Thermal and Mechanical System Simulation

ANSYS CONFERENCE & 27. CADFEM USERS' MEETING
18 – 20 November 2009, Congress Center Leipzig

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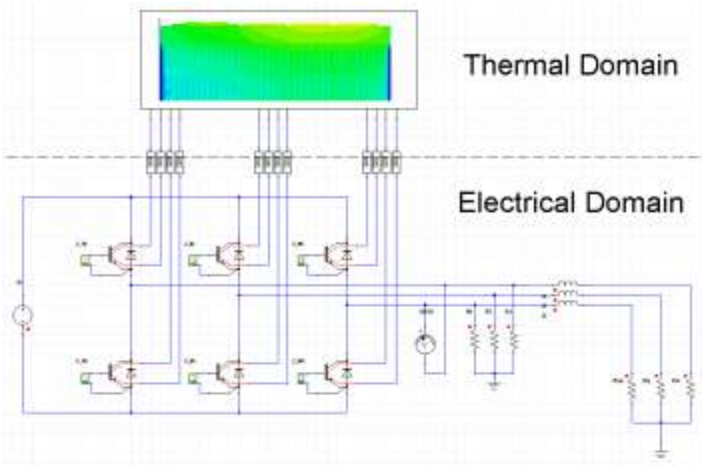
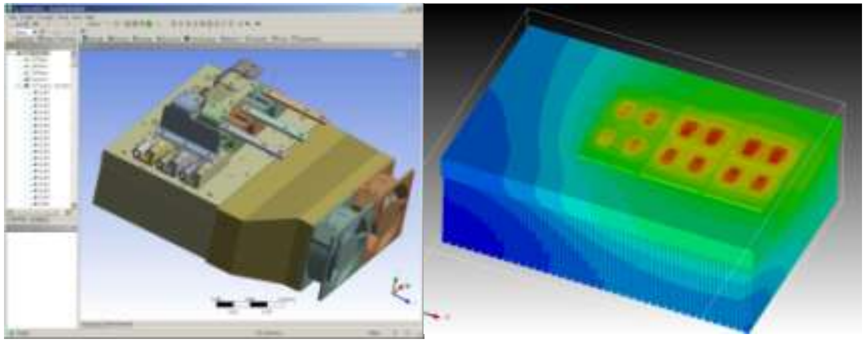
CADFEM

Outline

- System level simulation
  - Simplorer
- Coupling Workbench and Simplorer
  - Model Order Reduction
- Thermal simulation
  - Electrothermal
- Mechanical simulation
  - Control
- Other papers at ACUM





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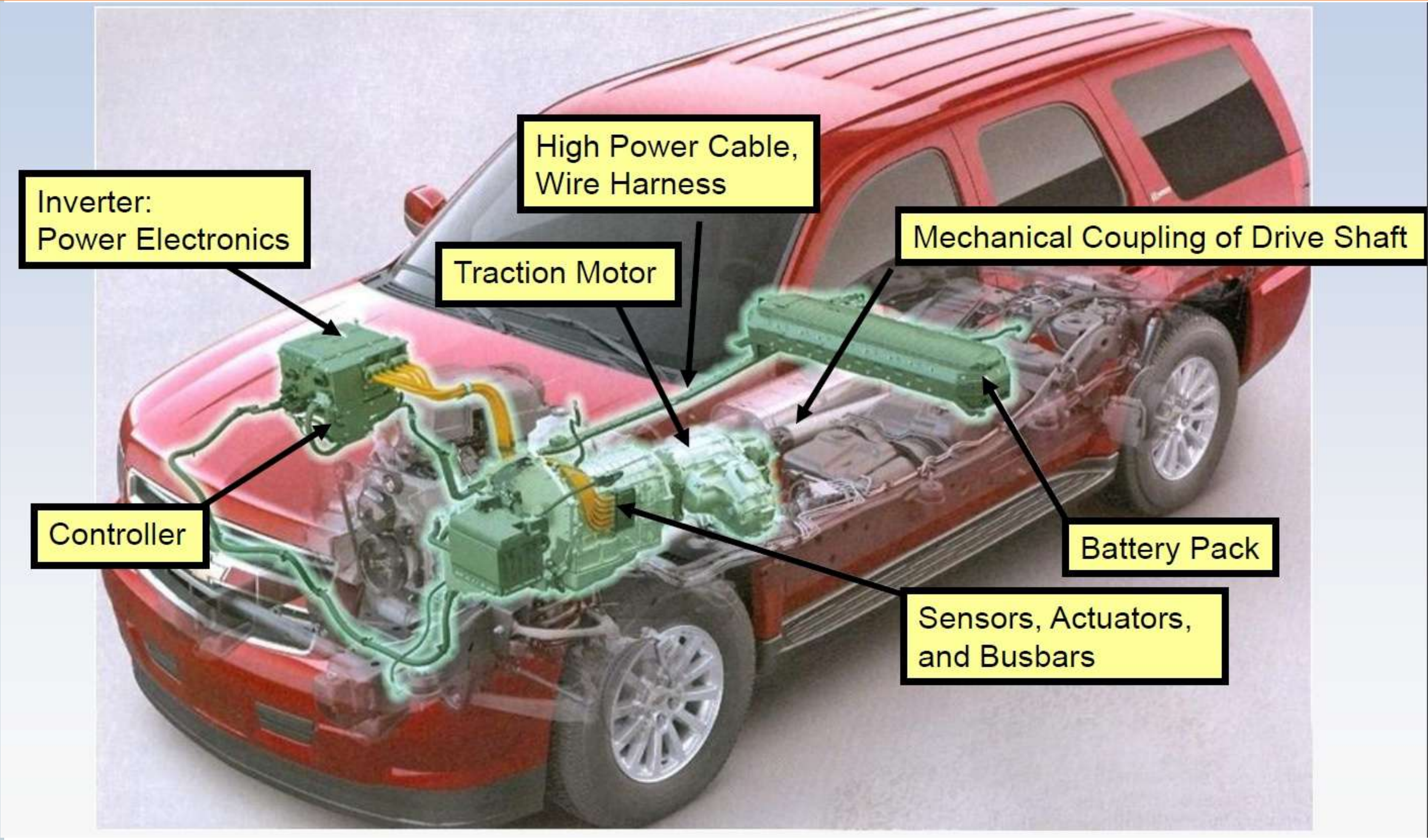
Mechatronics: mechanical + electrical + computer sciences



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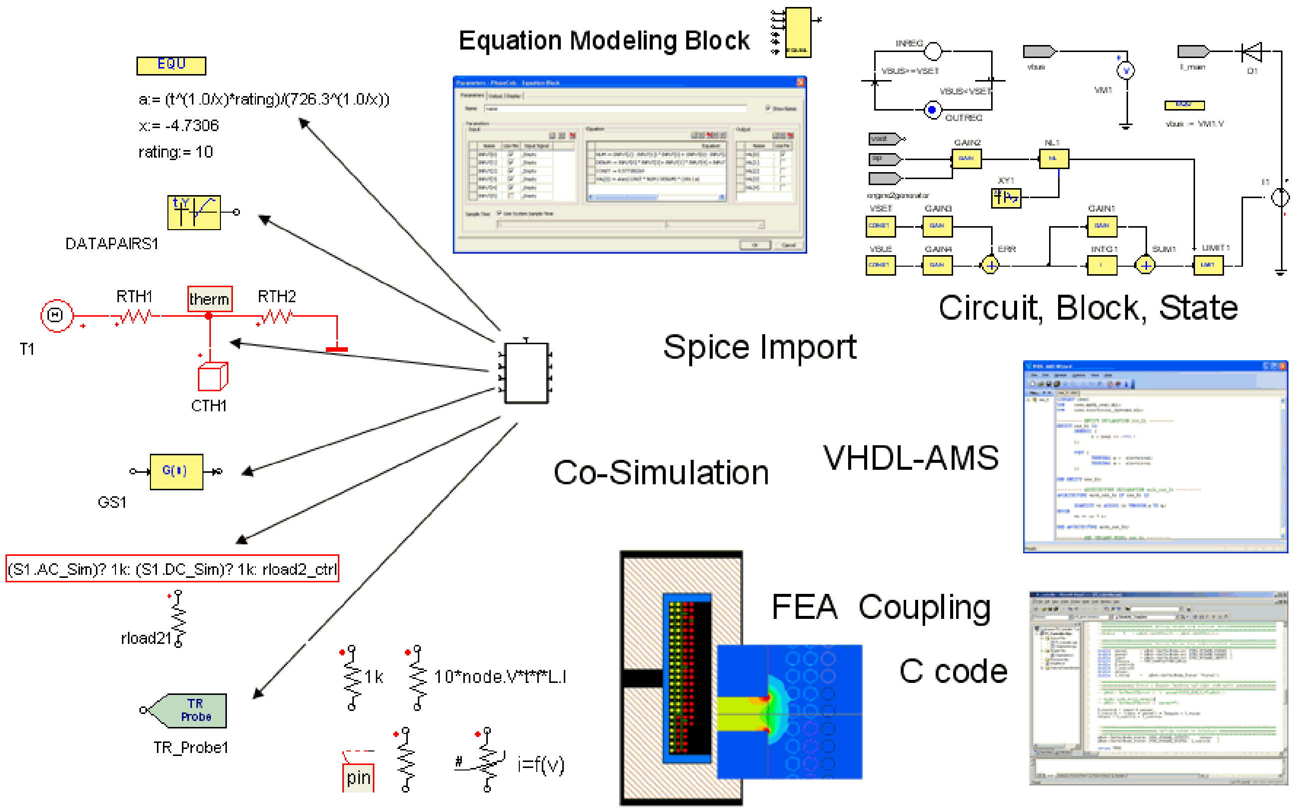
Simplorer: http://www.ansoft.com/

- Circuits
- Block Diagrams
- State Machines
- Equation Blocks
- VHDL-AMS



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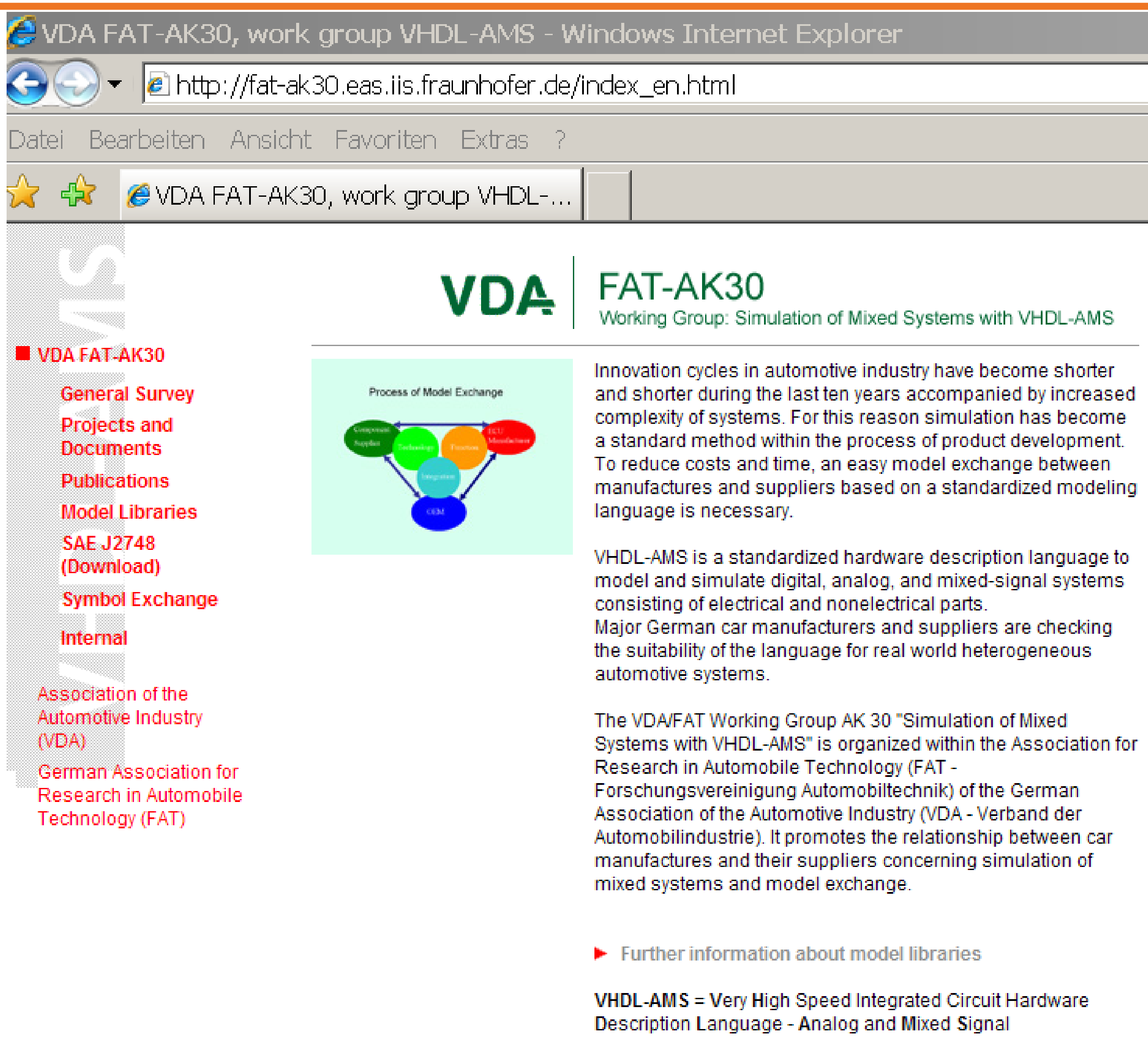
Example of VHDL-AMS



VDA FAT-AK30, work group VHDL-AMS - Windows Internet Explorer

http://fat-ak30.eas.iis.fraunhofer.de/index_en.html

Datei Bearbeiten Ansicht Favoriten Extras ?

VDA FAT-AK30, work group VHDL-...

VDA | FAT-AK30
Working Group: Simulation of Mixed Systems with VHDL-AMS

- VDA FAT-AK30
  - General Survey
  - Projects and Documents
  - Publications
  - Model Libraries
  - SAE J2748 (Download)
  - Symbol Exchange
  - Internal

Association of the Automotive Industry (VDA)

German Association for Research in Automobile Technology (FAT)

Process of Model Exchange

Innovation cycles in automotive industry have become shorter and shorter during the last ten years accompanied by increased complexity of systems. For this reason simulation has become a standard method within the process of product development. To reduce costs and time, an easy model exchange between manufactures and suppliers based on a standardized modeling language is necessary.

VHDL-AMS is a standardized hardware description language to model and simulate digital, analog, and mixed-signal systems consisting of electrical and nonelectrical parts.
Major German car manufacturers and suppliers are checking the suitability of the language for real world heterogeneous automotive systems.

The VDA/FAT Working Group AK 30 "Simulation of Mixed Systems with VHDL-AMS" is organized within the Association for Research in Automobile Technology (FAT - Forschungsvereinigung Automobiltechnik) of the German Association of the Automotive Industry (VDA - Verband der Automobilindustrie). It promotes the relationship between car manufactures and their suppliers concerning simulation of mixed systems and model exchange.

