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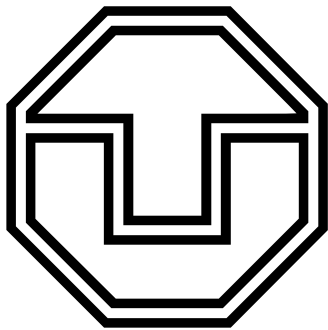
# Overview of Free Software Packages for Compact Modeling

M. Müller<sup>1,3</sup>, P. Kuthe<sup>1,2</sup>, M. Krattenmacher<sup>1,3</sup>, M. Schröter<sup>1</sup>

<sup>1</sup>Chair for Electron Dev. & Integr. Circ., TU Dresden, 01062 Dresden, Germany

<sup>2</sup>Infineon Technologies AG, 85579 Neubiberg, Germany

<sup>3</sup>SemiMod UG (haftungsbeschränkt), Dresden, Germany



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# Outline

- Introduction
- Circuit Simulators
- Measurement Automation
- Parameter Extraction Tools
- TCAD Tools
- DMT\_core
- Summary

# Introduction

- tasks faced by device engineers
    - dealing with large quantities of data
    - mathematical optimization
    - interfacing measurement equipment
    - interfacing circuit/TCAD simulators
    - dealing with complicated model equations
    - documentation of extraction results
- => These are software problems!*
- for solving most of these problems, either custom scripts or proprietary software are used in industry and academia
  - free/open source software exists that can help

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## Why License Free/Open Source software?

- save money
- no longterm licensing issues
- can easily be customized for specific problem at hand
- vast knowledge and support available online (Stackoverflow...)
- enables cooperation

### Examples:

- control an instrument but drivers are not available in ICCAP? => *Python with GPIB interface or SweepMe*
- run circuit simulations but company has limited licenses? => *NGspice, Xyce, QucsStudio...*
- automate generation of GDS2 layouts, e.g. for test-structure design? => *Python and/or KLayout*

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# Circuit Simulators

- NGspice: open source, no GUI, based on Spice3, quite limited Verilog-A support, very fast, many models (including HICUM/L2 v2.4.0) built-in
- Xyce: open source, no GUI, Verilog-A code linking difficult, limited number of built-in models
- QucsStudio: not open source, nice GUI, weird netlist format, good Verilog-A support, not available for Linux

*=> Live Demo: Exemplary Ngspice and Xyce netlist*

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## Circuit Simulator Issues and Outlook

- Typically, open source simulators run faster in batch mode than commercial ones due to overhead w.r.t. to licensing and utilities not required for compact modeling.

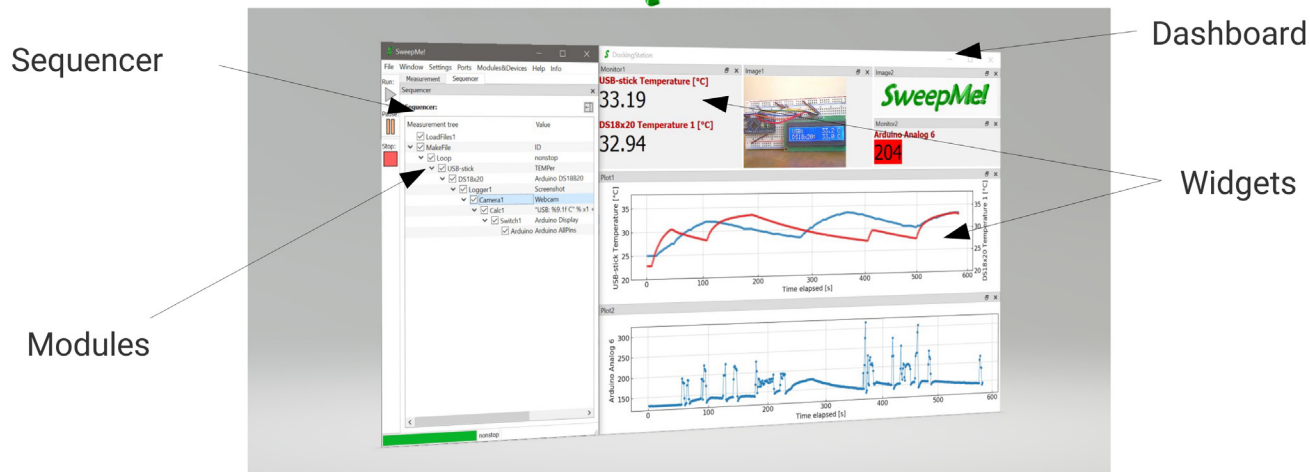
*=> Live demo: ADS simulation of same netlist as before*

