ETH zürich

IEEE Power Electronics Society
FEPPCON Future of Electronic Power Processing & Conversion

Power Electronics Integration

Economic / Technological / Environmental Benefits & Barriers

Johann W. Kolar & Jonas Huber

Swiss Federal Institute of Technology (ETH) Zurich
Power Electronic Systems Laboratory
www.pes.ee.ethz.ch

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Outline

- *Levels & Categories*
- *State-of-the-Art*
- *Benefits & Barriers*
- *Future Research Areas*

Acknowledgment

J. Azurza
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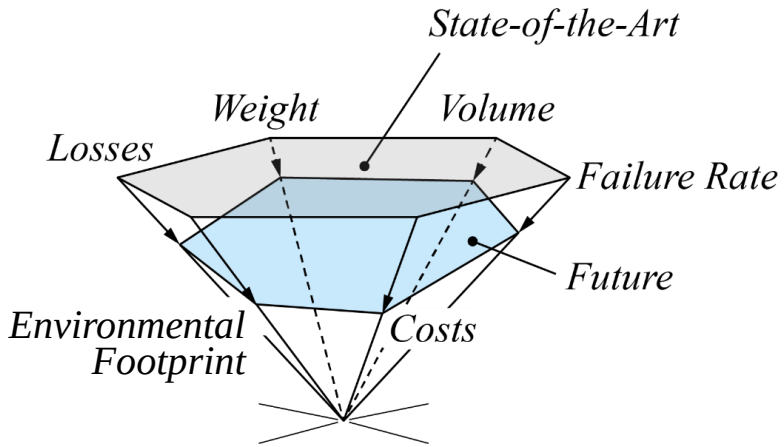
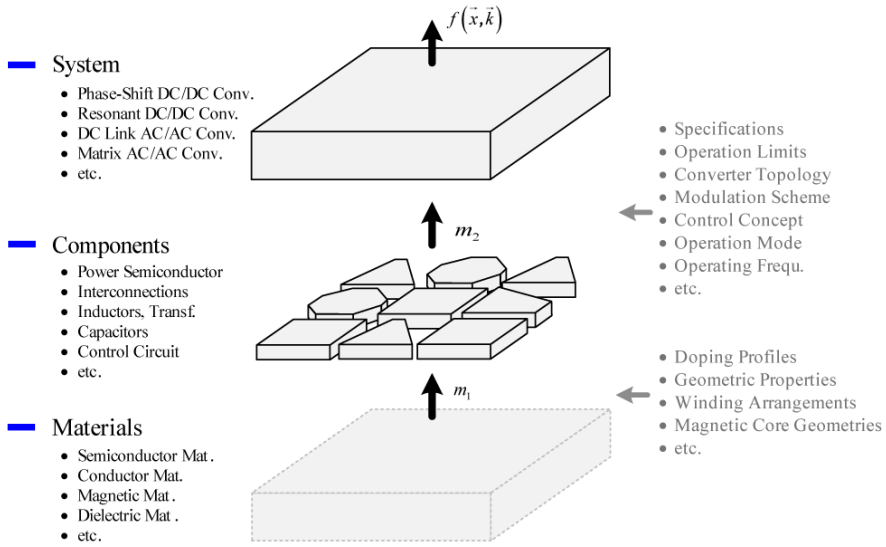
J. Schäfer

Integration Drivers / Levels / Categories

- *Power Electronics — Def. Interconnection of Active & Passive Power Components / Sensors / Signal Electronics etc.*
- *Market Pull — Lower Costs / Lower Functional Volume / Lower Losses / Higher Reliability*

