Modeling and Simulation for Design support of 3D-Systems

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Outline

- **Introduction**
- Methodology for multi-level and multi-physics analysis of interconnect structures
- Thermal analysis and electro-thermal simulation
- Modeling of electrical behavior at low and high frequencies
- Design flow integration and system level simulation
- Conclusions

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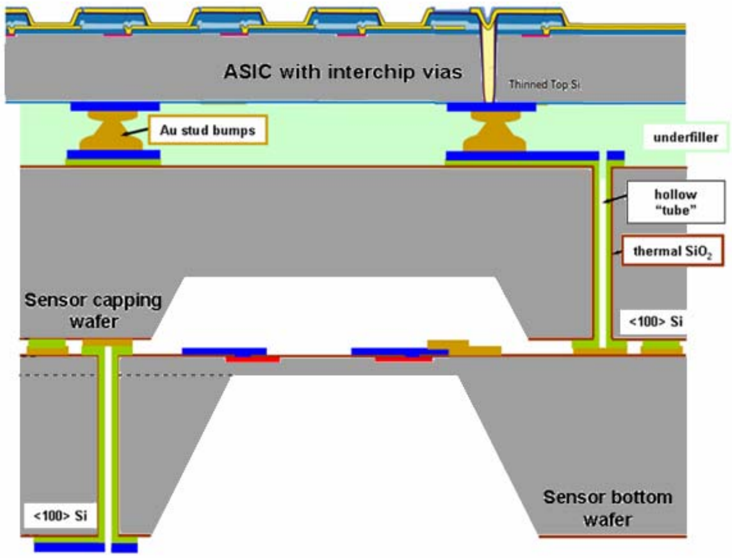
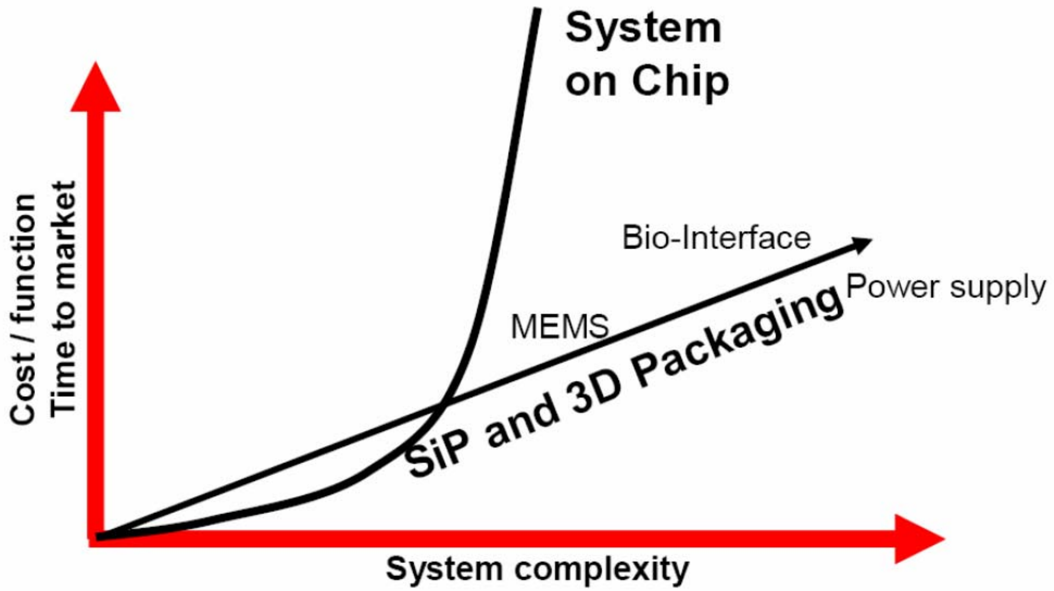
Key elements of SiP / 3D integration technology



Source: SINTEF



Source: ITRS-Roadmap 2005

- system partitioning/modularization
- chip-package co-design (on chip, off chip)
- integration of different functions in one package
- application of "add-on" technologies
- high-density component integration
- short time to market cycles

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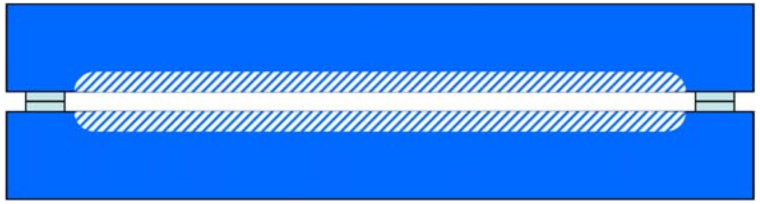
Basic approaches for 3D integration

Structure	**Possible physical effects**

face to face



- Cross talk between metal layers
- Thermal coupling between active areas

back to face

- Electrical influence of trough vias
- Heating in stack structure

Back to face with thinned die

- Heating in stack structure
- Substrate coupling between layers

Back to face with MEMS die

- Heating in stack structure
- Electrical influence of trough vias
- Mechanical stress due to different thermal expansion

3D Integration – Impact on System Behavior

Very high density of inter-chip wiring and functional blocks

leads to some physical effects with influence on device functions and system behavior:

– signal integrity

– cross talk

– interconnect delays

– power and thermal behavior

– thermo-mechanical issues

Design of 3D systems is a multi-criteria optimization problem !!!

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Methodology for multi-level and multi-physics analysis of interconnect structures

Goal

Derive information from integration technology and provide it for system design

Basic elements

1. Modular multi-level modeling approach
2. Simulation on component level, e.g. using FEM
3. Methods for computer-aided model generation for system level (e.g. reduced order modeling)
4. Model validation
5. Integration of equivalent circuit or behavioral models into the design flow
6. Derivation of design guidelines for interconnect structures

Representation of structures

Tool independent descriptions of basic structures

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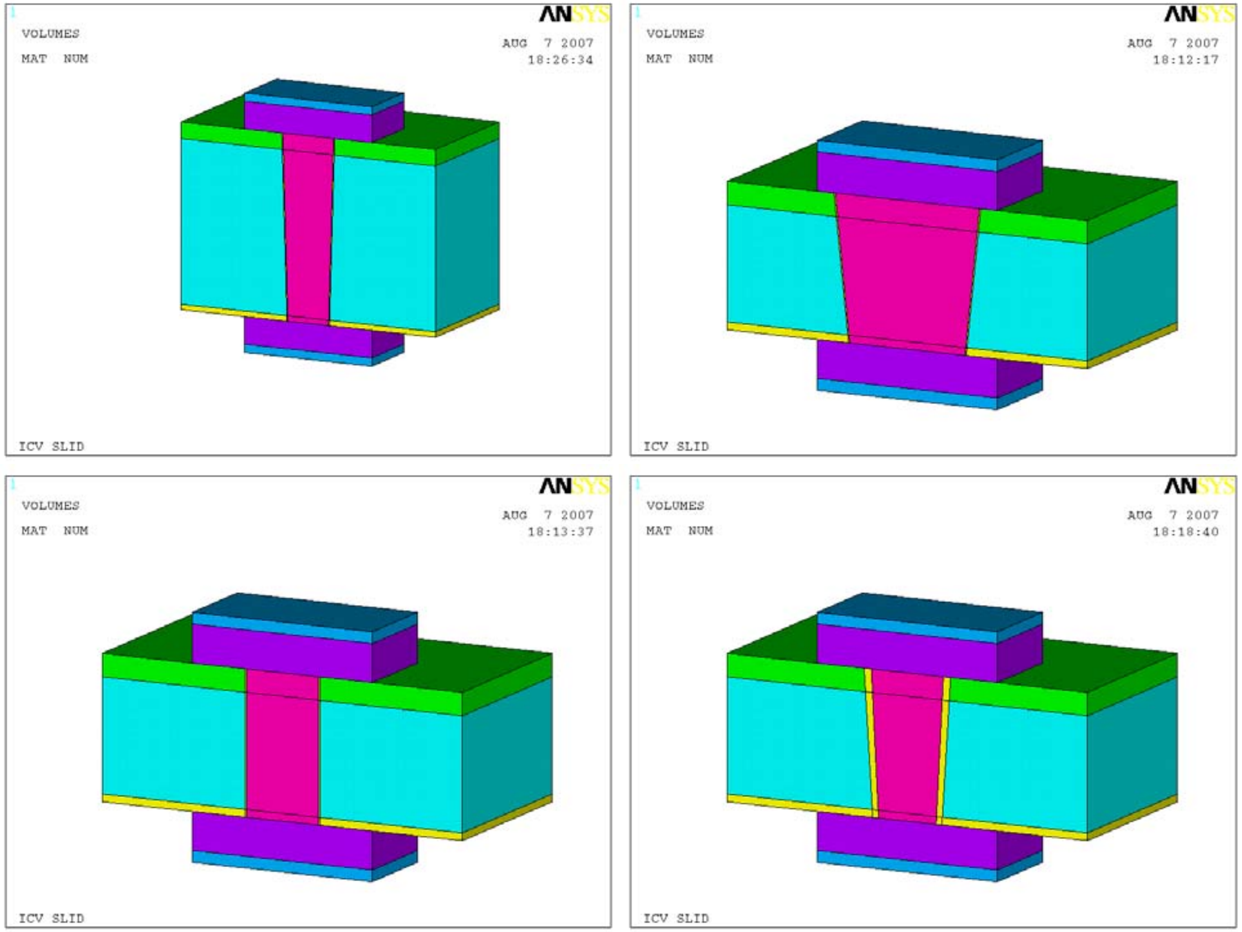
Geometry
Material
„Physics“
Mesh quality

