Simulation of IGBT converter

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Outline

- The work has been done for the ECPE workshop Thermal Engineering of Power Electronics Systems, 2009
- Overview
- Thermal Simulation in Icepak
- Compact Thermal Model through Model Order Reduction

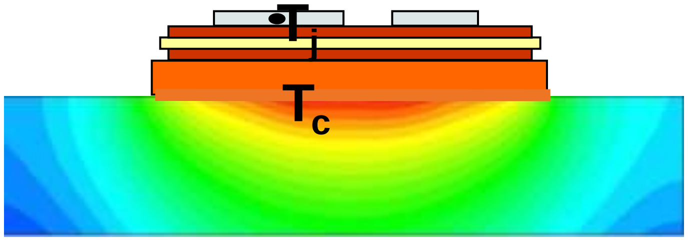
European Center for Power Electronics

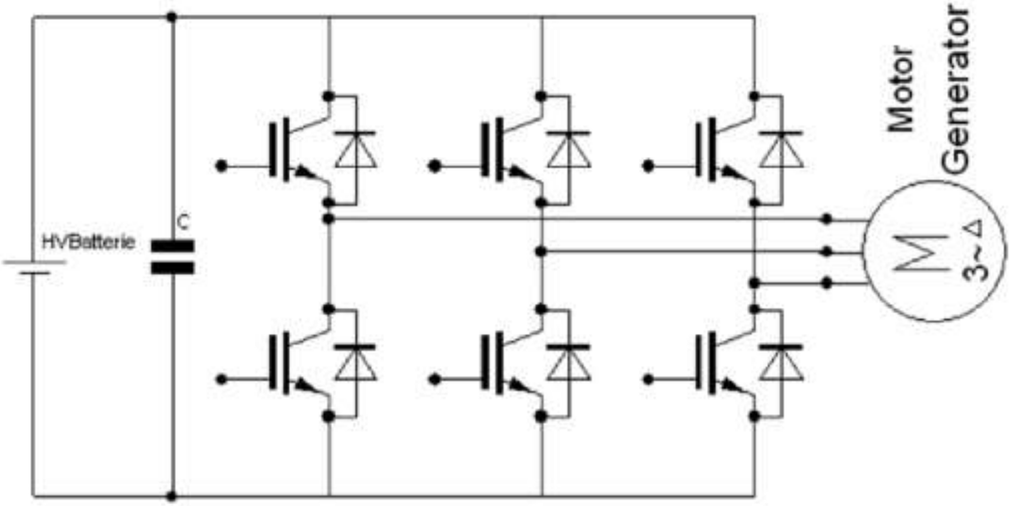
ECPE Network: 39 Industrial Members

BOSCH
TRANSIC Power Transistors in Silicon Carbide
Schneider Electric
Continental
EADS
ST
PLECS
Heraeus
Danfoss
Kunze The Heatmanagement Company
CONTROL TECHNIQUES
vacon DRIVEN BY DRIVES
Vincotech
ECPE
EPCOS
LIEBHERR
Minebea European Operations
ALSTOM
SMA
emotron DEDICATED DRIVE
Schofer powertrain
REFU Elektronik
J-LASSLOP INDUKTIVE BAUTEILE
SEMIKRON innovation+service
Infineon
SEME LAB
FRIWO
iti Energy
CADFEM
ABB
SILVER ATENA
MACCON MOTION UNDER CONTROL
micro GaN GmbH
DAIMLER
SIEMENS
DYNEX
TRIDONIC.ATCO
ENERGIEregion Nürnberg e.V.
SEW EURODRIVE
AAVID THERMALLOY ONE COOL IDEA AFTER ANOTHER

IGBT Converter

- Insulated Gate Bipolar Transistor:
  - Very efficient – thermal losses about just 5%
  - However 20 kW converter produces 1 kW power dissipation.
- Electrothermal simulation is required:
  - Electrical properties of IGBT depends on temperature;
  - Too high temperatures reduces reliability and durability.





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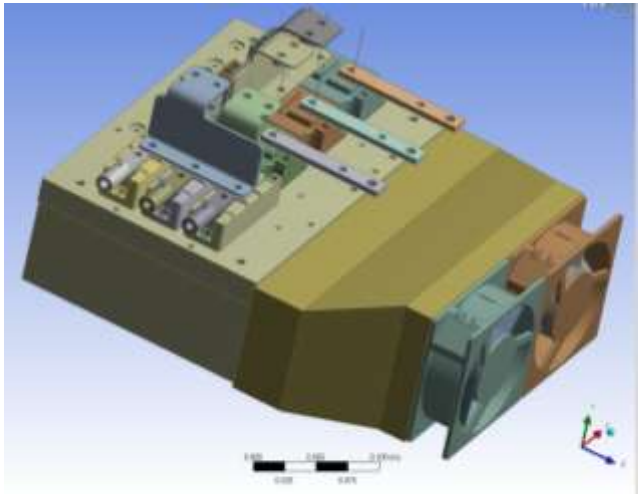
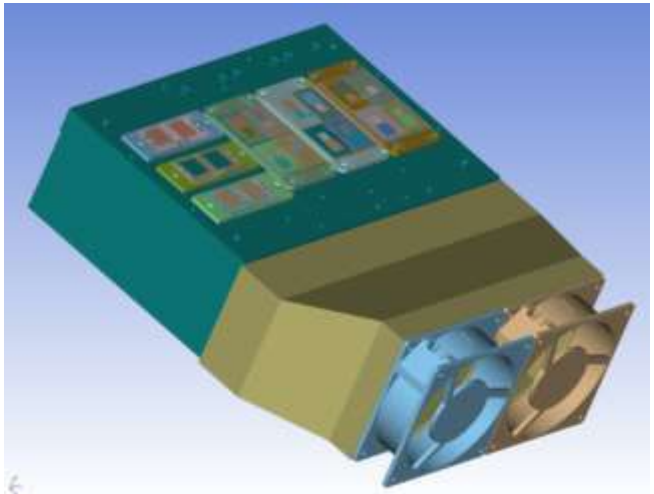
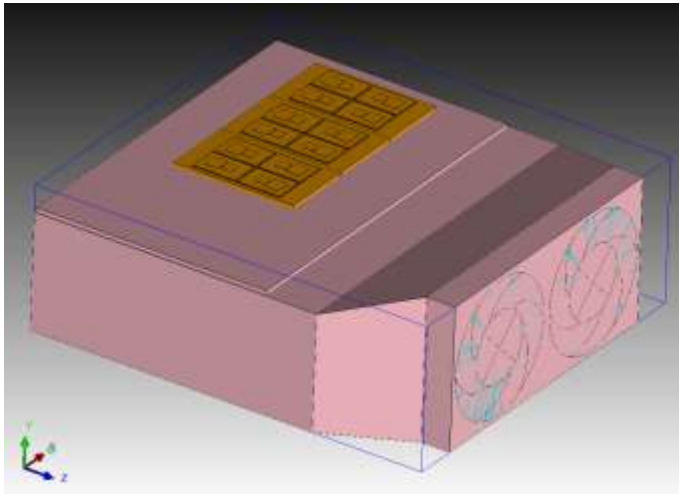
The Model of the Converter