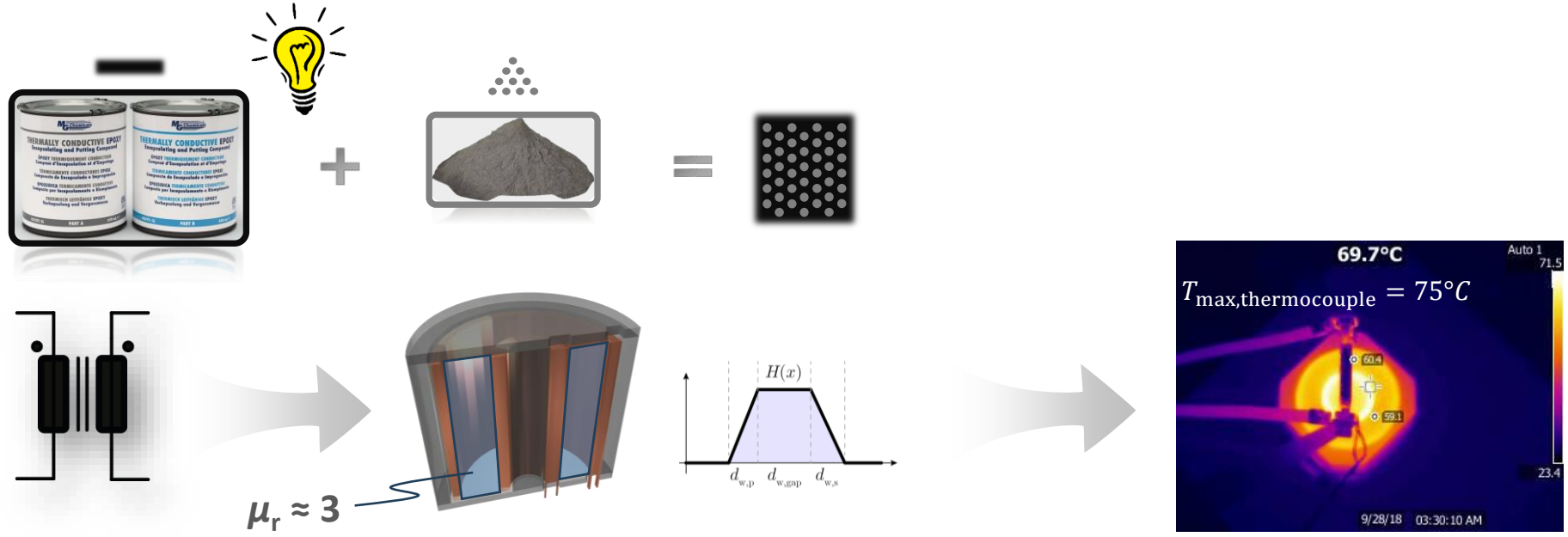




- *Material-Level | Component-Level | Topology-Level | Modulation & Control-Level | Package-Level | System-Level*
- *"Functional" Integr. & "Embedding" Enables Massive Performance Improvements / Hardware & Signal Layer*

"Material-Level" Integration

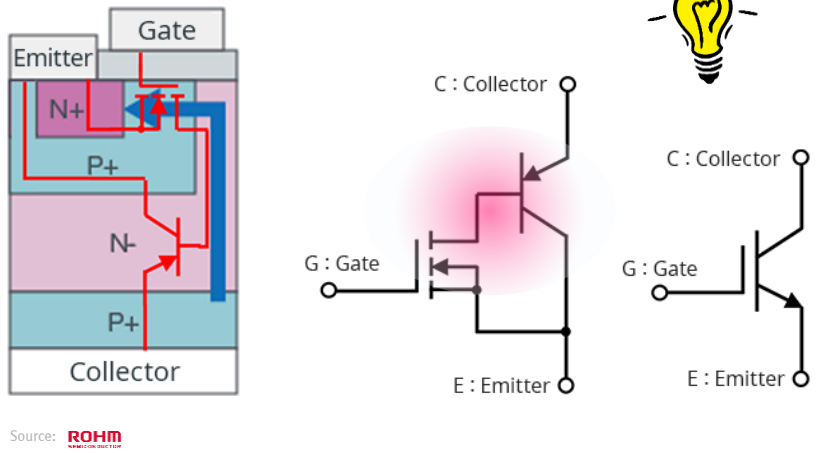
- *Application-Specific Composites Combining Favorable Properties of Individual Materials, incl. 3D-Grading*

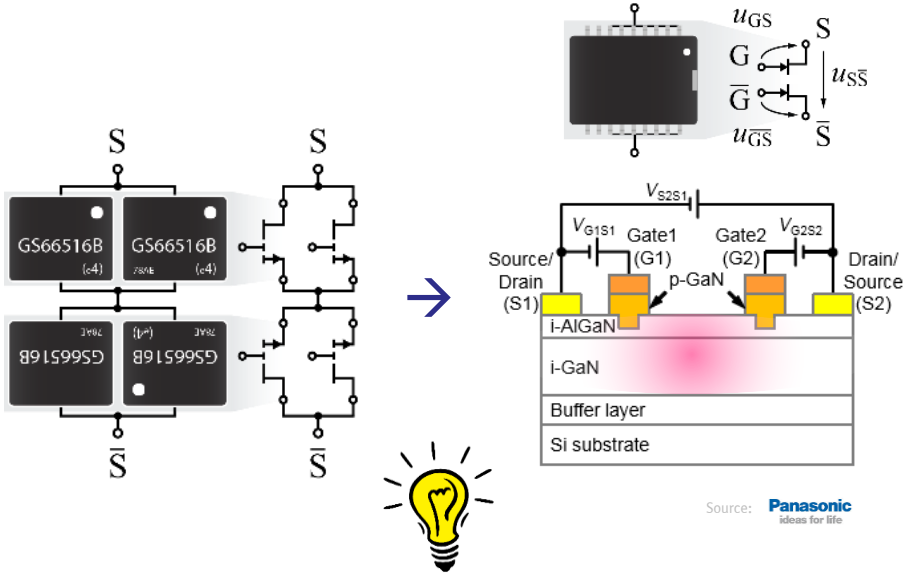


- *Low Permeability & High Heat Conductivity Material → Magnetic Integr. of Inductors into Transformers*

"Component-Level" Integration

- *Monolithic Integration of MOSFET & Bipolar Junction Transistor → IGBT*
- *Monolithic Integration of Inverse-Series Connected MOSFETs → "True" M-BDS*

