Next generation drive-train concept featuring self-learning capabilities enabled by extended IT functionalities

Alexander Otto, Sven Rzepka
Fraunhofer Institute for Electronic Nano Systems ENAS

Micro Materials Center
Head: Prof. Dr. Sven Rzepka

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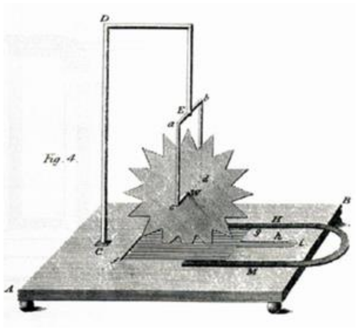
I. Introduction

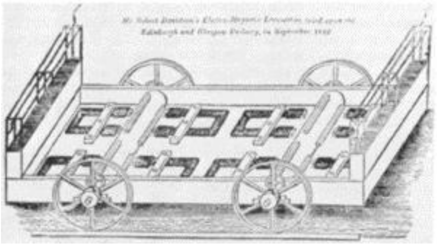
- Historical evolution of electric drives in automotive:
  - First fundamental understandings of magnetic fields, electromagnets etc. starting from approx. 1800
  - Invention of first electric motors in 1820s and 1830s
  - First electrical drives in second half of 19th centuries
  - First electric car (with 4 wheels) in 1888 (Flocken Elektrowagen)
  - Golden age of electric vehicles from approx. 1896 - 1912
  - Revival of interest in electric vehicles starting in 1990s
  - …
- Despite the various improvements in the details, the principle system architecture has not changed much!

Barlow's wheel, 1822



Source: Peter Barlow: A curious electro-magnetic Experiment. The Philosophical Magazine and Journal, Ausgabe 59, 1822

Electrical vehicle from Davidson, 1839



Source: T. du Moncel, Electricity as a Motive Power, London, 1883, fig. 32

Flocken Elektrowagen, 1903

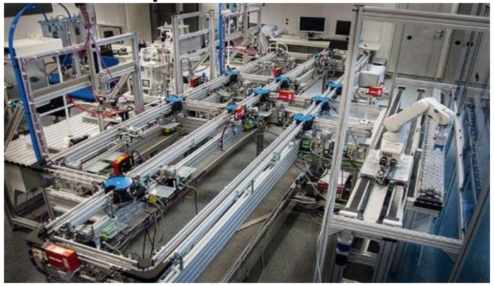
Source: Deutsches Museum

I. Introduction

Drive-trains today:

- Various applications reaching from industrial automatization (e.g. production processes) to traction applications (railway, automotive, …)
- Almost 50% of the overall world-wide produced electrical energy is consumed by electrical machines
- Besides the specific requirement in each of the application fields, there are universal needs for:
  - Maximum energy & power density
  - Maximum energy efficiency
  - High reliability & robustness
  - Minimum costs

