Application of Simulation
in Power Module Development

Christoph F. Bayer

12th October 2023,
Dr. Christoph F. Bayer

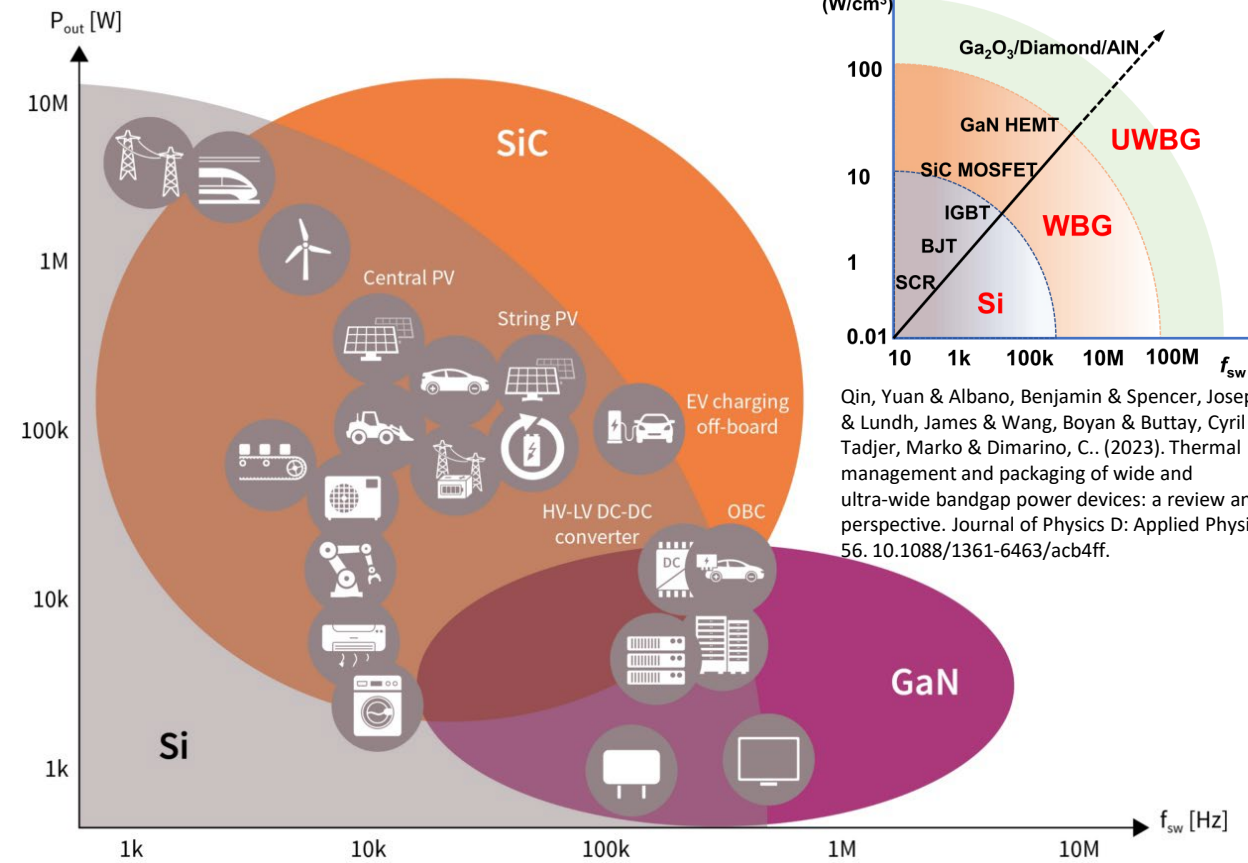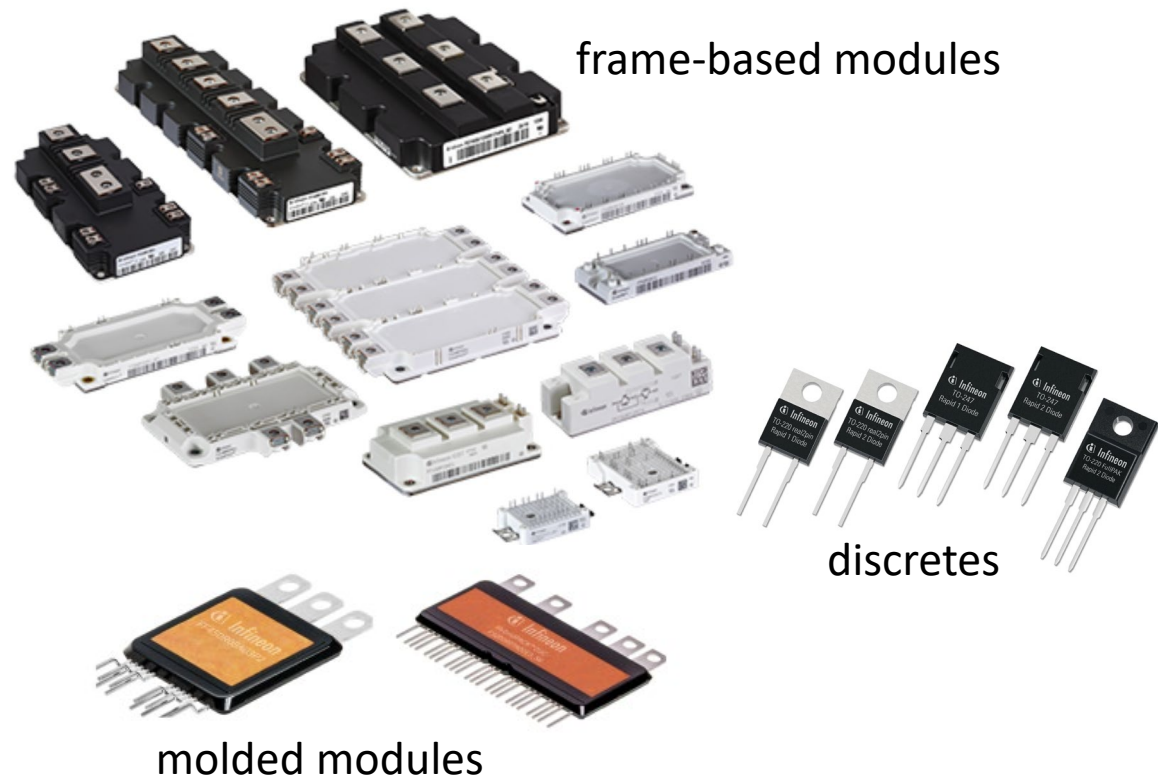# Table of contents

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Power Electronic Modules

- Every conversion of electrical energy – from generation to consumption – requires power semiconductors (Si, SiC, GaN)

frame-based modules

discretes

molded modules

Qin, Yuan & Albano, Benjamin & Spencer, Joseph & Lundh, James & Wang, Boyan & Buttay, Cyril & Tadjer, Marko & Dimarino, C.. (2023). Thermal management and packaging of wide and ultra-wide bandgap power devices: a review and perspective. Journal of Physics D: Applied Physics. 56. 10.1088/1361-6463/acb4ff.