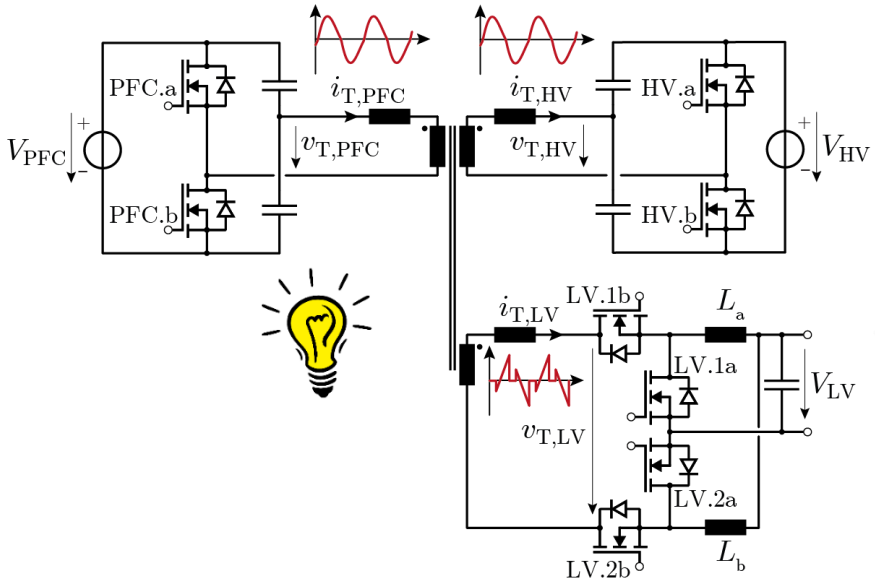


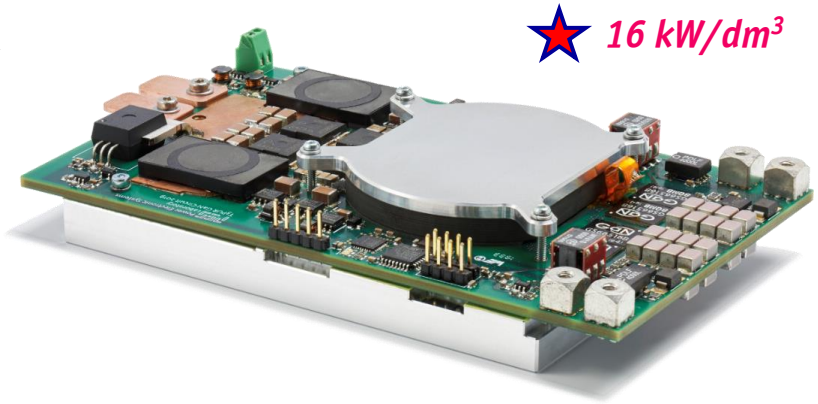


- *IGBT — Higher Blocking Voltages (Cond. Modulation) / Minority Carrier Inj. → Tail Current/Sw. Losses*
- *M-BDS — Lower Chip Area → Higher Thermal Stress (4x A_{chip} → A_{chip} BUT R_{th} → 4x R_{th})*

"Topology-Level" Integration

- *Isolated Three-Port DC/DC Converter Employing a Single Transformer / Future EV DC Power Distribution*
- *Charge Mode PFC → HV | Drive Mode HV → LV*