Production processes



Source: TU München

Traction applications

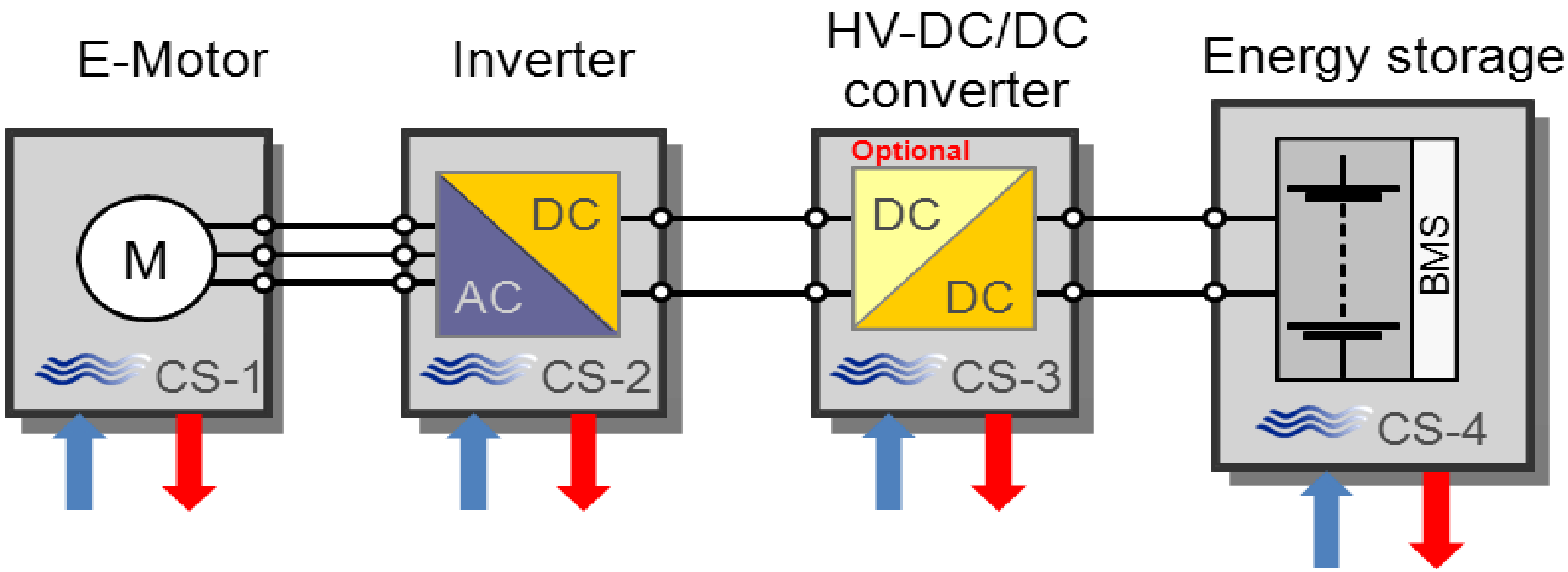
Source: Deutsche Bahn AG / Gert Wagner

Electric mobility

Source: BMW

II. State-of-the-art for electrical drive-train systems

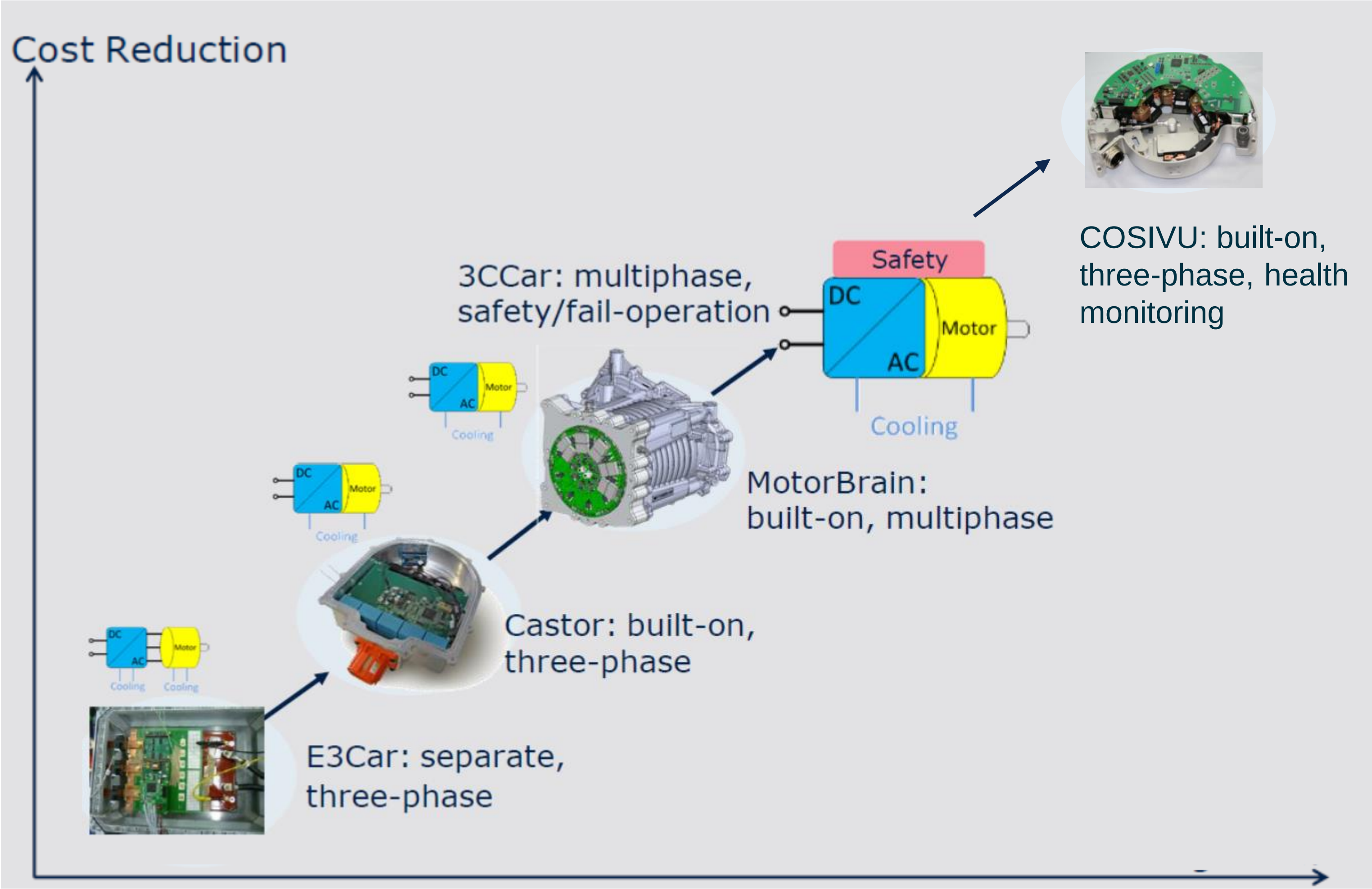
Example of state-of-the art HV system architecture