Original Model



Model in Icepro



Model in Icepak

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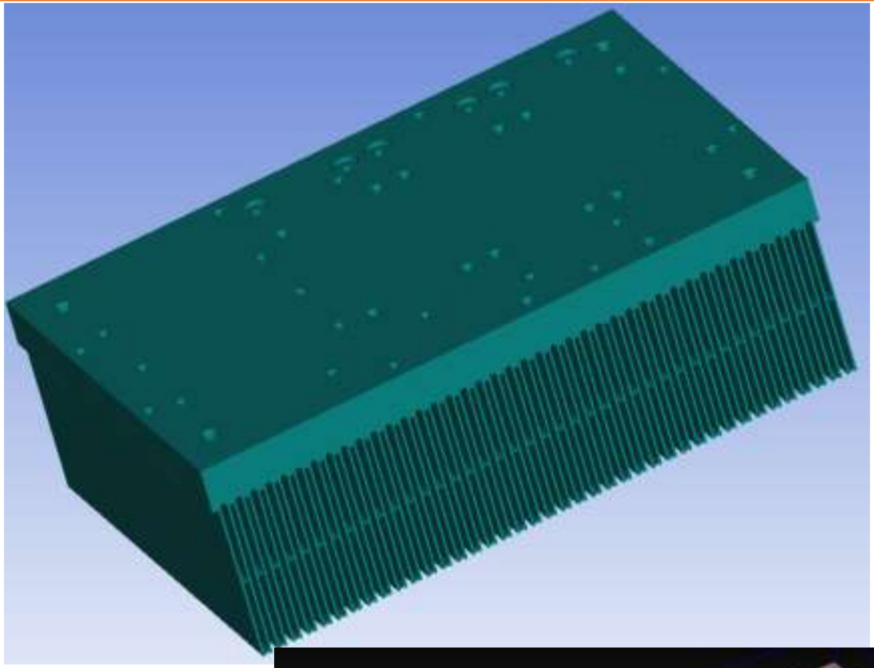
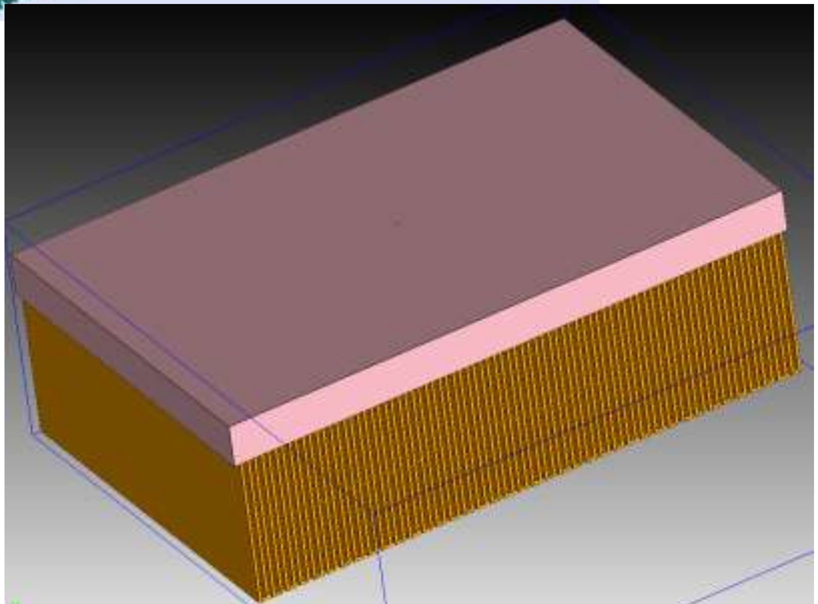
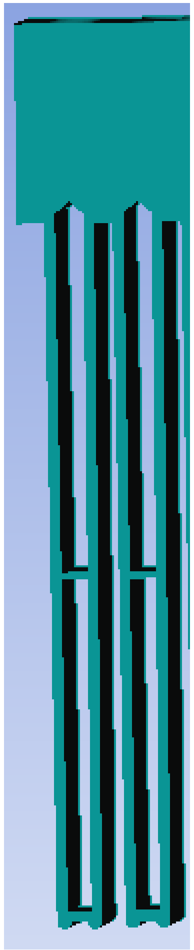
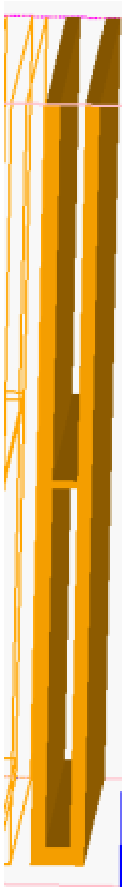
Simplifying the Heat sink In Icepro

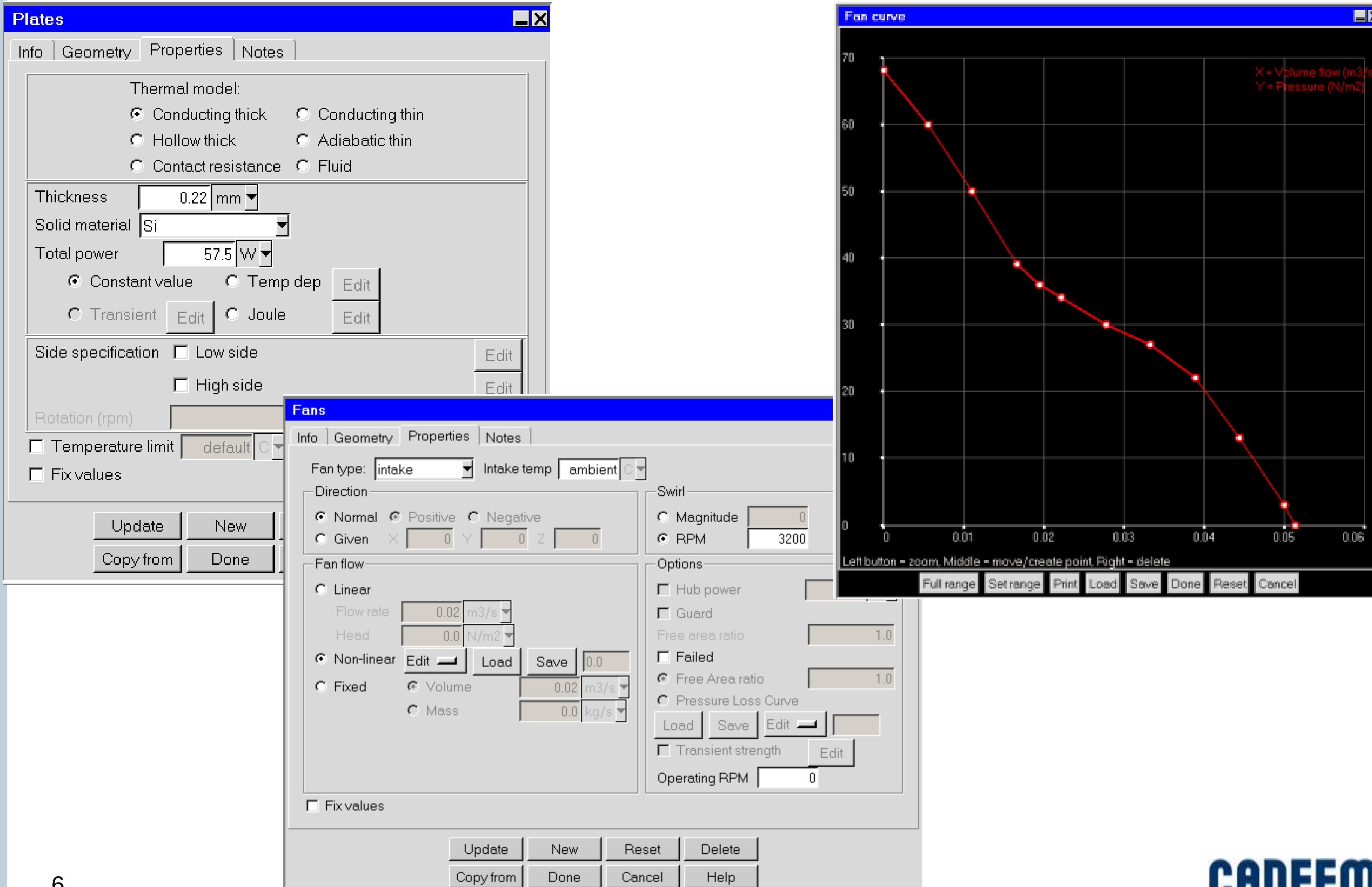








Power dissipation, materials, boundary conditions



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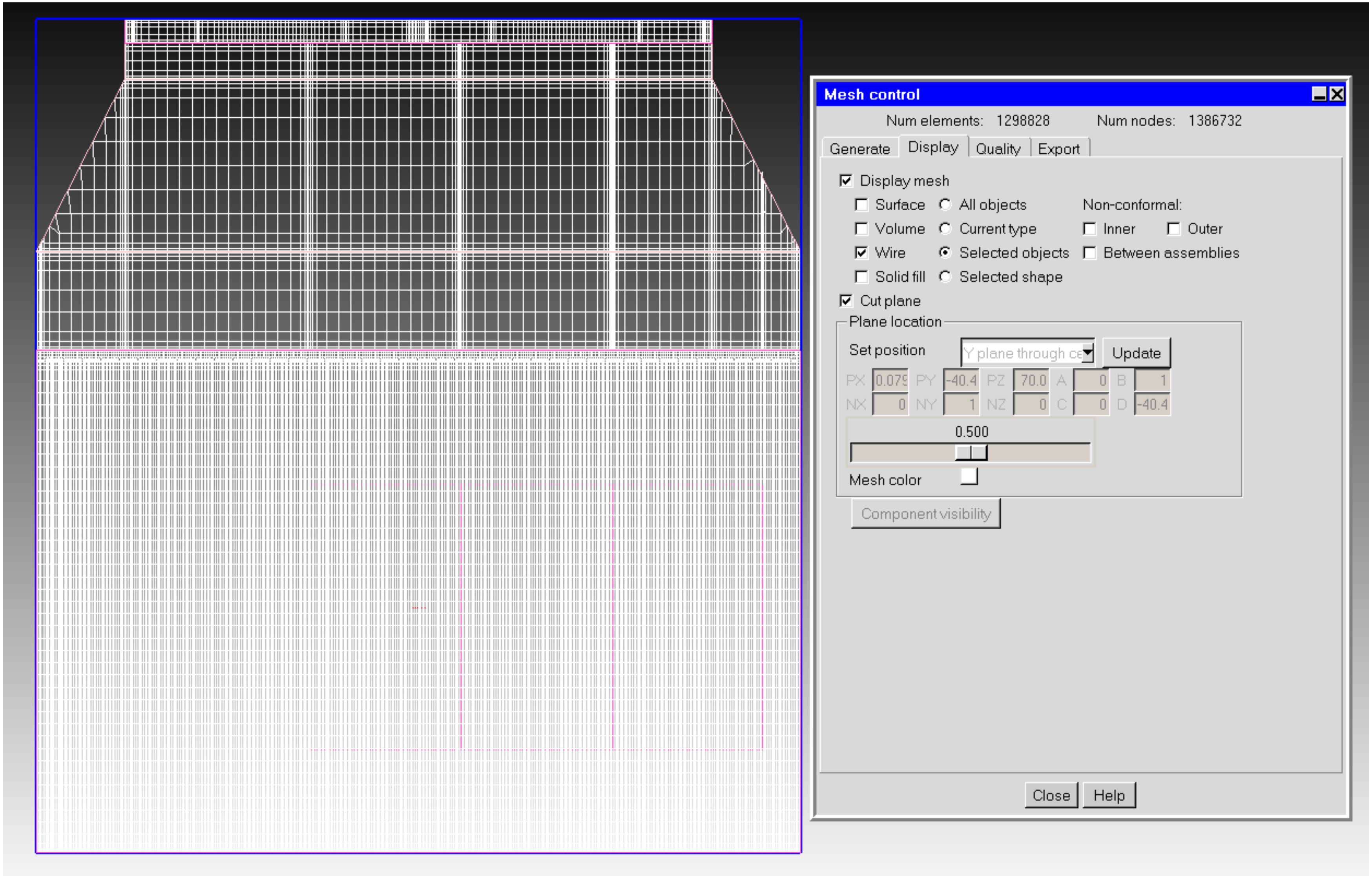
Mesh