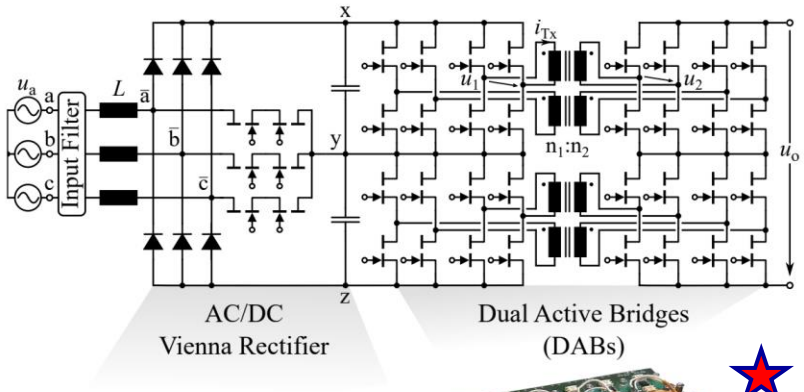




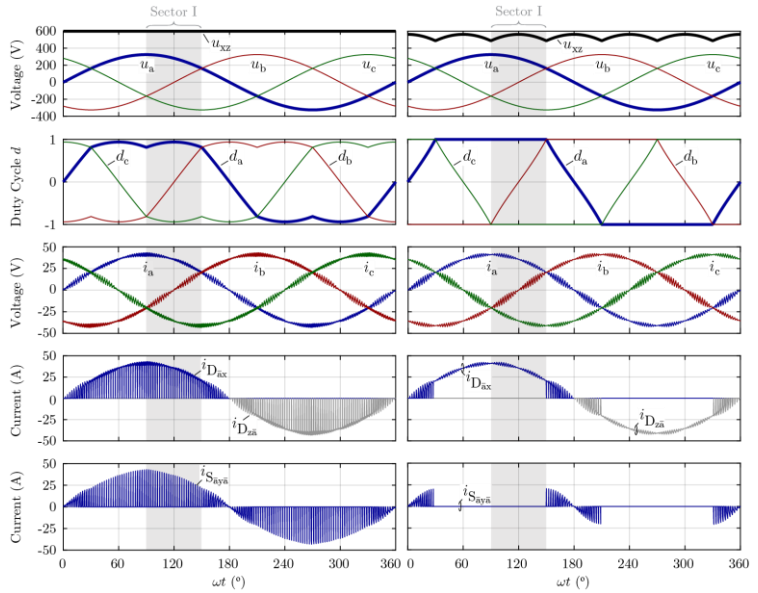
- *High Power Density | High Design & Control Complexity & Higher Stresses for Wide Inp./Output Range*

"Control-Level" Integration

- *Synergetic Control of Two-Stage Converters → Quasi-Single-Stage Isolated AC/DC Conversion*
- *DC/DC Converter Utilized for Control of Two Mains Phase Currents by DC-Link Voltage Shaping*



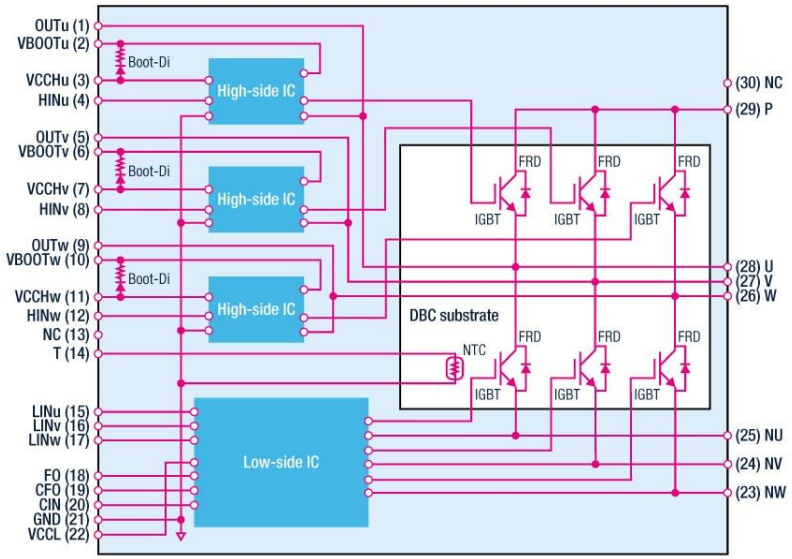
10 kW/dm³



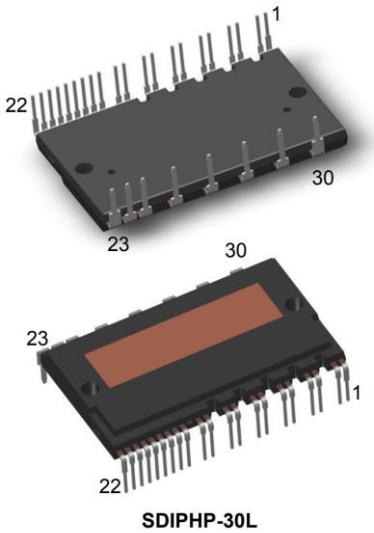
- *Lower Sw. & Cond. Losses | High Control/Commissioning Complexity & No Passive Load-Step Buffering*

"Converter-Level" (Heterogeneous) Integration 1/2

- *Three-Phase DC/AC Converter Intelligent Power Modules (IPMs) → HVAC, Pumps, Fans, Servo Drives*
- *Dual-in-Line Package w/ DBC Substrate Pad for Cooling*



Internal circuit of SLLIMM High Power IPM



SDIPHP-30L

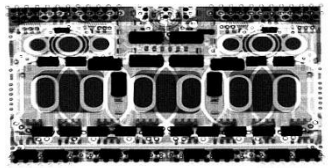
Source:

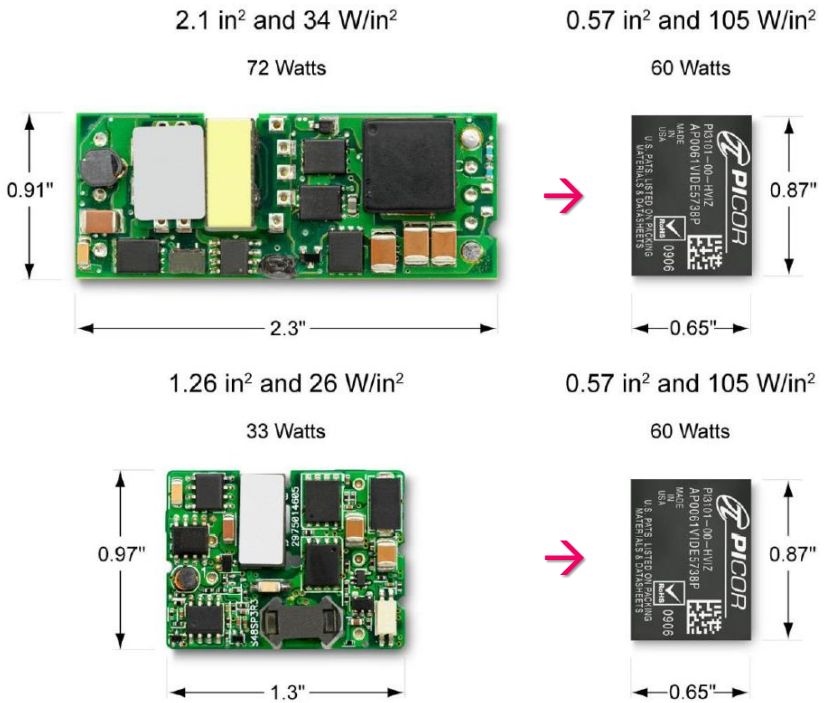
- *All-in-One (Inv. Stage, High-Side & Low-Side Gate Drivers, UV Lockout, Temp. Monitoring) / Shrinks BOM*
- *Pin-to-Pin Compatibility w/ Competitor Products Mandatory (2nd Source) — Standardization (?) & Recycling (?)*

"Converter-Level" (Heterogeneous) Integration 2/2

- *System in Package (SiP) Approach — Isol. & Non-Isol. DC/DC Converters, PFC Rectifiers, etc.*
- *Minim. of Parasitic Inductances / EMI Shielding / Integr. Thermal Management*

Source: VICOR



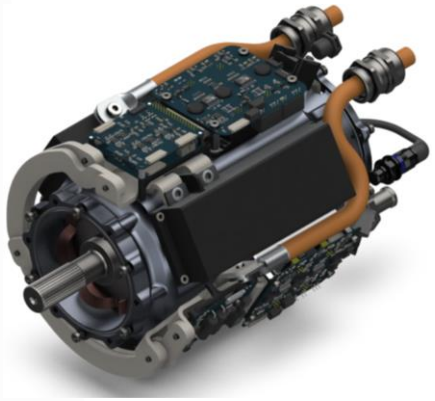


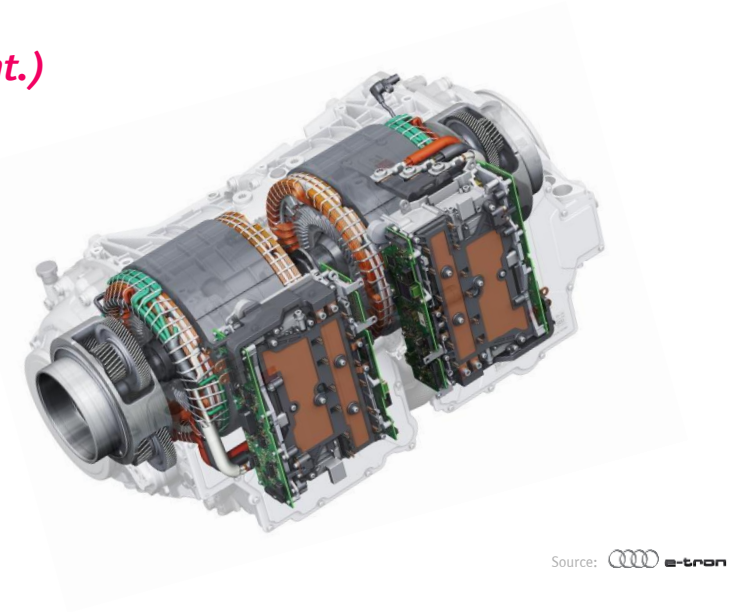
- *Extreme Power Density / Shrinks BOM*
- *Automated Manufacturing / High Reliability*
- *High $$$ / 2nd Source (?) / Recycling (?)*

"System-Level" (Hybrid) Integration

- *Motor & Inverter Integration for Future More-Electric Aircraft / eVTOL & Electric Vehicles*
- *"Embedded" Power Electronics*

10 kW/kg (cont.)





- *Increasing Level of Integration → High Torque/Power Density @ Increasing Thermal & Mechanical Stresses*
- *Limited Maintainability / Different Subsystem Lifetimes / No 2nd Source → Radial Outward Placement for EV*

Integration — Benefits & Barriers

- *Integration is Inherent to Innovation (Theory of Inventive Problem Solving)*
- *Economic / Technological & Technical / Environmental Aspects*