Source: Fraunhofer IISB

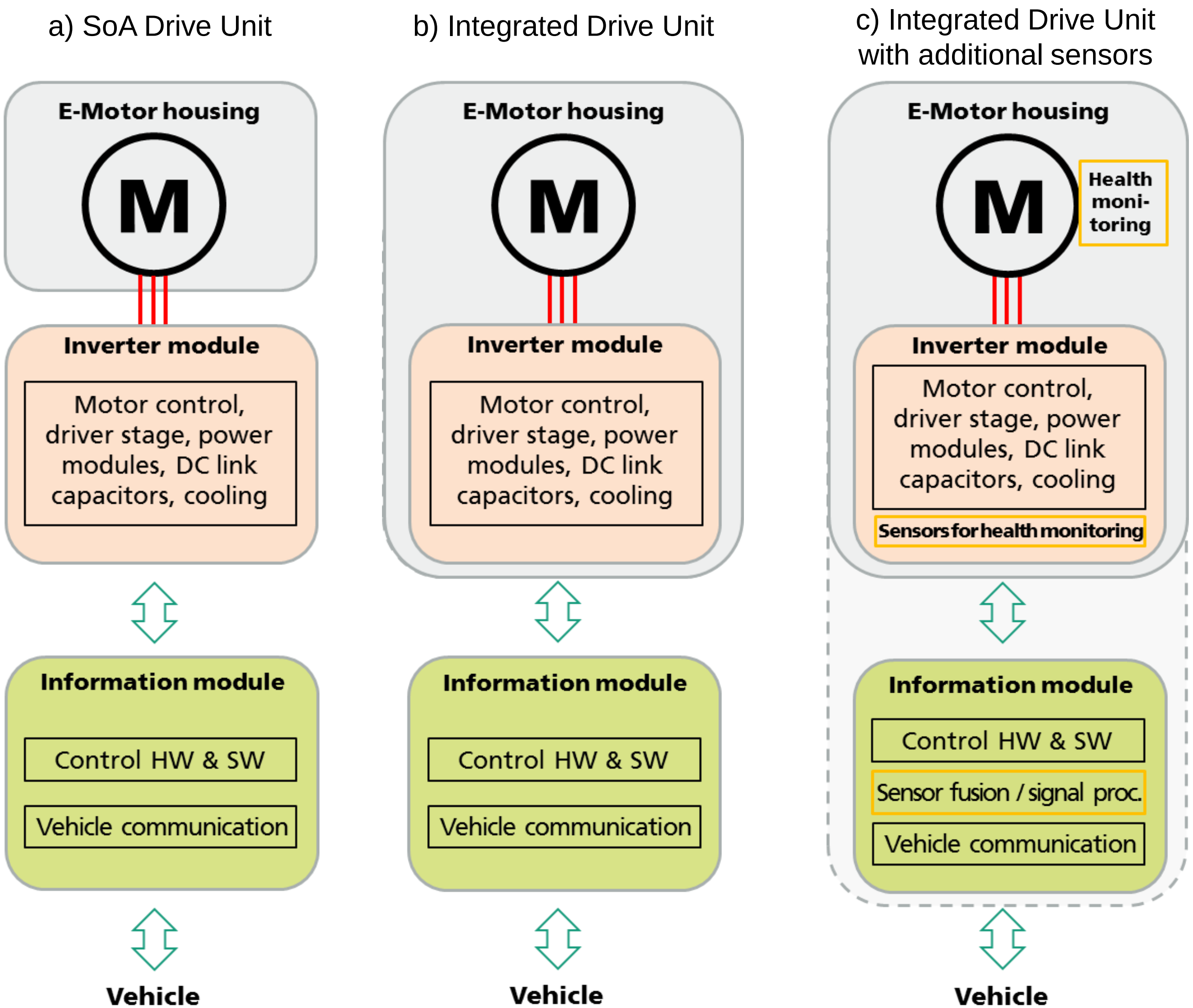
II. State-of-the-art for electrical drive-train systems