Power Electronic Modules

Screw thread   Silicone gel   Housing   Terminal

Wire bonds   Baseplate   Ceramic circuit carrier   Semiconductor device (transistor, diode)

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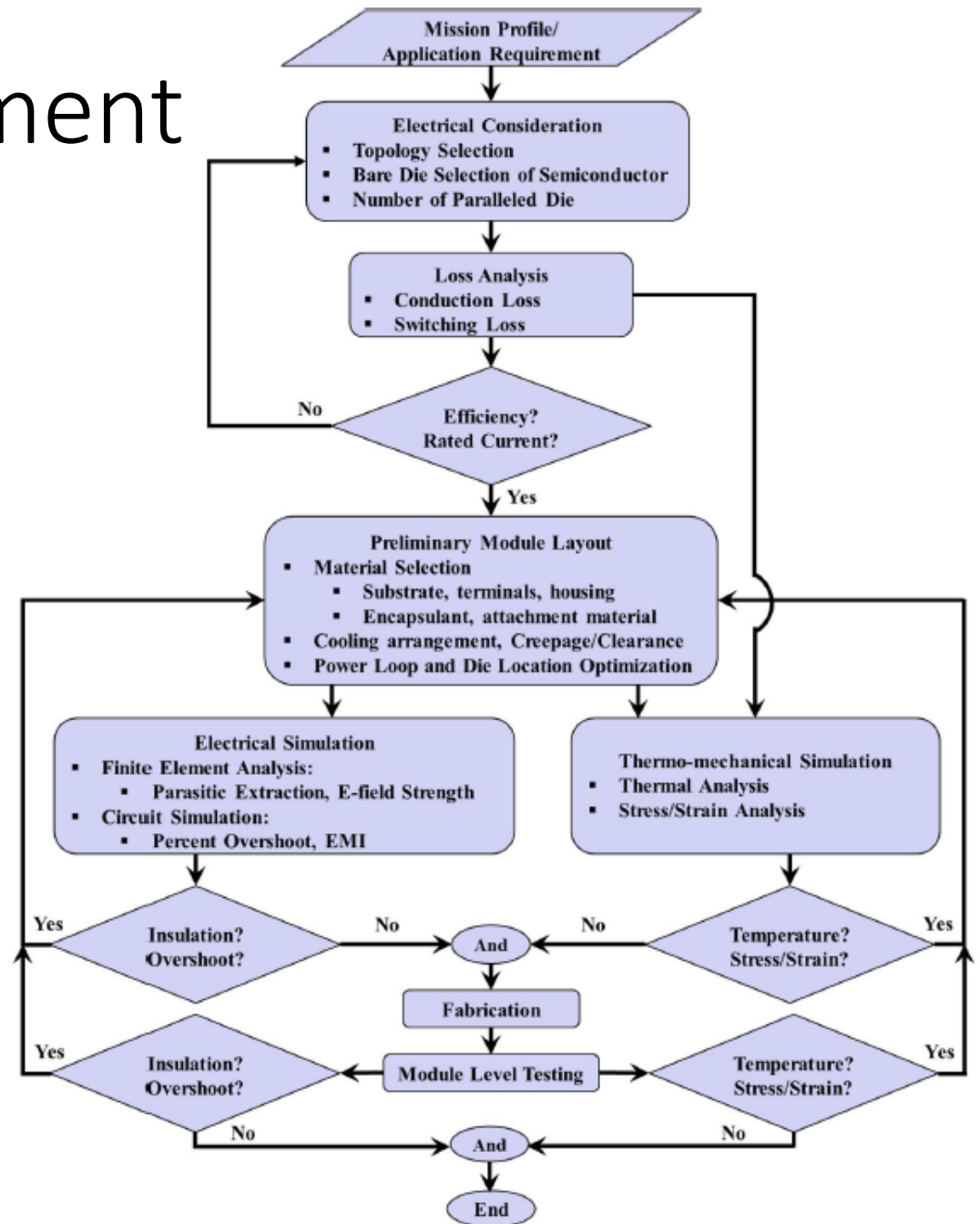# Power Module Development and Simulation

Fig. 2.   Generalized design process of a power module.

Power Module Development and Simulation

Electrical considerations and circuit simulations result in a preliminary module layout
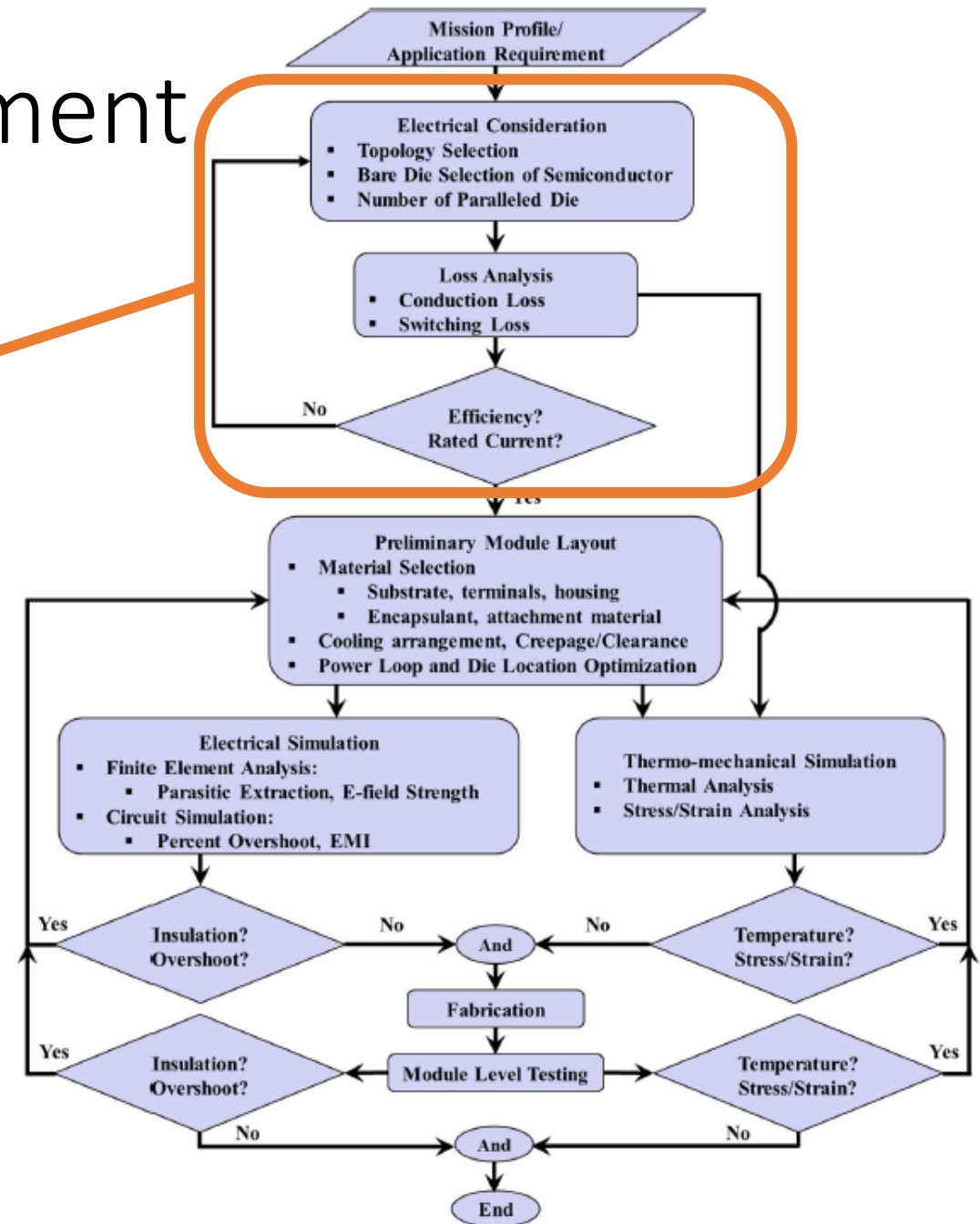
Fig. 2. Generalized design process of a power module.