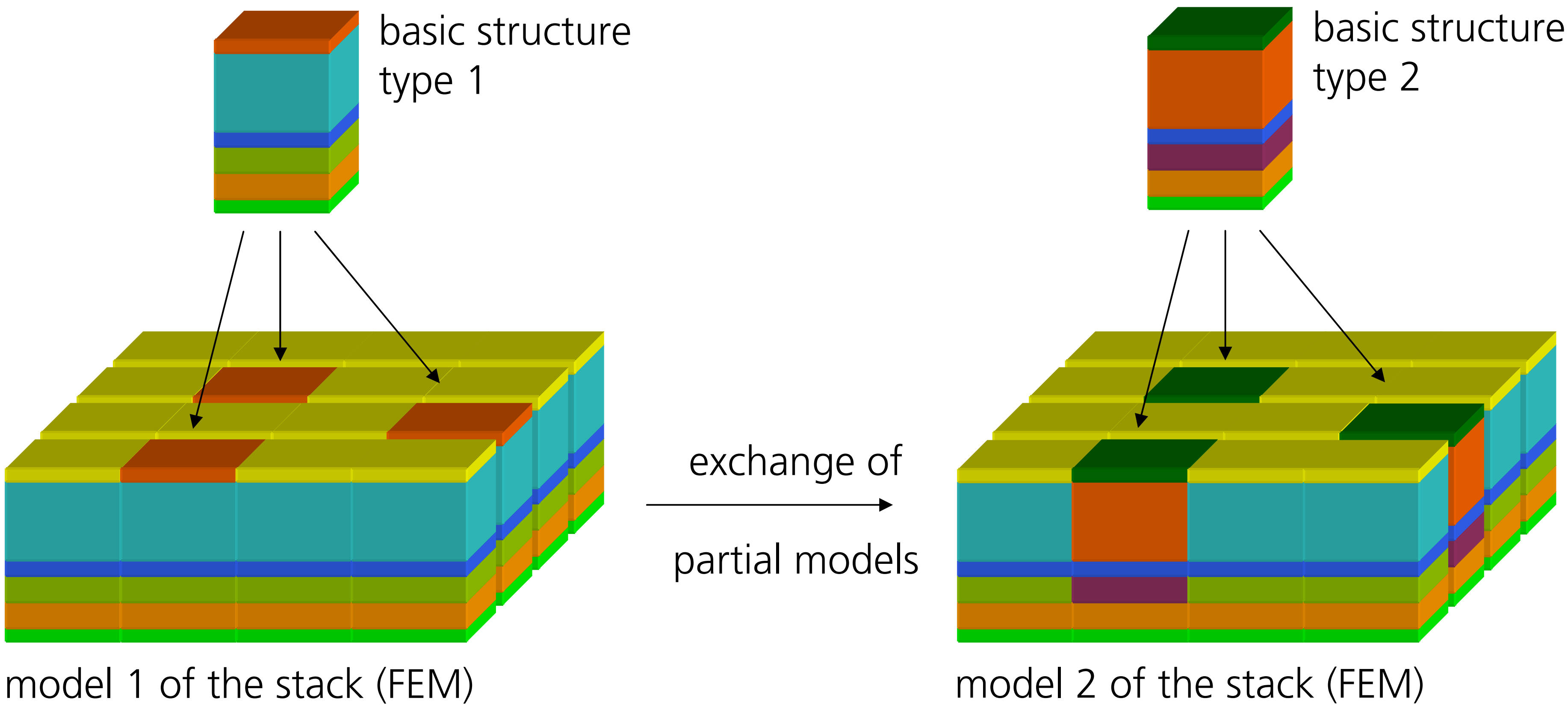
Model generation

FEM models for ICV-SLID with different geometry



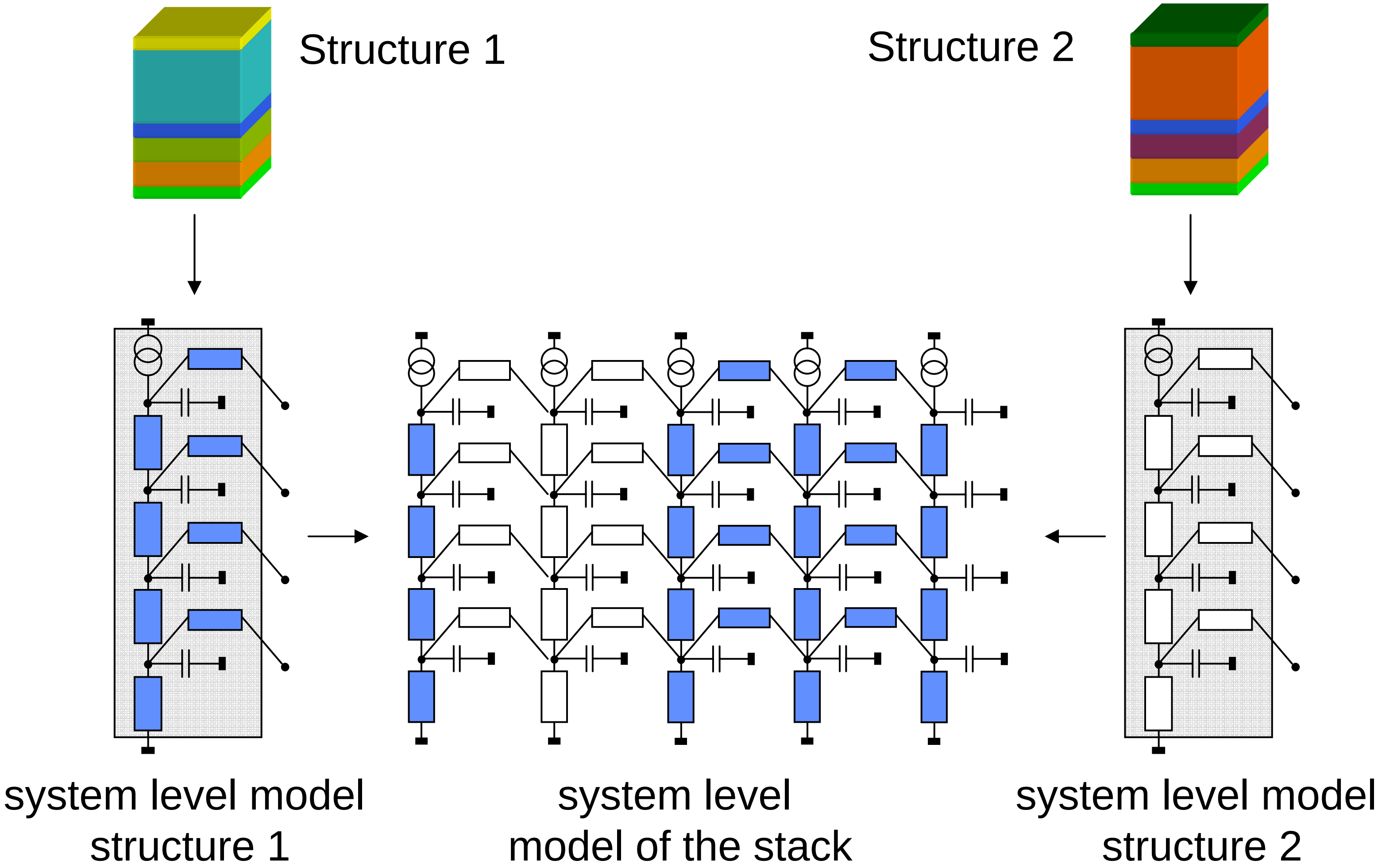
Representation of structures

Modular FEM modeling



Representation of structures

Modular system level modeling – equivalent circuit and/or behavioral model



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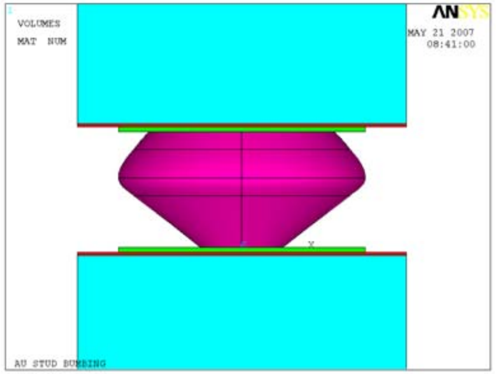
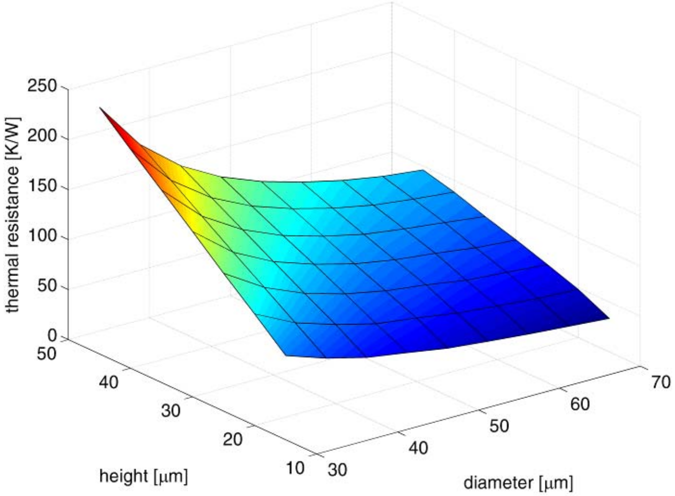
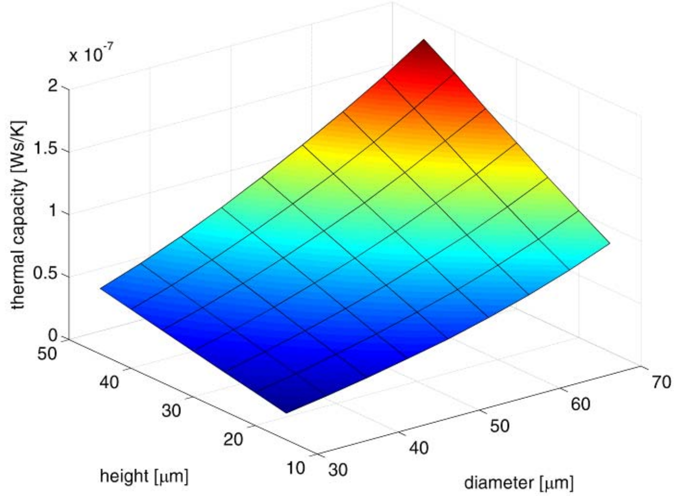
Thermal simulation