▶ Further information about model libraries

VHDL-AMS = **V**ery **H**igh **S**peed **I**ntegrated **C**ircuit **H**ardware **D**escription **L**anguage - **A**nalog and **M**ixed **S**ignal

Compact Modeling: Transistor Compact Model

$$I_E = I_{F0}(e^{qV_{EB}/kT} - 1) - \alpha_R I_{R0}(e^{qV_{CB}/kT} - 1)$$
$$I_E = \alpha_F I_{F0}(e^{qV_{EB}/kT} - 1) - I_{R0}(e^{qV_{CB}/kT} - 1)$$

Too much reliance on intuition

$$-\varepsilon\nabla^2\Psi = q(p - n + N_0)$$
$$\frac{\partial n}{\partial t} = \nabla \bullet (-\mu_n n \nabla\Psi + D_n \nabla n) - R_n$$
$$\frac{\partial p}{\partial t} = \nabla \bullet (\ \mu_p p \nabla\Psi + D_p \nabla p) - R_p$$

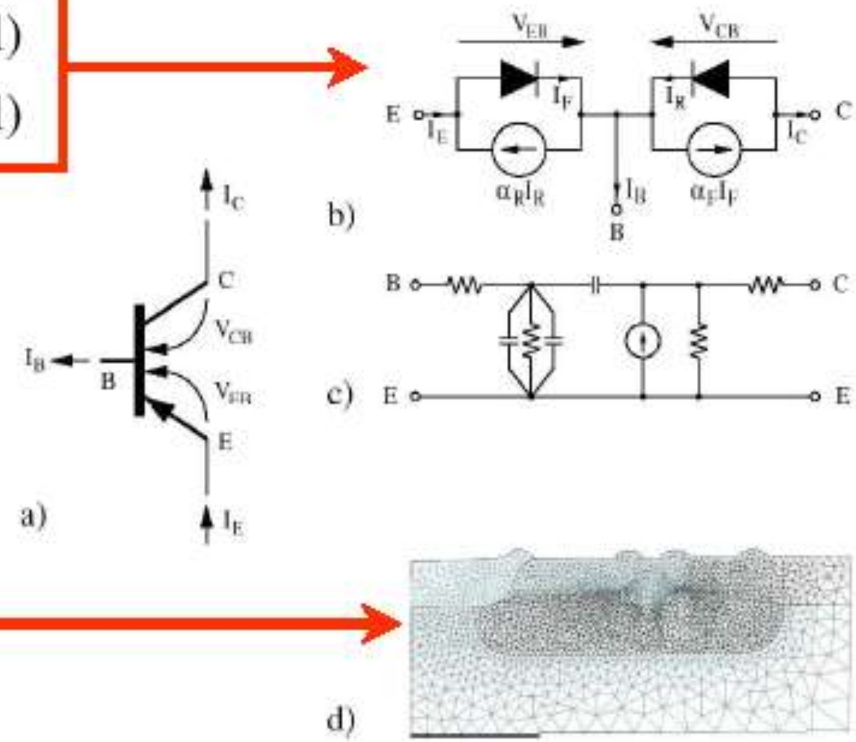


Figure from J. Lienemann, E. B. Rudnyi and J. G. Korvink. MST MEMS model order reduction: Requirements and Benchmarks. Linear Algebra and its Applications, v. 415, N 2-3, p. 469-498, 2006.

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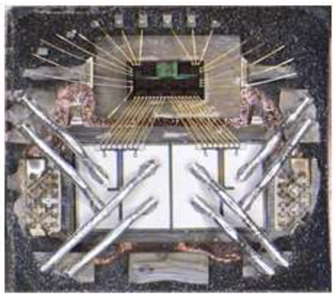
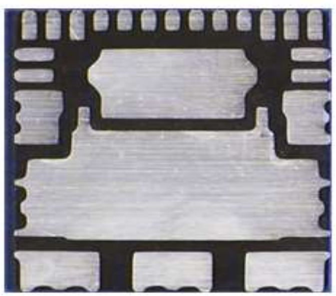
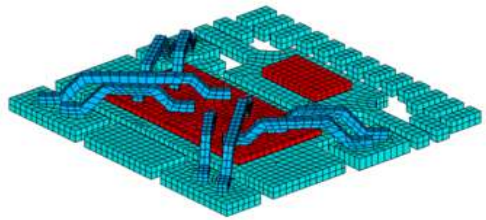
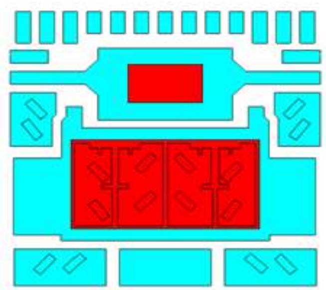
From Finite Elements to System Simulation

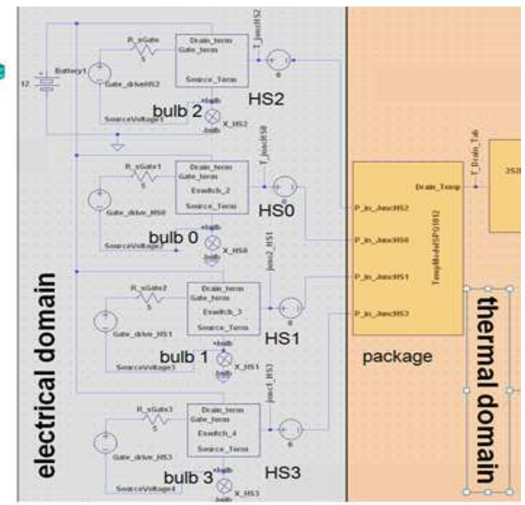
Physics & Geometry → **FEM** → System of n ODEs → **MOR** → Reduced System of $r << n$ ODEs











freescale semiconductor

- Electrothermal Simulation with power MOSFET:
  - From ANSYS Workbench to Simplorer

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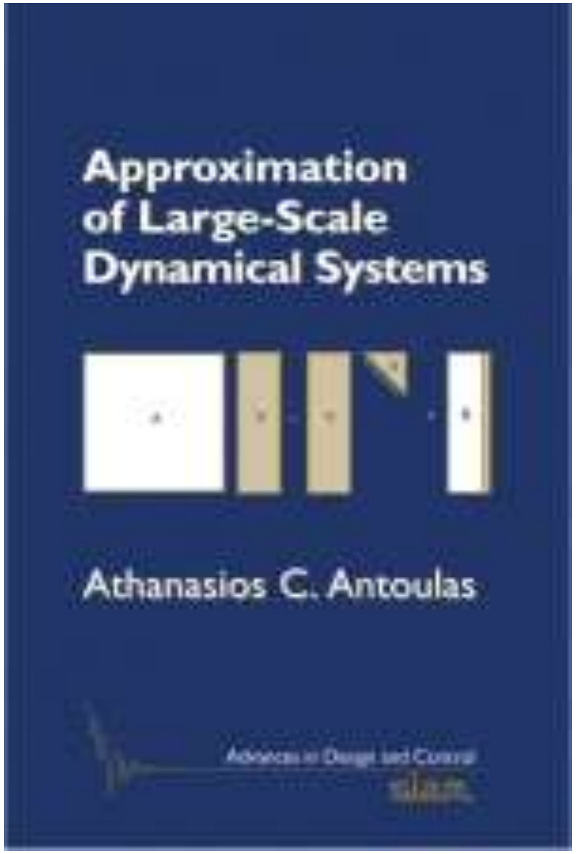
Model Order Reduction

- Relatively new technology
- Solid mathematical background:
  - Approximation of large scale dynamic systems
- Dynamic simulation:
  - Harmonic or transient simulation
- Industry application level:
  - Linear dynamic systems



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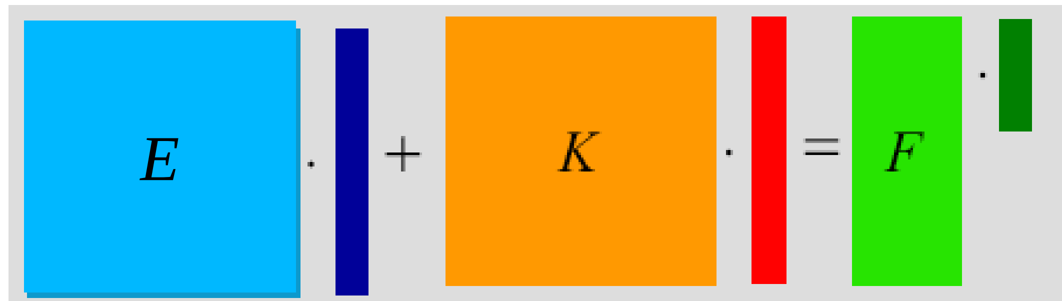
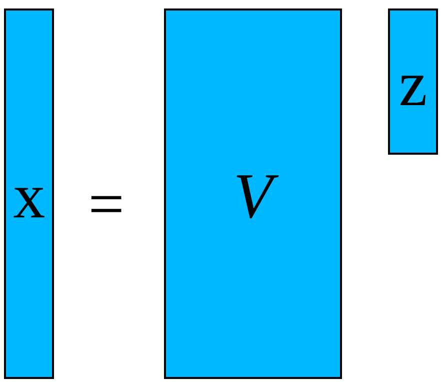
Model Reduction as Projection

- Projection onto low-dimensional subspace

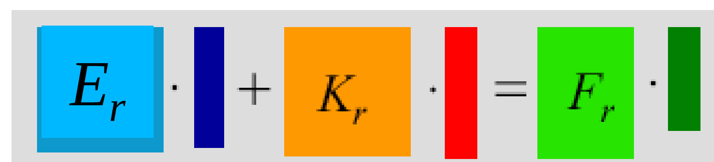
$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$



$$\mathbf{x} = V\mathbf{z} + \varepsilon$$



$$V^T E V \dot{\mathbf{z}} + V^T K V \mathbf{z} = V^T B\mathbf{u}$$



- How to find subspace?
- Mode superposition is not the best way to do it.

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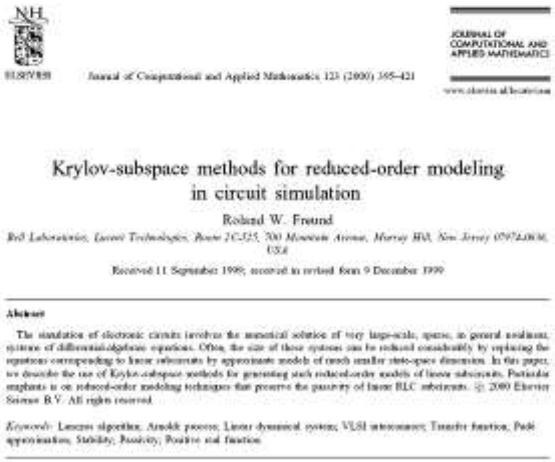
Implicit Moment Matching

- Padé approximation
- Matching first moments for the transfer function



JOURNAL OF COMPUTATIONAL AND APPLIED MATHEMATICS

Journal of Computational and Applied Mathematics 123 (2000) 395–421

Krylov-subspace methods for reduced-order modeling in circuit simulation

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Abstract

The simulation of electronic circuits involves the numerical solution of very large-scale, sparse, in general nonlinear, systems of differential-algebraic equations. Often, the size of these systems can be reduced considerably by replacing the equations corresponding to linear subcircuits by approximate models of much smaller state-space dimension. In this paper, we describe the use of Krylov-subspace methods for generating such reduced-order models of linear subcircuits. Particular emphasis is on reduced-order modeling techniques that preserve the passivity of linear RLC subcircuits.

Keywords: Lanczos algorithm; Arnoldi process; Linear dynamical system; VLSI interconnect; Transfer function; Padé approximation; Stability; Passivity; Positive real function

- Implicit Moment Matching:
  - via Krylov Subspace

$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$

$$H(s) = \left(sE + K\right)^{-1} B$$

$$H = \sum_{0}^{\infty} m_i (s - s_0)^i$$

$$H_{red} = \sum_{0}^{\infty} m_{i,red} (s - s_0)^i$$

$$m_i = m_{i,red}, \quad i = 0, \ldots, r$$

$$s_0 = 0$$

$$V = span\{\Im(K^{-1}E, K^{-1}b)\}$$

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MOR for ANSYS: http://ModelReduction.com

ANSYS Model

FULL files

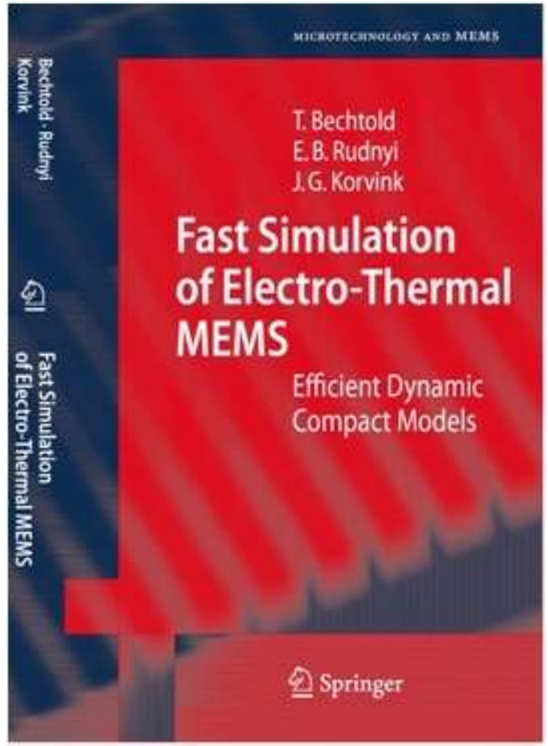
$$M\ddot{x} + E\dot{x} + Kx = Bu$$
$$y = Cx$$

Linear Dynamic System, ODEs

MOR Algorithm

Small dimensional matrices

Simulink, Simplorer, VerilogA, …

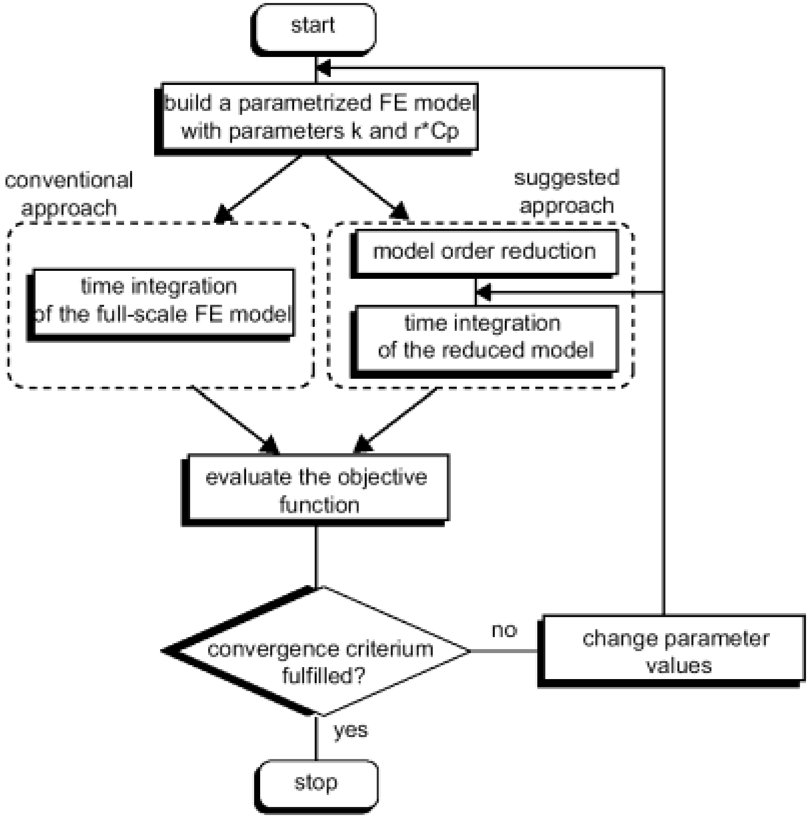


Current version 2.5

MOR for ANSYS Timing: MOR as Fast Solver

- Reduced model of dimension 30

Dimension, DoFs	nnz	MOR Time /ANSYS static
4 267	20 861	1.4
11 445	93 781	1.8
20 360	265 113	1.7
79 171	2 215 638	1.5
152 943	5 887 290	2.2
180 597	7 004 750	1.9
375 801	15 039 875	1.7



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System Thermal Simulation in Simplorer

- Current : Heat Flow
- Voltage : Temperature
- Resistor : Thermal resistance
- Capacitor : Thermal capacitor
- Voltage source : Temperature source
- Current source : Heat Flow source