Power Module Development and Simulation

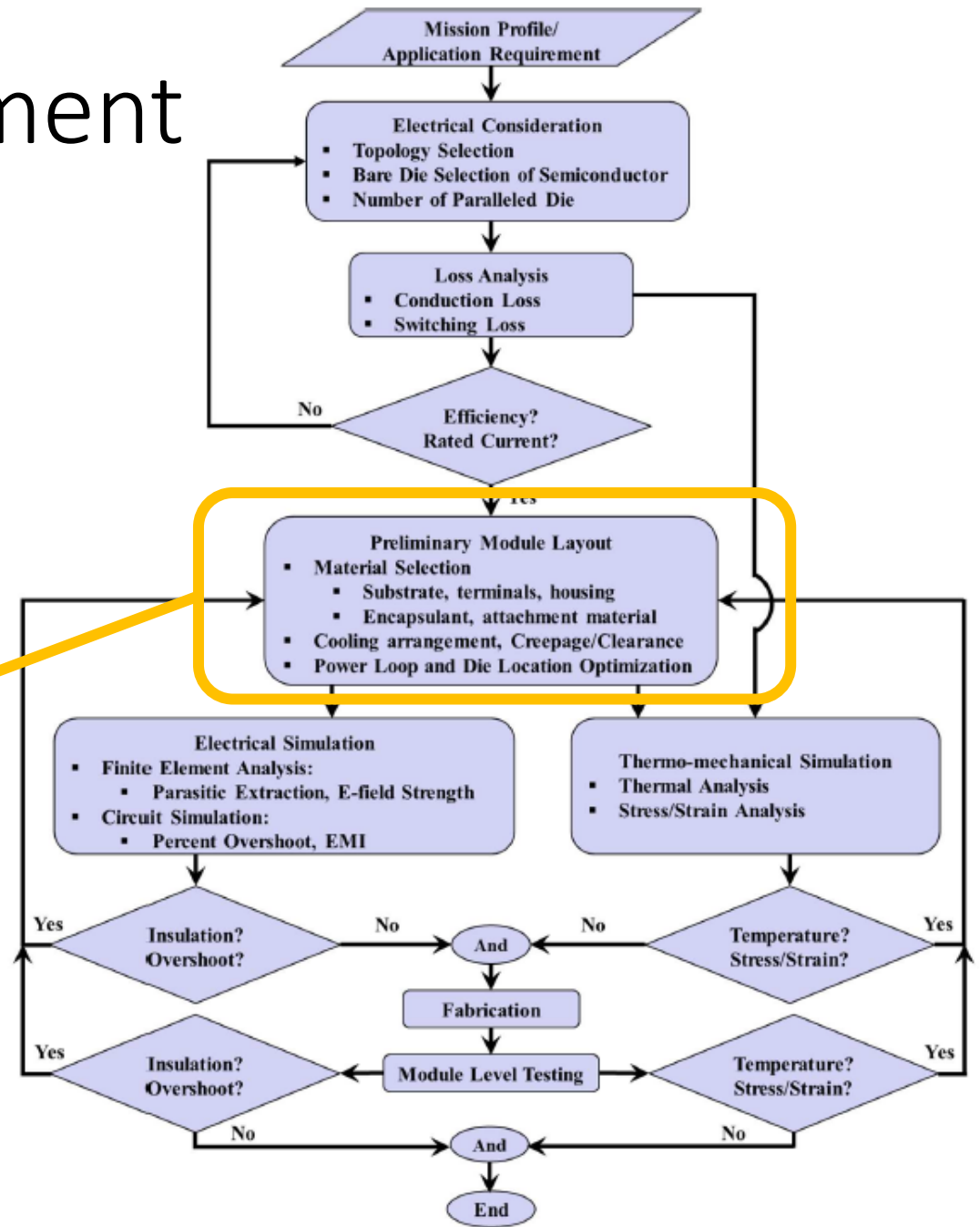Optimization options – arrangement, materials, technologies

Fig. 2. Generalized design process of a power module.

Power Module Development and Simulation

Electrical simulation section:
- Parasitics – R, C, and L – are extracted
- Electric Field simulation
- Circuit simulation
→ Improvement of module design:
layout and geometry; material