Thermal characterization of different interconnect technologies

Au stud bumps



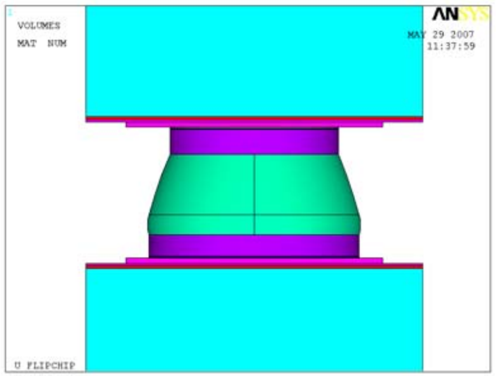


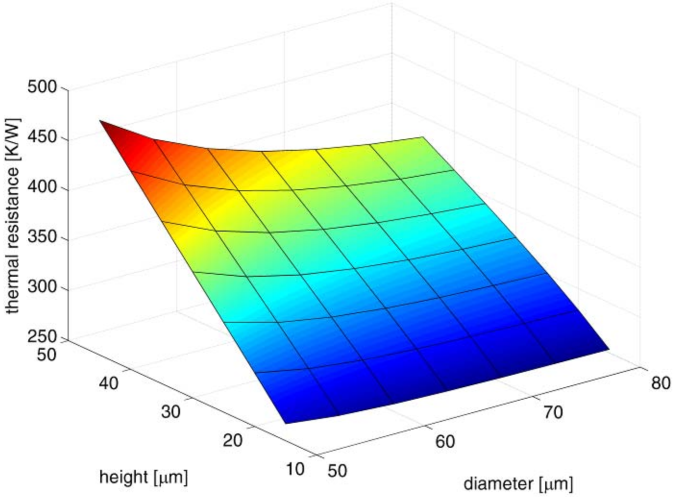


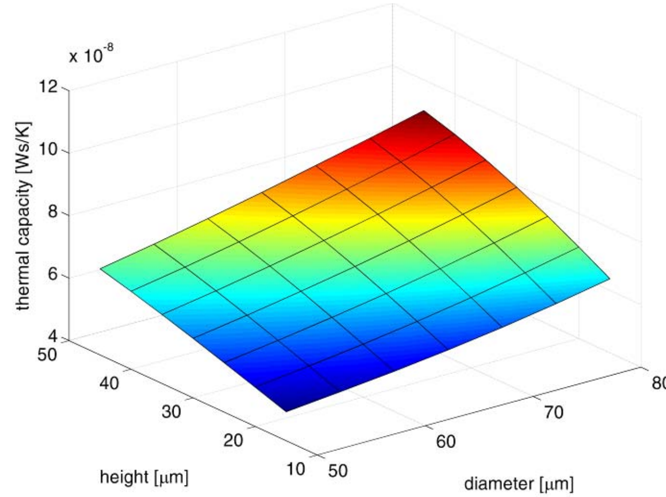
Thermal resistance

Thermal capacity

m-flip-chip



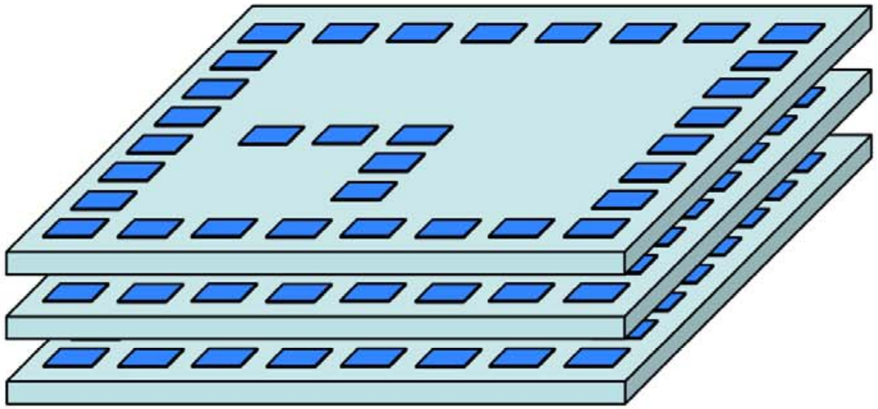




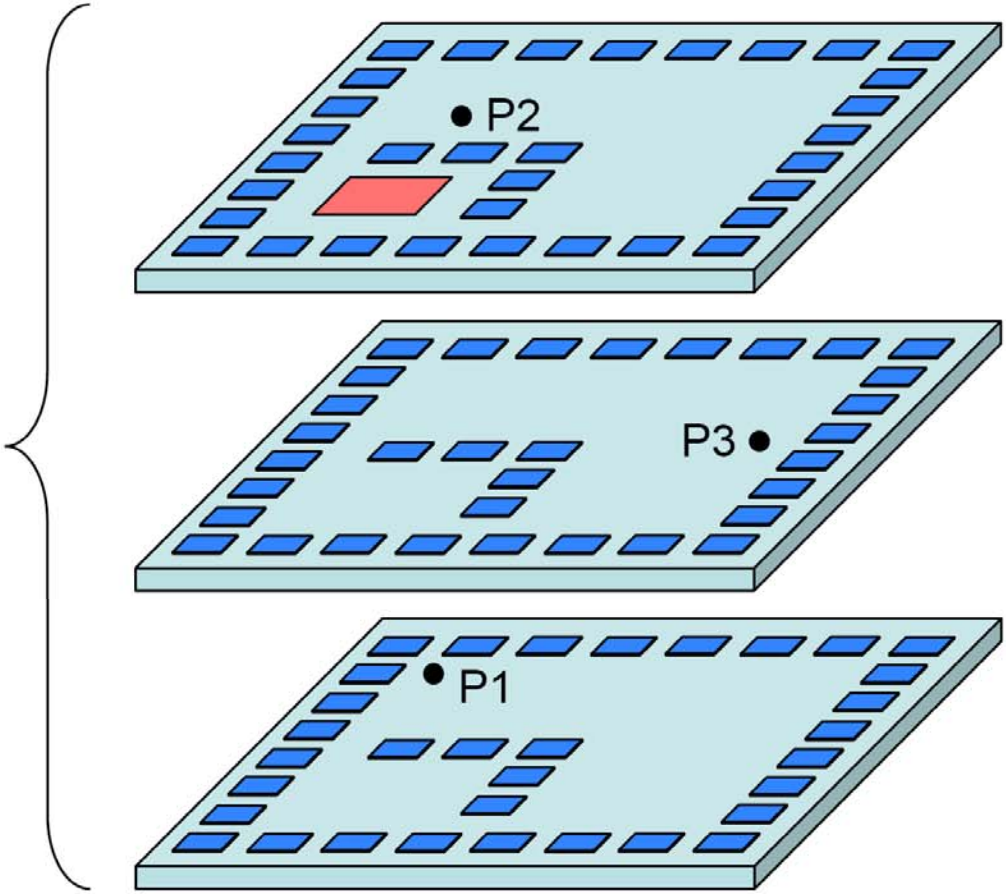
Thermal simulation

Thermal analysis of entire stack structure

Stack structure with vias for heat spreading

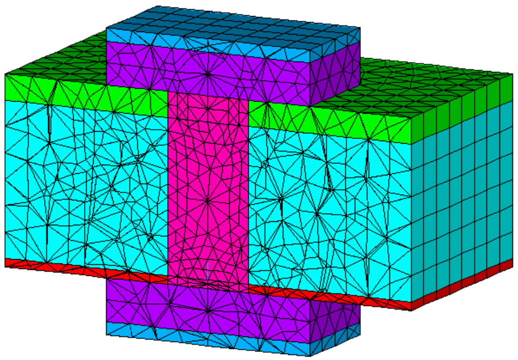


Stack layers with heat source (red square) and sensitive devices at P1, P2 and P3