Mesh control
Num elements: 1298828
Num nodes: 1386732
Generate
Display
Quality
Export
Display mesh
Surface
Volume
Wire
Solid fill
All objects
Current type
Selected objects
Selected shape
Non-conformal:
Inner
Outer
Between assemblies
Cut plane
Plane location
Set position
Update
PX
PY
-40.4
PZ
70.0
A
0
B
1
NX
0
NY
1
NZ
0
C
0
D
-40.4
0.500
Mesh color
Component visibility
Close
Help

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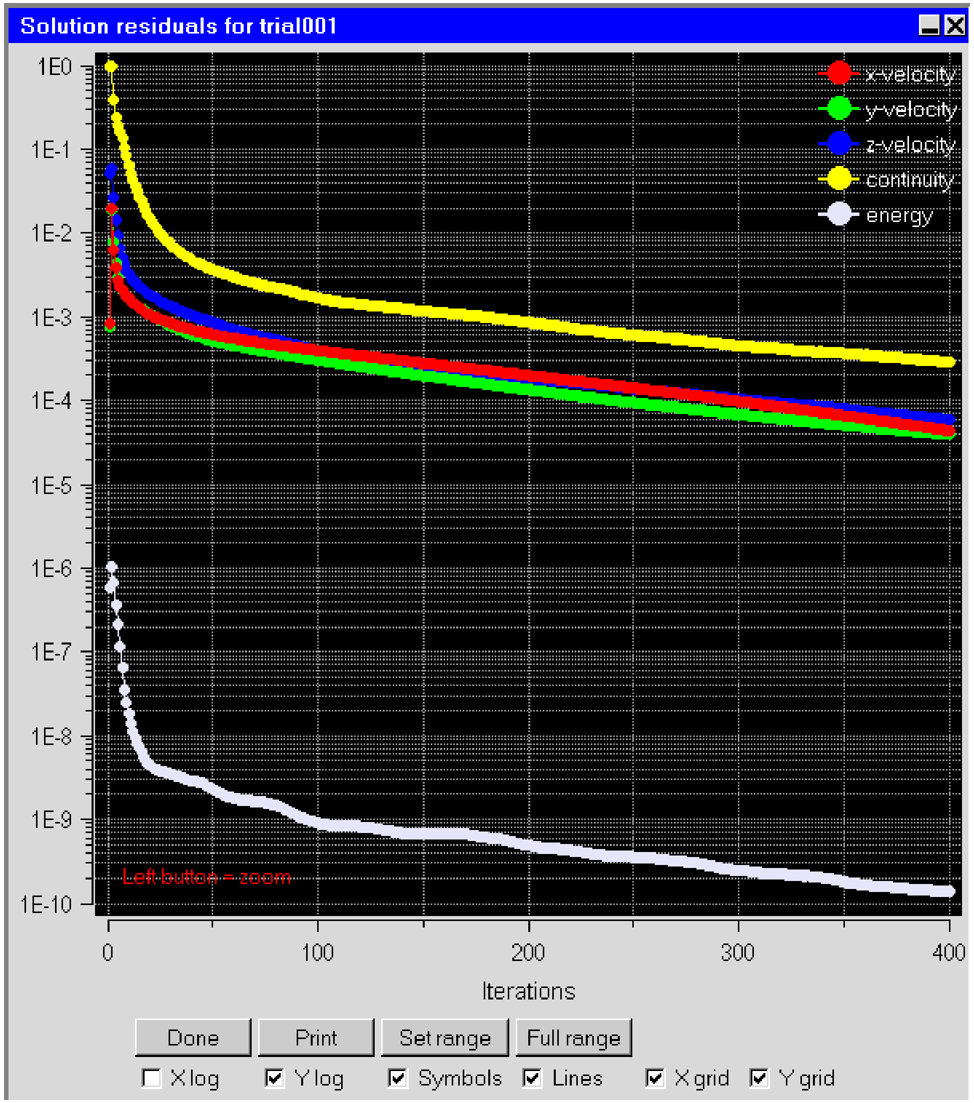
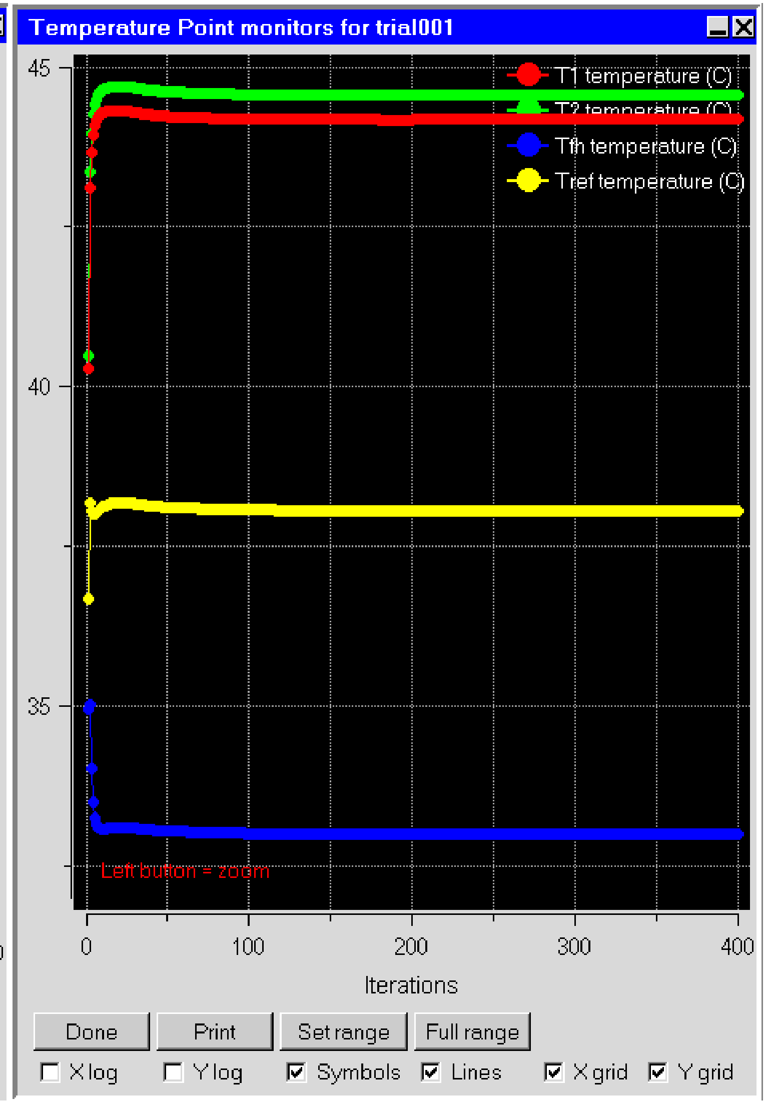
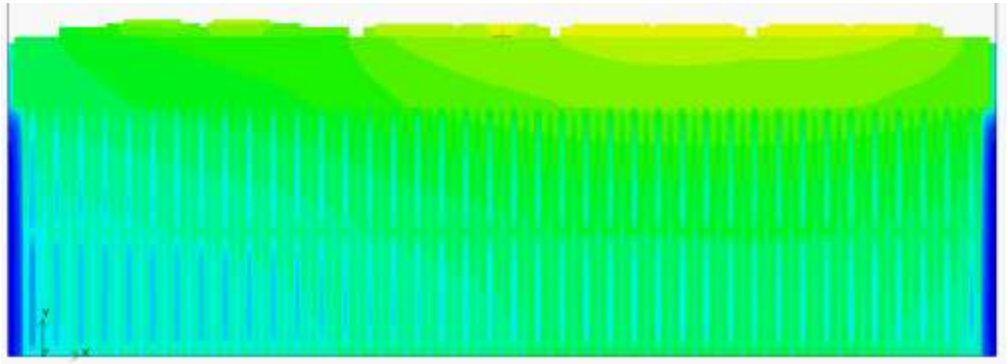
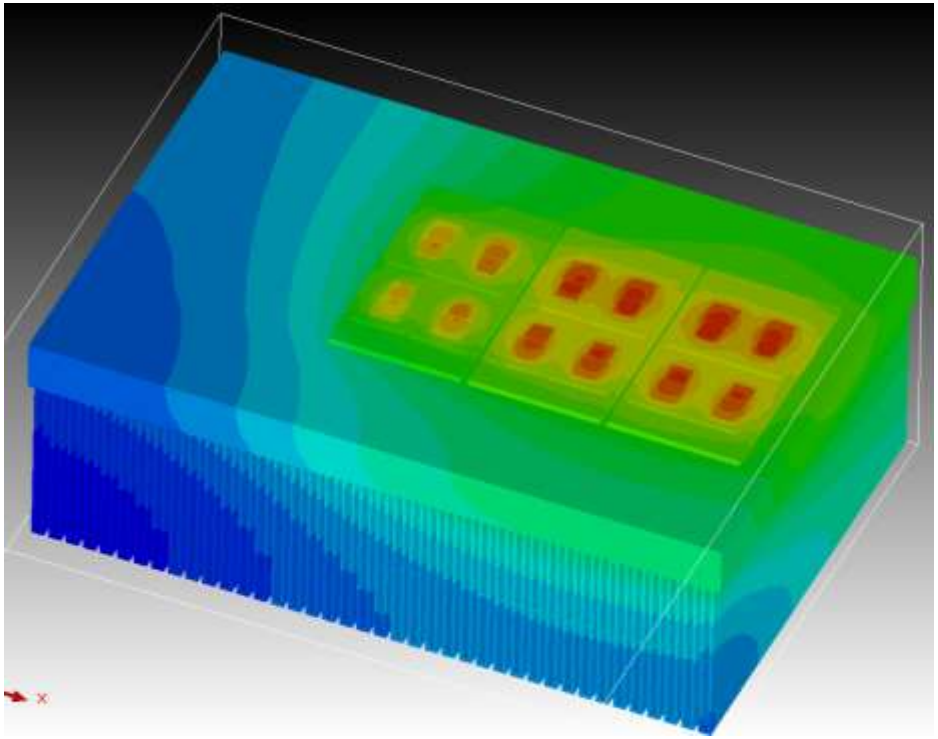
Solution - convergence

