Behavioral compact models of IGBTs and Si-diodes for data sheet simulations using a machine learning based calibration strategy

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Motivation
Customer point of view

www.infineon.com/ifxdesigner

- Infineon product portfolio „discrete“
- 225 a&p products in 20 technologies
- 167 Duo Packs (IGBT + diode)

- Web-based simulator **IFX Designer**
- No license costs, no installation
- **Fast & robust** simulation performance

- Behavioral compact models (Level 1) IGBT & Si-diode
- Automated calibration routine based on **machine learning**

- Thermal design?
- Parasitical turn-on?
- Current/Voltage class?
- Gate driver?
- …?
Agenda

1. Compact modelling
2. Machine learning
3. Results
4. Conclusion
Compact modelling
Compact modelling
Equivalent circuit of the IGBT Level 1 model
Compact modelling
Model approach used for the IGBT

Requirements

- Fast, robust & accurate

Behavioral model = Black box model

- Evaluation at the outer nodes C, G, E, K
- but not at the inner nodes

Behavioral modelling based on

- physical elements (pn, MOS)
- pure fitting elements
- but not on the real device structure
  - Oxide thickness, doping concentration, …
  - Differential equations, FDM-method,
  - … in contrast to a physics-based Level 2 model

Quality of the Level 1 model depends on

- the quality of the reference characteristics
- the availability of different characteristics
Machine learning
Machine learning
Overview of the calibration strategy

"Input data"
- Behavioral model (IGBT & Si-diode)
- Active chip area
- Parameter ranges
- Test circuits

"SPICE simulator"

"Reference data"
- Data sheet
  - Curves
  - Table values

"Consistency check"
References

"Stage 1"
Diode static $T_{\text{min}}$ & $T_{\text{max}}$

"Stage 2"
Diode switching $T_{\text{min}}$ & $T_{\text{max}}$

"Stage 3"
IGBT static $T_{\text{min}}$ & $T_{\text{max}}$

"Stage 4"
IGBT dynamic

"Stage 5"
IGBT switching $T_{\text{min}}$ & $T_{\text{max}}$

"Calibrated Level 1 model"
Machine learning
Flow chart for each individual stage

Data preparation
› Data cleaning
› Data validation
› Redundancy reduction

Model input/output
› Input
  - Stimuli
  - Model parameters
› Output
  - Simulation responses
  - Reference responses

Error weighting
› Specific weightage of individual errors

Machine learning
› Differential evolution algorithm
Machine learning
Differential evolution algorithm used for calibration

Machine learning algorithm
- Inspired by real life evolution
- The **fittest** species survive...
- ... and gives **offspring**
- **Mutations** happen...
- ... and the **population** gets “better”

Error evolution

Population size of \( x \)

- **Initialization**
  - Target member
- **Mutation**
  - Donor
- **Recombination**
  - Trial
- **Selection**
  - Survivor

- \( \Delta = \ldots \)

Error evolution [1]
Machine learning
Fitting evolution on the example of stage 3

Output characteristic

Transfer characteristic

Reference: solid line
Simulation: dashed line

\[ I_C \text{ [A]} \]

\[ V_{CE} \text{ [V]} \]

\[ I_C \text{ [A]} \]

\[ V_{GE} \text{ [V]} \]
Results
Results
Infineon DuoPack AIKW50N60CT

Stage 1
9 parameter / 10 responses

Stage 2
4 parameter / 4 responses

Stage 3
24 parameter / 60 responses

Stage 4
8 parameter / 35 responses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data sheet</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{rr}$ [$\mu$C] (25°C)</td>
<td>1.80</td>
<td>1.80</td>
</tr>
<tr>
<td>$Q_{rr}$ [$\mu$C] (175°C)</td>
<td>4.30</td>
<td>4.30</td>
</tr>
<tr>
<td>$I_{rms}$ [A] (25°C)</td>
<td>27.7</td>
<td>27.7</td>
</tr>
<tr>
<td>$I_{rms}$ [A] (175°C)</td>
<td>40.7</td>
<td>40.7</td>
</tr>
</tbody>
</table>
Results
Infineon DuoPack AIKW50N60CT

Stage 5
6 parameter / 12 responses

Weighting Factors
- Switching energies ($E_{on}$, $E_{off}$)
- Switching times ($t_{don}$, $t_{r}$, $t_{doff}$, $t_{f}$)
Conclusion

Compact modelling

› Improved robustness…
› Simulation time reduced by a factor of ~10-100…
› Model development time reduced…
   … in contrast to a physics-based Level 2 model

Future goals

› Availability of Level 1 models in addition to former Level 2 models
› Usability of a Verilog-A version for the Infineon simulation environment
› Extended implementation of physical effects in work

Machine learning

› No human errors…
› Calibration time reduced by a factor of ~200…
› High scalability of the setup…
   … in contrast to a human-based strategy

Customer support

› Usage of device models of the product portfolio
› Accurate reproduction of data-sheet characteristics
› Online/Offline simulation
   – IFX Designer
   – SIMetrix, PSpice, LTspice

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