- future developements targetting better Verilog-A integration in Ngspice and Xyce welcome
- major issue: Reading back data as time-intensive as circuit simulation itself due to inefficient data output formats  
*=> Output in HDF5 format would be useful*

# Measurement Automation - SweepMe!

- free to use software: SweepMe! ( [sweep-me.net](http://sweep-me.net) )
- test & measurement software
- results are visualized by drag & drop of modules in sequencer
- open-source instrument drivers are shared across all users
- one can pay for custom device drivers or program them oneself

*SweepMe!*



*=> Live: Video on SweepMe homepage*

# Measurement Automation - PyVisa

- first proposed option: Python with PyVisa package to control and automate measurements
  - extreme flexibility
  - know exactly what is happening
  - can use instruments not supported by ICCAP (Keysight focused)

Our scripts typically look like this:

```
def force_voltage(self, channel, voltage, current_limit=None):  
    if self.channel_available(channel):  
        if current_limit is not None:  
            self.set_current_limit(channel, current_limit)  
        # turn automatic ranging on  
        self.write("SOURCE%i:VOLTAGE:RANGE:AUTO 1" % channel)  
        self.write("SOURCE%i:VOLTAGE:AMPLITUDE %.4f" % (channel, voltage))  
        self.write("SOURCE%i:FUNCTION:MODE VOLTAGE" % channel)
```

=> However, this solution requires high implementation effort  
(days) by lab engineer



# VerilogAE

- Verilog-A compiler for use in Python ([www.dspom.gitlab.io/verilogae](http://www.dspom.gitlab.io/verilogae))
- provides access to all model equations in a given Verilog-A source file, information regarding model parameters and more ....
- useful for dealing with complicated models and implementing parameter extraction steps
- developed by Pascal Kuthe [1]

=> *Live: Compile HICUM/L2 and access  $I_T$  model equation*

Access full  $I_T$  model without implementing any equation by hand:

```
import hicumL2V2p4p0_vae
it = hicumL2V2p4p0_vae.functions["it"].eval(
    temperature=300,
    voltages={"br_biei": vbe, "br_bici": vbc,
    **modelcard,
)
```

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# Scipy

- open source software library for science and engineering
- provides mathematical algorithms, convenience functions and plotting capabilities in Python
- syntax similar to Matlab
- one of the most used software packages in the world  
=> great support by large community

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# PyLatex

- open source Python library for automatically generating Latex documents
- ideal for analyzing large amounts of measurement data and generating reports that need to be delivered regularly

Example for syntax:

```
with doc.create(Section('A section')):  
    doc.append('Some regular text and some ')  
    doc.append(italic('italic text. '))
```

```
with doc.create(Subsection('A subsection')):  
    doc.append('Also some crazy characters: $&#{{}')
```

=> *Live: Show measurement report generated with PyLatex*

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# KLayout

- widely used layout tool developed by Matthias Köfferlein
- view, edit, generate and analyze layouts
- very user-friendly GUI and intuitive controls
- comes with excellent Python library for automating layout tasks

*=> Live demo: Show exemplary layout and measure some distance*

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# TCAD

- for SiGe HBTs no open-source TCAD simulator is useful for modern technologies due to lack of material models and boundary conditions  
=> *TUD in-house DD&HD solver to become open source?*
- for MOSFETs several alternatives exist, see <https://tcadcentral.com/Software.html>
- recent publication: Open-source simulator NESS [2] provides many advanced transport formalisms
- Purdue Nanohub: wide range of TCAD programs

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# DMT\_core

- Device Modeling Toolkit (DMT) "glues" together all software components required for device engineers [3]:
  - data management with Pandas library
  - interface specification for circuit/TCAD simulators
  - electrical engineering relevant data transforms
- rights for DMT acquired by SemiMod, DMT split into two packages:
  - DMT\_core: Basic data management and interfaces to open-source circuit simulators

*=> DMT\_core is GPL licensed and will be released in the near future!*

- DMT\_other: interface proprietary tools, parameter extraction infrastructure

*=> DMT\_other will not be open-source, available for cooperation partners only.*

# Summary

- many device engineering related tasks can be solved using freely available software
- the more people contribute to open-source, the better for everyone involved (example: AI community, mobile communications community)

Open source/free software is important in our field and demand for it will only increase in the future

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Axel Fischer (SweepMe! GmbH)



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