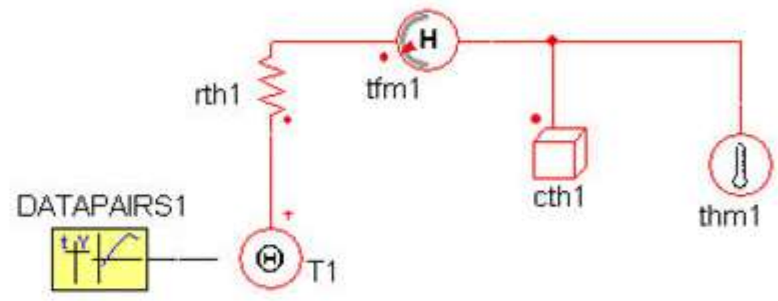


Figure 1. Application examples of the VHDL-AMS Temperature Source

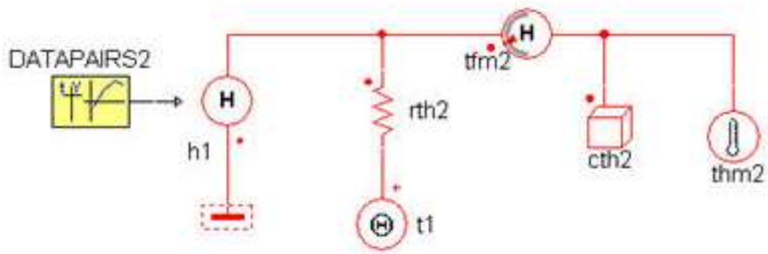
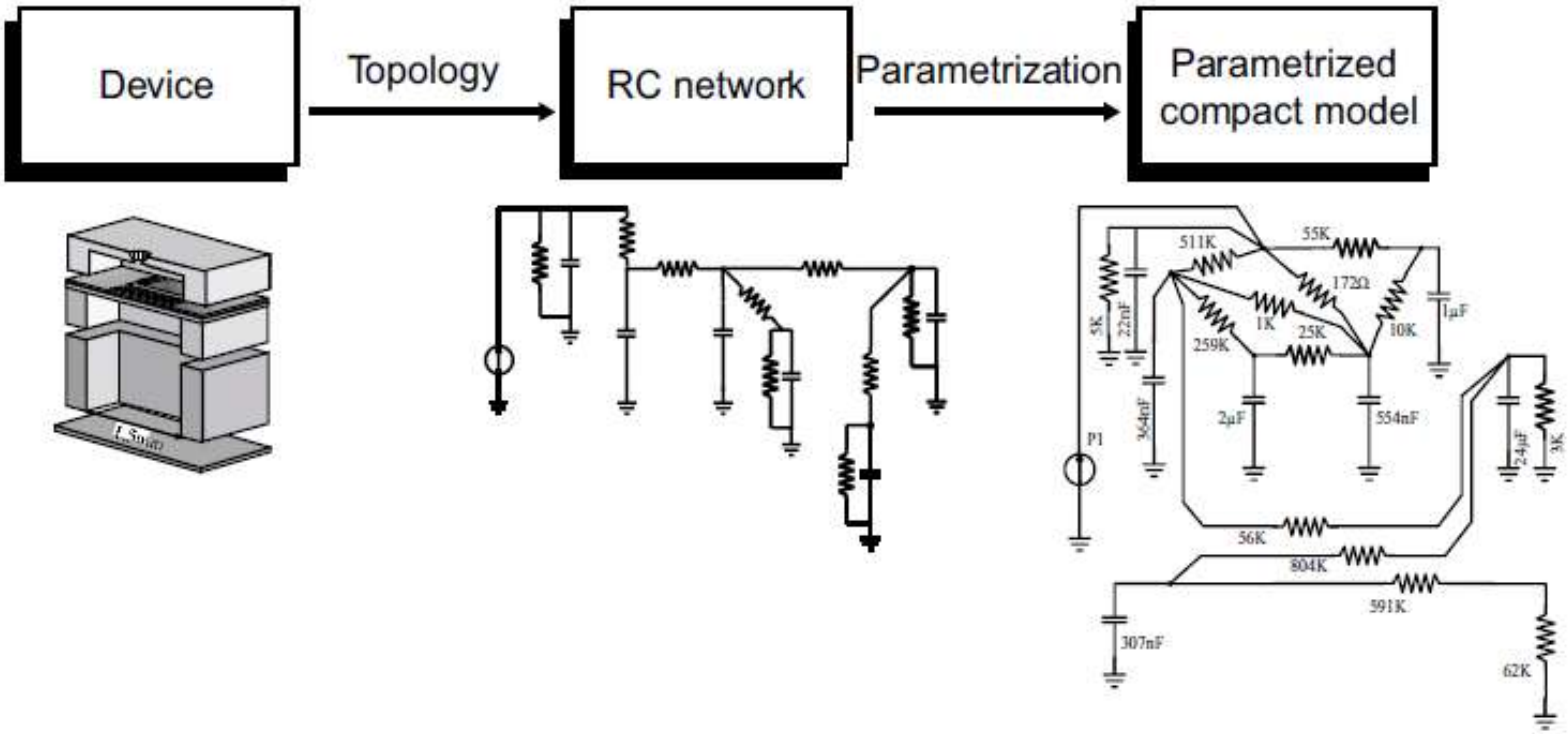


Figure 2. Application examples of the VHDL-AMS Heat Flow Source

Compact Thermal Models

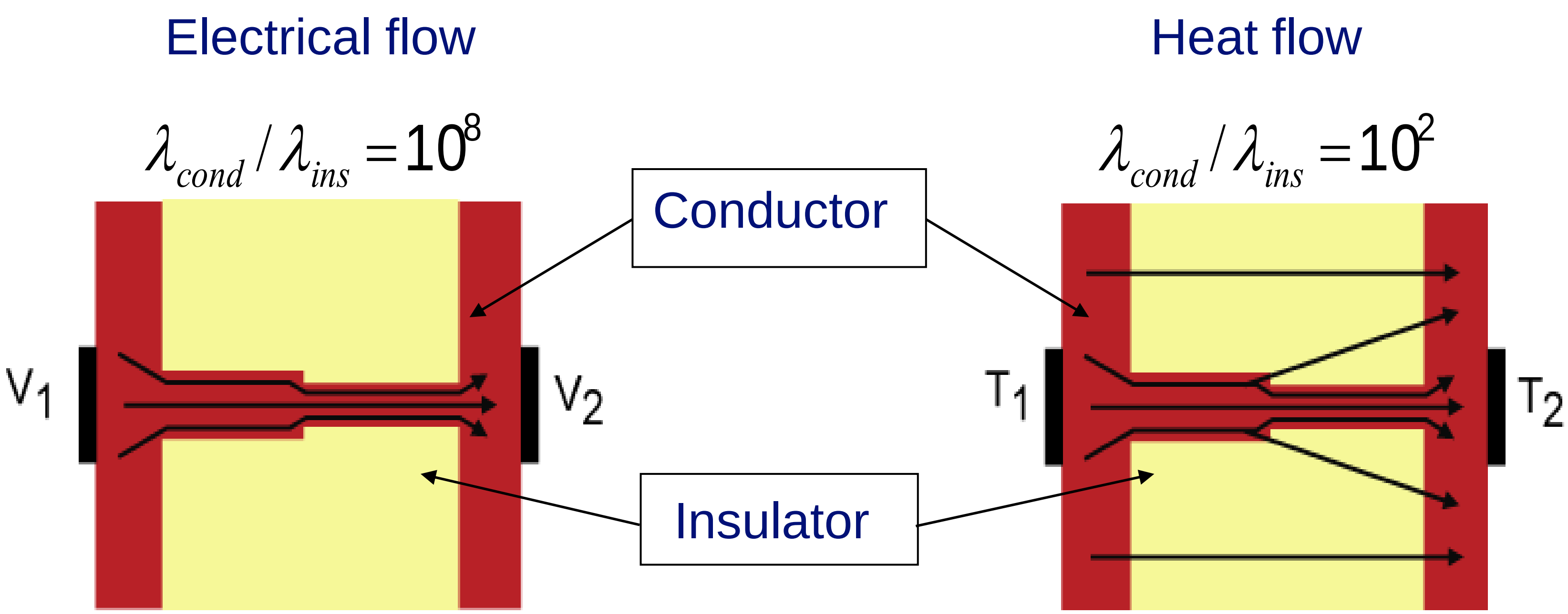


- Looks understandable – but how to do it in practice?

Figure from the book "*Fast Simulation of Electro-Thermal MEMS: Efficient Dynamic Compact Models.*" *Springer, 2006.*

CADFEM

Electrical vs. Thermal

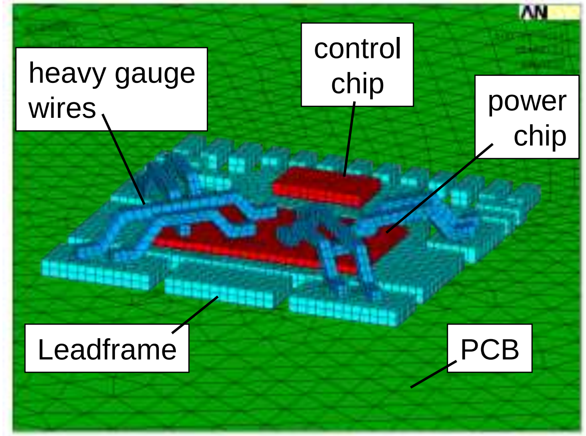


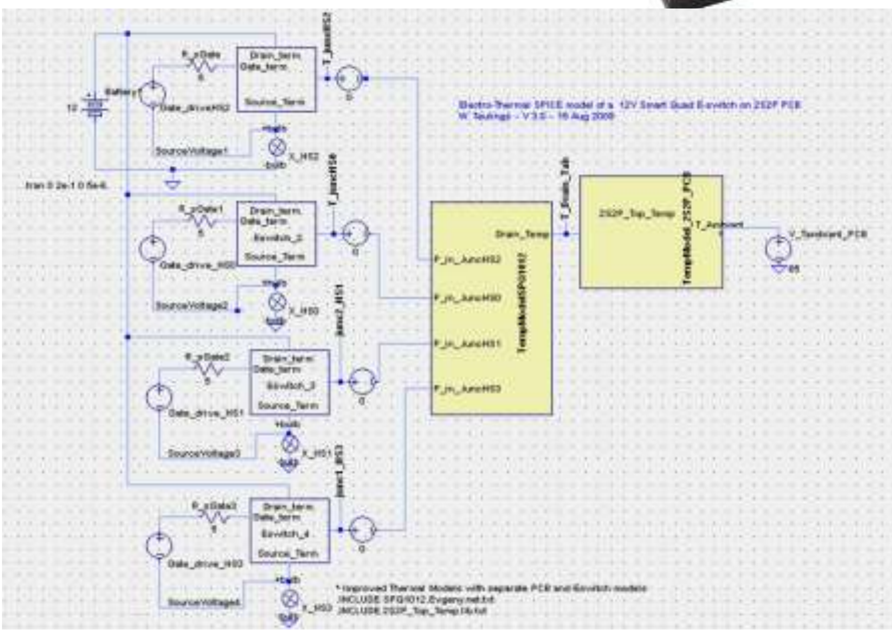
- Thermal phenomena are much more distributed, it is hard to lump them.

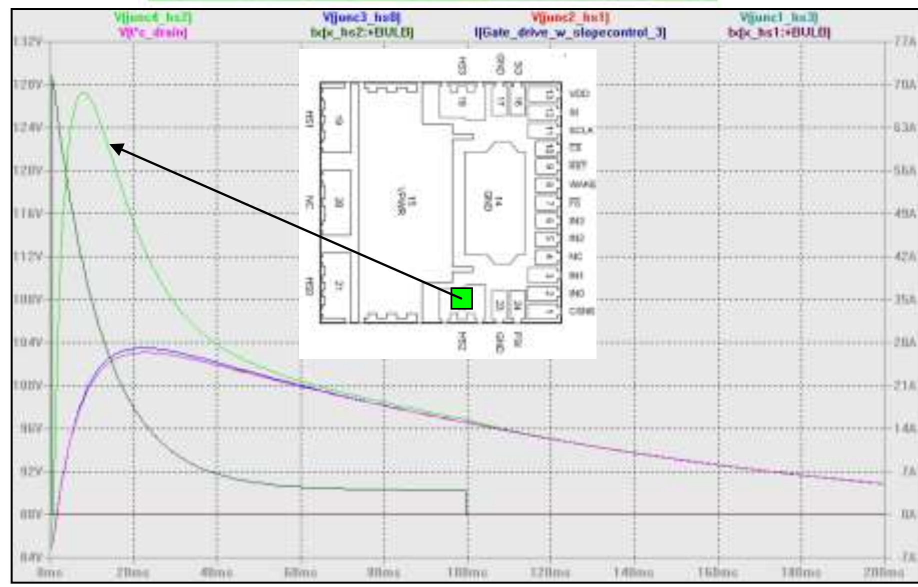
Figure from the book "*Fast Simulation of Electro-Thermal MEMS: Efficient Dynamic Compact Models.*" *Springer, 2006.*

Freescale Multi-channel Power Devices

MOR for ANSYS at Therminic 2009

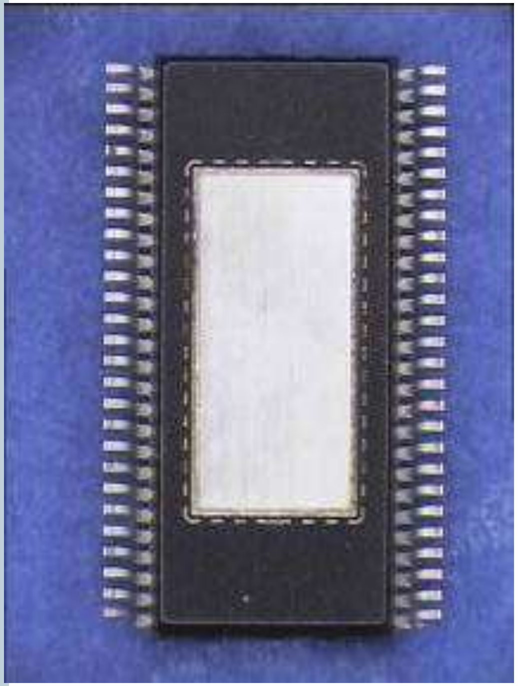
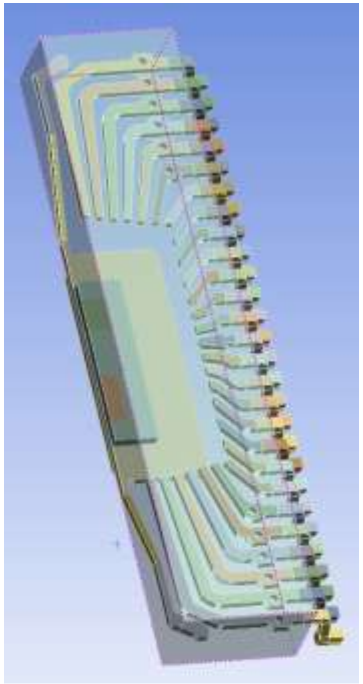
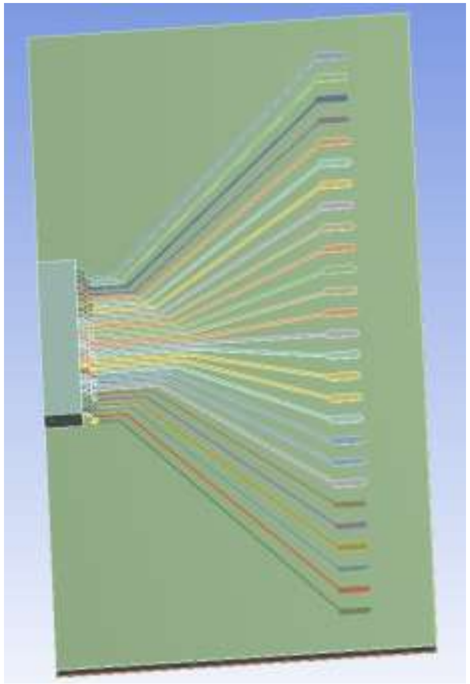
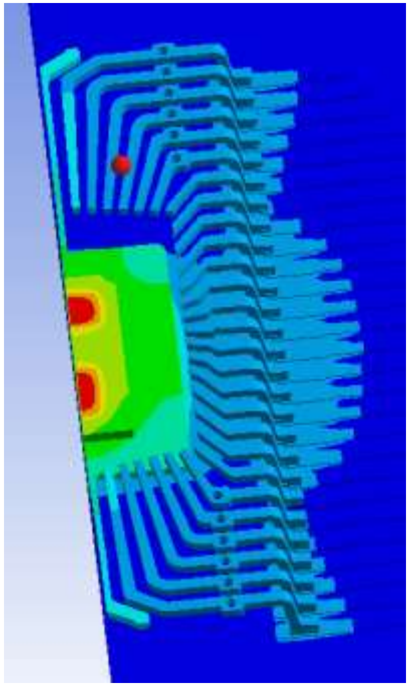