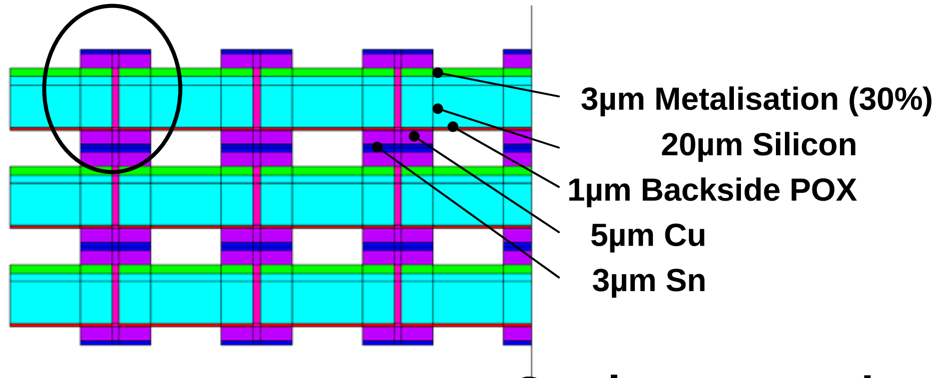


Thermal simulation

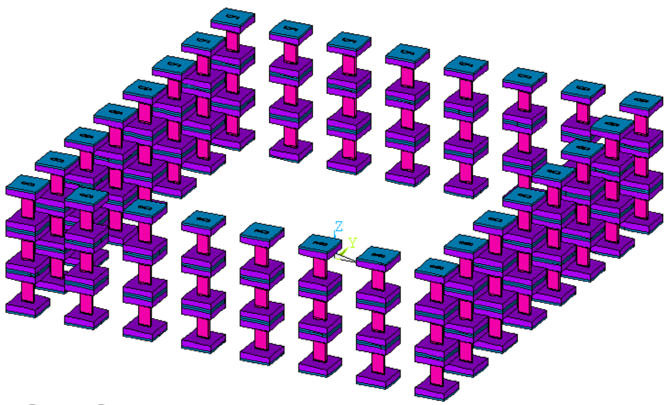
Modular modeling of stack structure



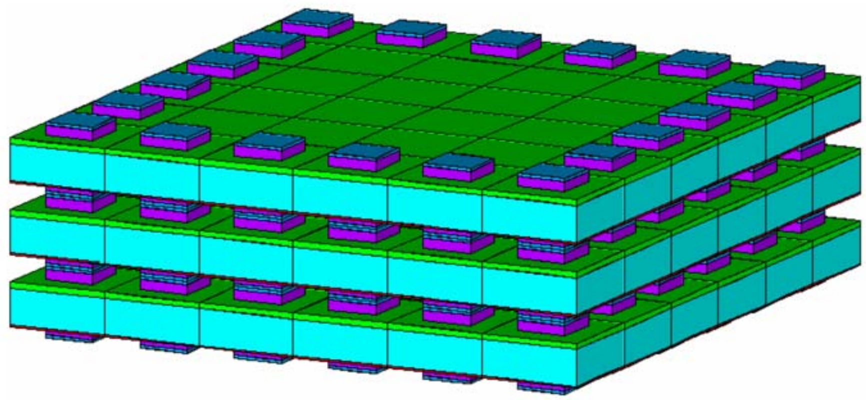
ICV SLID



Stack cross section



ICV SLID array

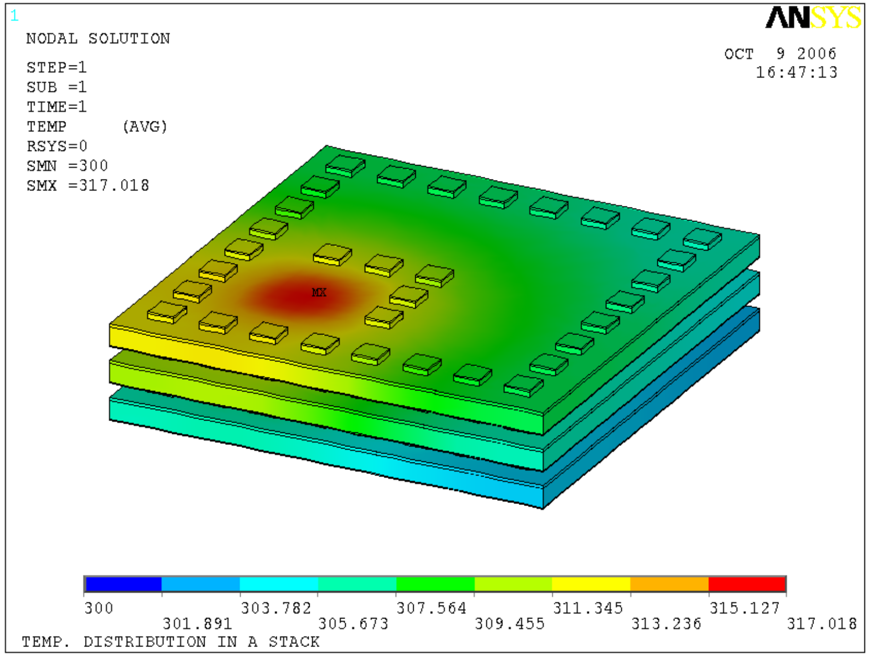


Stack model

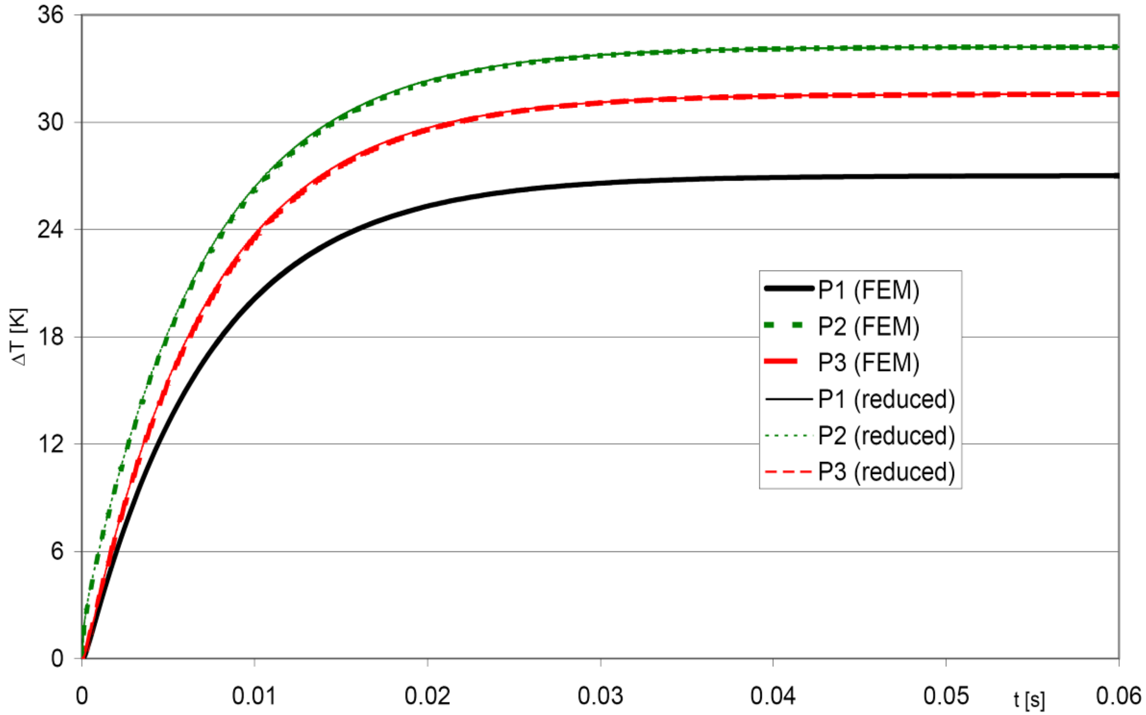
Thermal simulation

Results of FEM and system level simulation

FEM simulation with ANSYS



System simulation with reduced order model

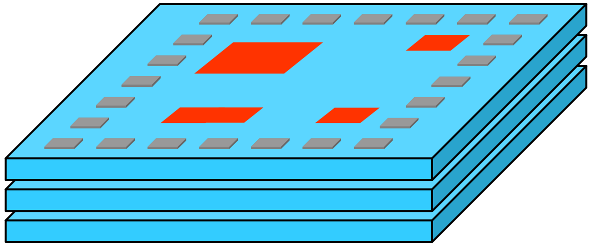


System level model for thermal system:

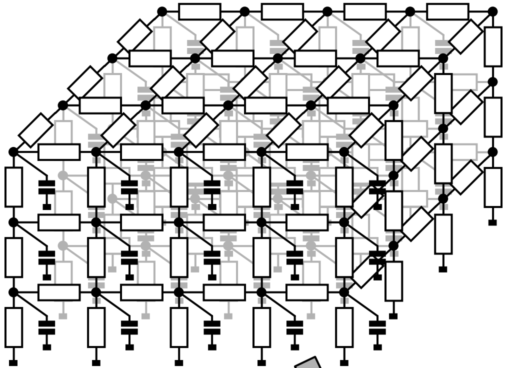
- 40 system variables
- derived from FEM description with 95,000 system variables by model order reduction
- Simulation carried out with SABER