Latest trends



Extension of image based on: Wolfgang Dettmann, Experience with ECSEL The 3Ccar project, SSI conference, 2015

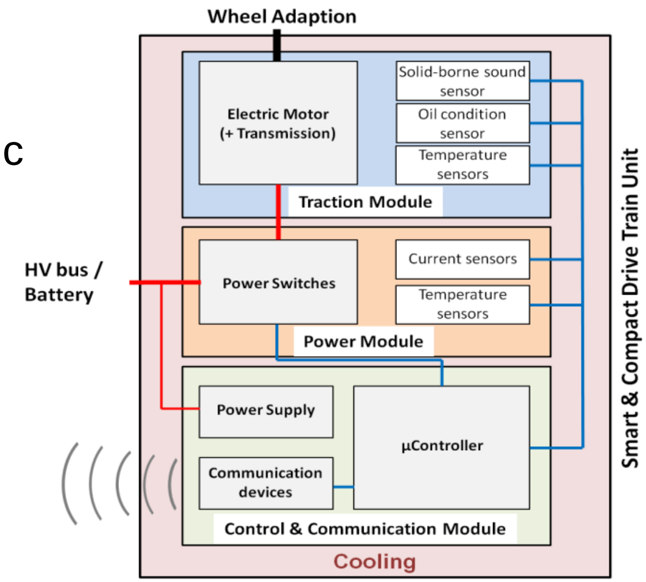
II. State-of-the-art for electrical drive-train systems



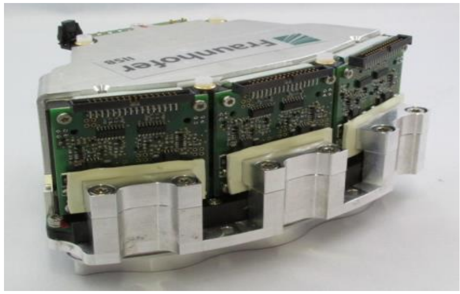
II. State-of-the-art for electrical drive-train systems

Example: Newly developed drive-train system within COSIVU project

- Modular inverter design with SiC BJTs and diodes, adaptable to different vehicle platforms
- High compactness (mechatronic integration of electric motor, power electronics, cooling system and control electronics)
- Superior efficiency (up to 50% less power losses compared to conventional systems)
- Health-monitoring for the SiC power modules (thermal impedance spectroscopy)
- Health-monitoring for the e-motor and gearbox (structure-borne sound analysis)



Project partner: Volvo CE, Hella, Swerea IVF, Elaphe, Sensitec, Fraunhofer IISB + ENAS, Berliner Nanotest, TU Chemnitz



Source: Fraunhofer IISB

Source: Elaphe Propulsion Technologies

III. Novel concept for drive-train architecture

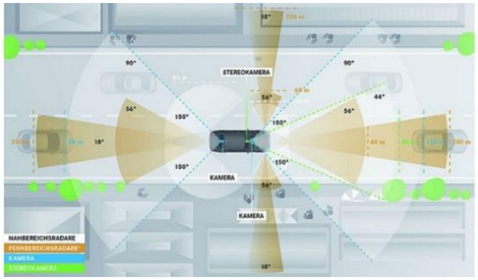
- Increasing requirements for electronic systems in vehicles due to introduction of electrified drive-trains, Car2X communication, autonomous driving features, …

- Paradigm shift:

Closed-loop-controlled systems

Truly self-deciding and self-learning automates

Autonomous driving

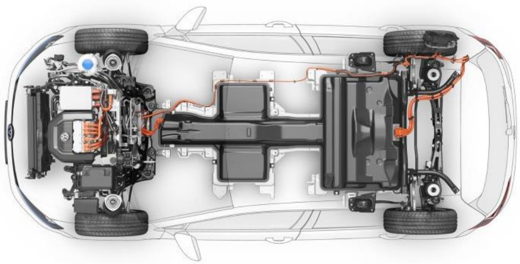


Source: Daimler

Car2X communication

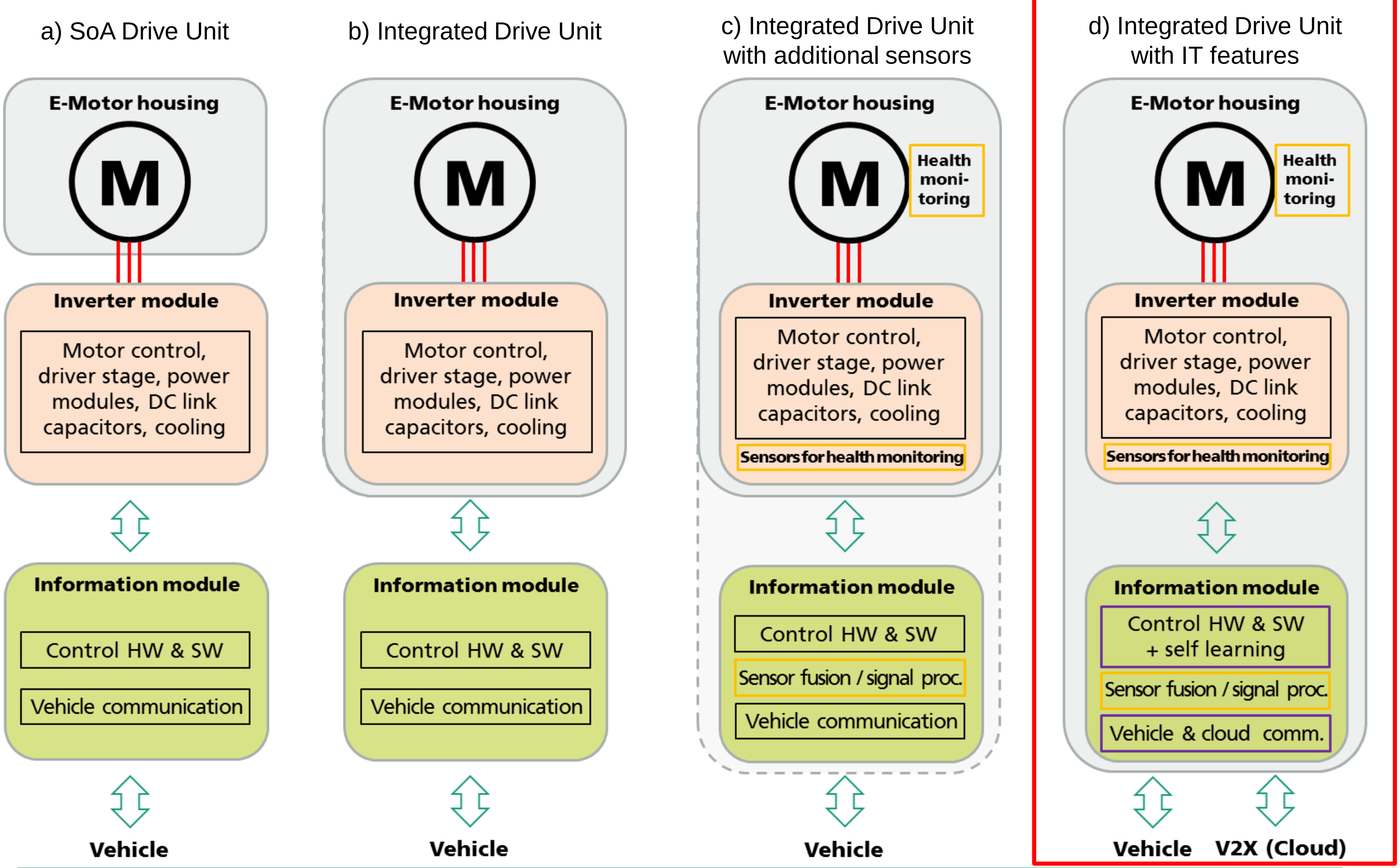
Source: University of Michigan

Drive-train electrification



Source: Volkswagen

III. Novel concept for drive-train architecture



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III. Novel concept for drive-train architecture

<u>Potential application scenario</u>: Detection of the actual road conditions and triggering of pro-active drive-train actions

Application

Monitoring of wheel-road interaction via measurement of torque, slip and rotation speed values for all individual wheels (e.g. paved/unpaved, handy/humpy/muddy, dry/wet/icy, …)

↓

Comparison of:

Pattern of the current set of input information ⟷ On-board library

↓

Local determination of optimum motor output parameters (based on best match / fast interpolations between the closest neighbors)

↓

Limiting of max. applicable power of the motor to the level in order to allow max. traction in the safe driving mode

Updating of on-board library with full-scale computed parameters

→ Improvement of data-base of sample cases for the interpolation schemes

Cloud

Applying of full algorithms for computing optimum motor parameters

Secure bi-directional communication with cloud
(no part of the real-time loop!)