— *Elimination of Components & Interfaces*	→ *Lower Functional Volume & Raw Material Use*
— *Lower Commutation Loop Inductance / Parasitics*	→ *Higher Conv. Efficiency*
— *Fully Automated Manufacturing*	→ *Lower Costs / Higher Quality & Reliability*
— *Hidden Complexity to the User*	→ *Plug & Play*
— *Higher Internal Complexity / Higher "Entropy"*	→ *Limited Repairability*
— *High Compactness & Complex Material Mix*	→ *Limited Critical Raw Mat. Recoverability*
— *Close Proximity of Power & Signal Components*	→ *Higher Thermal & Mechanical Stresses & EMI Levels*
— *Lower Number of Active Devices*	→ *Higher Control Complexity / Limited Control DOFs*
— *Highly Dedicated Functionality*	→ *Limits to Econ. of Scale / No 2nd Source*

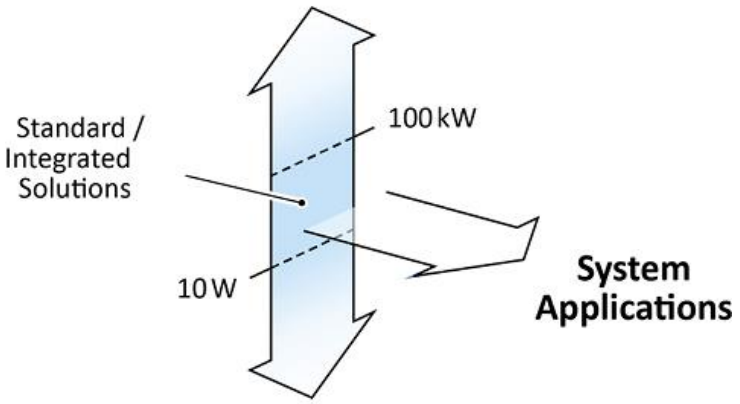
- *Environmental Aspects / Regaining Critical Raw Materials will be of Paramount Future Importance (!)*

Future Research Areas

Future Research Areas

- *Vertical Power Delivery for Clustered AI Processors — 100kA @ 0.75V*
- *Med.-Voltage/Frequ. High-Power SSTs for Ultra-Fast EV Charging, Datacenters, H_2 Production, MVDC Grids etc.*
- *Monolithic Integration*

"There is Plenty of Room at the Top"

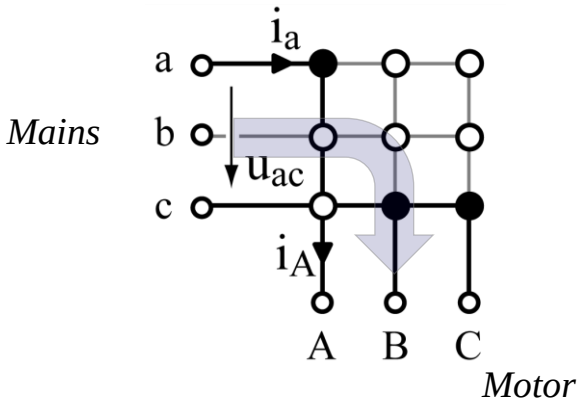


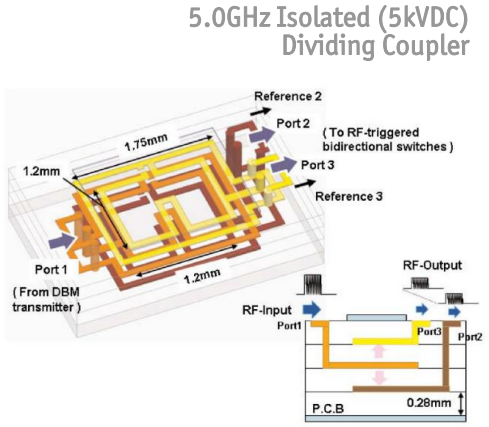
"There is Plenty of Room at the Bottom"

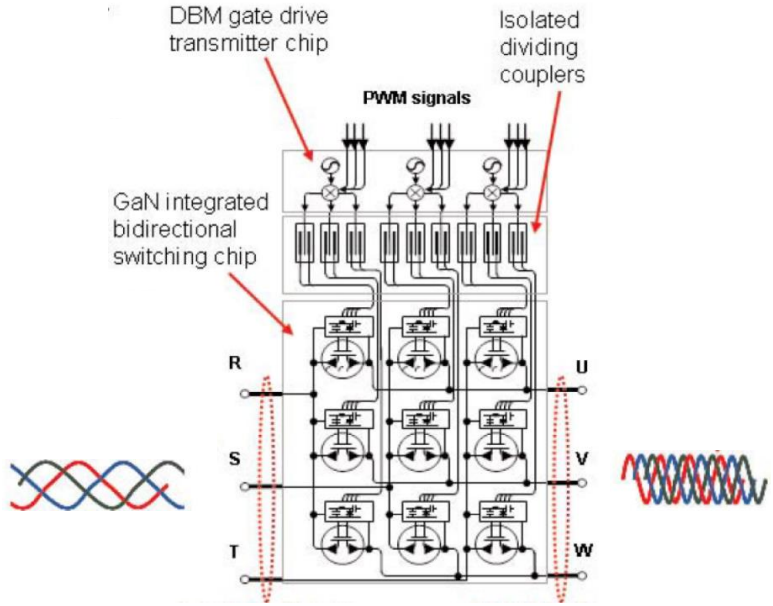
- *"There's Plenty of Room at the Bottom" (R. Feynman, Caltech, 1959) & There is Plenty of Room at the Top*
- *Key Importance of Technology Partnerships of Academia & Industry*