Fig. 2. Generalized design process of a power module.
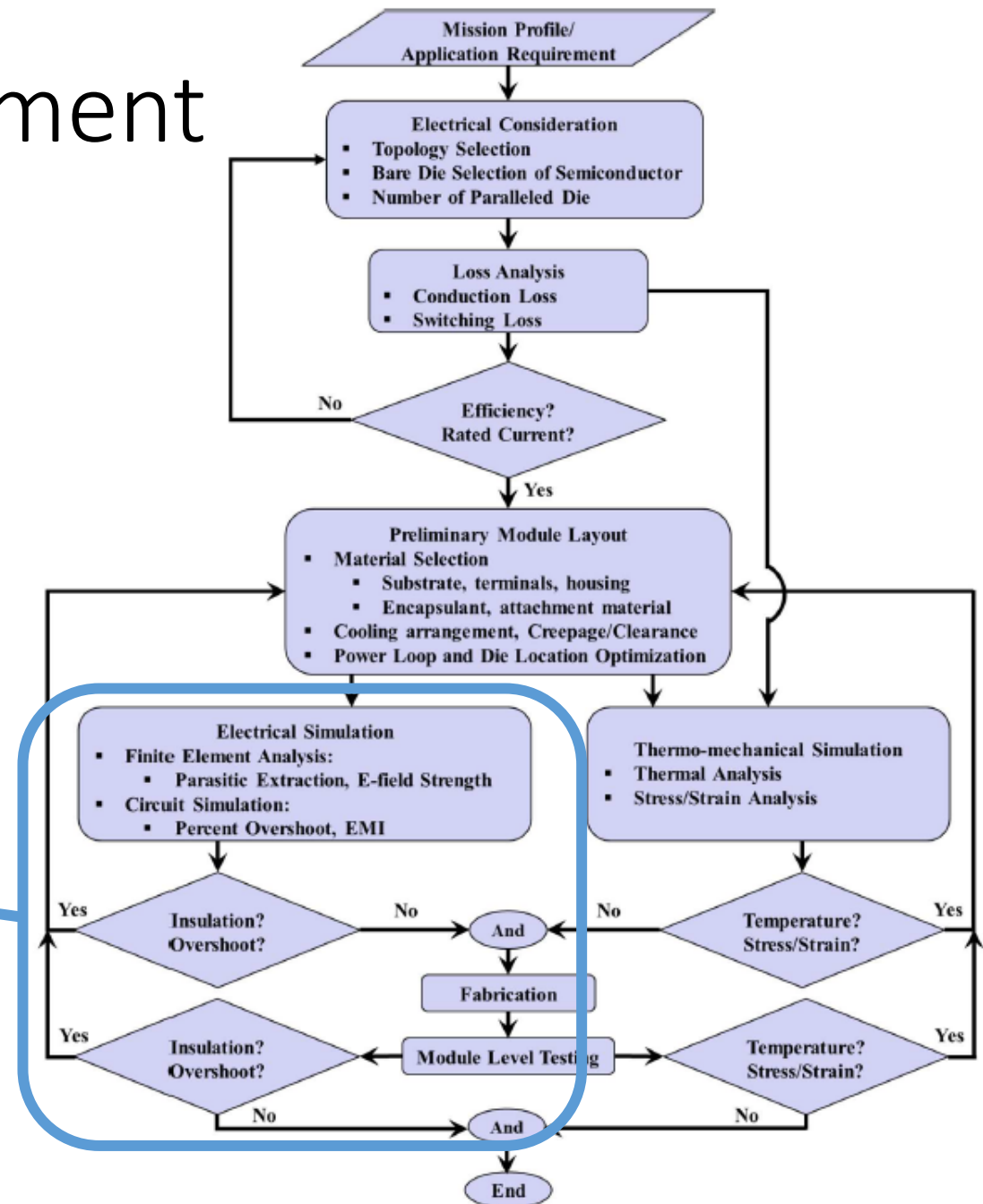
Power Module Development and Simulation

Thermo-mechanical section:
- Temperature distribution, R_{th} an Z_{th}
- Thermo-mechanical behavior
→ Improvement of module design:
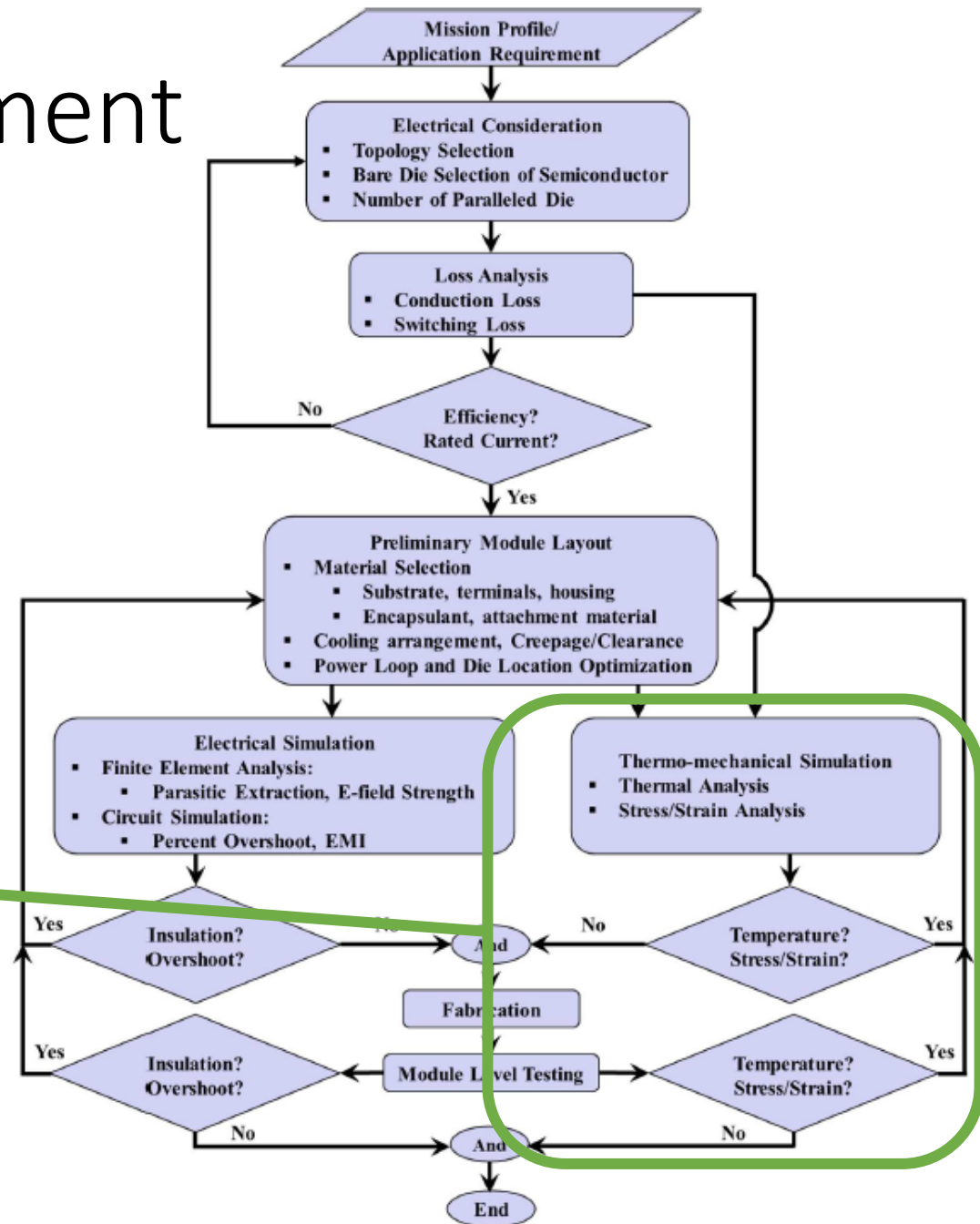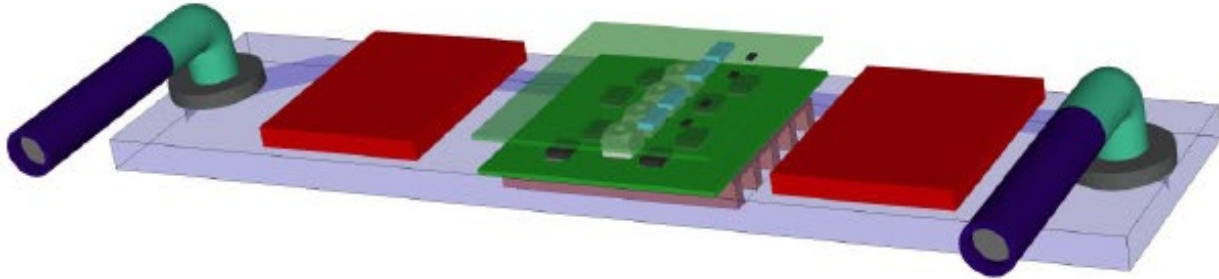layout and geometry; material