Electro-thermal simulation

FEM model

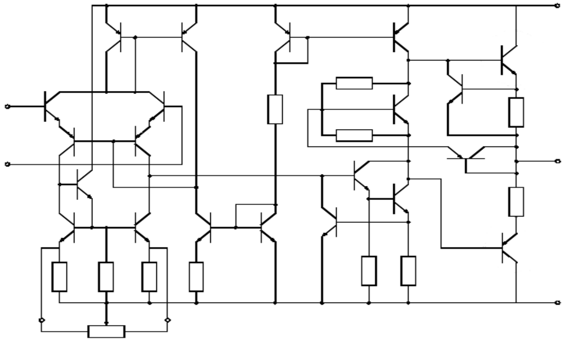


Thermal network

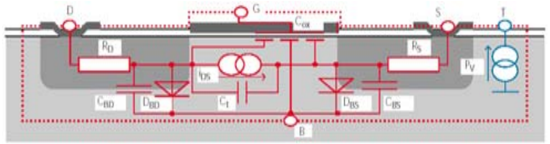


Reduced order behavioral model

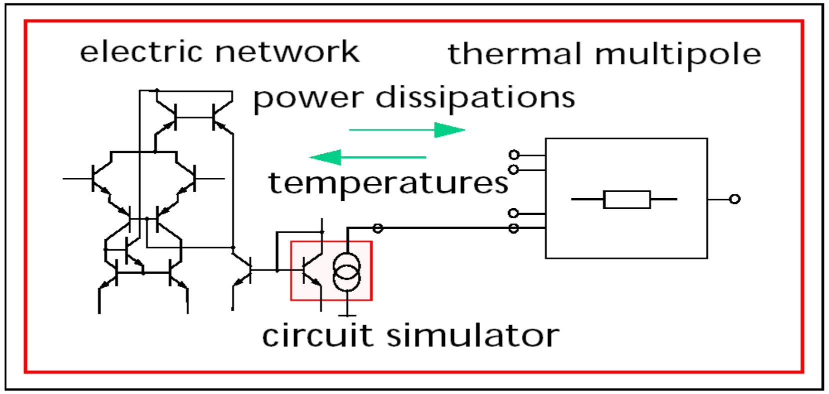
Electrical circuit



Electro-thermal device models



Electro-thermal simulation



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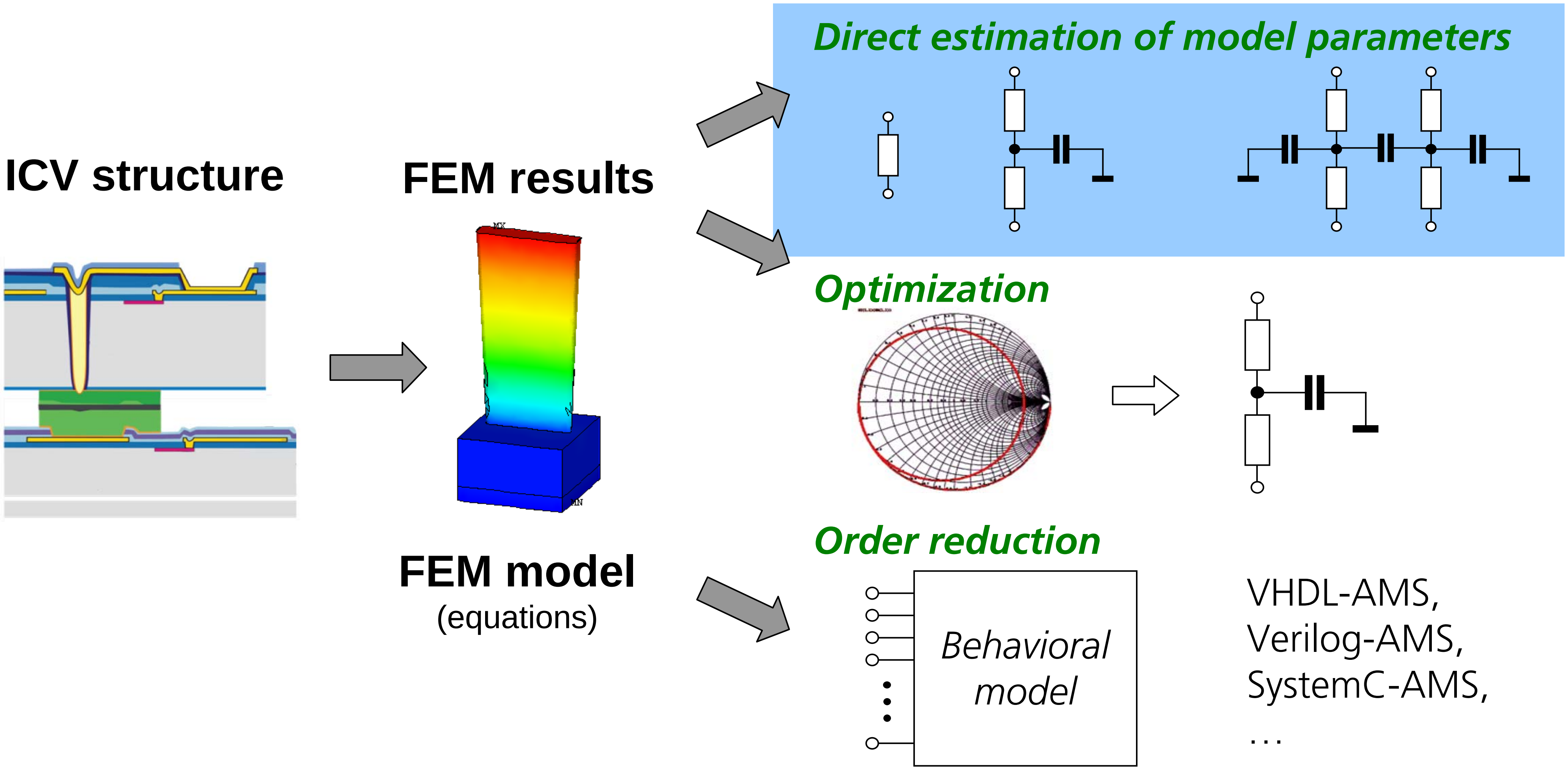
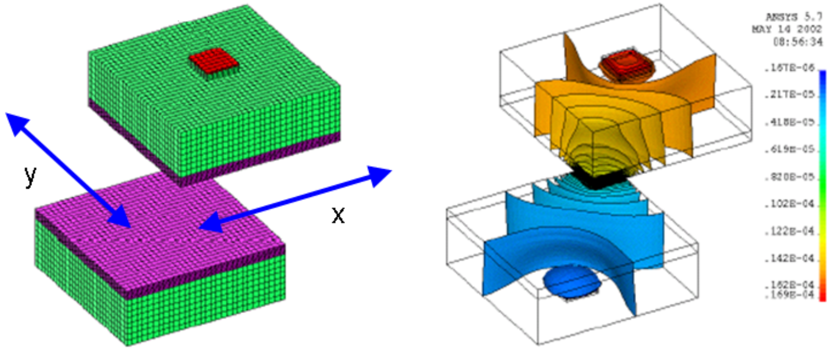
System level modeling



Calculation of circuit parameters

Modell

Äquipotentialflächen



Field calculation

network model

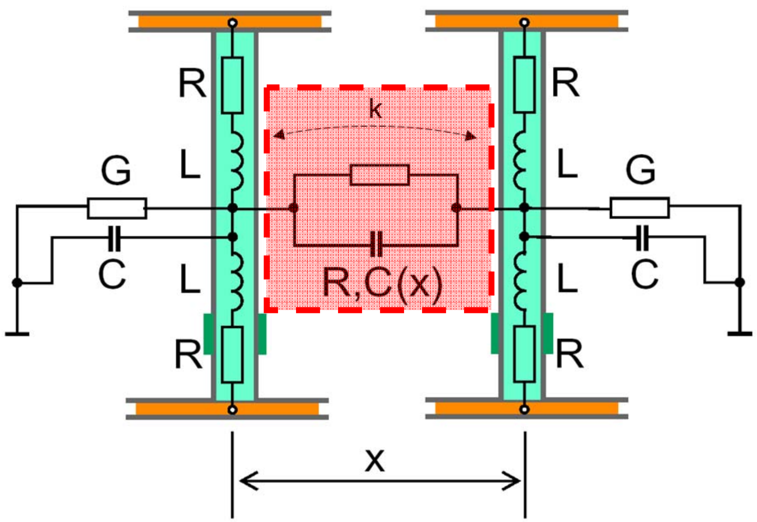
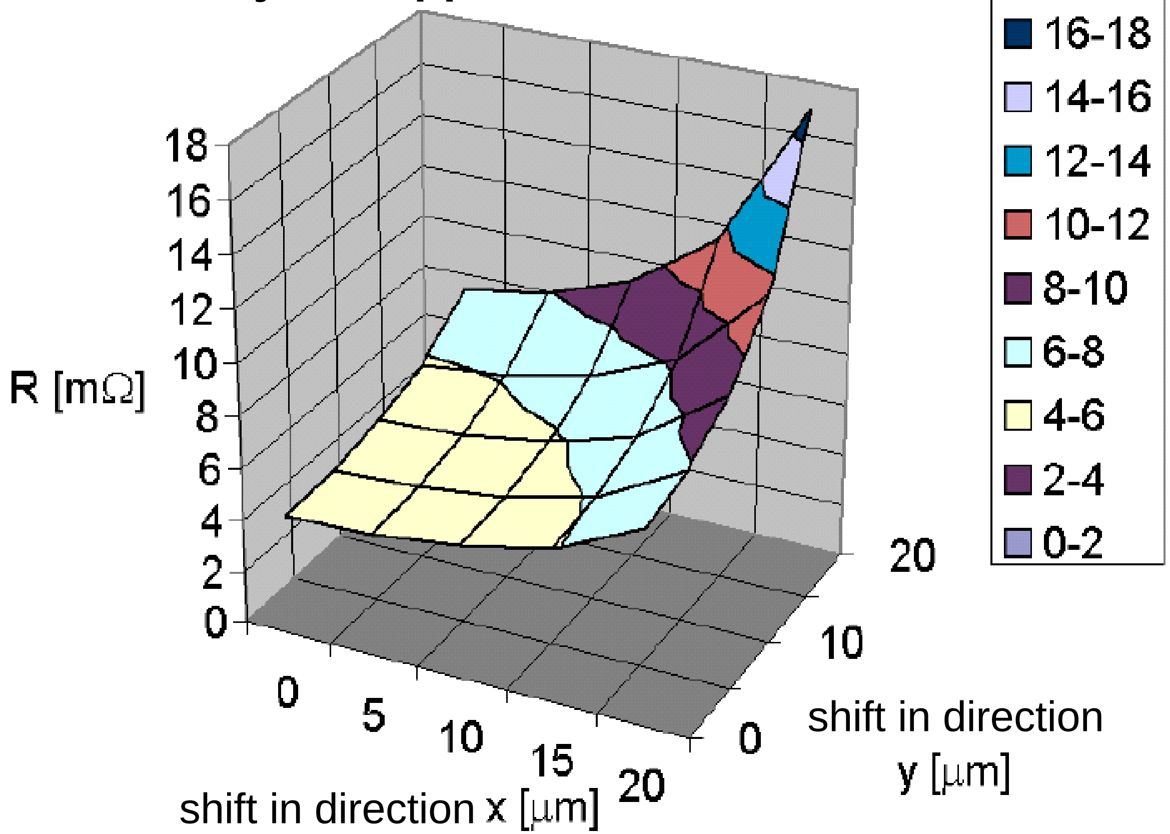