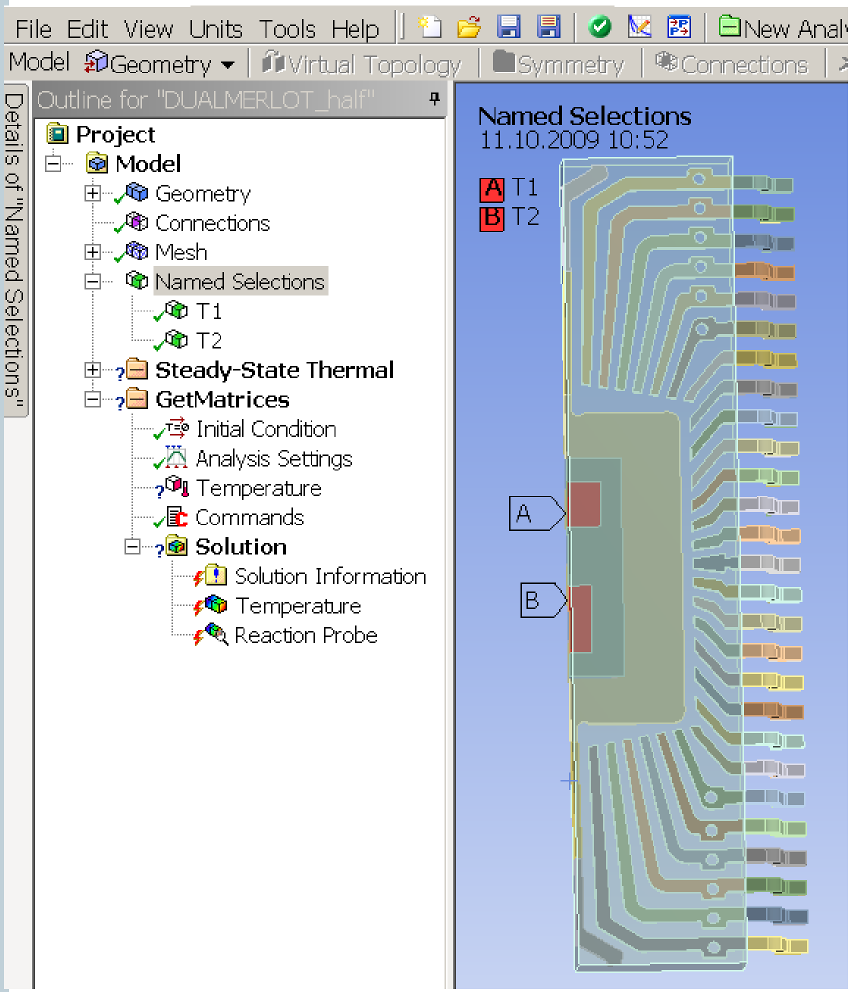
More information: Thursday 09:20 - 09:40 Thermoelectric System simulation: Compact Model Simulation with ANSYS Workbench, Freescale

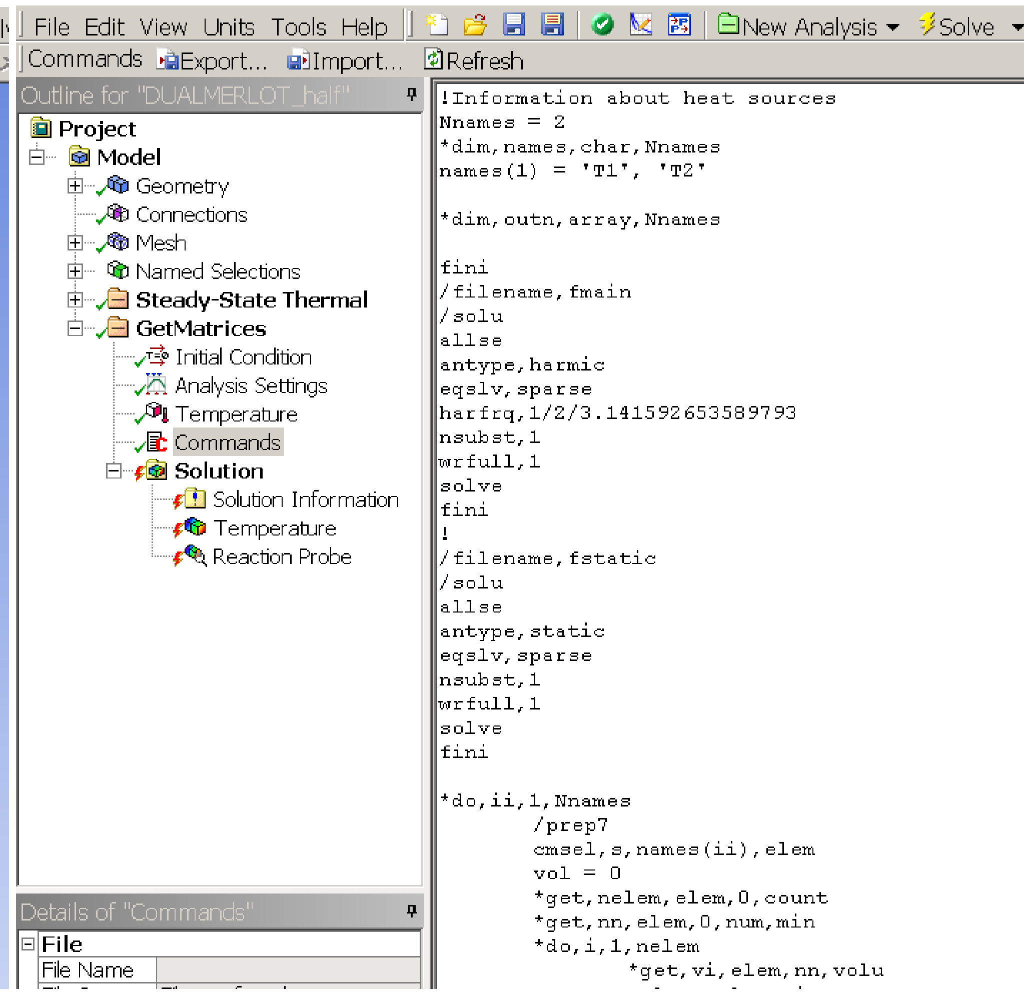
Chip and its Model in Workbench

- Two power MOSFET transistors

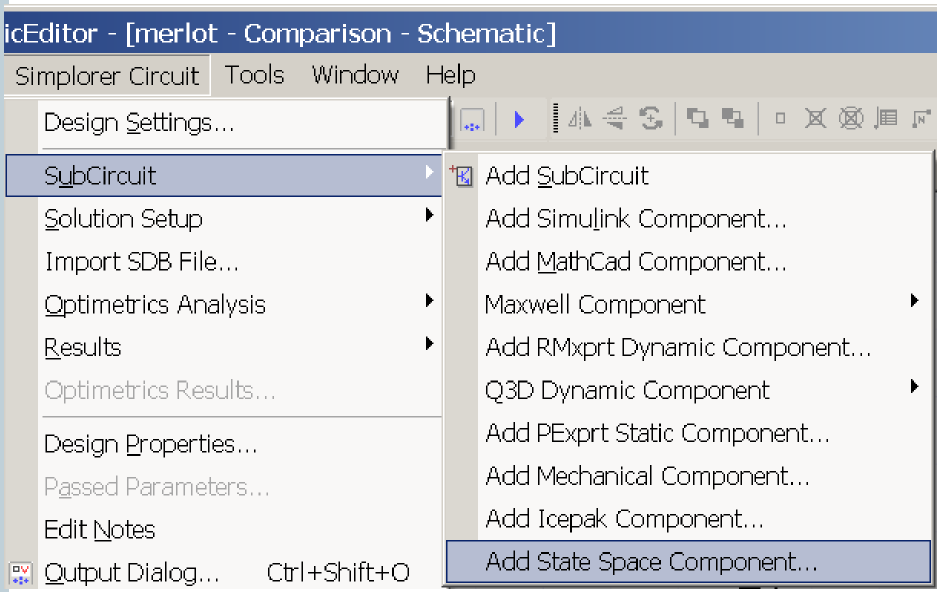
Interface to call MOR for ANSYS in Workbench

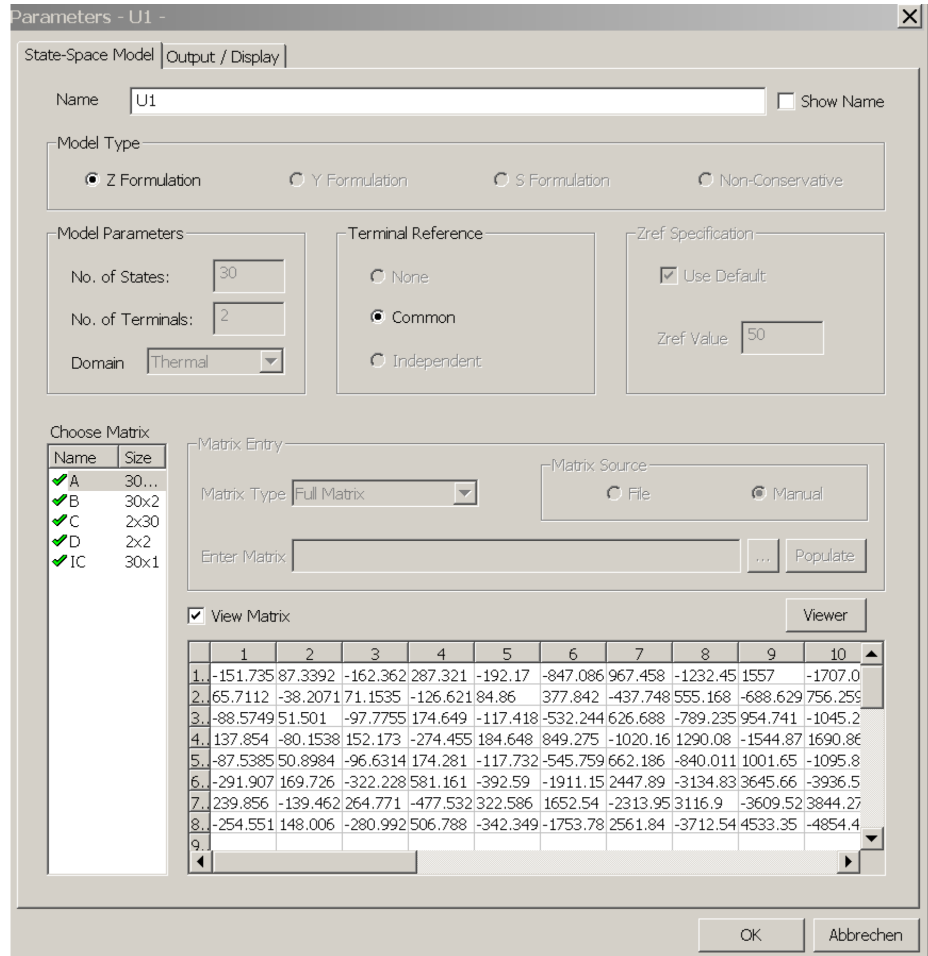




Import Reduced Model in Simplorer

- Simplorer supports state space model





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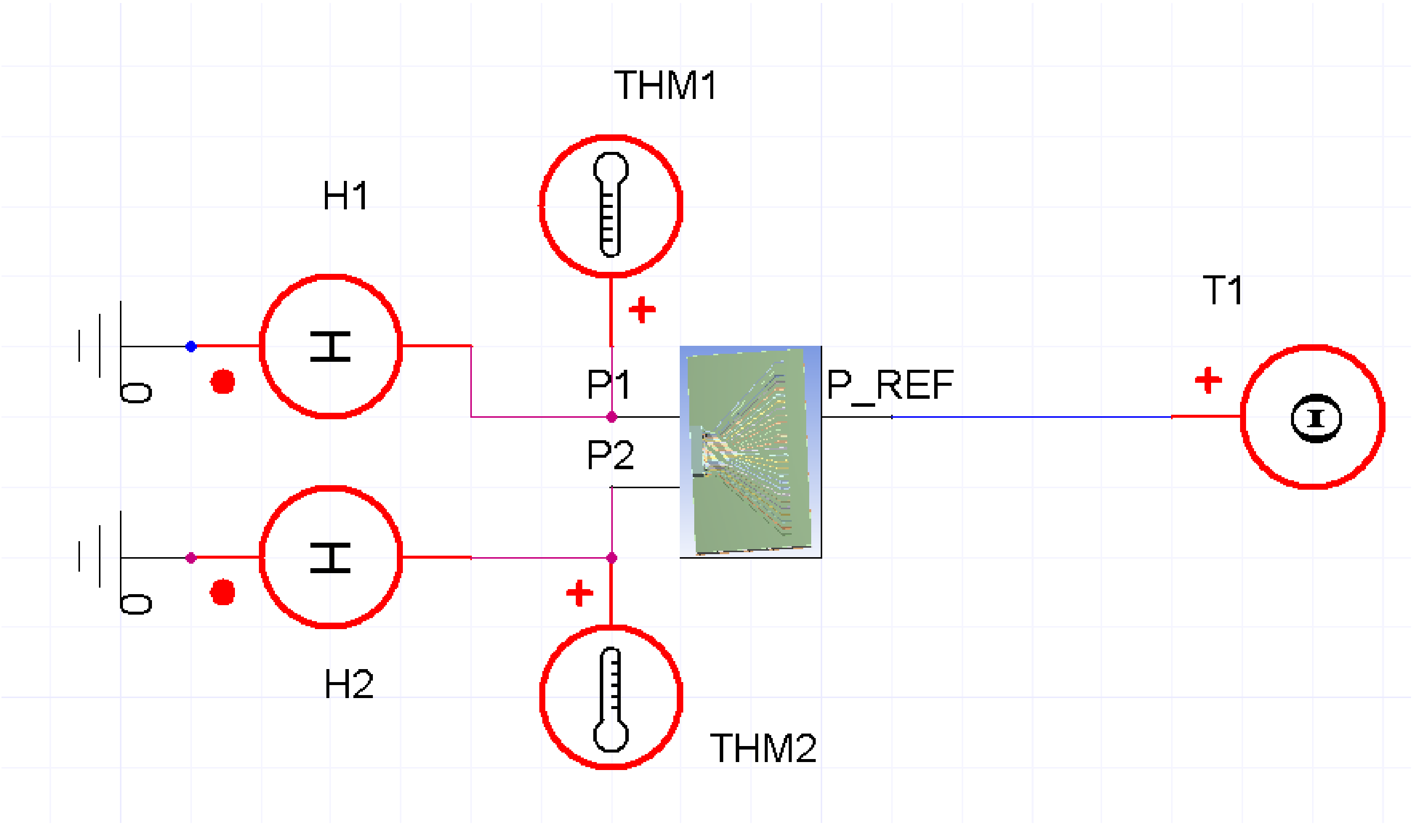
Test Thermal Circuit in Simplorer

- Conservative thermal subsystem in Simplorer
  - Voltage – Temperature
  - Current – Heat flow



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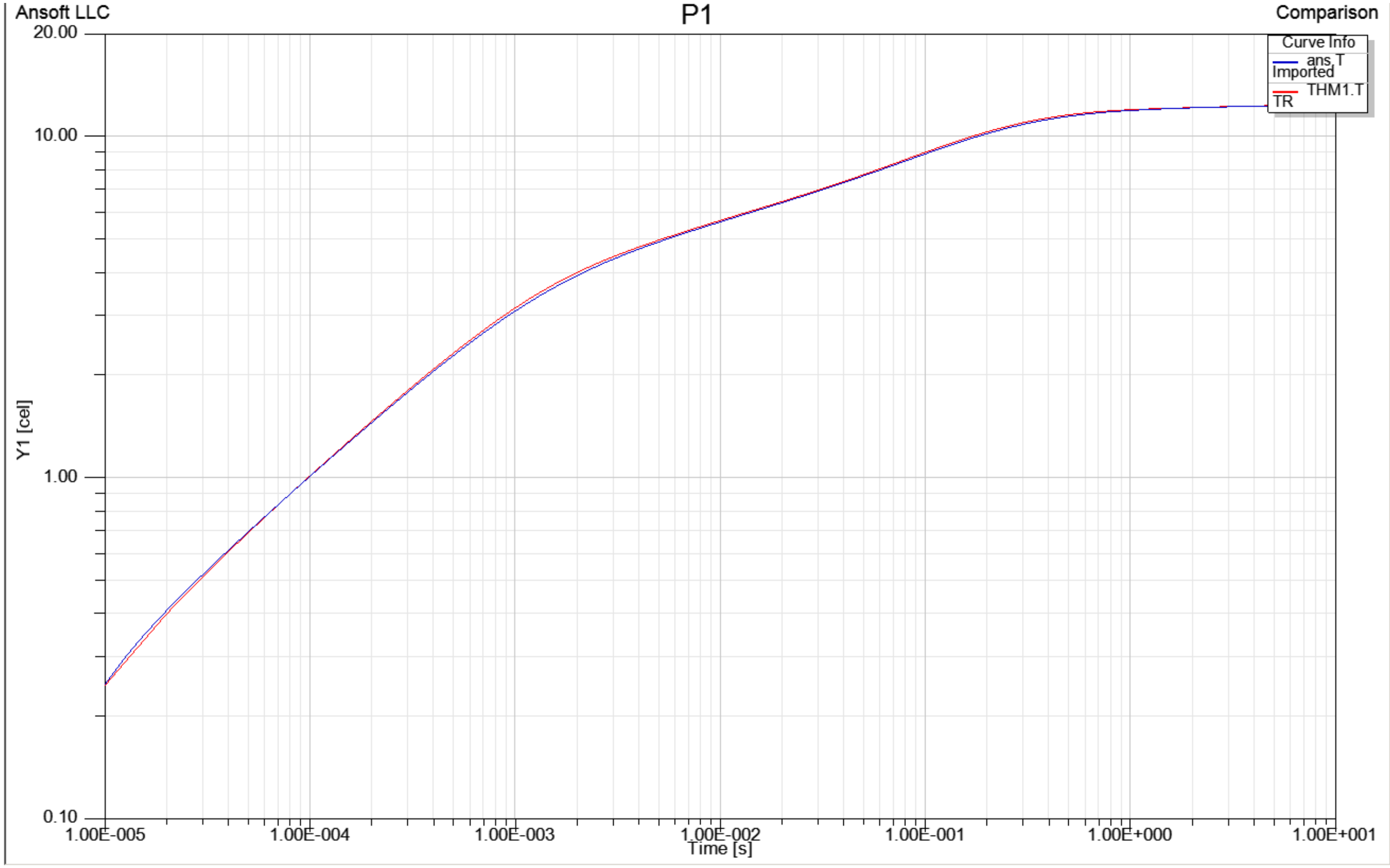
Thermal Impedance and Comparison with ANSYS