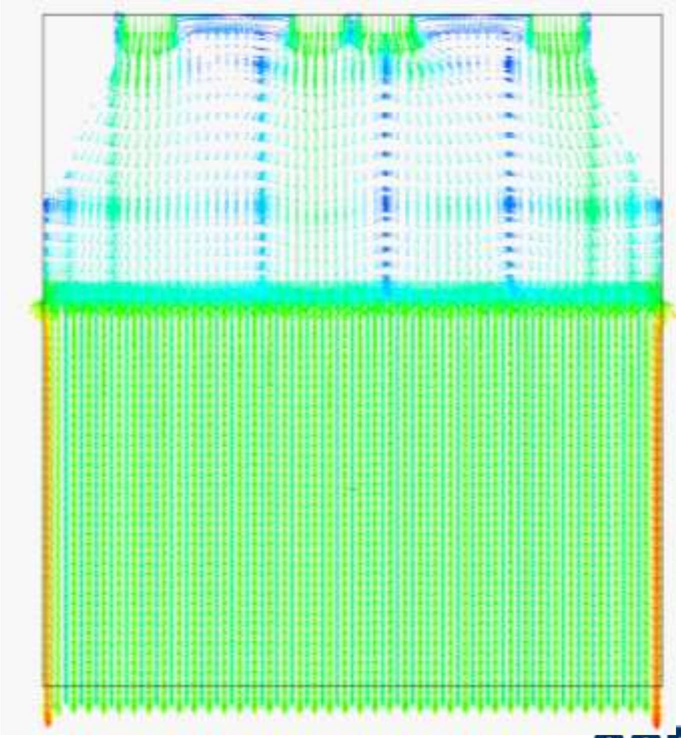




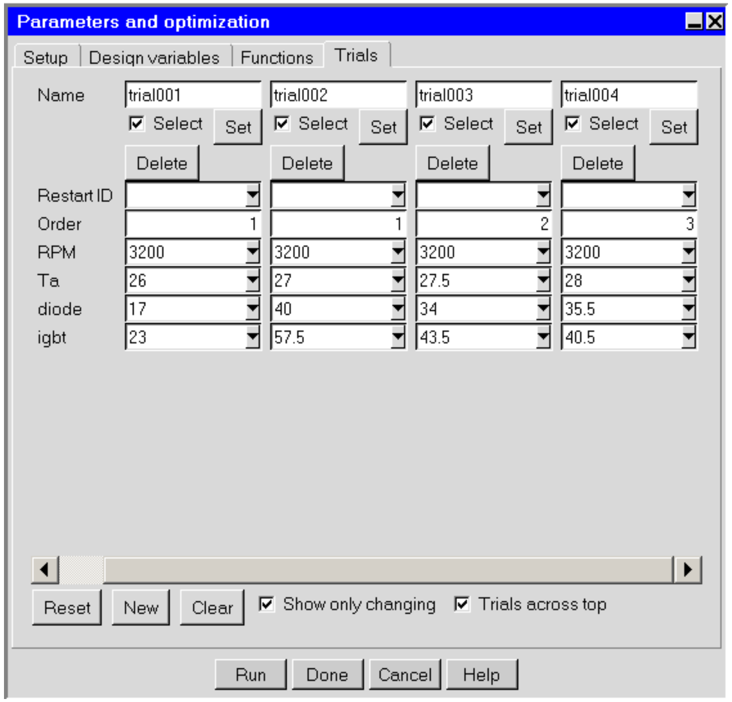
Typical Simulation Results

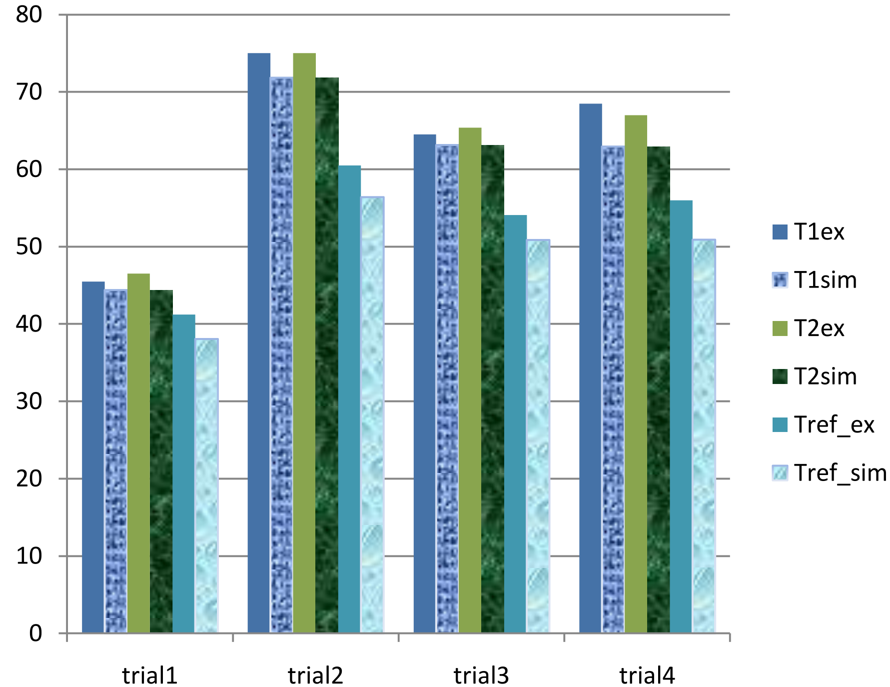






Comparison with Experimental Measurements





Parametric trials

	Functions							
Trial	T1	T2	Tfh	Tref	Ta	RPM	diode	igbt
trial001	44.39	44.39	33	38.06	26	3200	17	23
trial002	71.84	71.82	44.06	56.4	27	3200	40	57.5
trial003	63.14	63.13	41.06	50.86	27.5	3200	34	43.5
trial004	62.94	62.94	41.29	50.9	28	3200	35.5	40.5