New optimization parameters

Sharing / using of experience gained by similar systems in the field

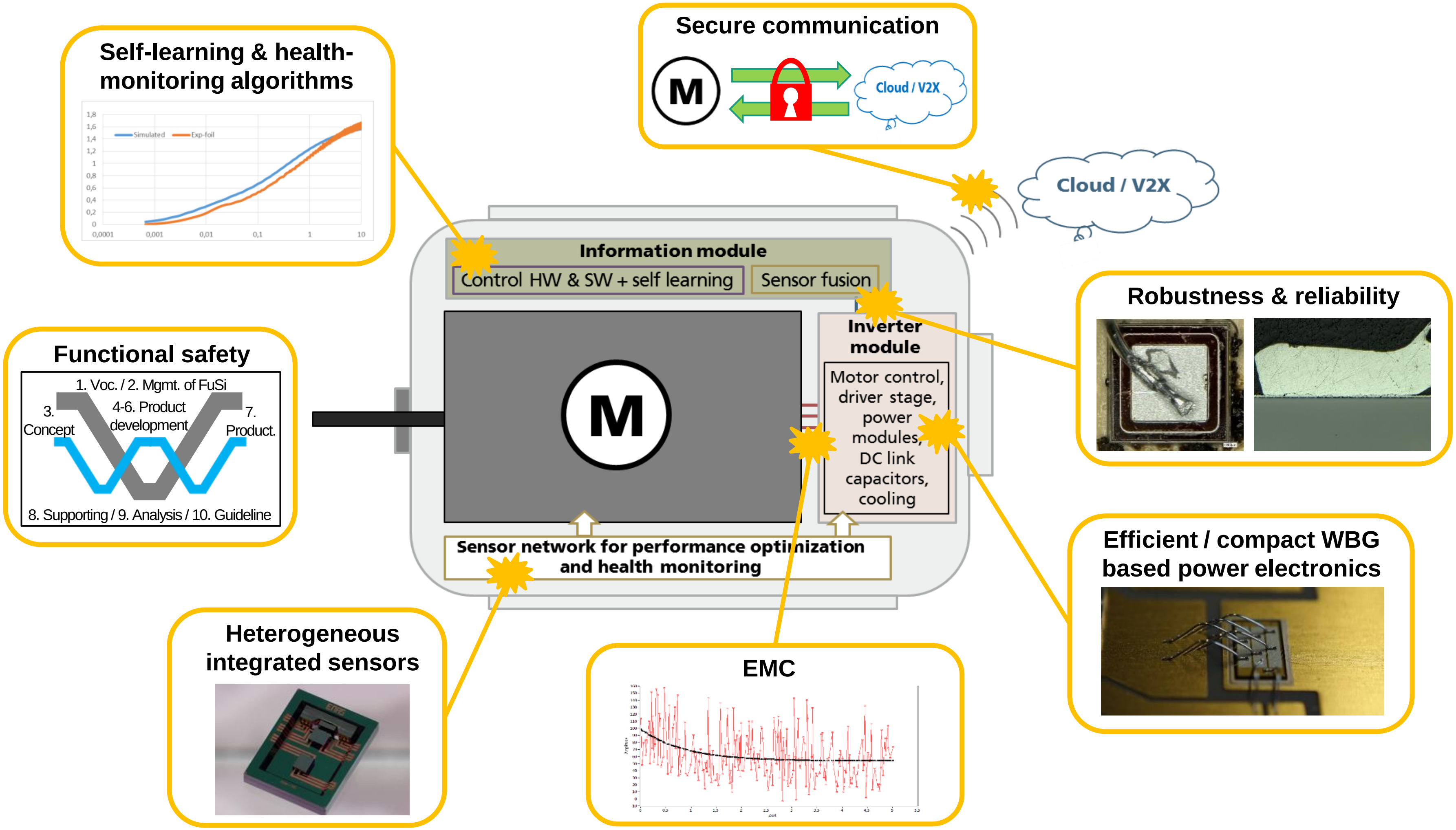
Neighboring Applications

Self-learning approach:

- The systems gains and uses experience to act and to adjust to the real time needs faster and better every day
- Computational power at the vehicle level is sufficient for pattern recognition; complex calculations are out-sourced to the cloud