- ANSYS: about 300 000 DoFs, Reduced model: 30 DoFs
  - The difference is less than 1%
  - Timing: 60 timesteps is about 30 min in ANSYS



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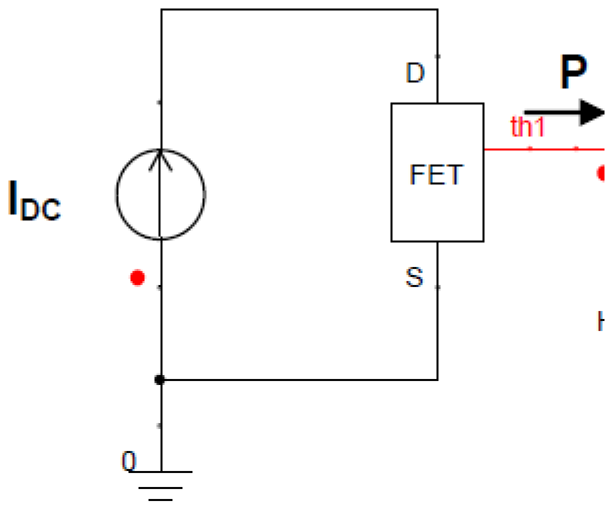
Thermal Runaway

- Transistor is considered as temperature dependent R_{DSon}
  - The VHDL-AMS model




```
LIBRARY IEEE;
USE IEEE.ELECTRICAL_SYSTEMS.ALL;
USE IEEE.THERMAL_SYSTEMS.ALL;

ENTITY RDS_MODEL IS
   PORT (          QUANTITY RDS1 : RESISTANCE := 0.035;
                   QUANTITY t0 : IN TEMPERATURE := 298.0;
                   QUANTITY KC1 : REAL := 0.35e-3;
                   QUANTITY CTRL: REAL := 0.0;
                   TERMINAL th1 : thermal;
                   TERMINAL p,m  : ELECTRICAL);
END ENTITY RDS_MODEL;

ARCHITECTURE behav OF RDS_MODEL IS
                   QUANTITY v ACROSS i THROUGH p TO m;
                   QUANTITY t_val ACROSS h THROUGH th1 TO thermal_ref;
BEGIN
         IF (CTRL <= 0.0) USE
                   i == 0.0;
                   h == 0.0;
         ELSE
                   v == i*(RDS1+KC1*(t_val-t0));
                   h == -i*v;
         END USE;
END ARCHITECTURE behav;
```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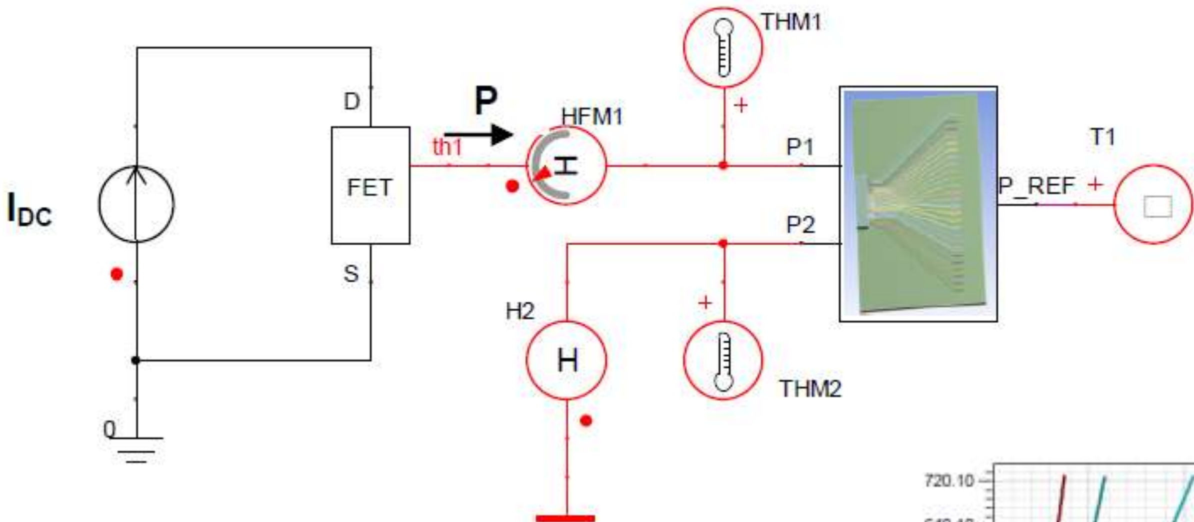
Thermal Runaway Model

- Conservative coupling between electrical and thermal part



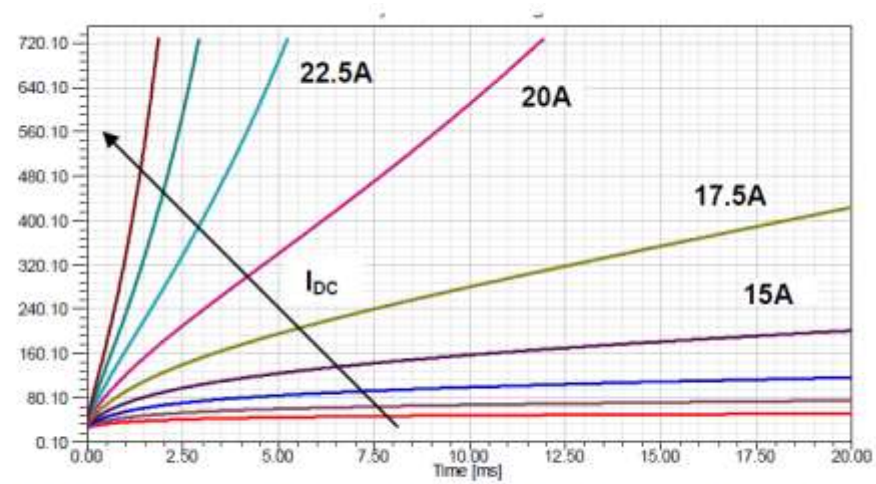


Fig. 13. Transient junction temperature curves as a function of dc loading level $T_A = 25°$, $k = 3.5e\text{-}4$, $R_0 = 35\text{mOhm}$, $T_0 = 25°C$,

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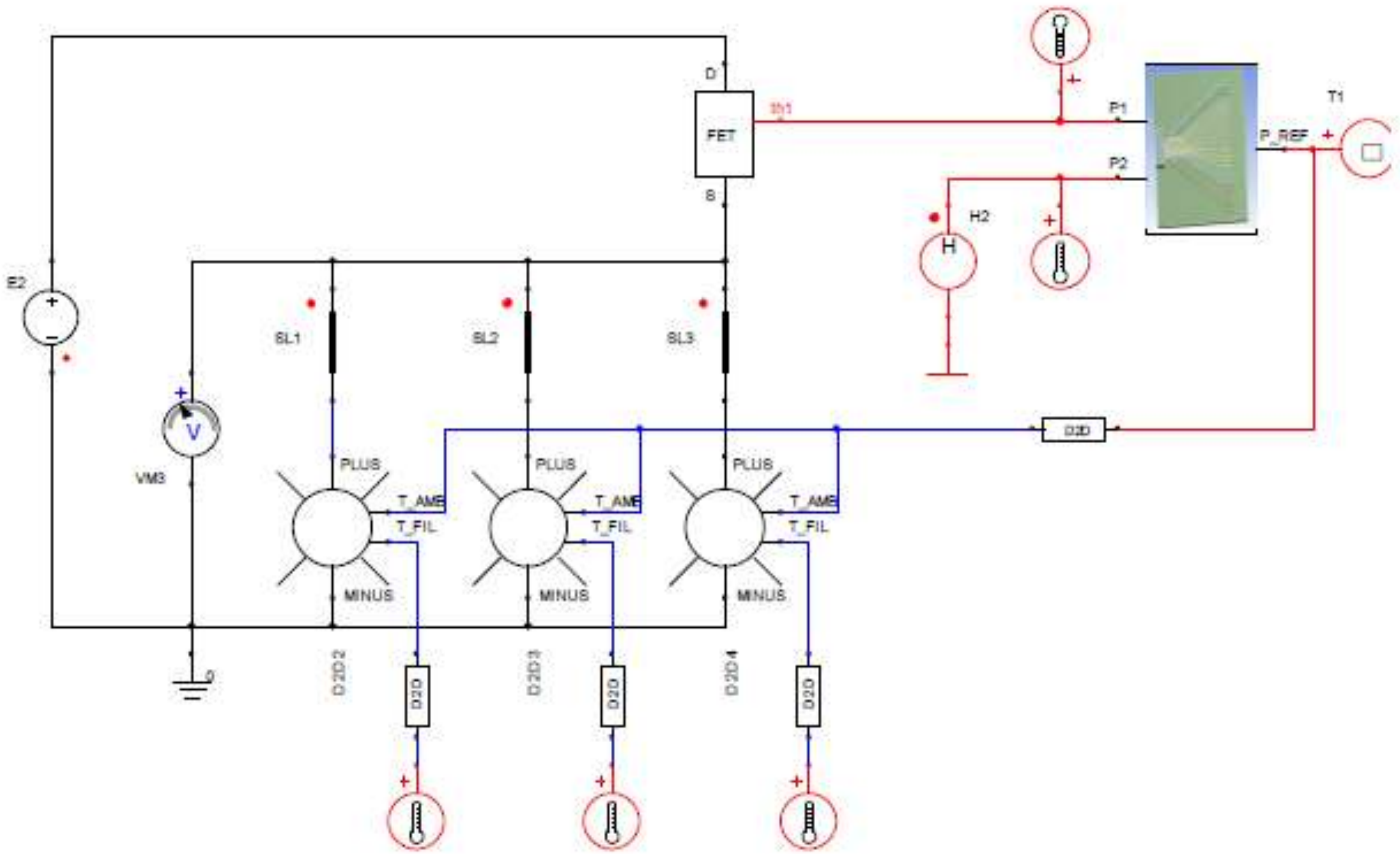
Transient Turn-on of an Automotive Light-Bulb



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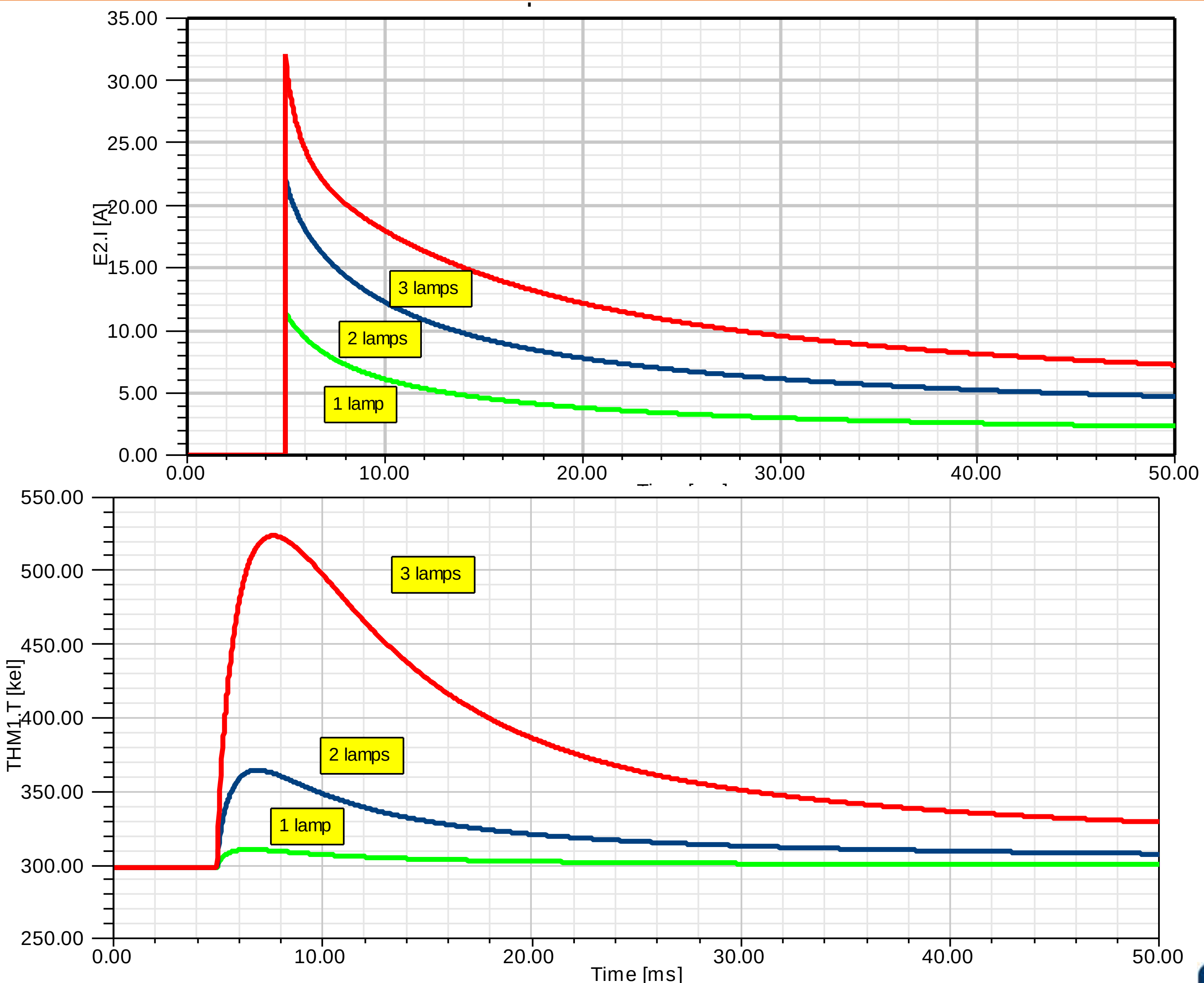
Transient Turn-on of an Automotive Light-Bulb



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Example of Mechanical System

Lehrstuhl für Regelungstechnik
Fakultät für Maschinenwesen
Technische Universität München

Aktive Schwingungsisolation in Kfz-Motoraufhängungen –
Systemkonfiguration und Methoden