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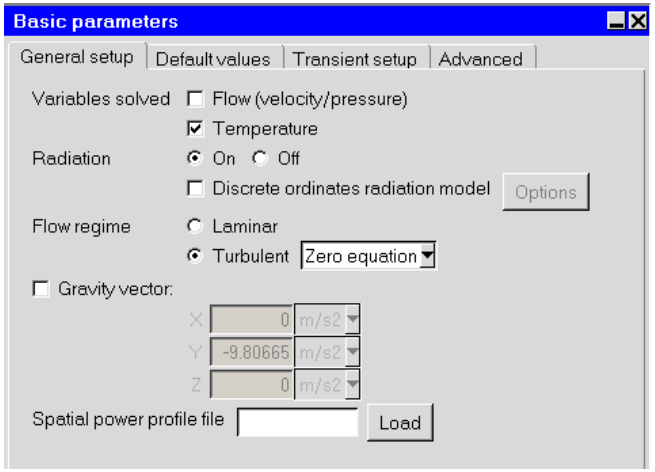
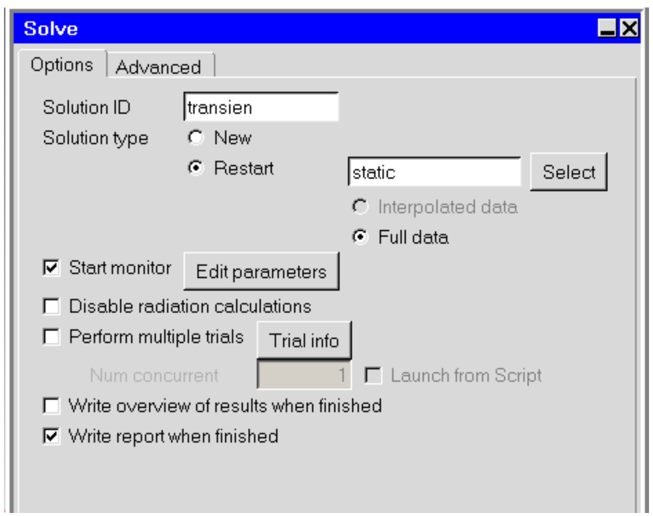
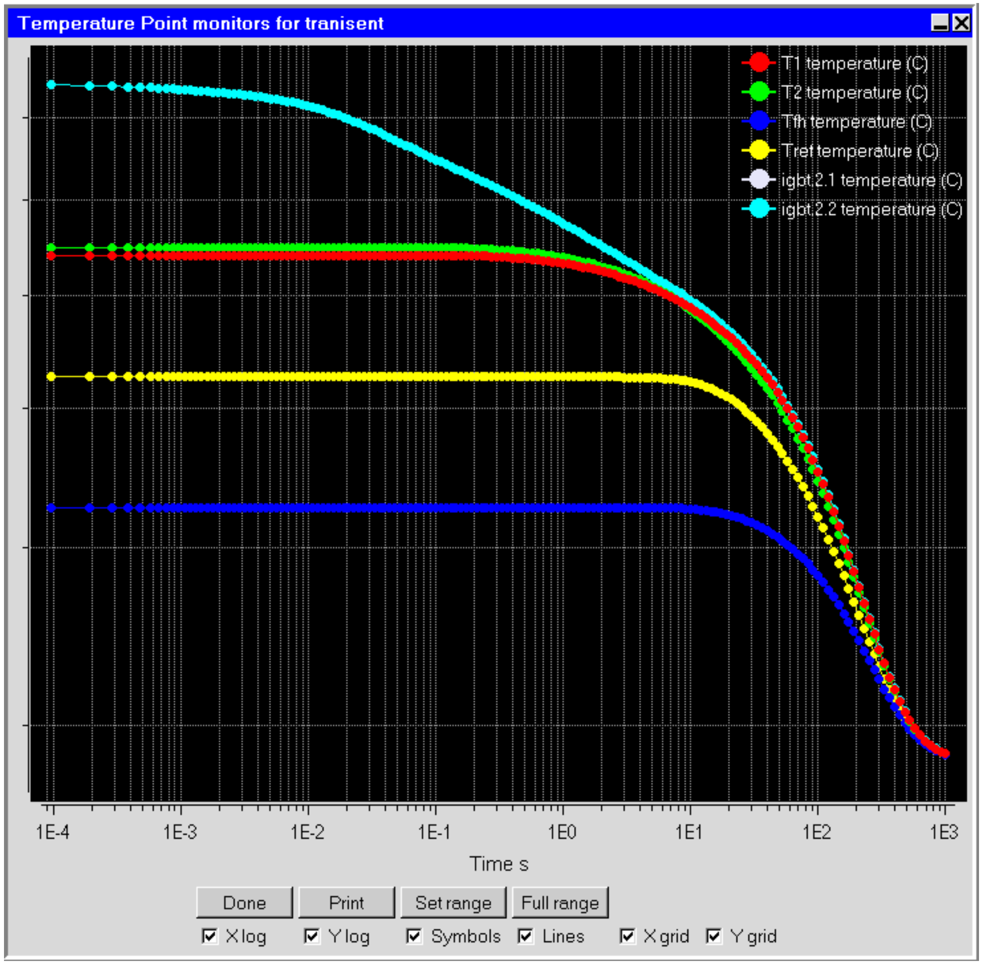
Transient Simulation in Icepak

- Flow is developed: We need to solve only energy equation.

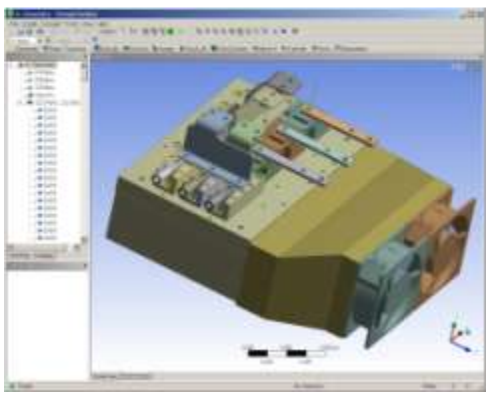


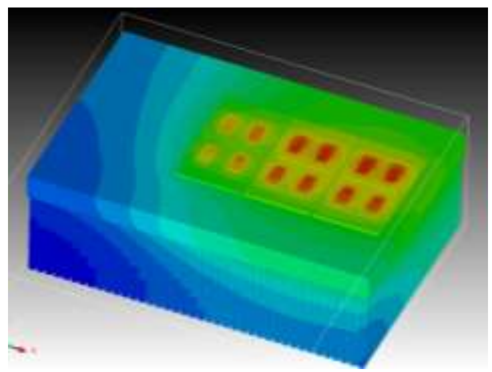


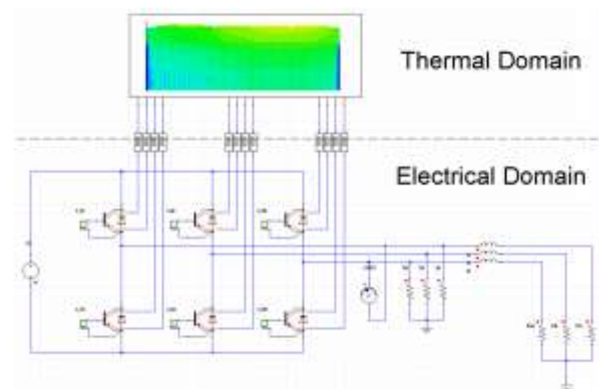


From Finite Elements to System Simulation

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



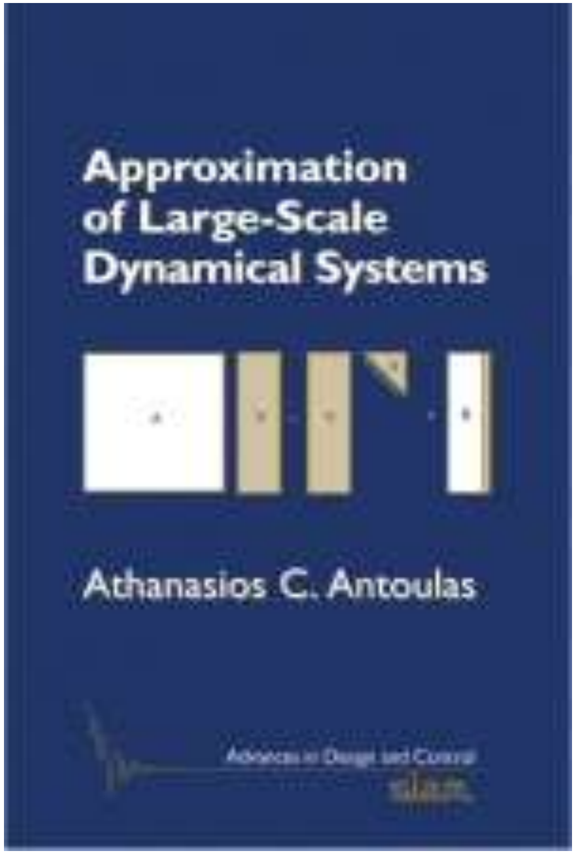




- Electrothermal Simulation with IGBTs:
  - From ANSYS Workbench to System Level

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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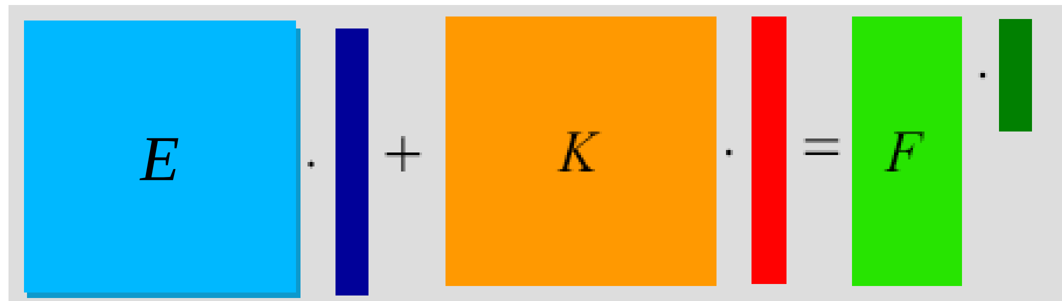
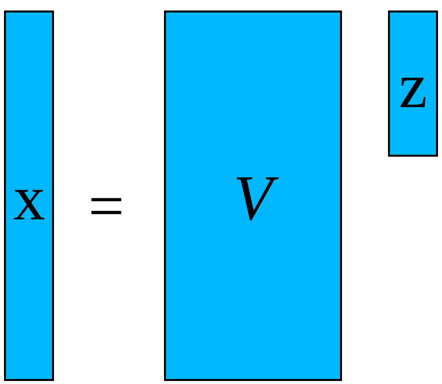
Model Reduction as Projection

- Projection onto low-dimensional subspace

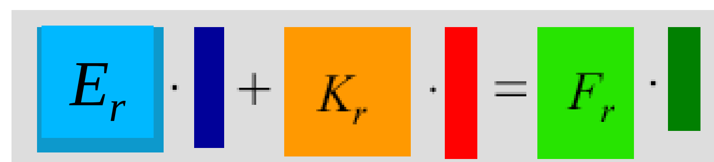
$$E\dot{\mathbf{x}} + K\mathbf{x} = B\mathbf{u}$$