Monolithic 3D-Integration

- *3x3 Three-Phase AC/AC Matrix Conv. — 9 GaN M-BDSs w/ Isol. Drive-By-Microwave (DBM) Technology*





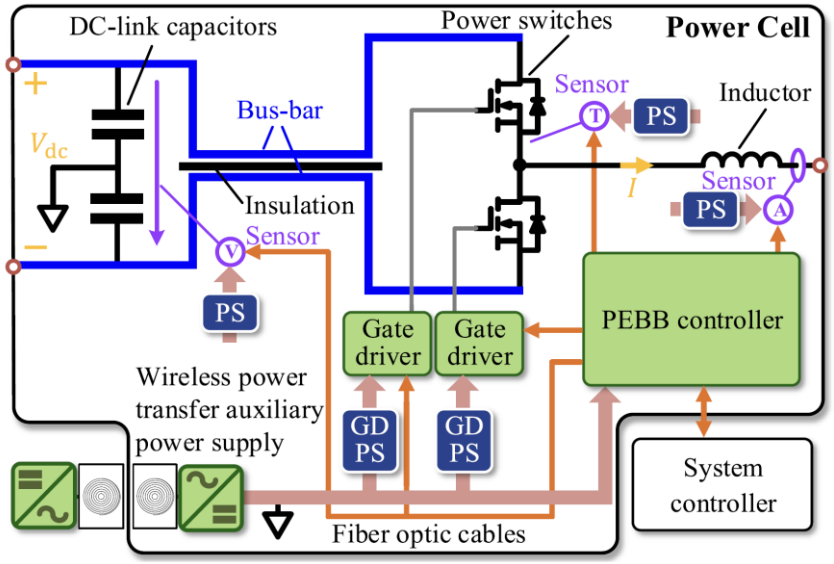


- *Ultra Compact → 25 x 18 mm² (600V, 10A – 5kW Motor)*

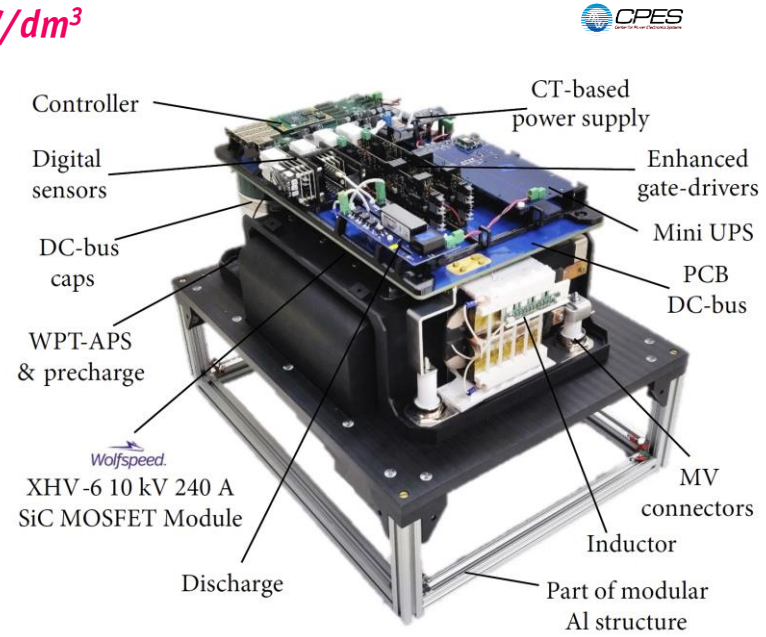
Source: Panasonic ISSCC 2014

Medium-Voltage Intelligent PEBBs

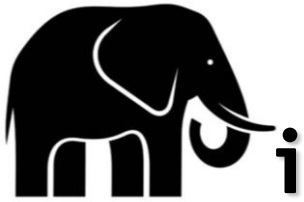
- *Half-Bridge Intelligent MV Power Electronics Building Blocks (i-PEBBs) w/ Integrated Output Inductor*
- *Realization of MMLCs or in Direct Series Connection / Isol. Coord. for 20+ kV DC-Link*