Jörg Paschedag

Bild 4.1: Motoraufhängung im Audi A6

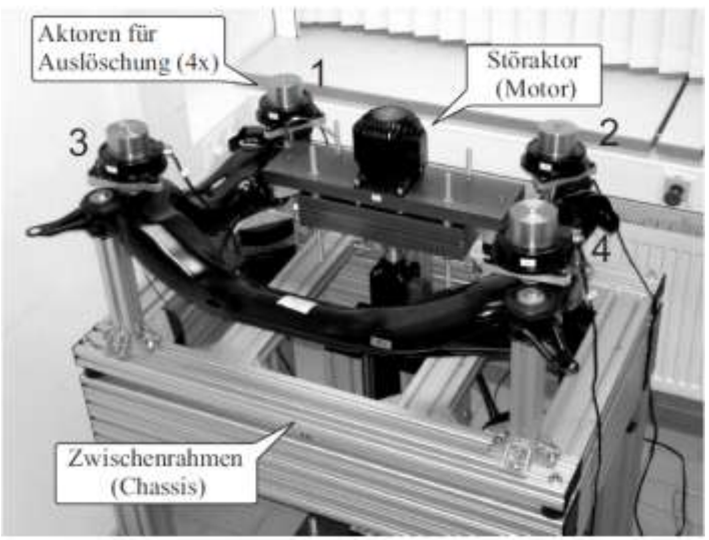


Bild 4.6: Vollständiger Mehrkanalprüfstand

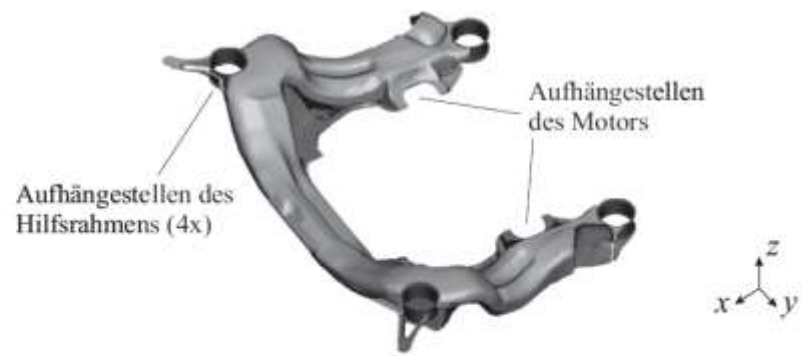
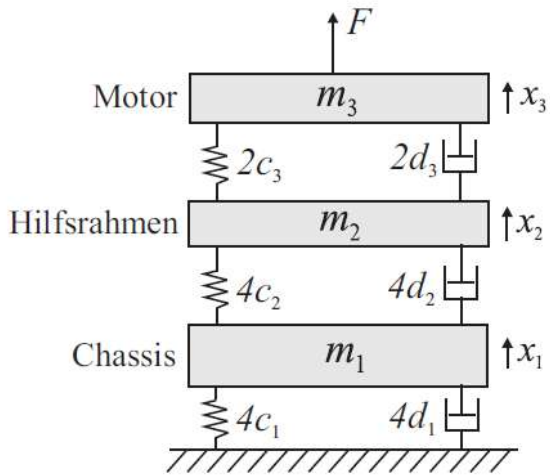
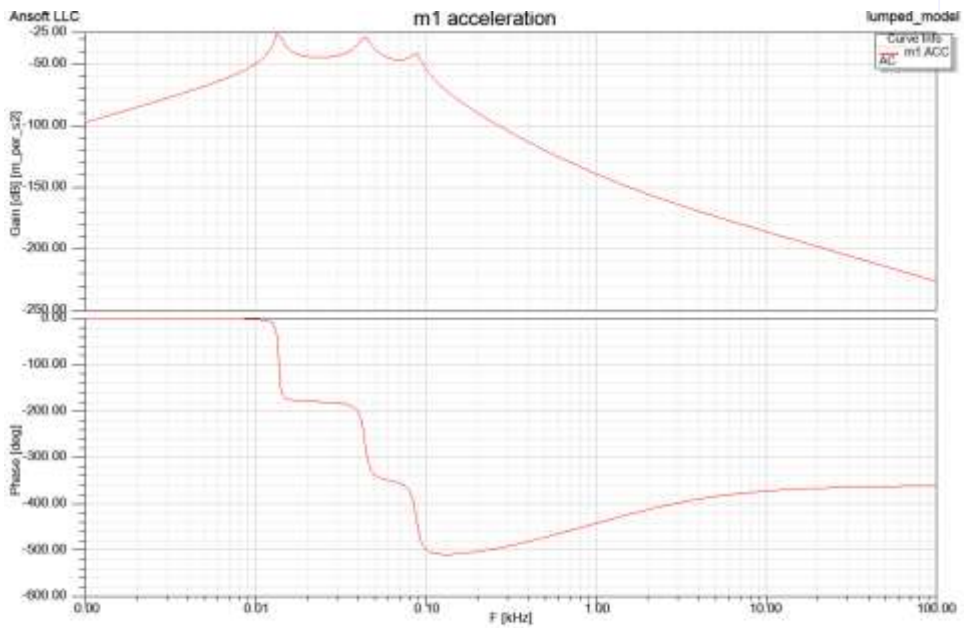
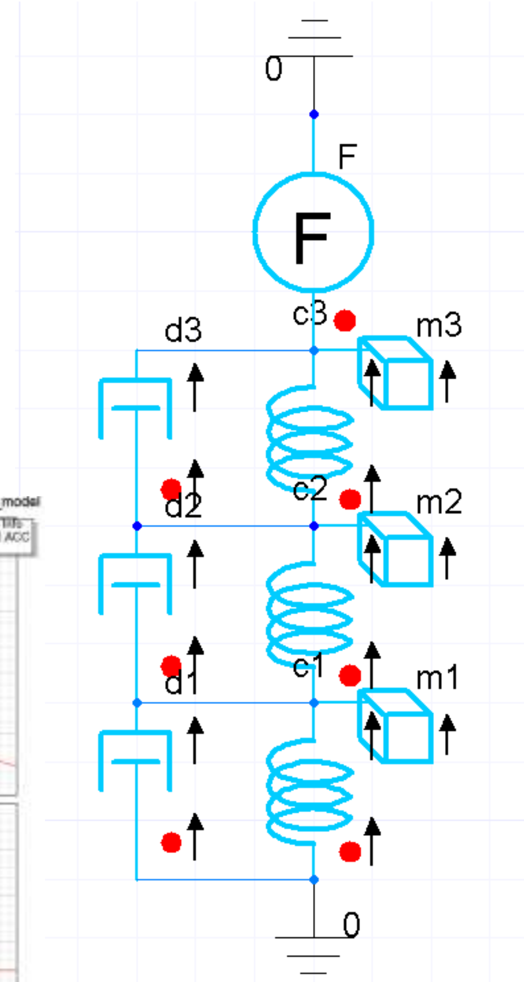


Bild 4.2: Hilfsrahmen mit Lagerstellen

System Level Simulation







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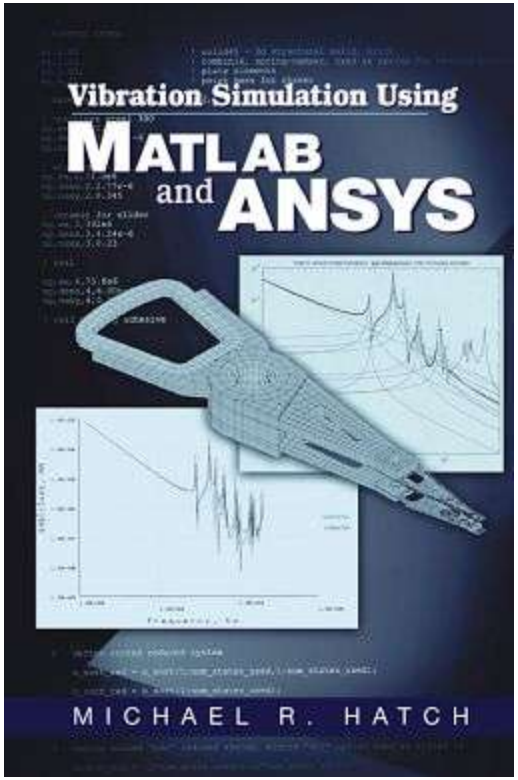
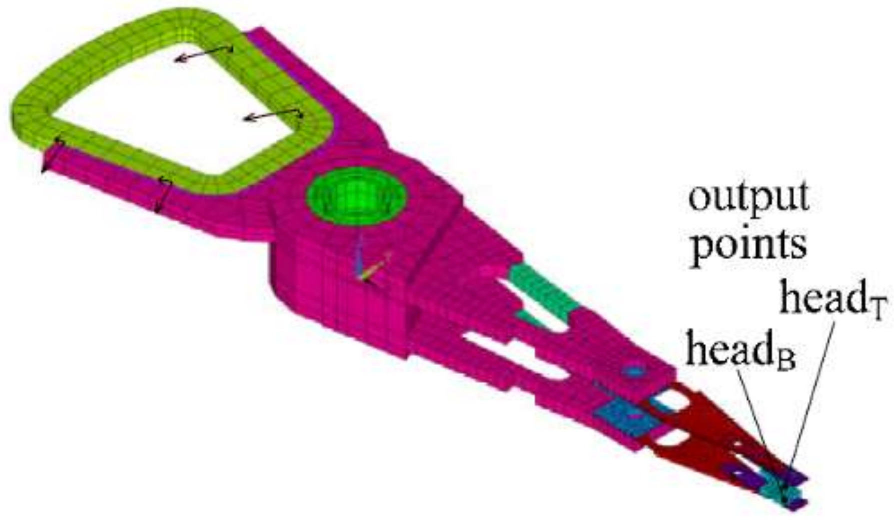
Hard Disk Drive Actuator/Suspension System

- Michael R Hatch, Vibration Simulation Using MATLAB and ANSYS

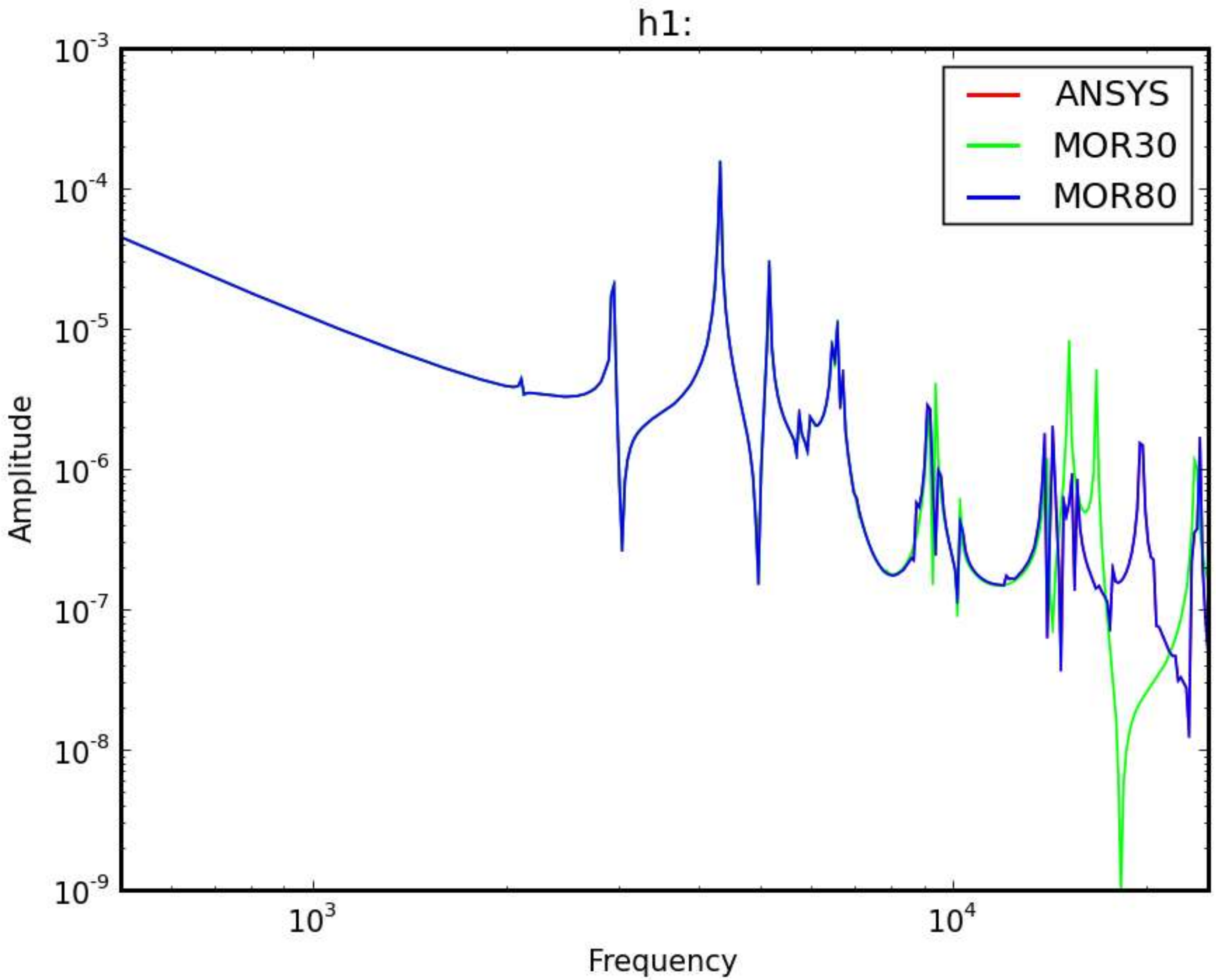


Model Reduction

- 3352 elements
- 7344 nodes
- 21227 equation
- 400 frequencies takes about 12 min
- MOR takes only 3 s
- Comparison for head
  - ANSYS
  - MOR 30
  - MOR 80



Comparison



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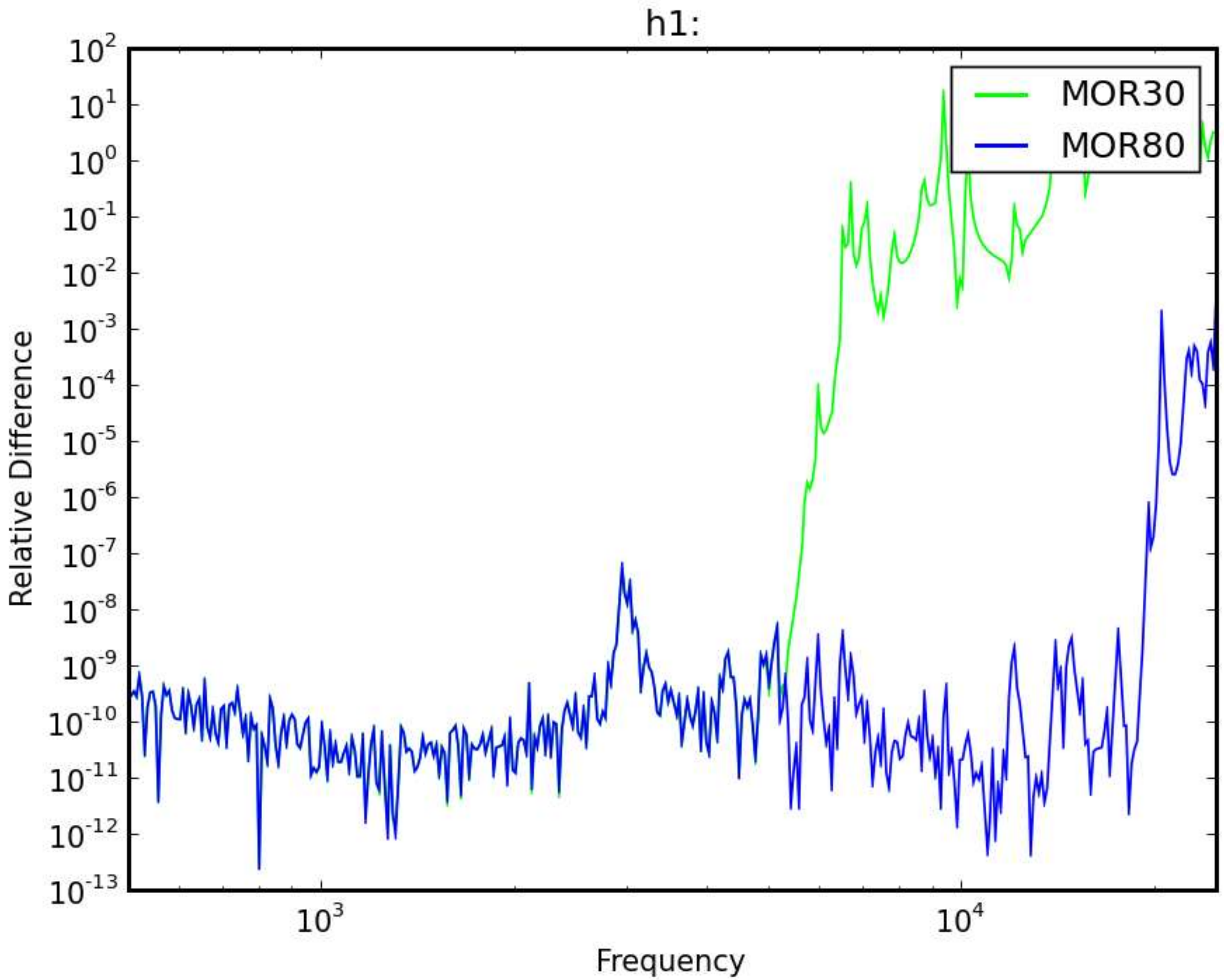
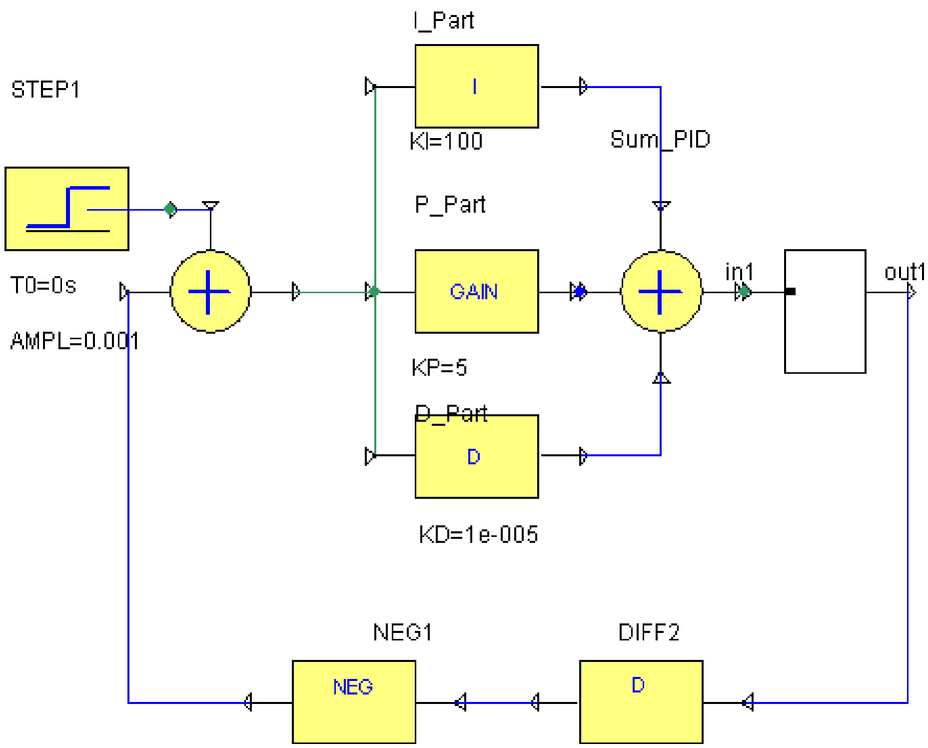
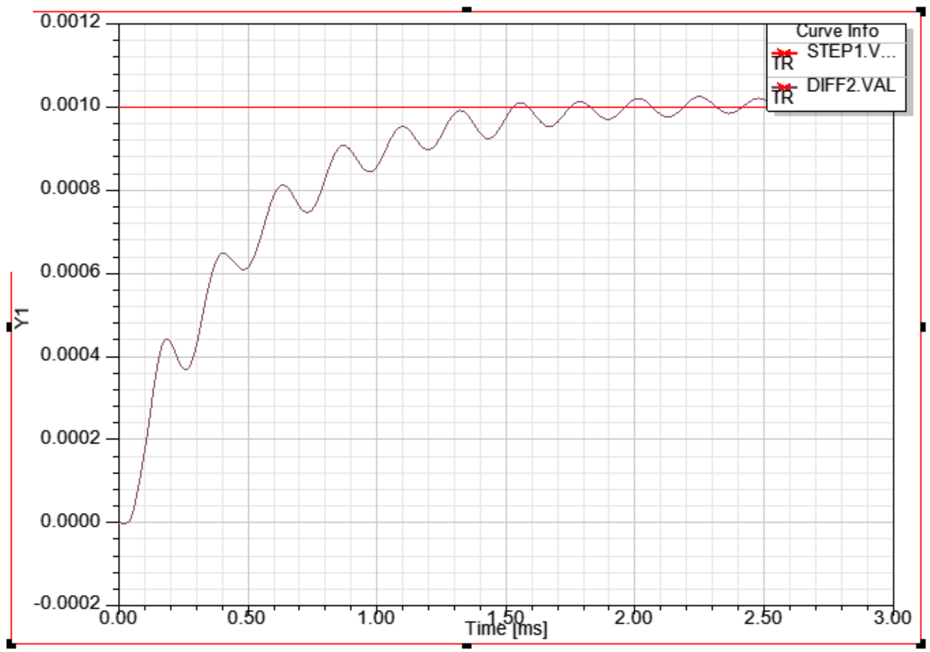
Comparison