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



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



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

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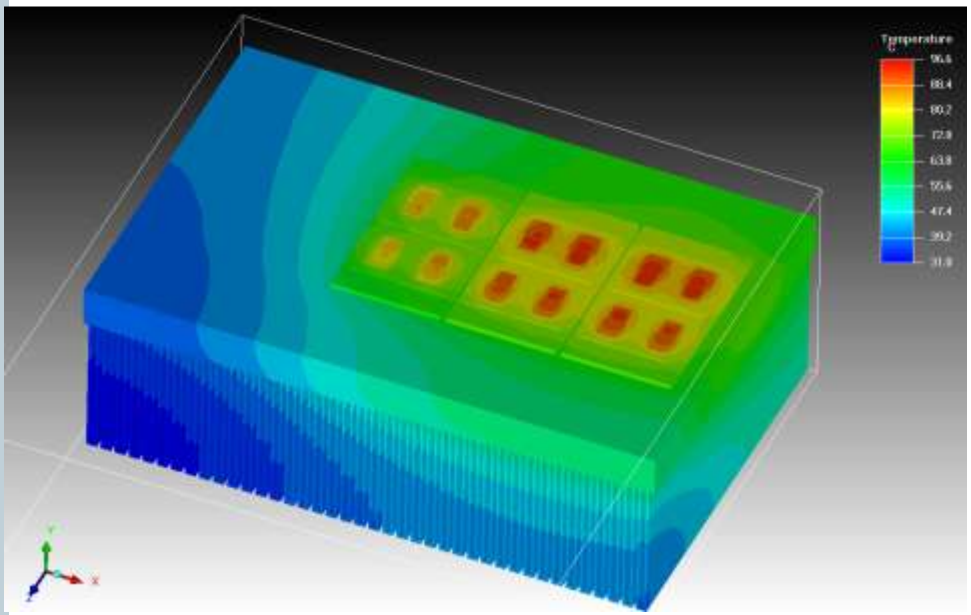
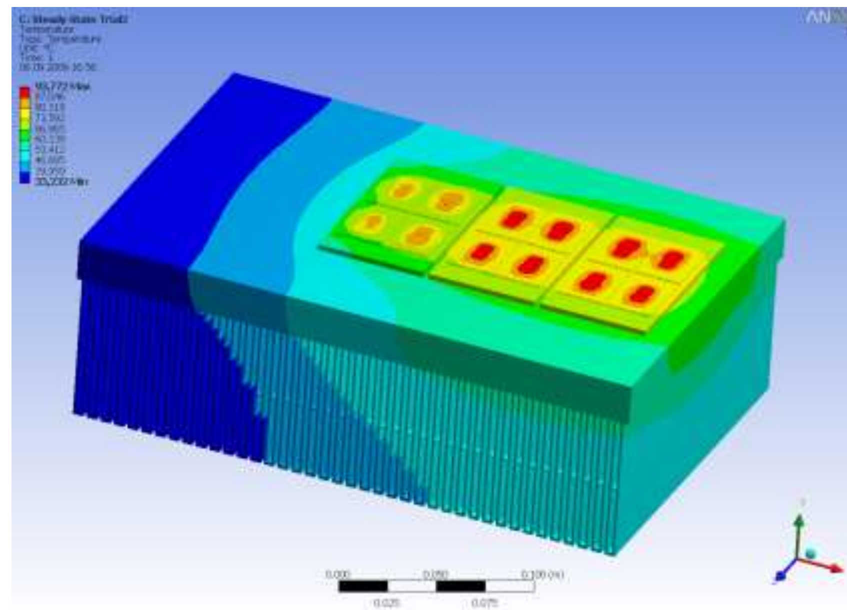
Transferring Model from Icepak to Workbench

Report summary data

Section	Sides	Value	Min	Max	Mean	Stdev	Total	Area/volume
All	All	Heat tr. coeff (W/K-m2)	-3.31558	331.76	22.7281			2.58861 m2
All	All	Heat tr. coeff (W/K-m2)	-3.31559	331.762	22.7275			2.58861 m2
All	All	Heat tr. coeff (W/K-m2)	-3.31559	331.762	22.7285			2.58861 m2
All	All	Heat tr. coeff (W/K-m2)	-3.31558	331.762	22.7295			2.58861 m2

$$Q = hA(T - T_{bulk})$$





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MOR for ANSYS: http://ModelReduction.com

Workbench 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

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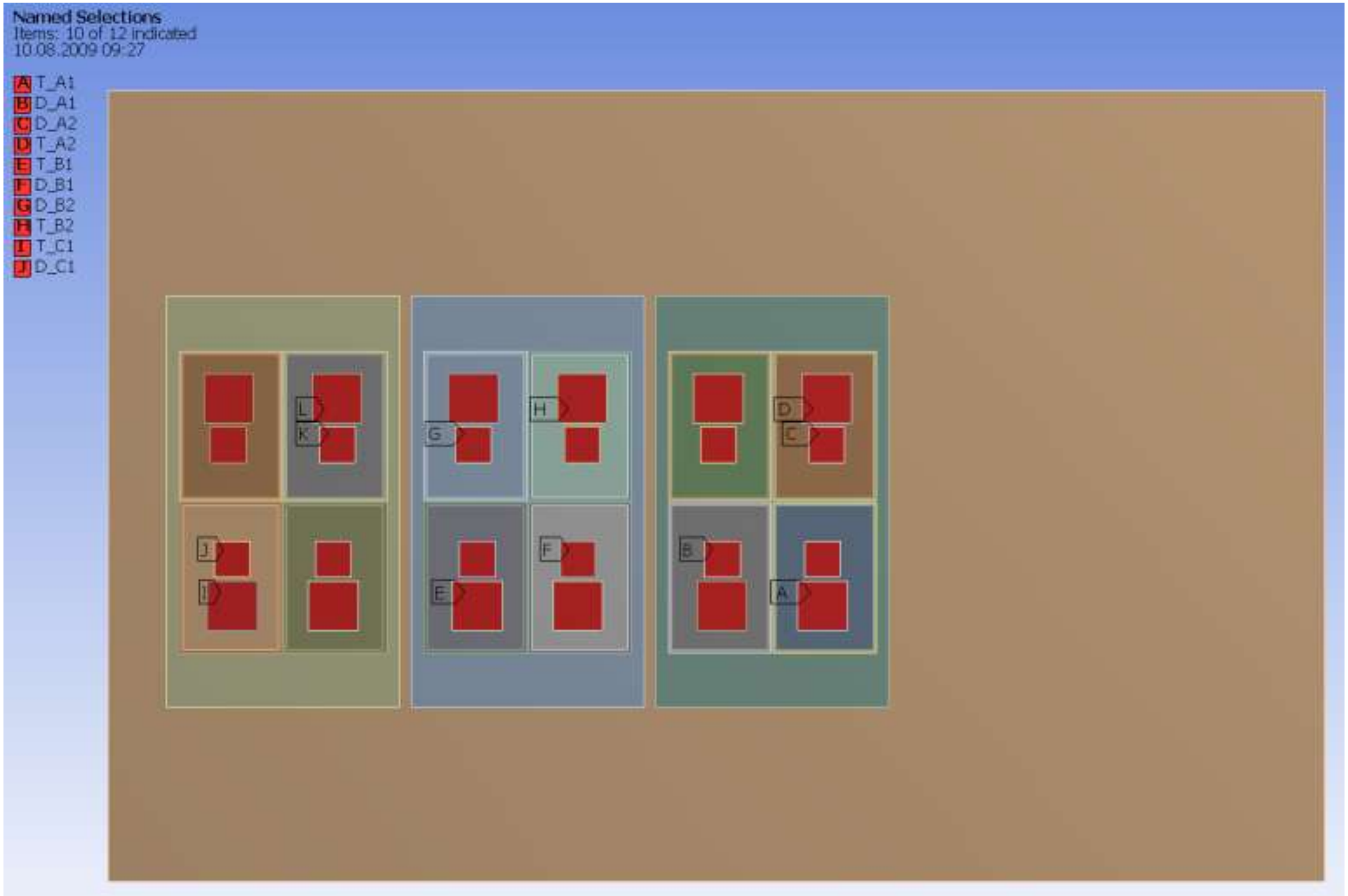
Model Reduction: Inputs and Outputs