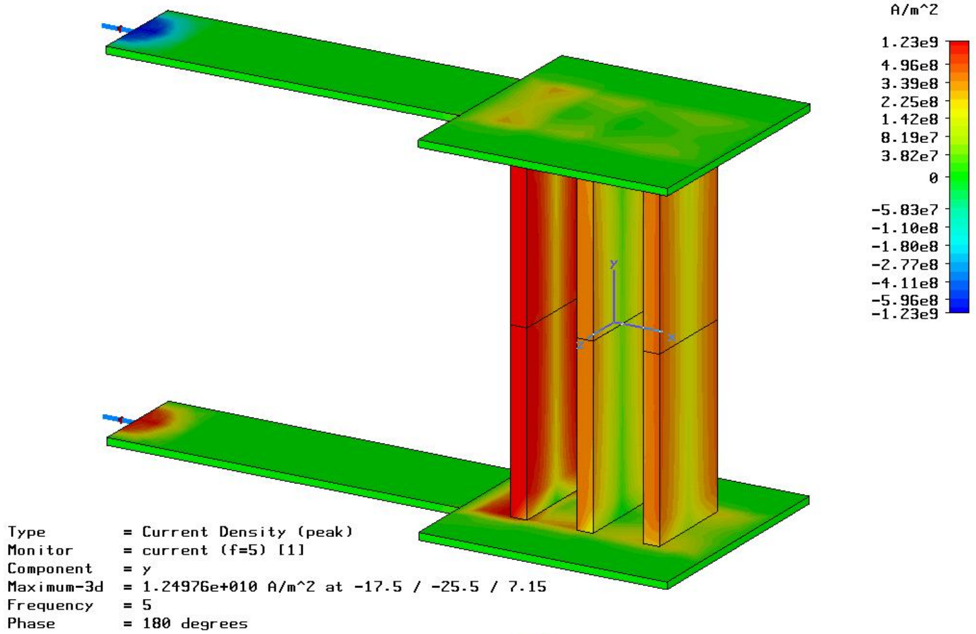
Table models or analytical approximation