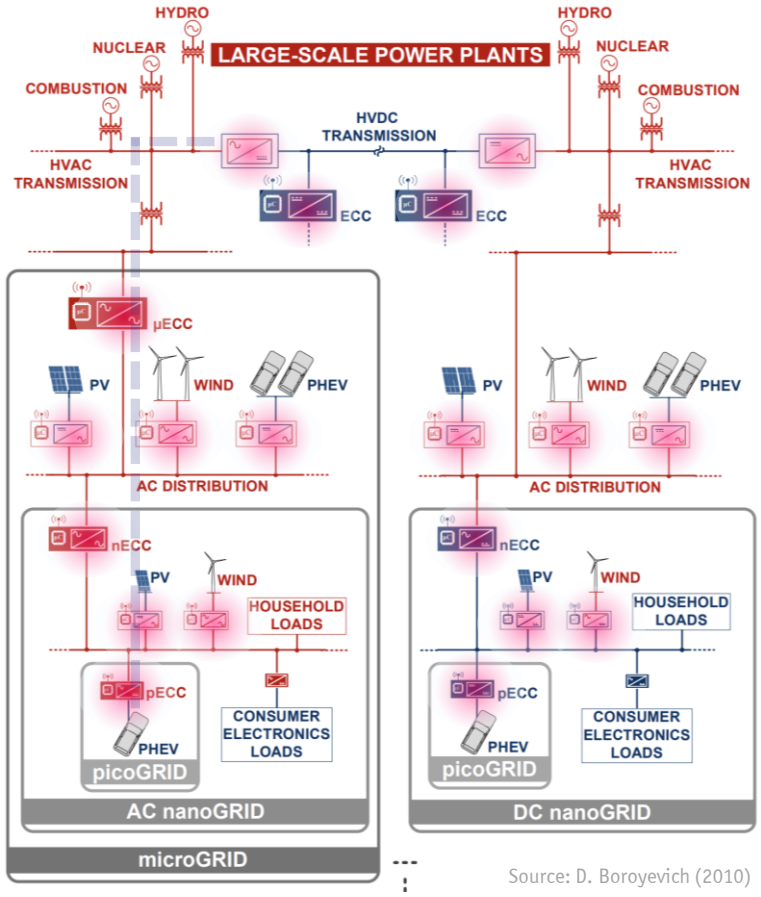


12 kW/dm³



- *6kV Multi-Layer PCB DC-Bus | Gate Driver for 100V/ns Sw. Speed | PCB Rogowski Coil Sw. Curr. Sensing / Protection*
- *Local Controller & Voltage/Current Sensors | Wireless Aux. Supply | Curr. Loop GD Supply | Temp. Sensing etc.*

The  in the Room



Source: D. Boroyevich (2010)

- *Global Population by 2050 — 10bn*  *2.5 kW/Capita*
- *25´000 GW Installed Ren. Generation in 2050*

- *4x Power Electr. Conversion btw Generation & Load*
- *100´000 GW of Installed Converter Power*
- *20 Years of Useful Life*

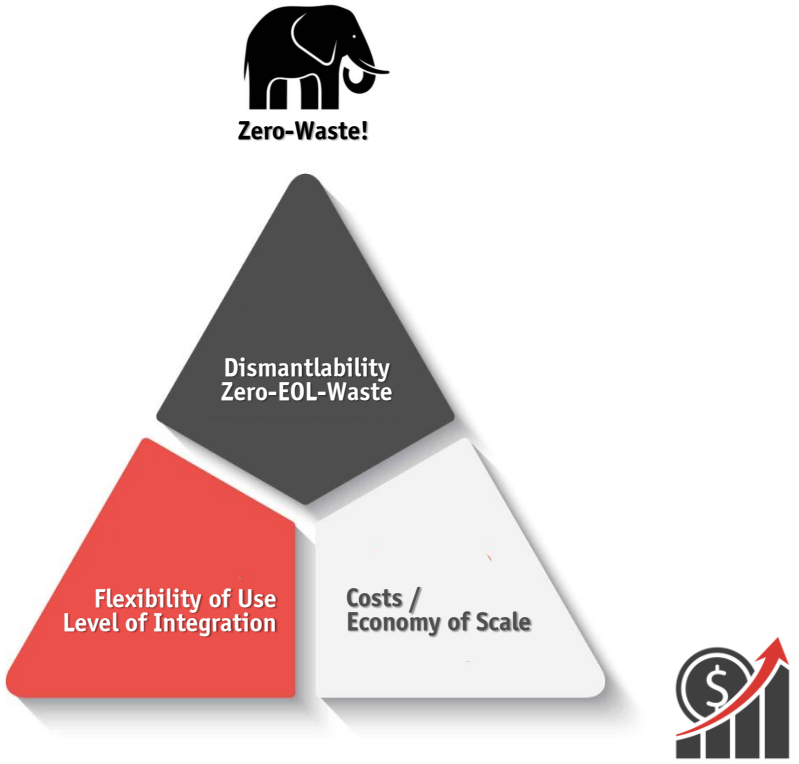
Source: www.e-waste-recyclers.co.in

- *5´000 GW_{eq} = 5´000´000´000 kW_{eq} of E-Waste / Year (!)*
- *10´000´000´000 $ of Potential Value*

Conclusion

- *Monolithic Integration*
- *Medium-Voltage / High Power i-PEBBs*
- *New Multi-Domain Coupled Modeling & Design Tools*
- *Novel Test & Measurement Systems*
- *Design for Circularity of Critical Raw Materials*
- *Smart Hybrid Systems / Sector Coupling*

Thank you!


Zero-Waste!
Dismantlability
Zero-EOL-Waste
Flexibility of Use
Level of Integration
Costs /
Economy of Scale