Lifetime simulation

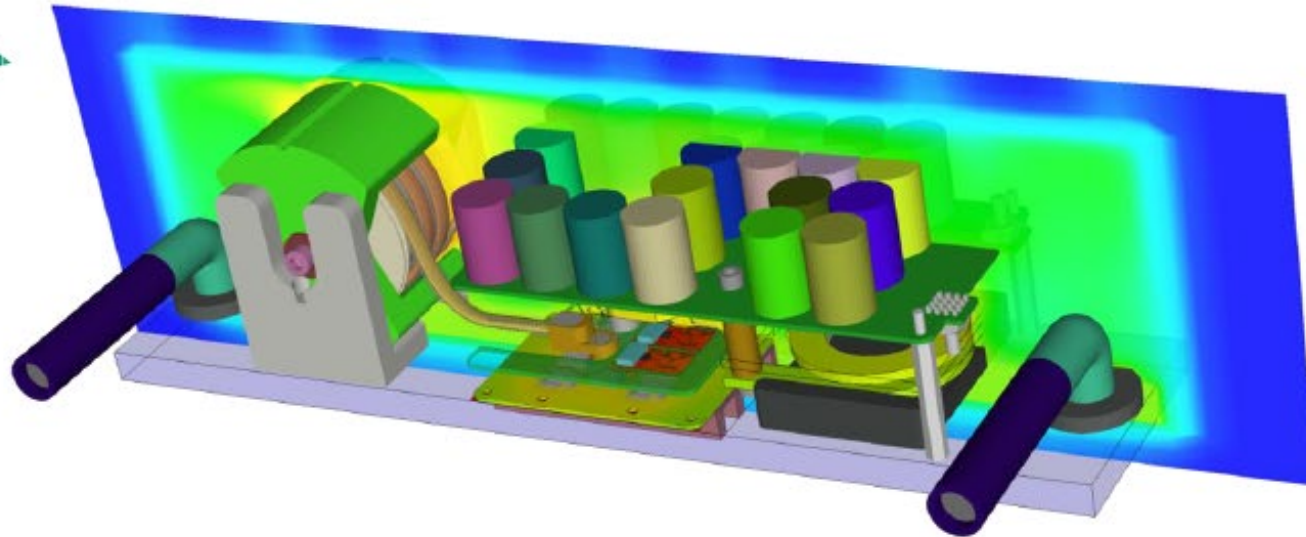Fig. 2. Generalized design process of a power module.

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Thermal Simulation

- Thermal simulation in…
  - Device heating on the circuit carrier
  - Cooling performance of the heat sink
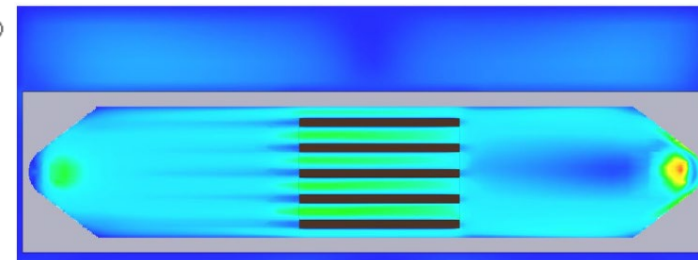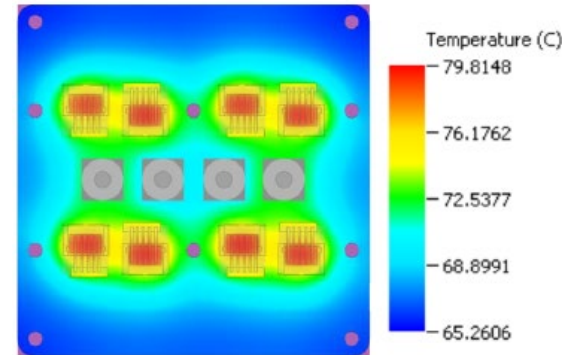 - Convection of heat in the converter arrangement

Exemplary tools…
- Mentor Graphics FloTHERM
- **6SigmaET**
- CD-adapco STAR-CCM+
- Ansys Icepak
- Autodesk
- SOLIDWORKS Flow
- Siemens NX Electronic Systems Cooling
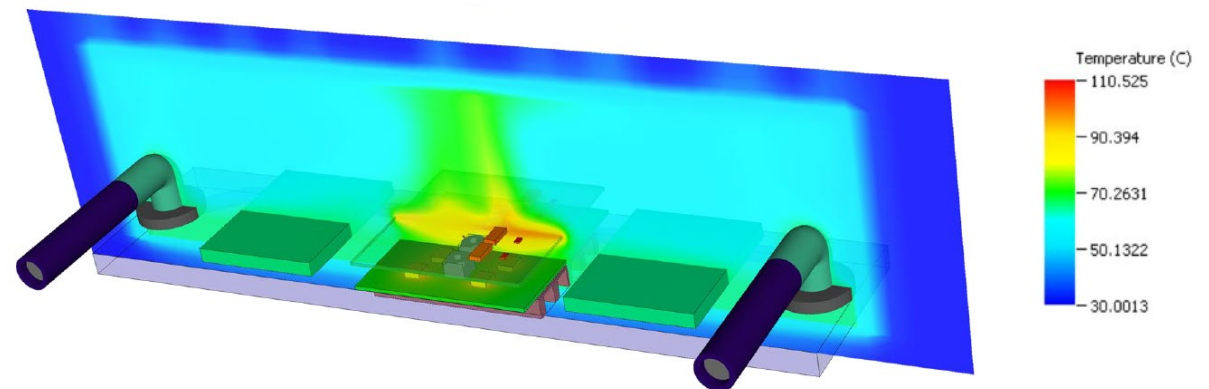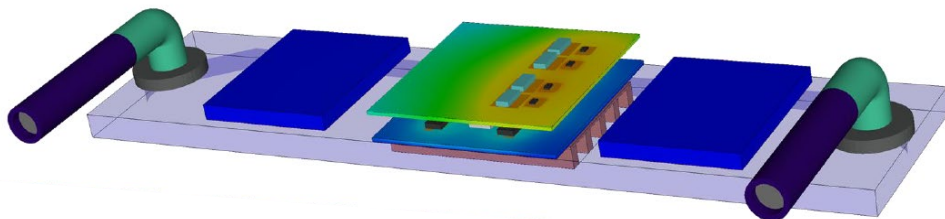- Comsol Heat Transfer Module

Ref. „Thermal simulation during the design processof Electronic Systems - Conjugate Heat Transfer", ECPE Training: Simulation in Power Electronics, Thomas Menrath 2016.