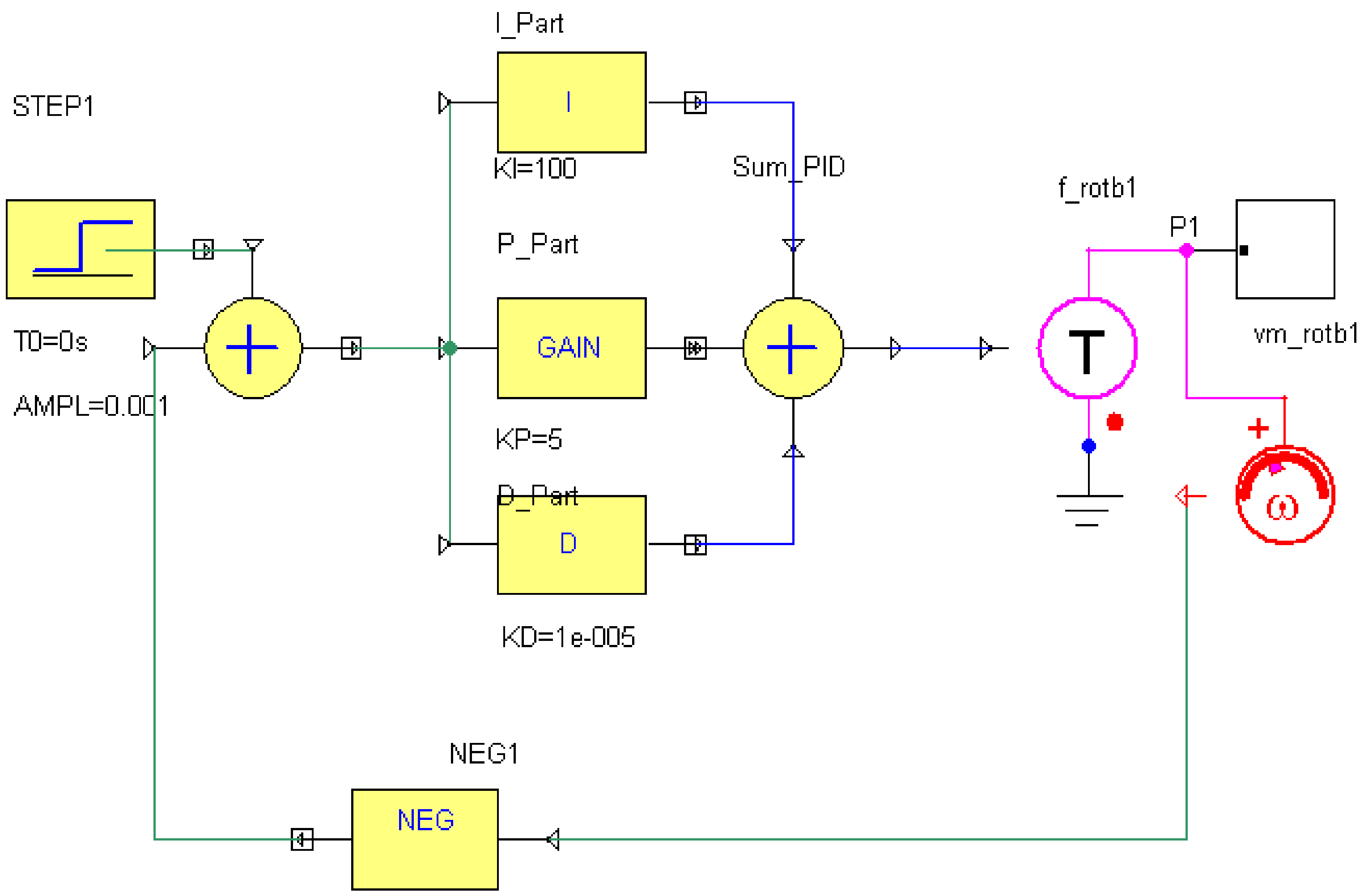
CADFEM

Velocity Control: Device as a Black Box

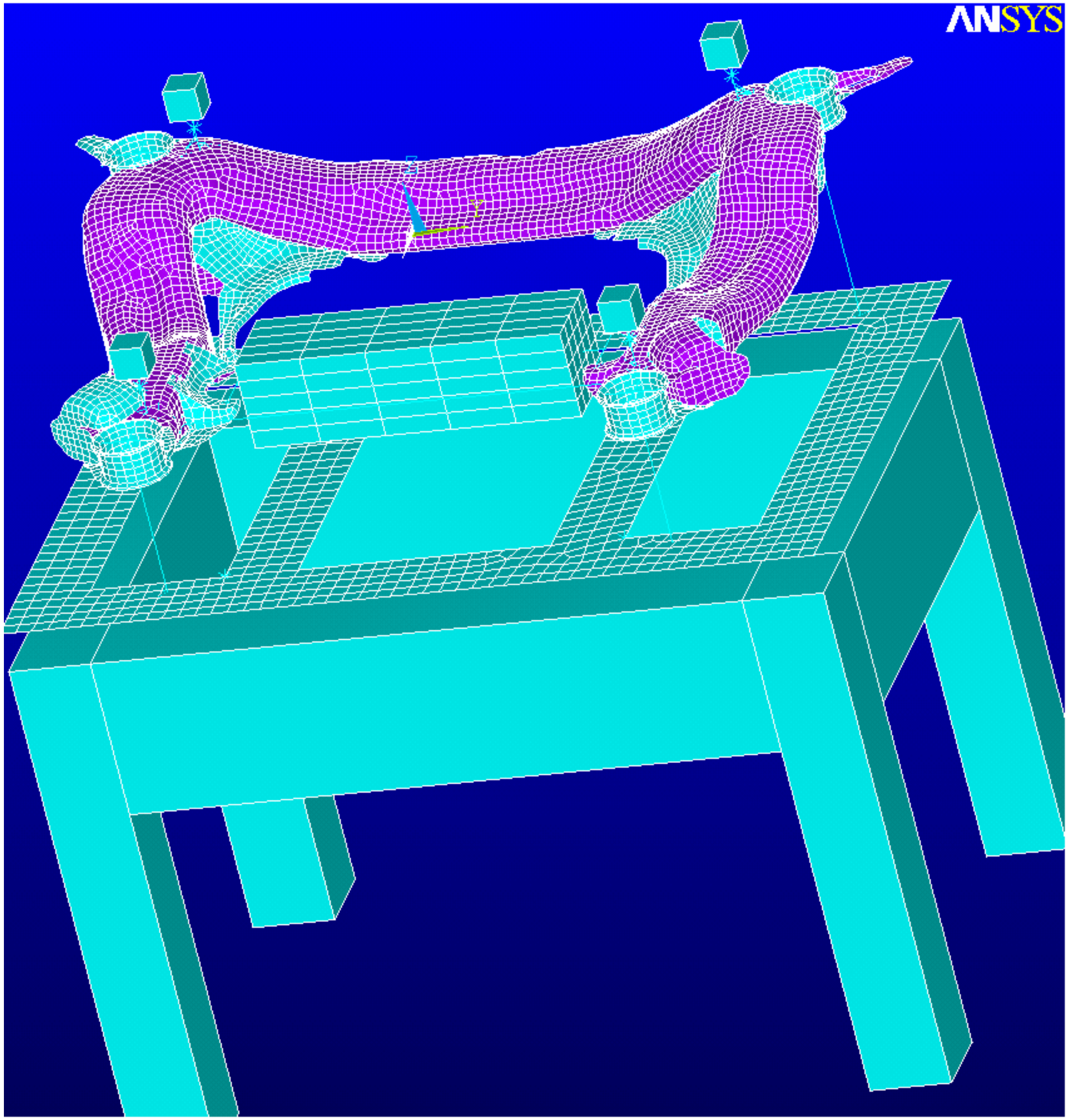




Velocity Control: Multiphysics Modeling

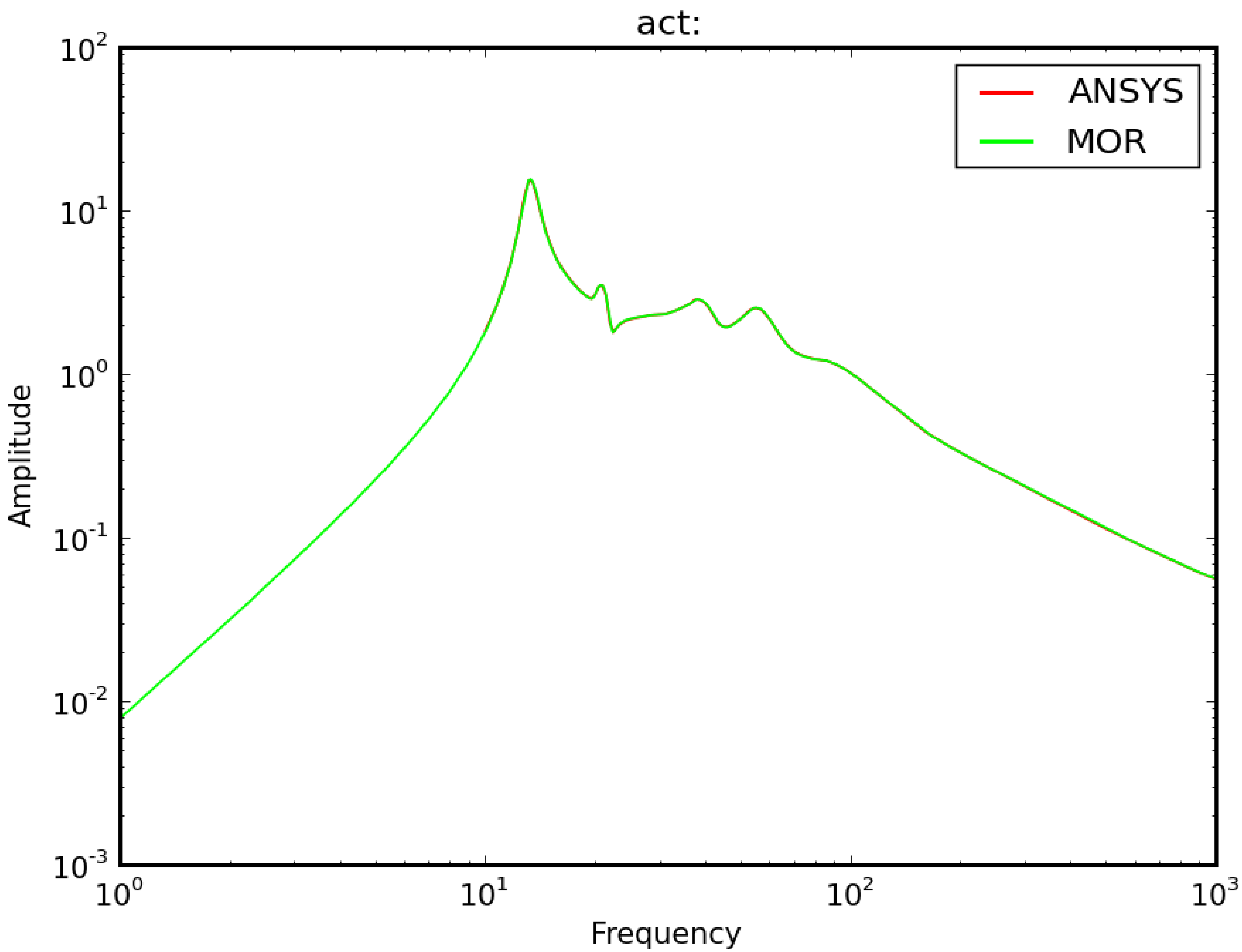


Model Reduction for the FEM Model



- 13 347 elements
- 11 765 nodes
- 55 481 equations to solve
- 200 frequencies takes about 20 min
- Model reduction takes 8 second

