>-1.09E+02</td>
<td>-4.07E+05</td>
<td>0.0000000</td>
<td>0.0000000</td>
</tr>
</tbody>
</table>

- new parameters (ahq) were implemented in mmsim11.1.0.isr12
- parameters aje and alt0 changed real part of sensitivity
QA of model implementations in different Simulator versions

Example: HICUM, Level 0, Version 1.2

<table>
<thead>
<tr>
<th>Compared mmsim versions</th>
<th>No. of changed parameter sensitivities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Version 1</td>
<td>Version 2</td>
</tr>
<tr>
<td>mmsim/6.0.2.164</td>
<td>mmsim/6.2.0.isr5</td>
</tr>
<tr>
<td></td>
<td>DC</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td></td>
<td>AC</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td>mmsim/6.2.0.isr5</td>
<td>mmsim/7.1.0.isr3</td>
</tr>
<tr>
<td></td>
<td>clean</td>
</tr>
<tr>
<td></td>
<td>clean</td>
</tr>
<tr>
<td>mmsim/7.1.0.isr3</td>
<td>mmsim/7.2.0.isr15</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
</tr>
<tr>
<td>mmsim/7.2.0.isr15</td>
<td>mmsim/10.1.0.isr1</td>
</tr>
<tr>
<td></td>
<td>clean</td>
</tr>
<tr>
<td></td>
<td>clean</td>
</tr>
<tr>
<td>mmsim/10.1.0.isr1</td>
<td>mmsim/11.1.0.isr12</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td>VerilogA (5 nodes)</td>
<td>mmsim/11.1.0.isr12 (5 nodes)</td>
</tr>
<tr>
<td></td>
<td>1 (vr0c)</td>
</tr>
<tr>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>
QA of model implementations in different Simulator versions

- Complete results

Microsoft Office Excel Worksheet

- Questions?
- Let’s discuss!
ENERGY EFFICIENCY
MOBILITY
SECURITY

Innovative semiconductor solutions for energy efficiency, mobility and security.