Thermal and Thermo-Mechanical Simulation

- **Thermal Simulation in…**
  - Device heating on the circuit carrier
    - Temperature distribution
    - R_{th}, Z_{th}
  - Cooling performance of the heat sink
  - Convection of heat in the converter arrangement

Ref. „Thermal simulation during the design processof Electronic Systems - Conjugate Heat Transfer", ECPE Training: Simulation in Power Electronics, Thomas Menrath 2016.

Thermo-Mechanical Simulation

- Temperature distribution and the resulting deformation as well as mechanical stress

temperature distribution

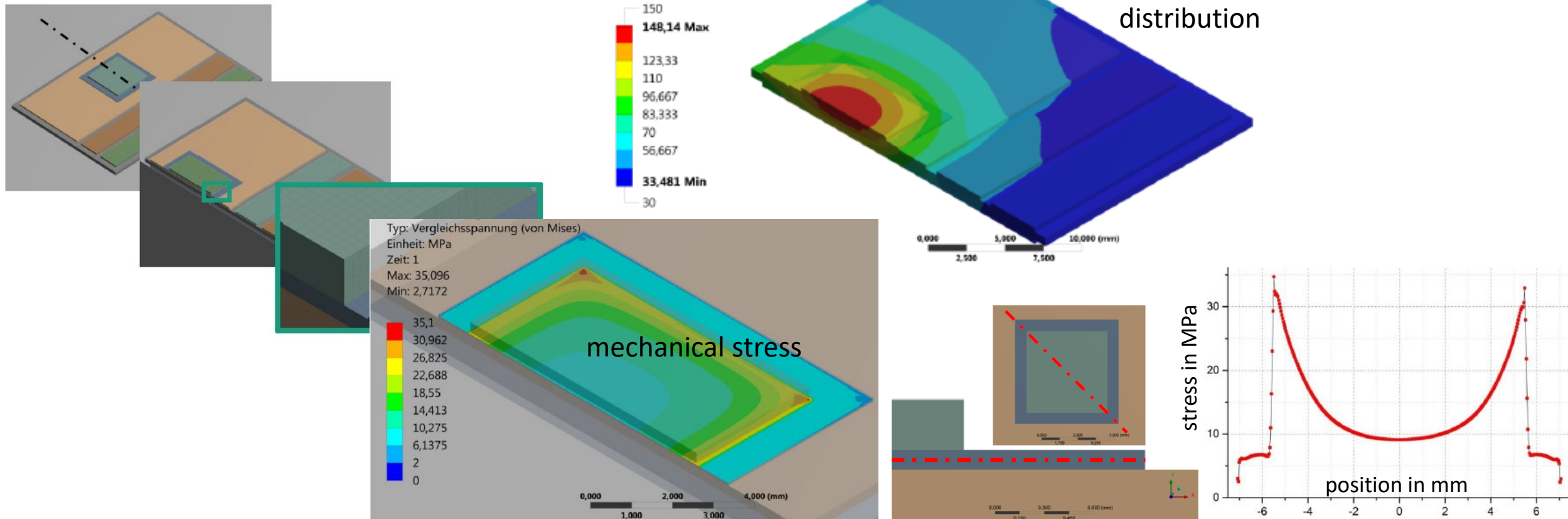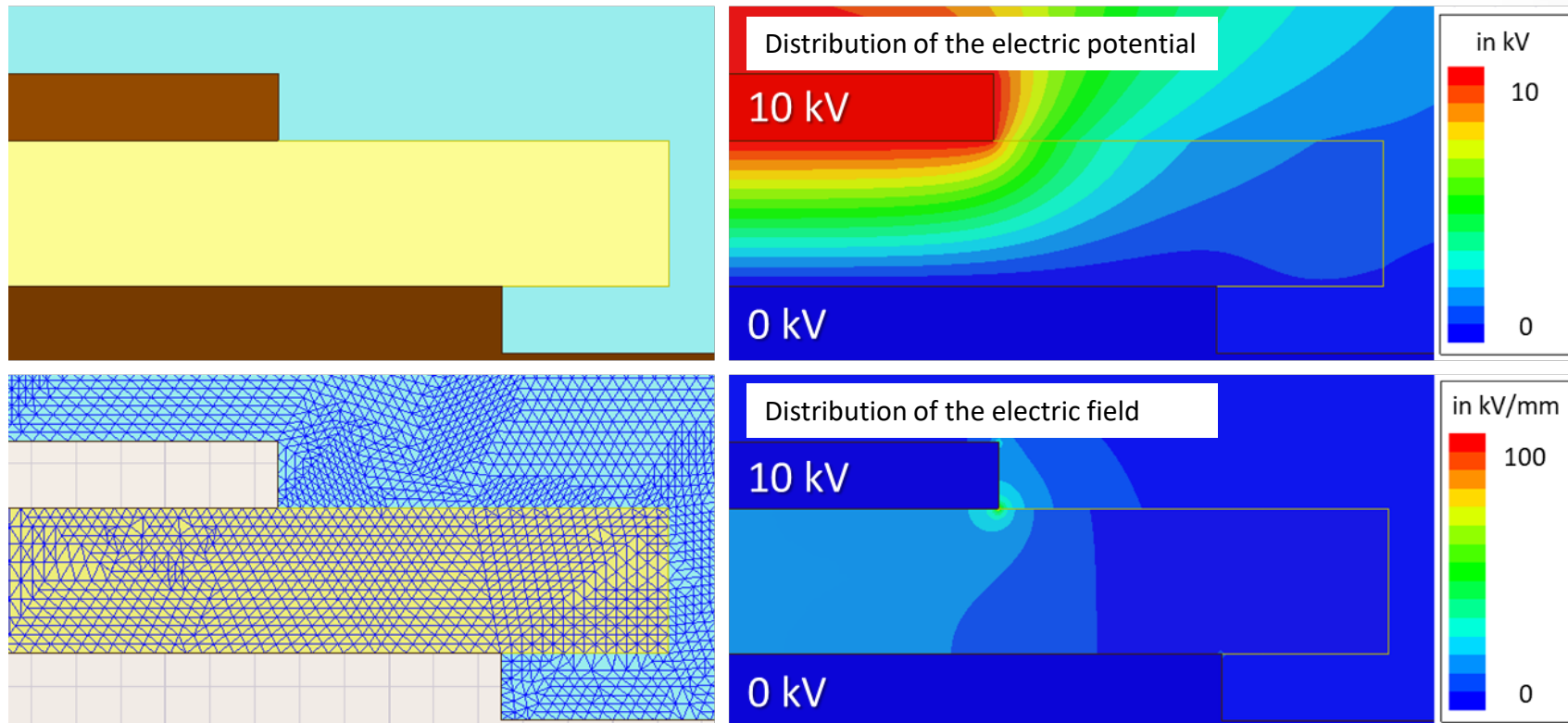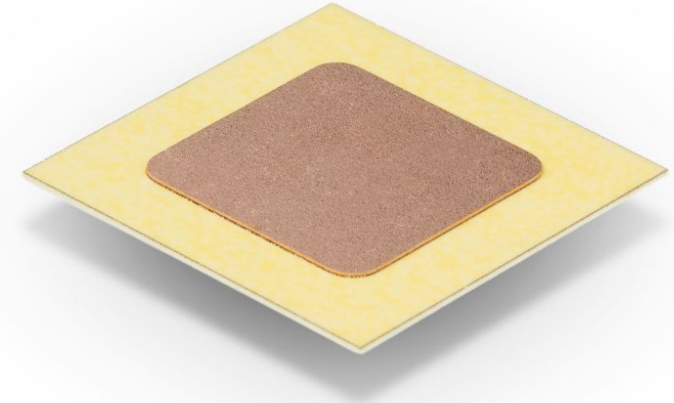mechanical stress

Ref. "Heat dissipation and deformation in power electronic modules," ECPE Training: Simulation in Power Electronics, Uwe Waltrich 2016.