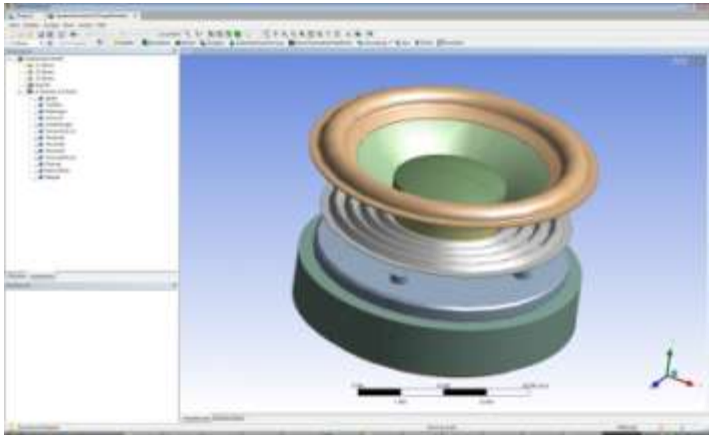
Comparison

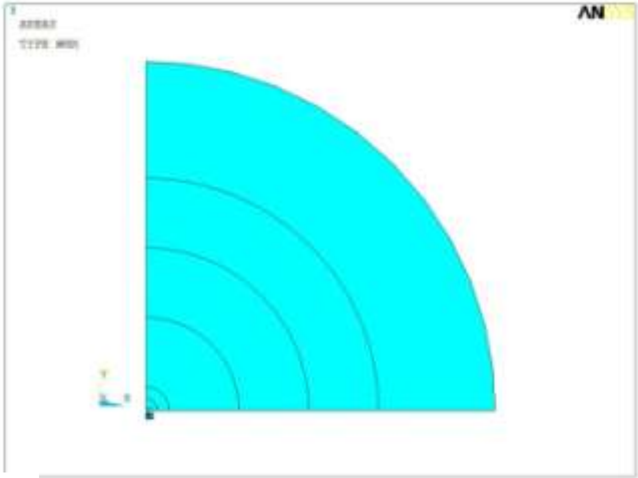


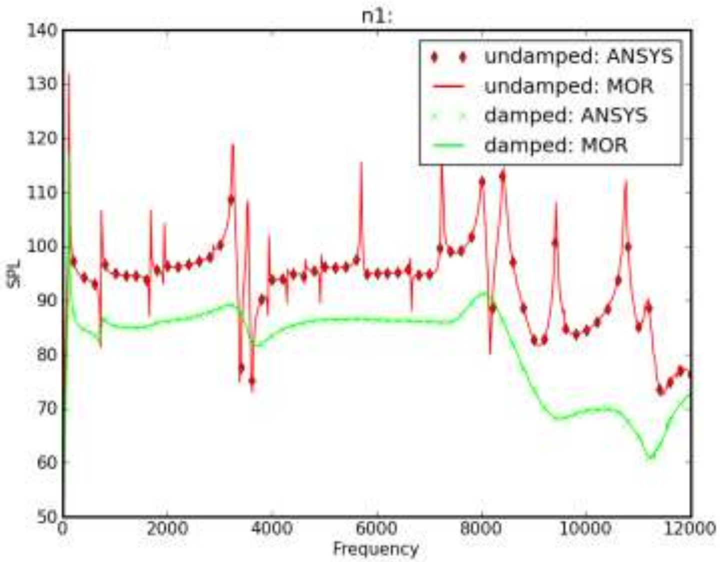
CADFEM

Efficient Simulation of Acoustic FSI

- Wednesday 17:00 - 17:20, CADFEM + Simetris



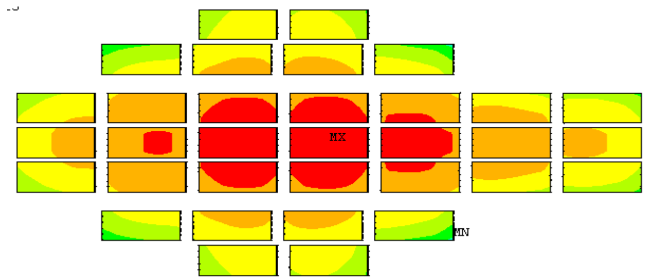


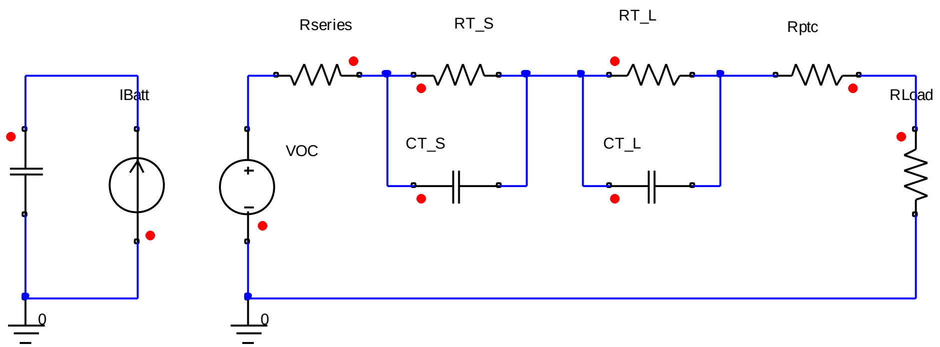


CADFEM

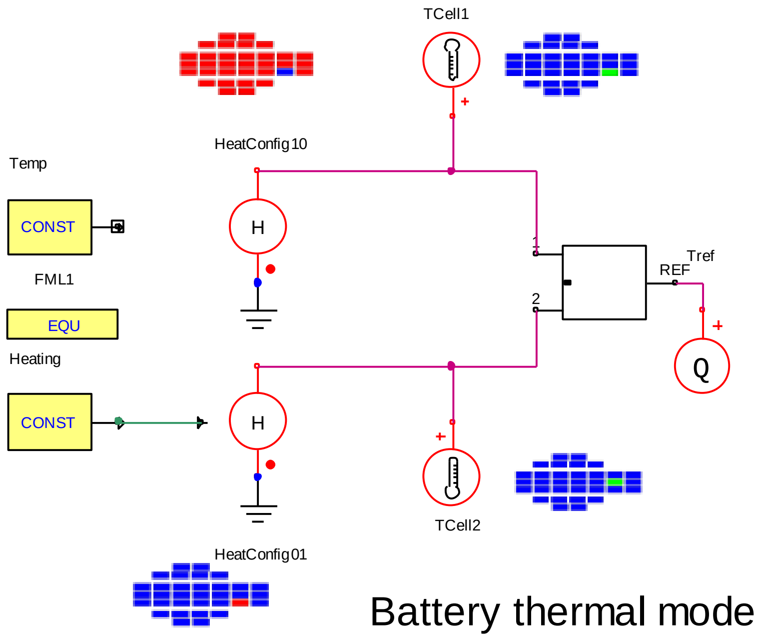
System Level Battery Thermal Behavior Study

- Thursday, 12:20 - 12:40, CADFEM





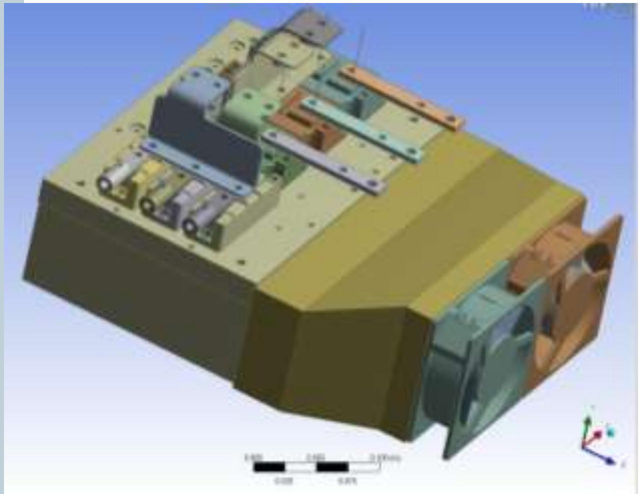
Electrical cell model (cell1)

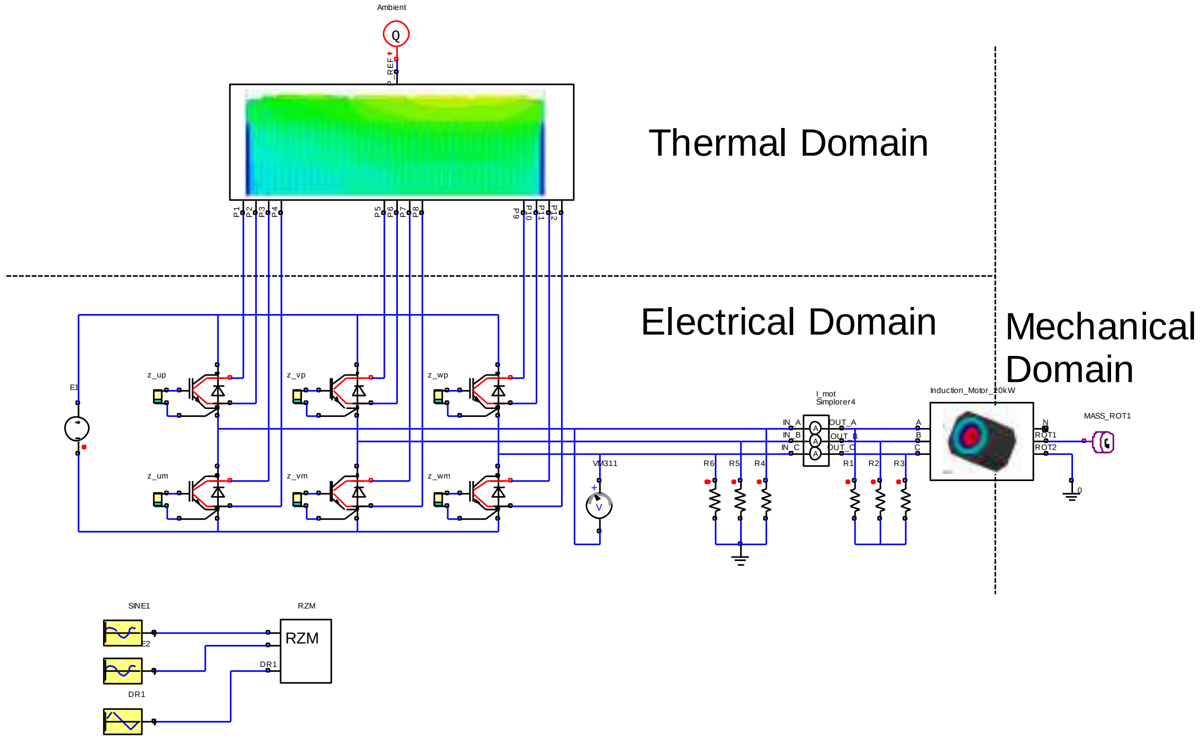


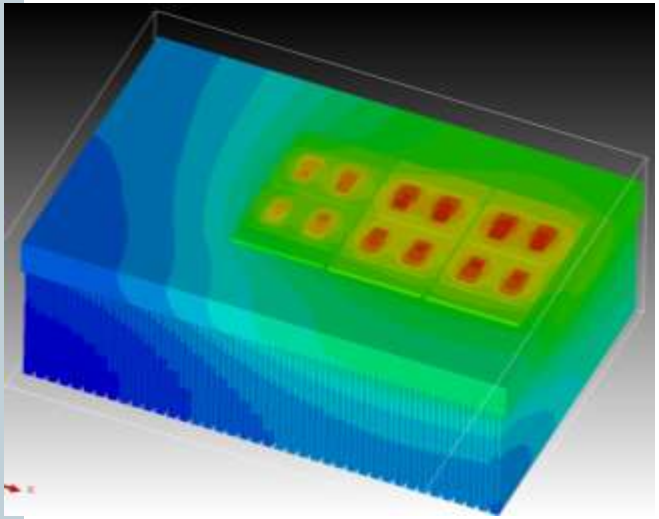
Battery thermal model

Elektrothermische Simulation eines IGBT Wechselrichters

- Thursday 11:40 – 12:20, CADFEM + ANSOFT



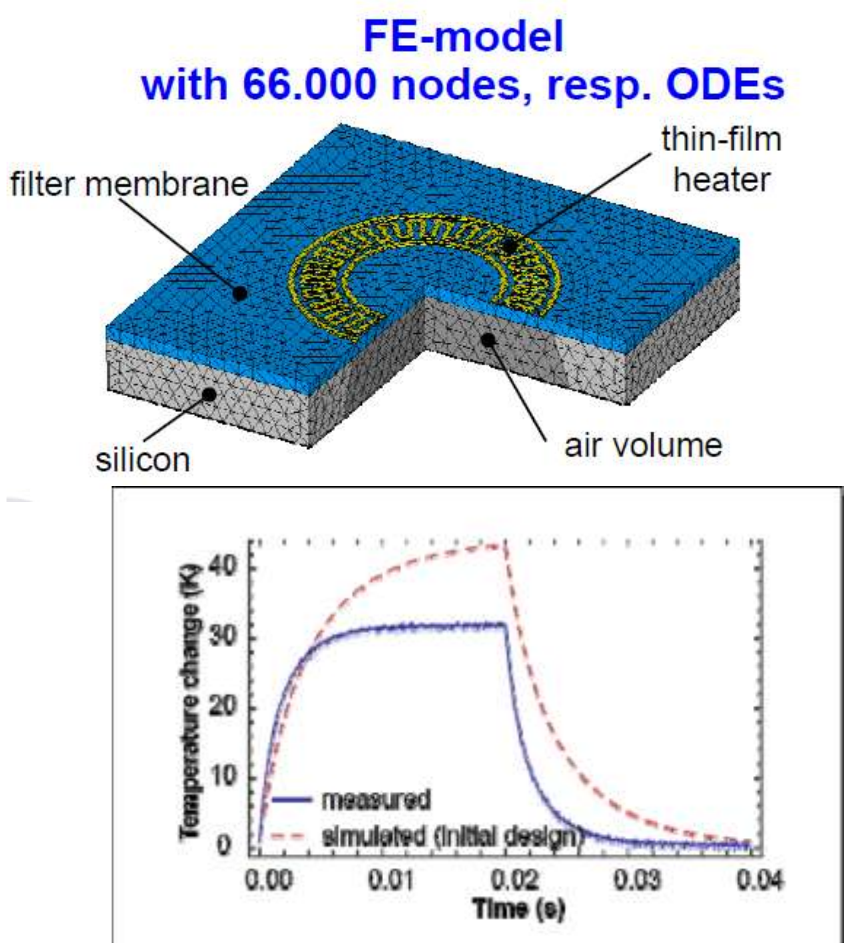


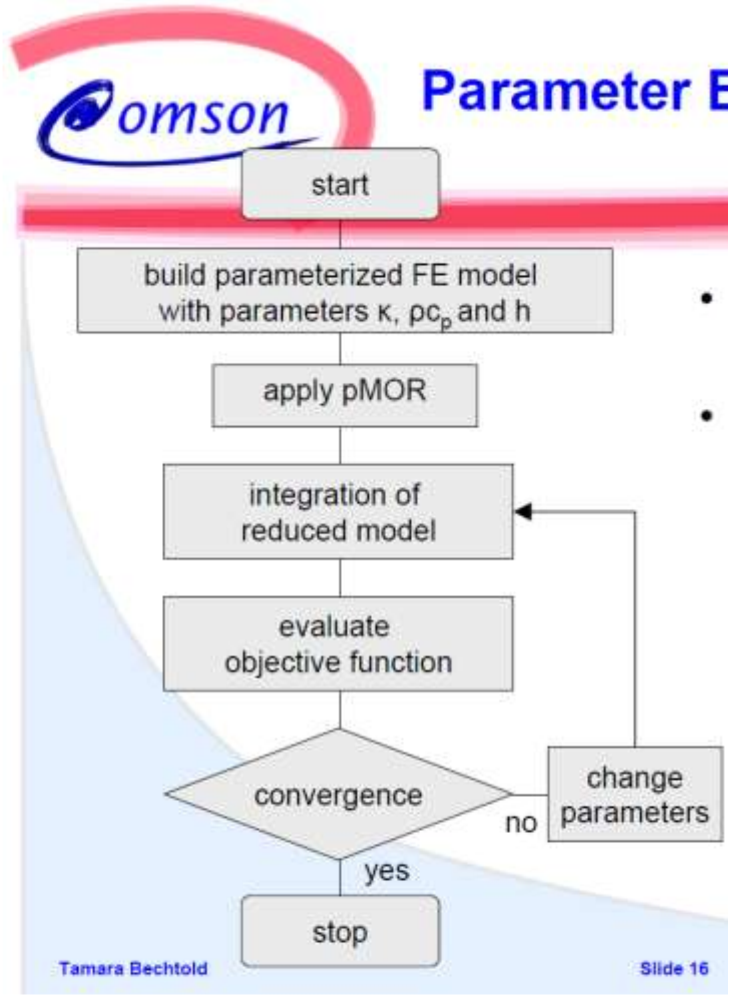


CADFEM

Extraction of Thermal Properties of Thin Films

- Thursday, 12:20 - 12:40, T. Bechtold, NXP
  - Parametric Model Reduction





CADFEM

Also on Thursday

- 16:20 - 16:40, Export von modal reduzierten Körpern aus ANSYS und deren Echtzeitberechnung, P. Sekler, A. Dadalau
- 17:00 - 17:20 Application of MOR for ANSYS to Hydro Turbine Runner Dynamics, F. Lippold (Voith Hydro Holding GmbH & Co. KG, Heidenheim)
- 17:00 - 17:20 Zustandsraumbeschreibung von piezo-mechanischen Systemen auf Grundlage einer Finite-Elemente-Diskretisierung, B. Kranz (Fraunhofer-Institut IWU, Dresden)
- 17:20 - 17:40 Parametric Reduction of Multiphysics Models, J. Mohring (Fraunhofer-Institut ITWM, Kaiserslautern)
- 17:40 - 18:00 Novel Model Reduction Techniques for Control of Machine Tools, P. Benner (Technische Universität Chemnitz)

Conclusion

- ANSYS – device level model
- Simplorer – system level simulation
- MOR for ANSYS – model reduction for ANSYS models