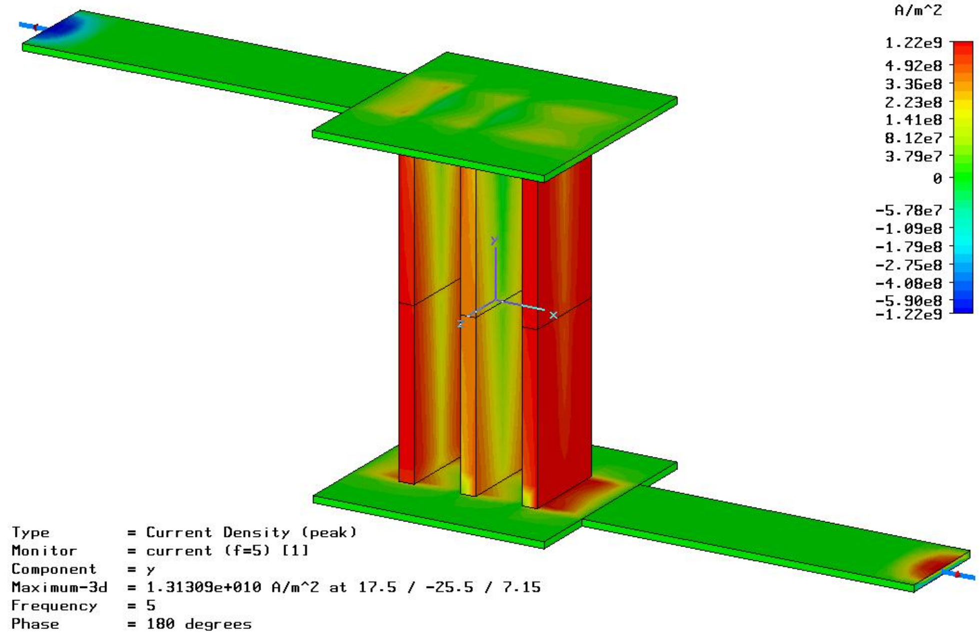


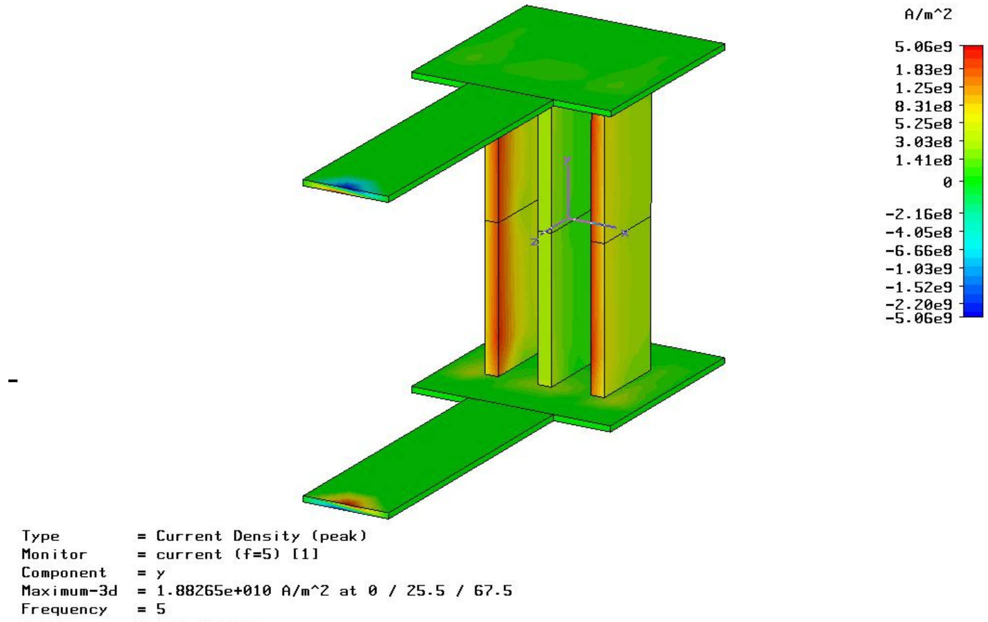
Electromagnetic analysis

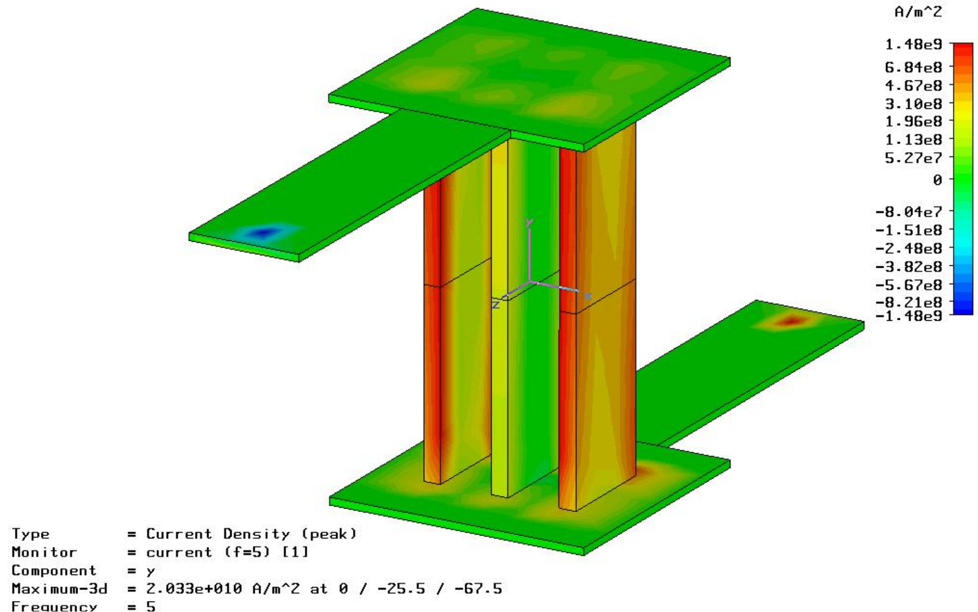
3D simulation

Simulation with CST Microwave Studio - Current density in via structures





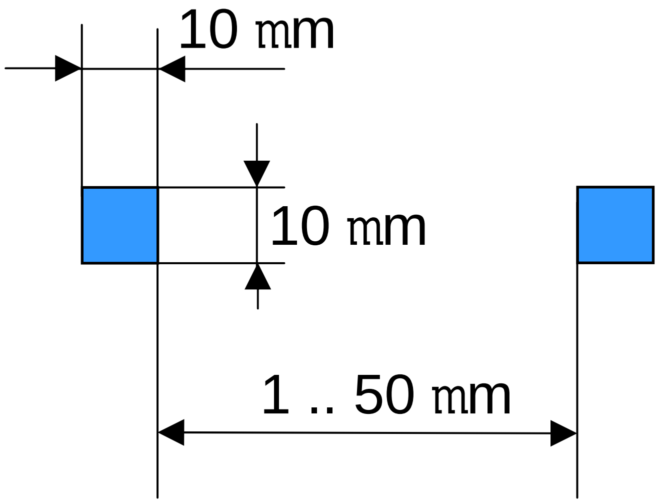


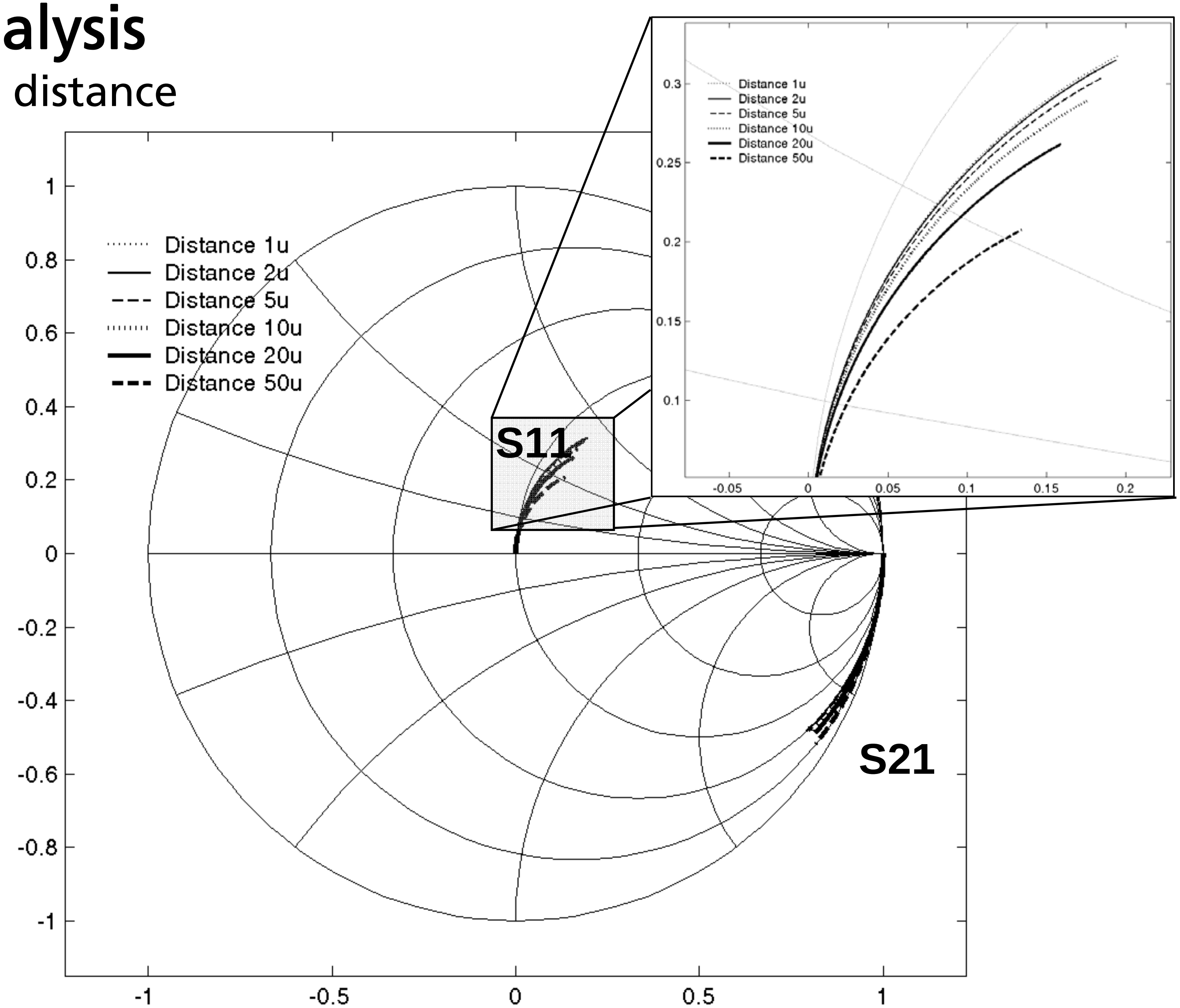


Electromagnetic analysis

S Parameter for varying via distance

Tungsten via structure





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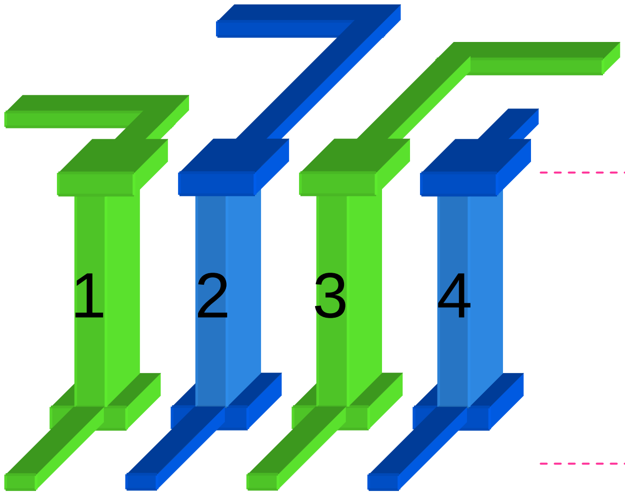
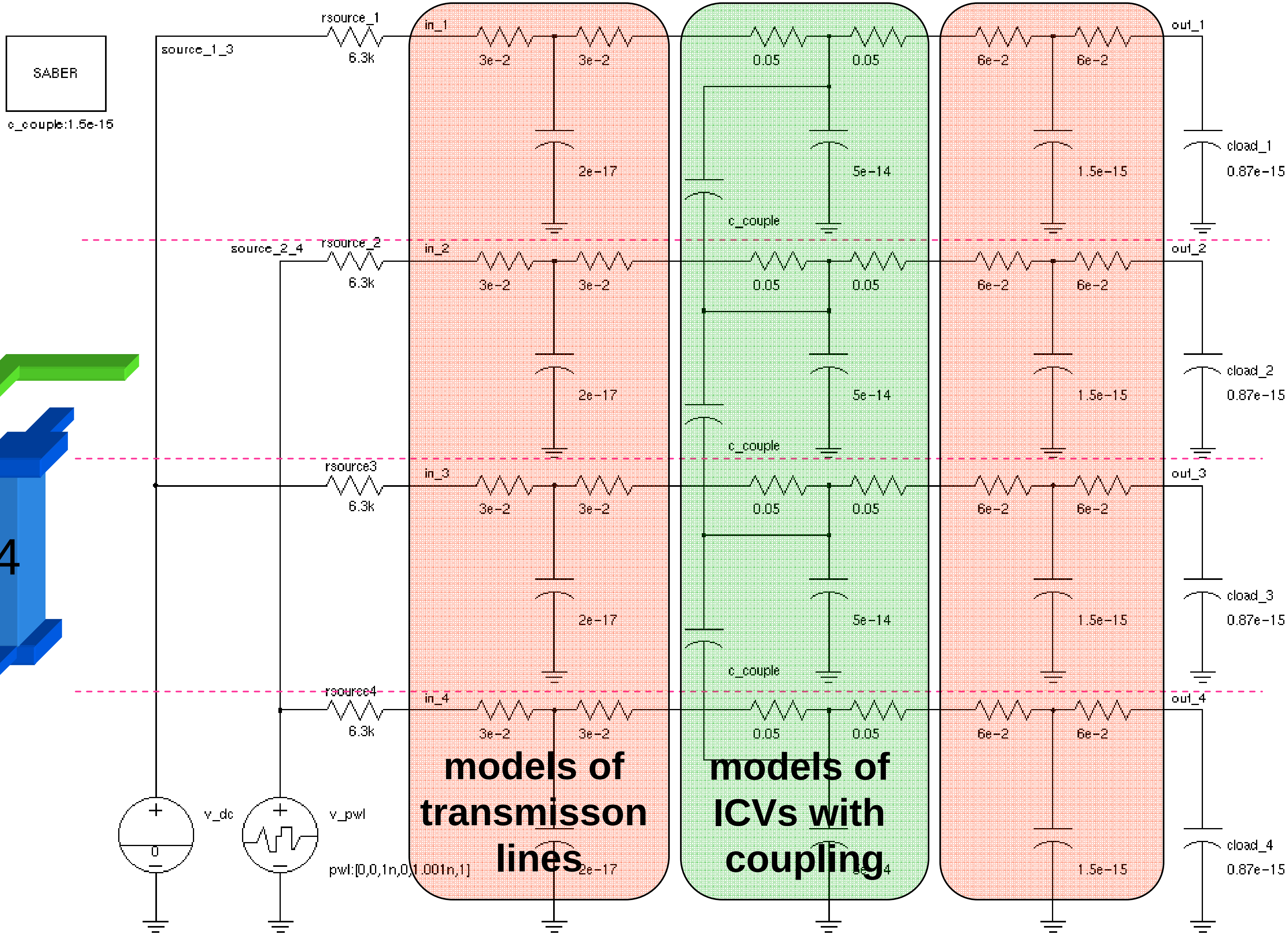
System level modeling – crosstalk simulation