III. Novel concept for drive-train architecture

Technological challenges



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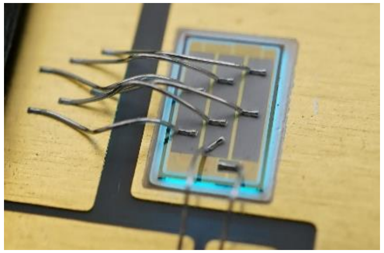
III. Novel concept for drive-train architecture

Efficient and compact WBG based power electronics

- Increasing importance of wide-bandgap devices (SiC, GaN, …) due to their superior electrical and thermal properties (E_c, T_m, λ, v_{sat}, …)

  → higher switching frequencies → improved energy efficiency

WBG devices



EMC issues

- Due to high switching edges (dv/dt) enabled by WBG dev.
- Optimized signal forms, which include pre-distortions intended to counter-balance the intrinsic imperfections of the motor coils for maximum over-all motor efficiency, will amplify this effect
- Increased risks of interference for IT electronics part where sensors generate signals in the range of just a few μV to be processed, evaluated, and memorized.

→ Protective measures / strategies for assuring EMC required!

Reliability issues

- Thermo-mechanical risks due to potentially higher operational temperature of WBG devices
- Reduces the cooling efforts leading to significant reductions in size and weight of the power modules
- <u>But</u>: Also IT electronics will be exposed to temperatures ≥200°C

→ New high-temperature resistant system-in-package (SiP) solutions for the (information) modules are required

Alexander Otto
Micro Materials Center, 23.09.2016

Micro Materials Center
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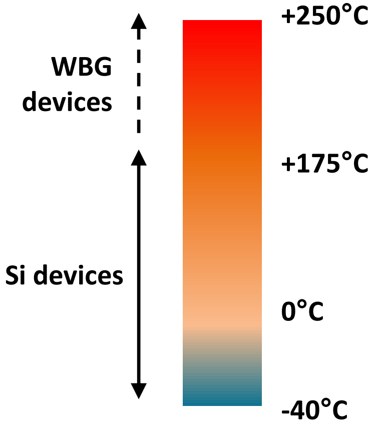
III. Novel concept for drive-train architecture

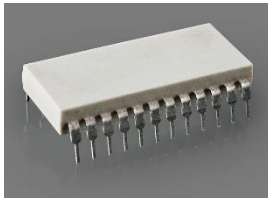
Reliability / Robustness

- New integration and assembling technologies for high operation temperature
- New high-temperature resistant molding and potting materials
- New cooling concepts with a reduced number of interfaces between heat source and sink as well as solutions for inter-layer heat removal



Encapsulation (molding compound)

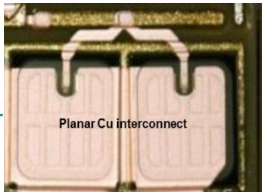
Polymer ceramics, High T_g materials, …



Source: Fraunhofer IKTS

Top-side connection

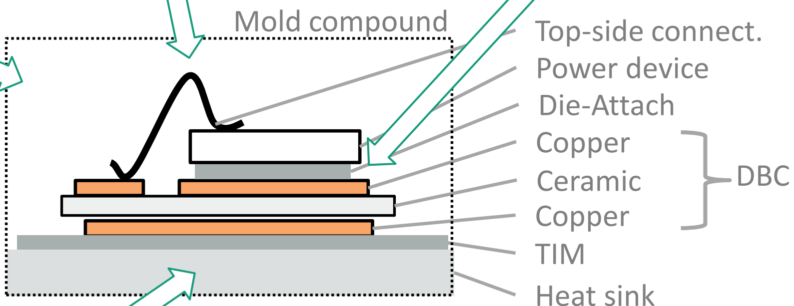
Copper wires, planar technology, …



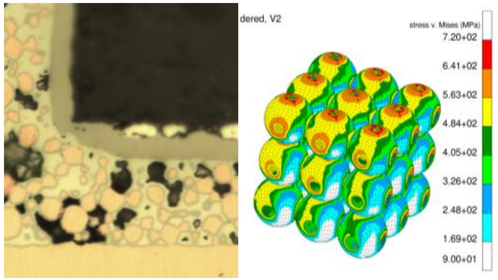
Source: Project EHLMOZ

Die-Attach

E.g. silver or copper sintering, transient liquid phase diffusion (TLP) soldering, solid-liquid inter-diffusion bonding (SLID)



TLP soldered interconnect



Source: Project HotPowCon

Cooling concepts

Alexander Otto
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Fraunhofer ENAS