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Electric and Electronic Simulation

- Electric field strength in the vicinity of the metallization edge of a ceramic circuit carrier

  ➢ Insulation to the base plate / heat sink

Distribution of the electric potential

in kV

10 kV

10

0 kV

0

Distribution of the electric field

in kV/mm

10 kV

100

0 kV

0

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Electric and Electronic Simulation

- Extraction of parasitics – R, C, and L

Ref. "Parasites in the power module – on tour with Henry, Farad, and Ohm," ECPE Training: Simulation in Power Electronics, Christoph F. Bayer 2016.

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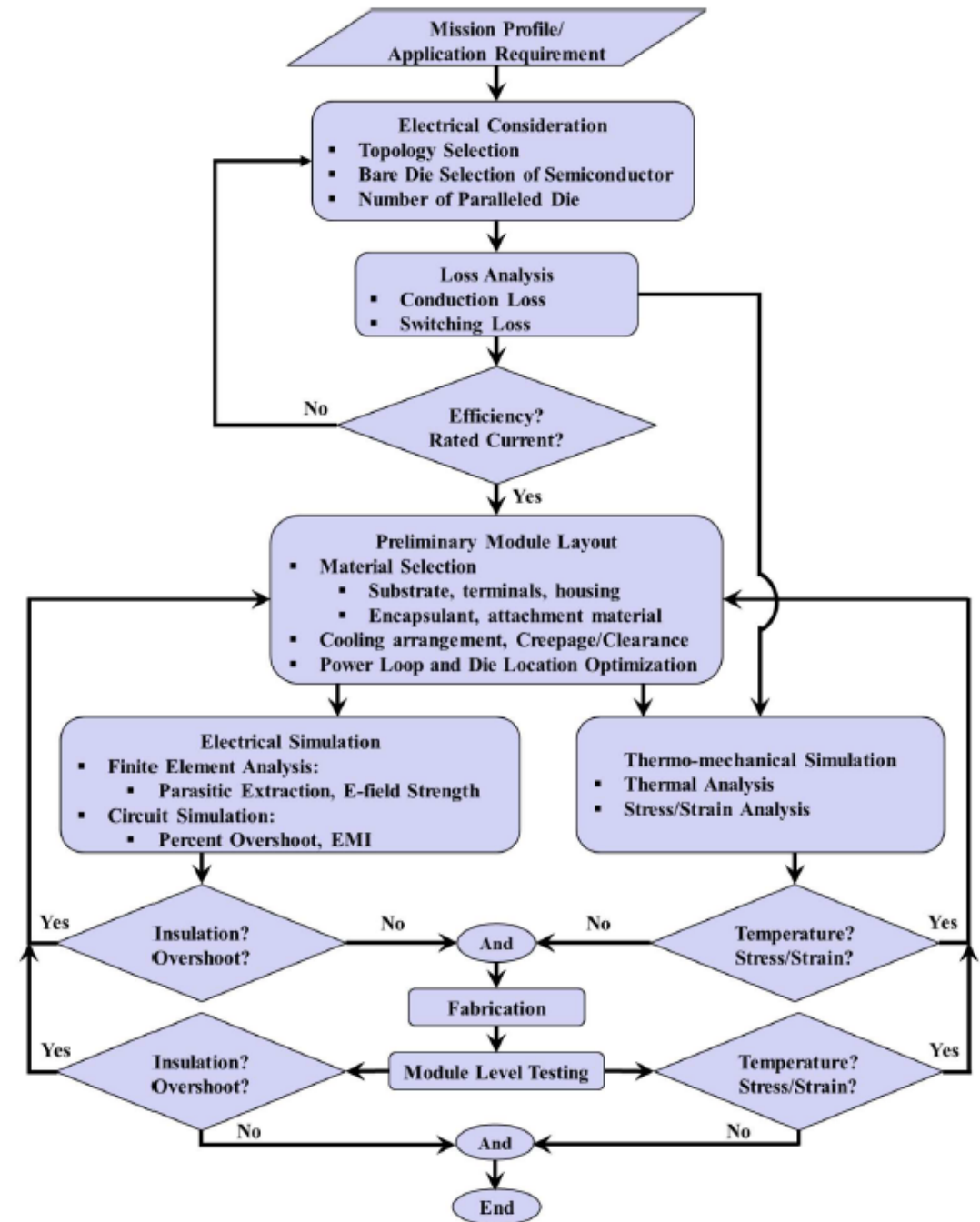# Coupled Simulation and Outlook to Future Module Design Flows

Fig. 2. Generalized design process of a power module.