- 12 inputs and outputs have been defined



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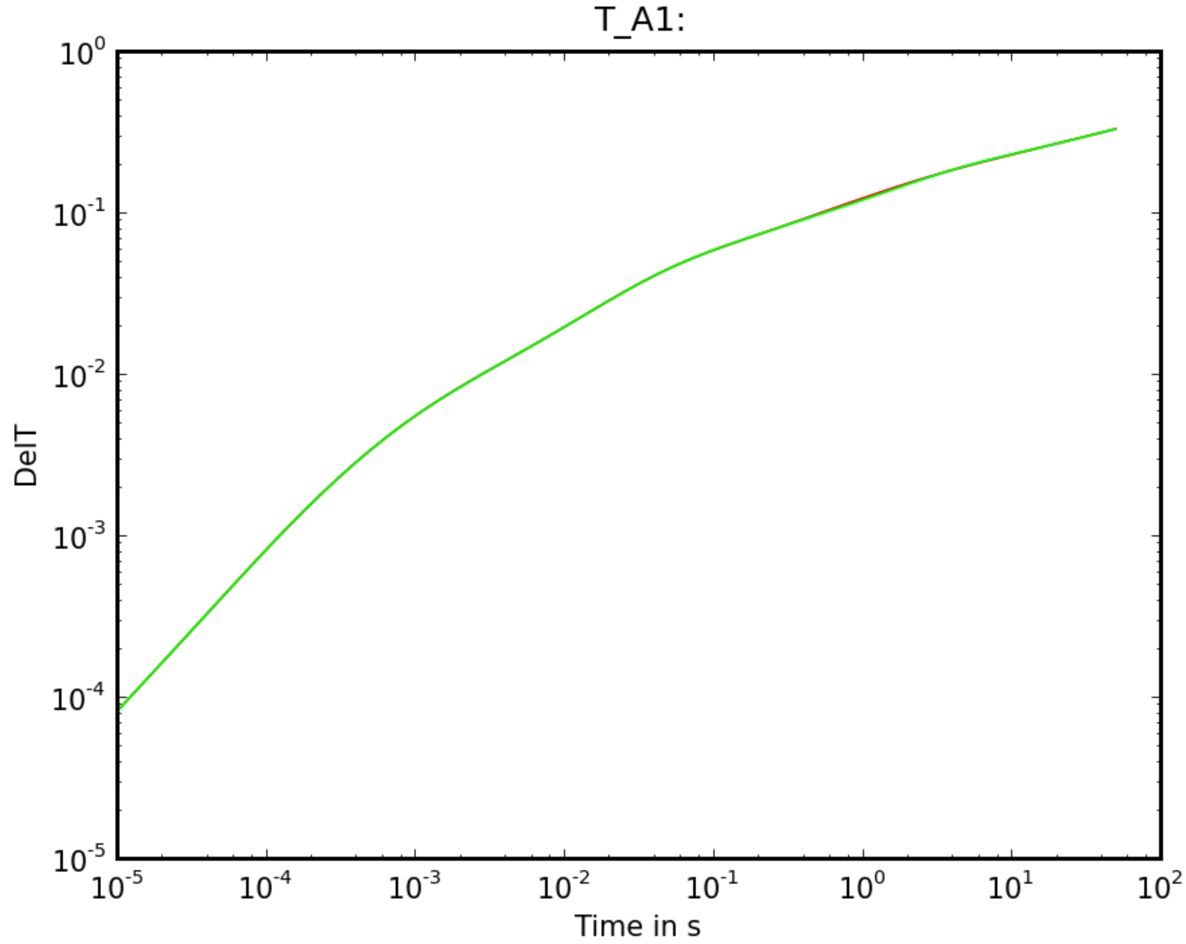
Model reduction

- Dimension of the model in ANSYS is about 900 K DoFs.
- Dimension of the reduced model is 15 DoFs per input = 15*12 = 180.
- The reduced model covers all heat sources and thermal cross talk at once.
- Transient simulation when 1 W has been applied only on device. Step response.
- On the next slides there is comparison between the simulation of the full model in ANSYS and the reduced model for T_A1. This curve corresponds to thermal impedance.

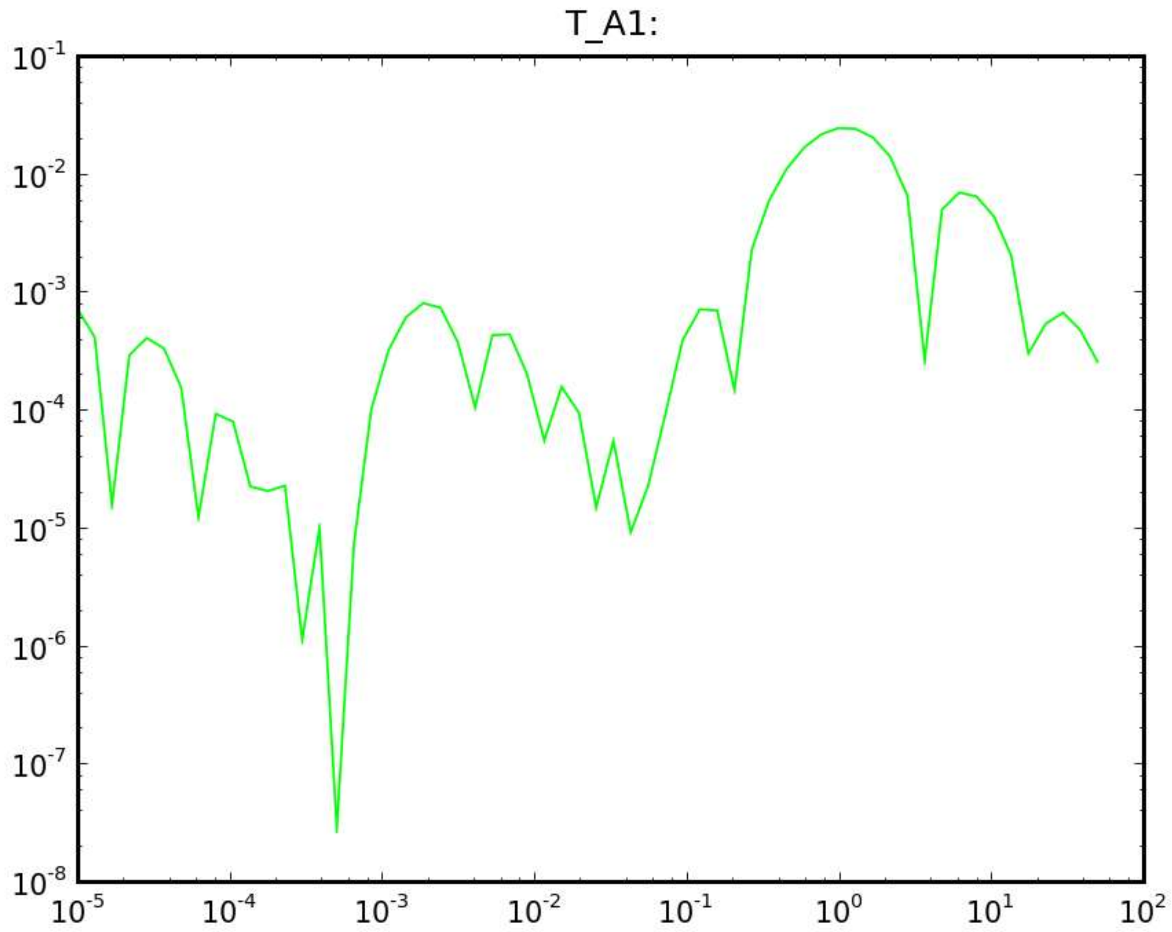
Comparison

- Red line – ANSYS, green line – reduced model. Difference is close to the line thickness. For such accuracy, one needs 15 DoFs per input.



Comparison

- Relative error between results in ANSYS and reduced model.