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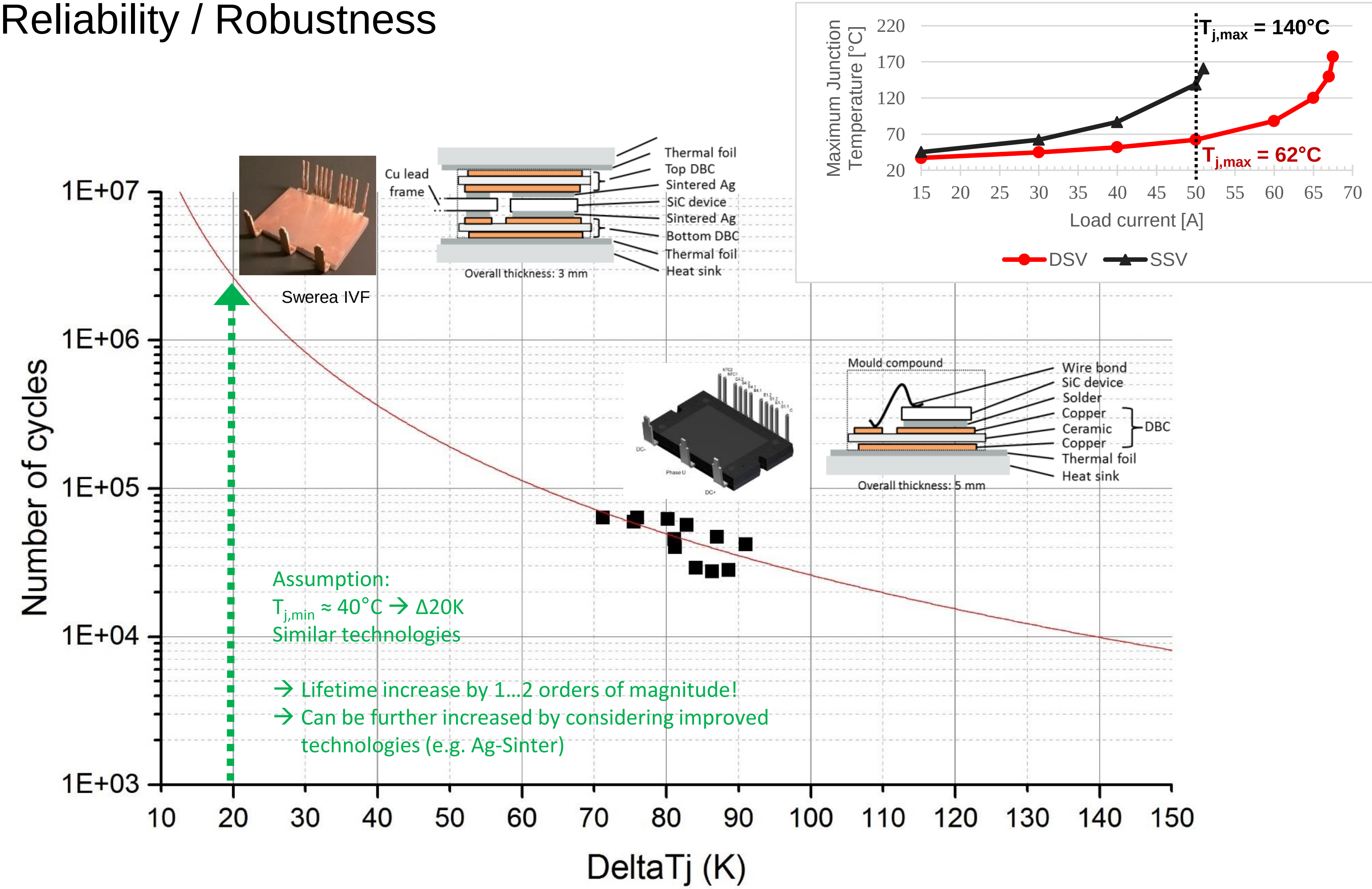
Reliability / Robustness



IV. Summary & Conclusion

- Introduction of novel concept for next generation drive-train architectures based on a modular and ultra-compact design with extended information and communication technologies:
  - Novel sensor network and implemented health-monitoring algorithms allows to improve significantly fault susceptibility and up-time
  - Pattern recognition capabilities will enable performance optimization based on self-learning and cloud computing

- Discussion of some mayor technological challenges such as:
  - WBG devices and EMC issues
  - Efficient cooling
  - Reliability & robustness

Thank you for your attention!

Contact: Alexander Otto
alexander.otto@enas.fraunhofer.de
Micro Materials Center, Fraunhofer ENAS
Technologie-Campus 3, 09126 Chemnitz, Germany