Coupled Simulation and Outlook to Future Module Design Flows

Outlook: automized layout design
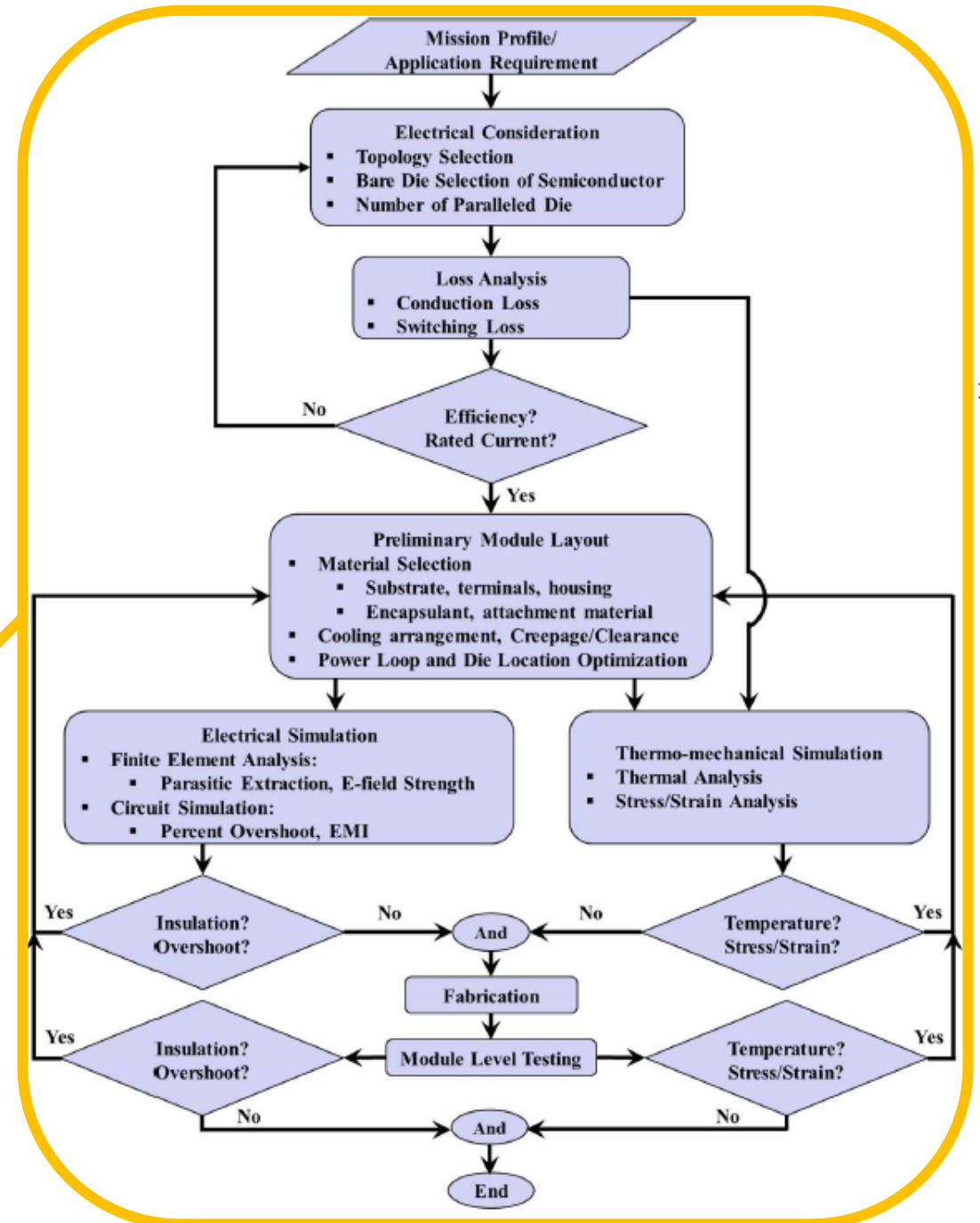and optimization through
the coupled simulation sections

Fig. 2. Generalized design process of a power module.

Coupled Simulation and Outlook to Future Module Design Flows

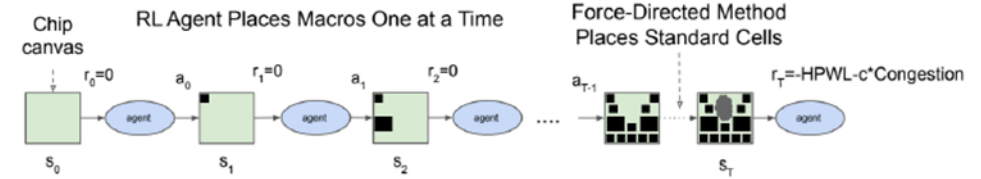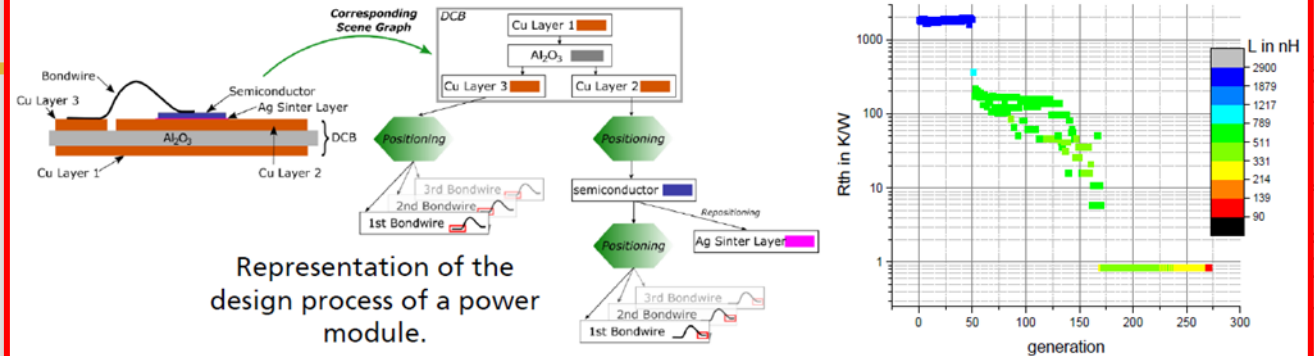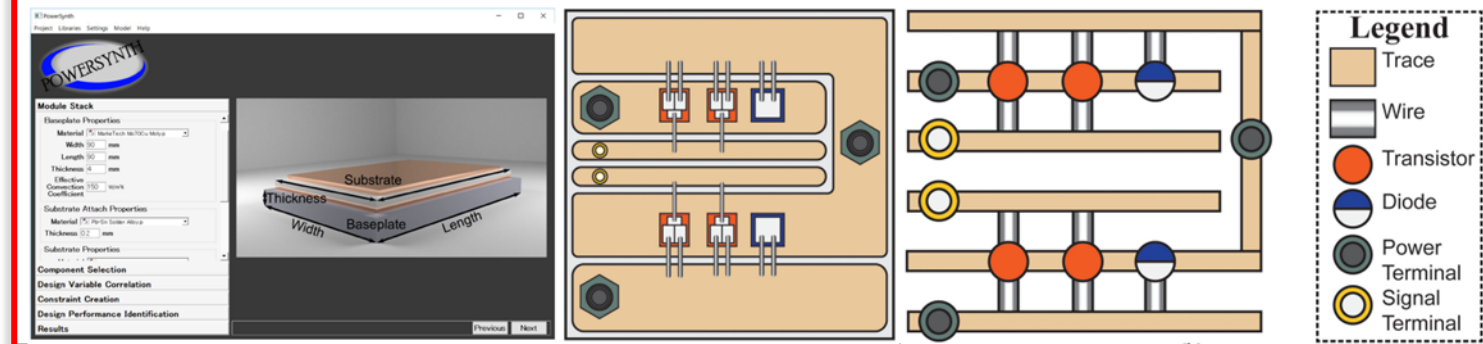"Chip Placement with Deep Reinforcement Learning", 04/2020: https://arxiv.org/pdf/2004.10746.pdf

Figure 1. The RL agent (i.e., the policy network) places macros one at a time. Once all macros are placed, the standard cells are placed using a force-directed method. The reward, a linear combination of the approximate wirelength and congestion, are calculated and passed to the agent to optimize its parameters for the next iteration.

" ...automatic topology creation using Optimization of target parameters...", 09/2019: master thesis, M. Groccia Fraunhofer IISB

Representation of the design process of a power module.

Outlook: automized layout design and optimization through the coupled simulation sections

"PowerSynth: A Power Module Layout Generation Tool", Evans et al., 09/2018: DOI: 10.1109/TPEL.2018.2870346

Thanks for your attention!