4 coupled ICVs

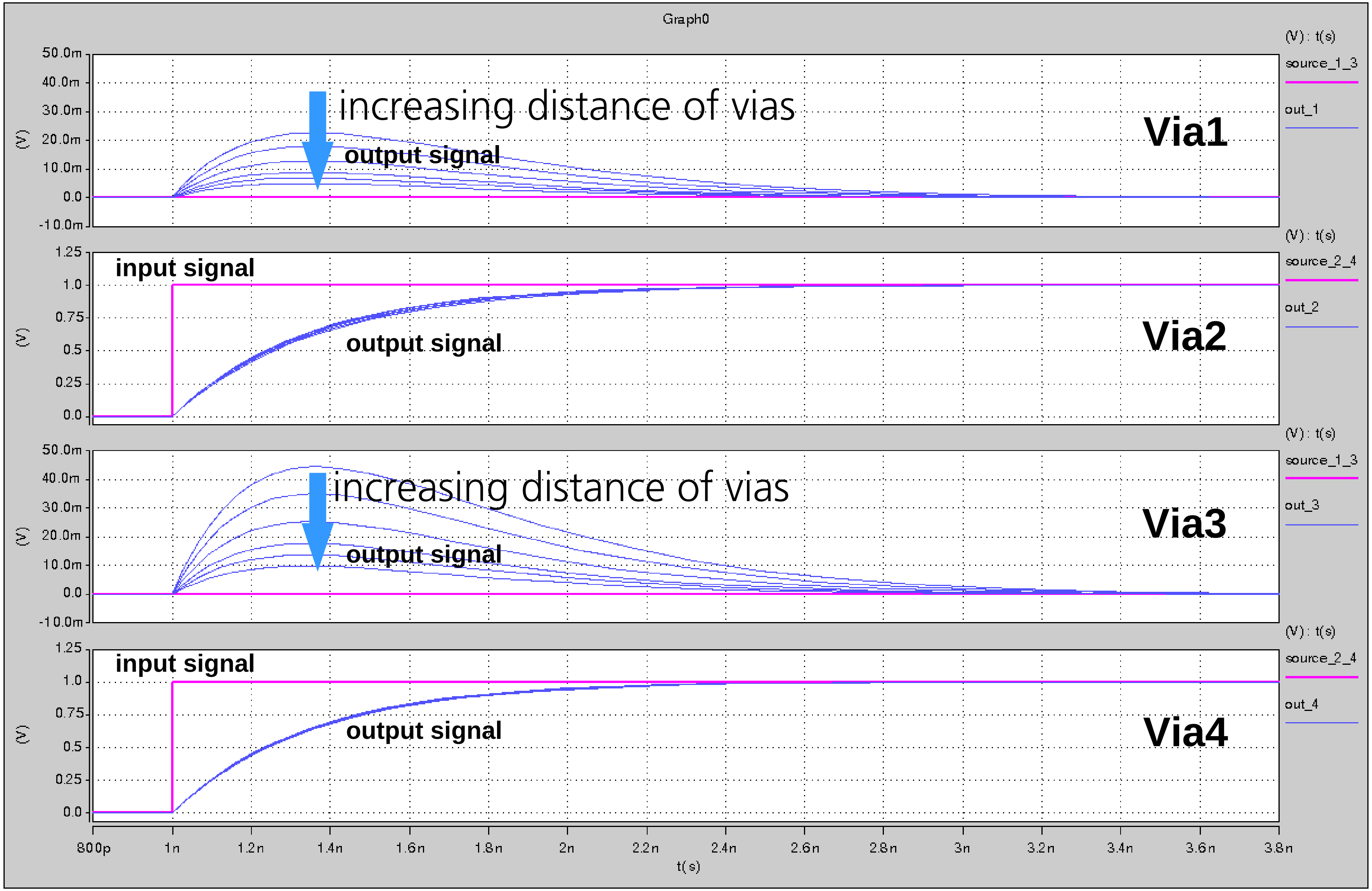




System level modeling – crosstalk simulation

crosstalk
2->1

crosstalk
2 ->3<-4



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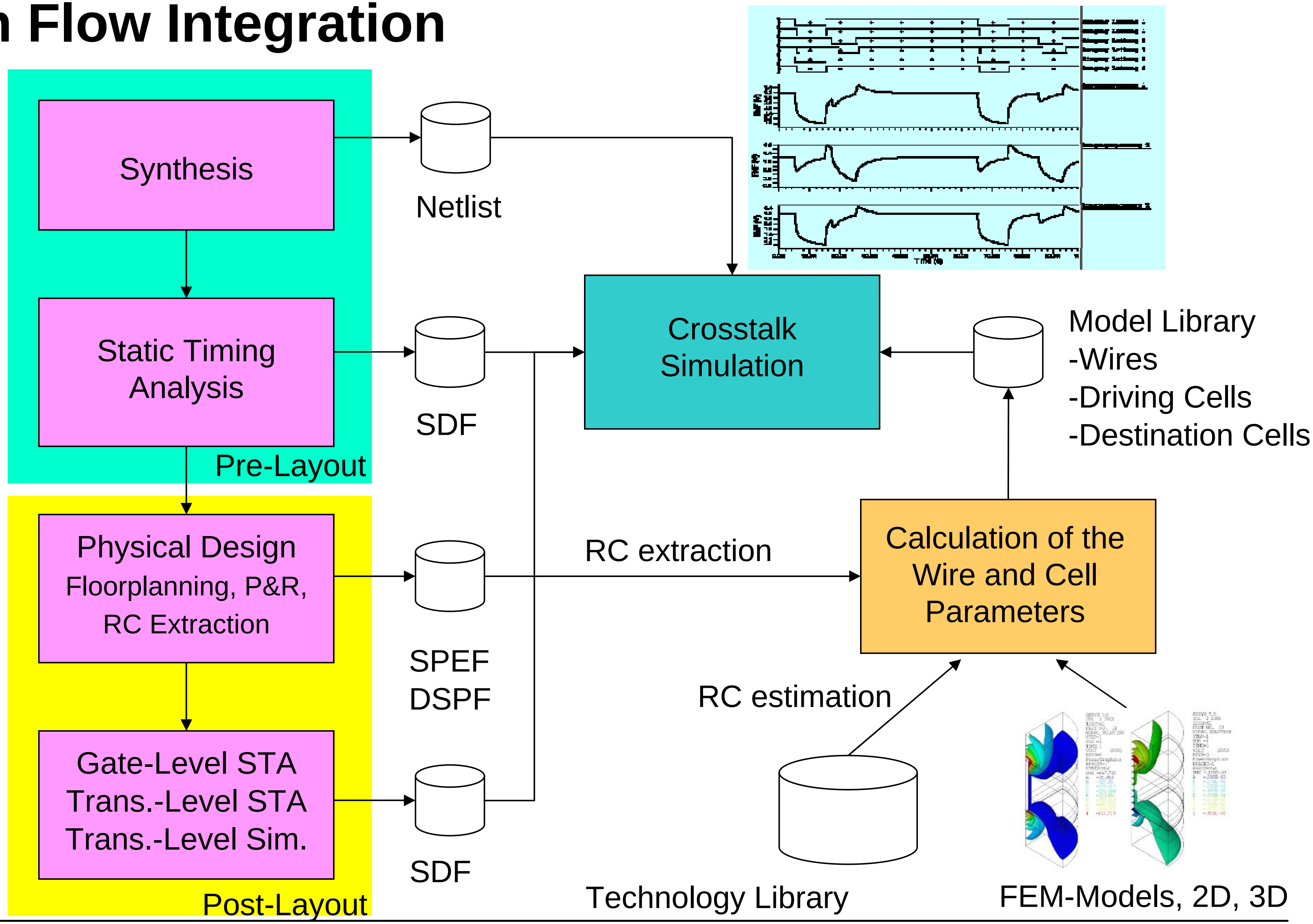
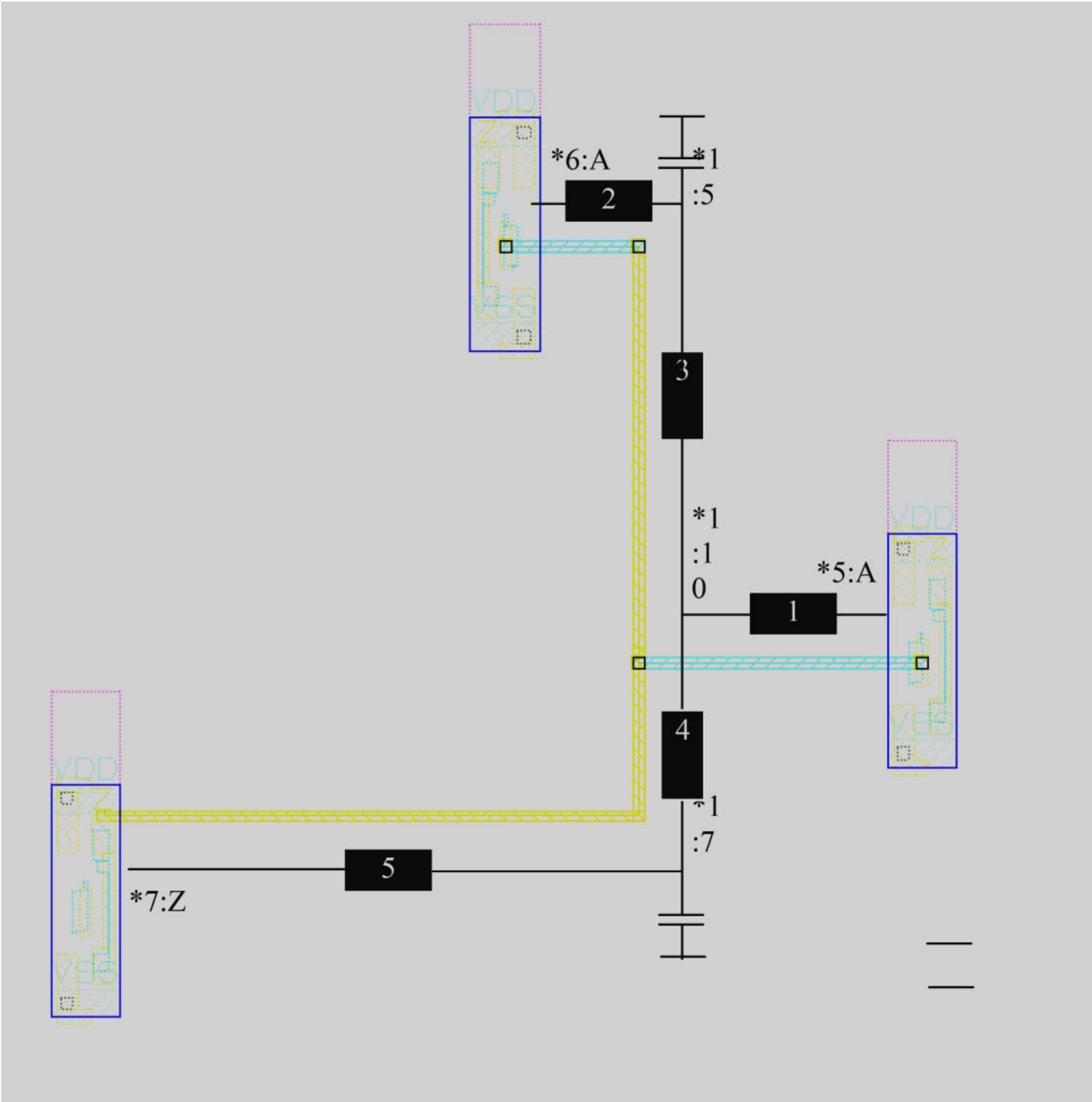
Design Flow Integration



Design Flow Integration

Standard Parasitics Exchange Format – Layout structure and SPEF file

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*VENDOR "Synopsys"
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*VERSION "2006.06                "
*DESIGN_FLOW "PIN_CAP NONE" "NAME_SCOPE
LOCAL"
*DIVIDER /
*DELIMITER :
*BUS_DELIMITER []
*T_UNIT 1.00000 NS
*C_UNIT 1.00000 FF
*R_UNIT 1.00000 OHM
*L_UNIT 1.00000 HENRY

…

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2 *1:7  0.0210339
*RES
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2 *6:A  *1:5  1.85000
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Conclusions and outlook

Main challenges for design automation

- Multi-technology / multi-functional / multi-disciplinary / multi-physics
- handling of complexity by hierarchical modeling methodology

Knowledge about interconnect implementation

- is mandatory for robust design of actual system concepts
- enables the development of *new* system concepts and architectures

Development of manufacturing and design technology has to go hand in hand

Improvements in both technologies will be driven by applications

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