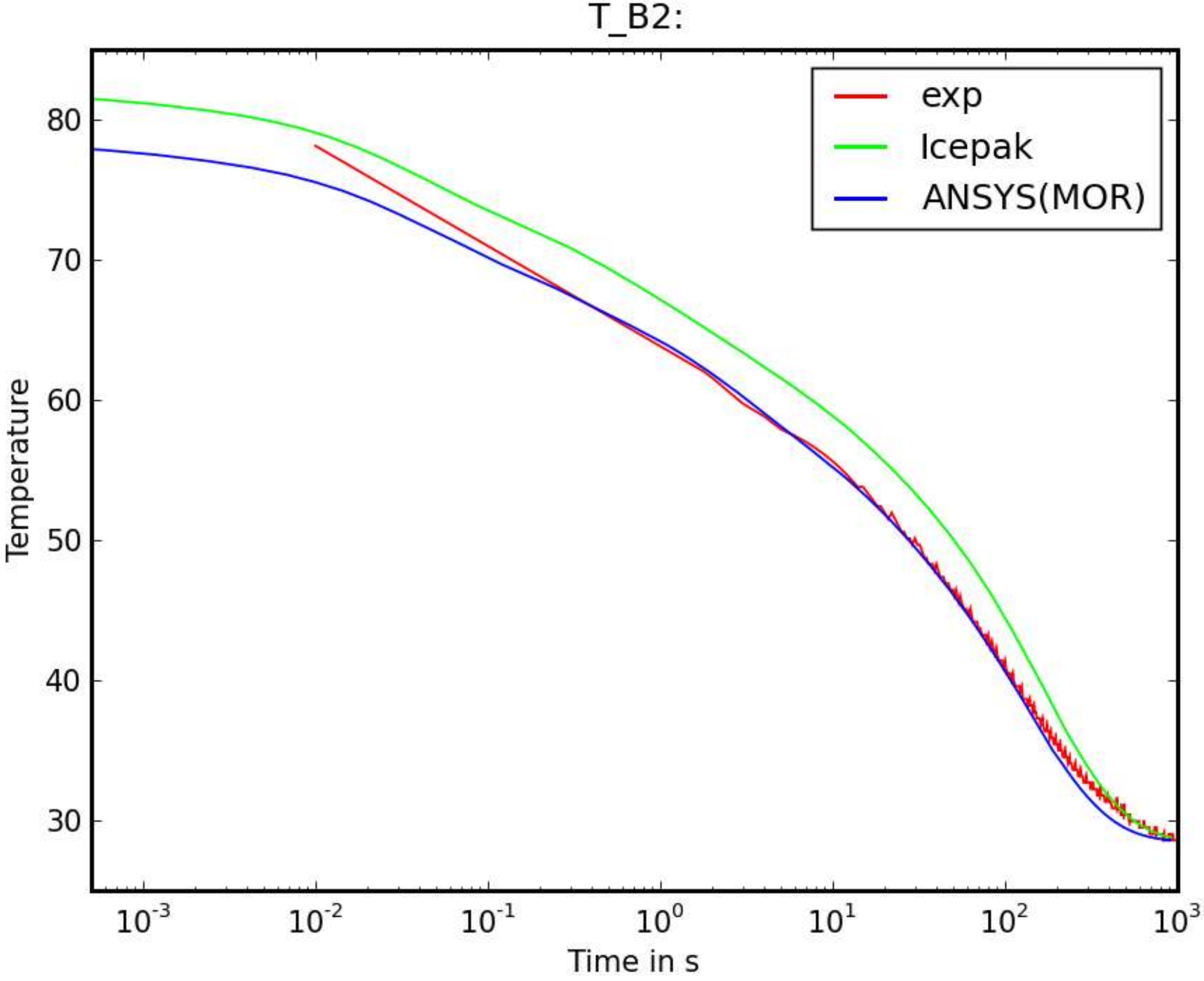


Comparison with Measurements

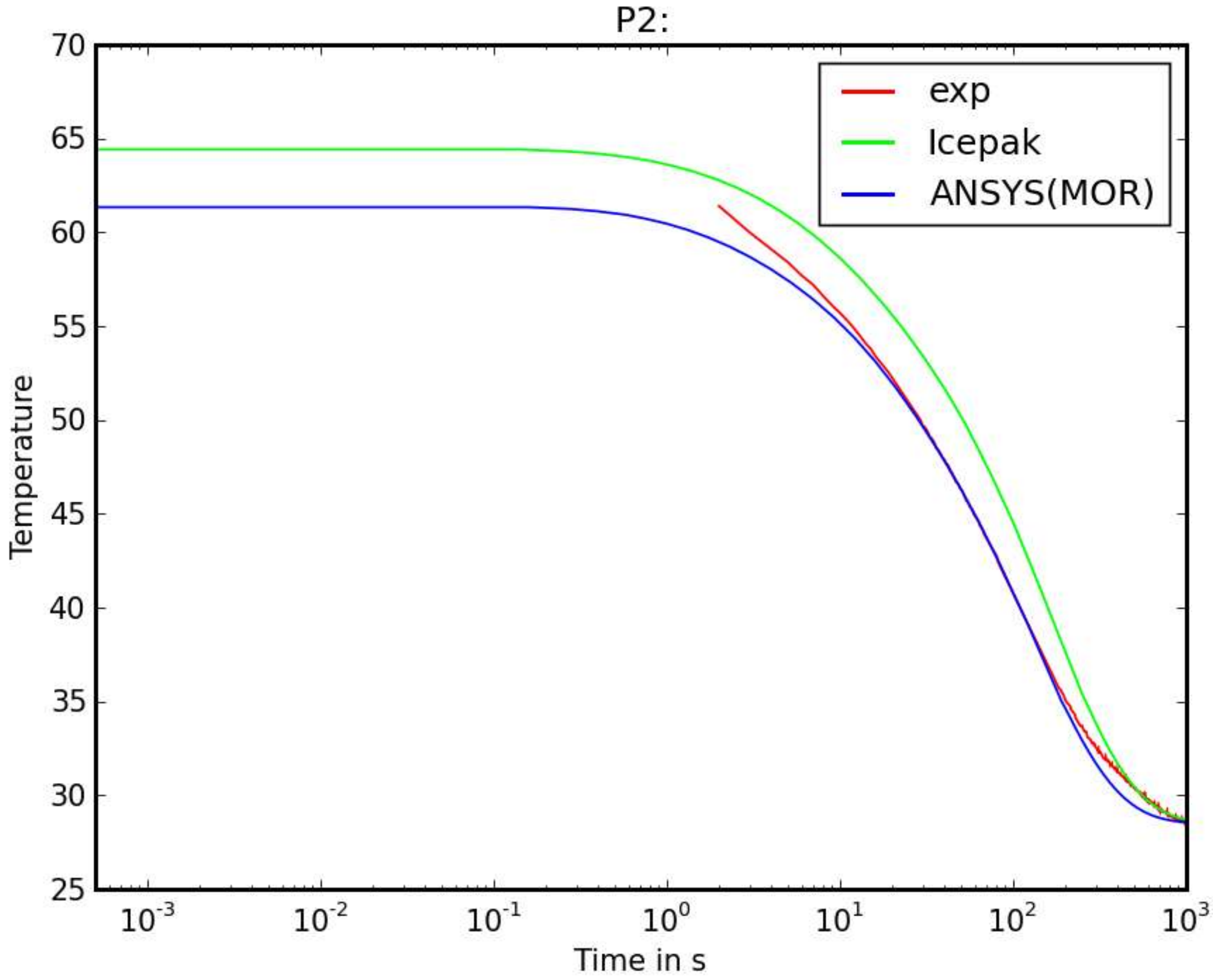
- Cooling curves from the stationary state with:
  - 75 W on IGBTs
  - 0 W on diodes
  - T ambient = 28.5

- Using point T2 (P2) and the average on the upper face of IGBT T_B2 for comparison with the measurements

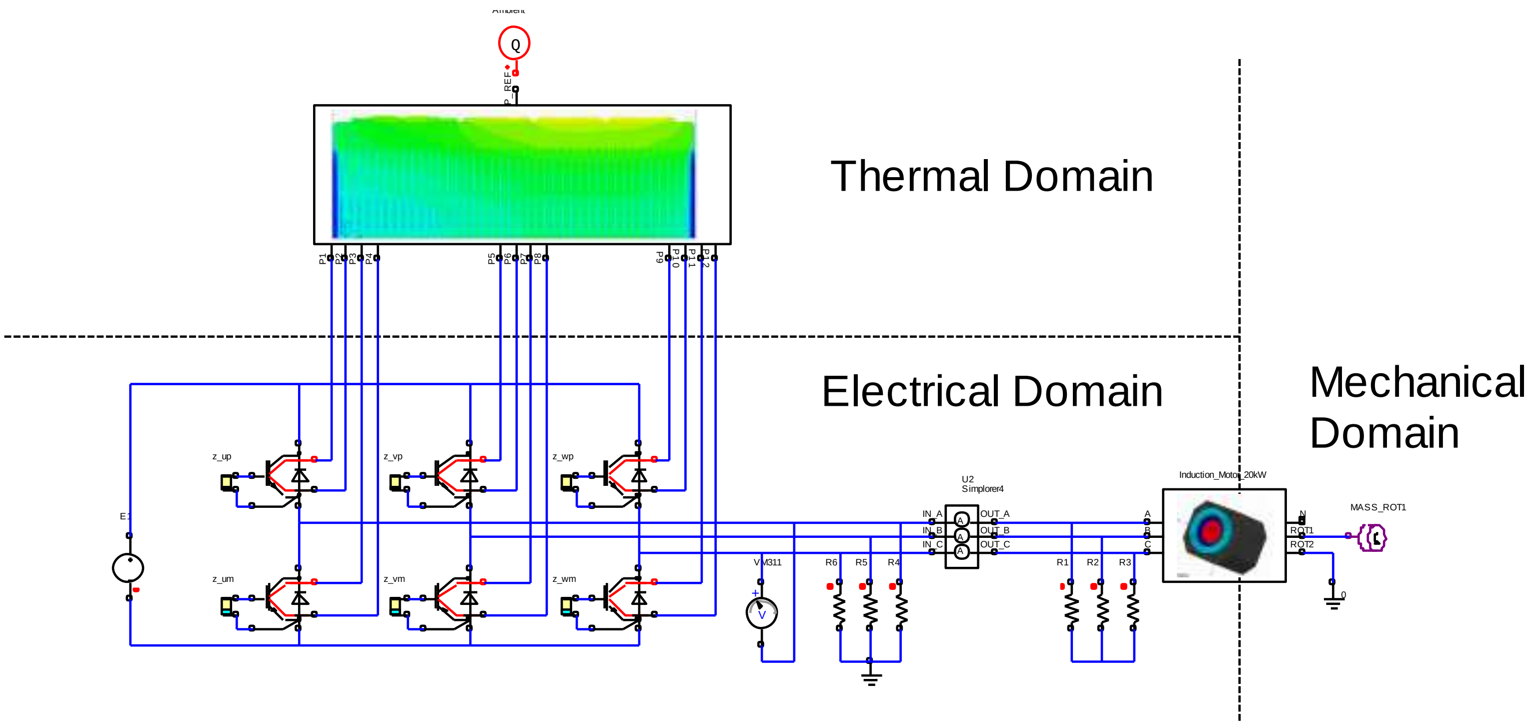
Temperatures on IGBTs



Temperatures under IGBTs



Simulation in Simplorer



Conclusion

- Icepak to quickly simulation IGBT converter
- Compact dynamic thermal model are necessary
- Transfer to ANSYS Workbench with convection boundary conditions
- Compact thermal model are obtained through model reduction