

Design of a 3kW power converter using PCB-embedding technology

From Nano to Micro Power Electronics And Packaging
Workshop, Tours, France

Rémy CAILLAUD¹, Johan LE LESLE¹, Cyril BUTTAY²,
Florent MOREL², Roberto MRAD¹, Nicolas DEGRENNE¹,
Stefan MOLLOV¹

¹Mitsubishi Electric Research Centre Europe, Rennes, France

²Laboratoire Ampère, Lyon, France

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Introduction

PCB Embedding Technology

Design of an embedded converter

Manufacturing Process

Experimental Results

Conclusions

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PCB Embedding Technology

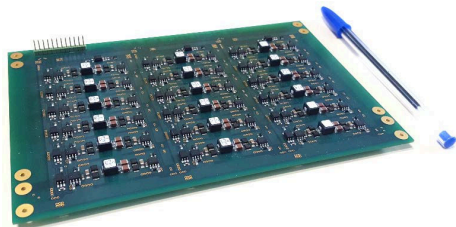
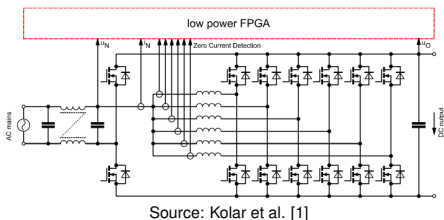
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Power electronics – Areas for Progress



Source: Kerachev et al. [2]

- ▶ Excellent active devices are now available (SiC, GaN)
- ▶ Many topologies introduced over the years;
 - ▶ Recent changes: multicellular structures
- ▶ Integration and Packaging are the main areas for progress [1, 3, 4, 5]
 - ▶ Reduce size and circuit parasitics, improve thermal management. . .
 - ▶ Manage increased interconnection density

Introduction

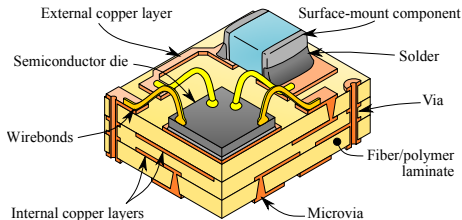
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Printed Circuit Board is

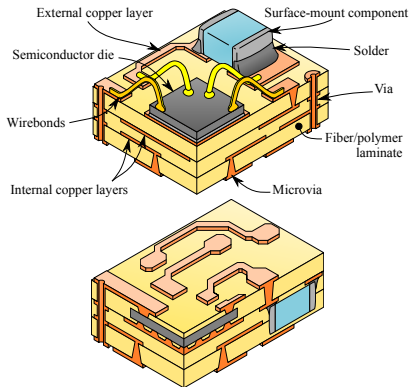
- Mature**
- ▶ Large range of available design software
 - ▶ Can be manufactured in large quantities, low price
 - ▶ Mainly oriented towards microelectronics and low power

- Flexible**
- ▶ Custom design
 - ▶ Many possible configurations

- Limited**
- ▶ Poor thermal conductivity

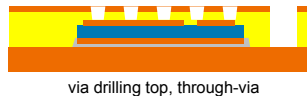
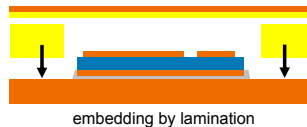
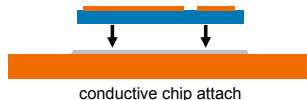
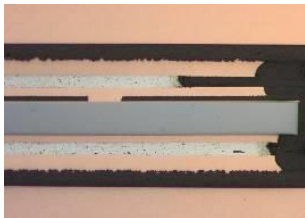
Why Embedding?

- ▶ Optimize thermal management
 - ▶ Heat sources closer to heatsink
 - ▶ Dual side cooling
- ▶ Improve performance
 - ▶ Shorter interconnects
 - ▶ Lower inductances
- ▶ Reduce size
 - ▶ Use substrate volume
- ▶ Manage complex interconnects
 - ▶ Batch process



Embedding of Power Dies

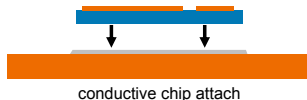
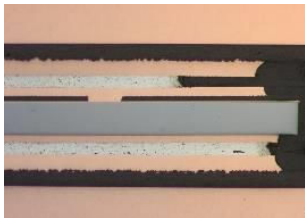
- ▶ Most embedding effort on power dies:
 - ▶ Most power density
 - ▶ Fastest voltage/current transients
- ▶ Requires special finish on dies
 - ▶ 5-10µm Cu (not standard)
 - ▶ Buffer for UV laser
 - ▶ Also for microetch in plating step
- ▶ Backside connection by sintering or vias
 - ▶ Sintering compatible with standard dies
 - ▶ Vias require Cu finish and adhesive



Left and above, source: Ostmann [6]

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conductive chip attach



embedding by lamination



via drilling top, through-via

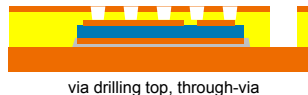
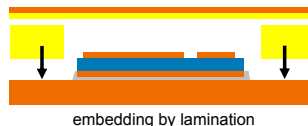
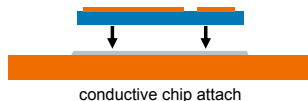
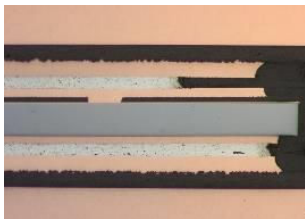


Cu plating and structuring

Left and above, source: Ostmann [6]

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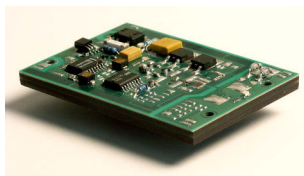


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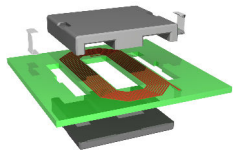
Embedding of Formed Components – Inductors

Magnetic Layer

- ▶ Relies on magnetic/polymer film \rightarrow Low μ_r
- ▶ Limited to 10 – 100 W



Source: Waffenschmidt et al. [7]

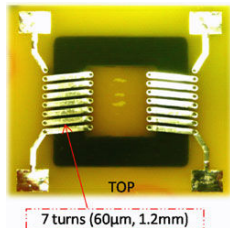


Planar magnetic components

- ▶ Very common, but not really embedded
- ▶ High performance
- ▶ Compatible with low (W) or high power (kW)

Embedded core

- ▶ Strong industrial development (Murata, AT&S, Würth)
- ▶ Currently limited to low power (W)



Source: Ali et al. [8]

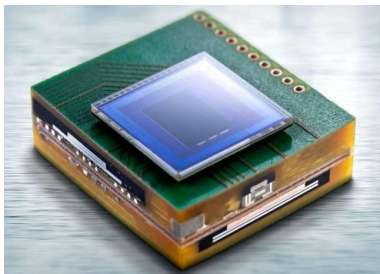
Embedding of Inserted Components

Soldered components:

- ▶ Suits most Surface-Mount Devices
- ▶ Connections with regular vias

Vias to components:

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- ▶ More compact (vias on components)



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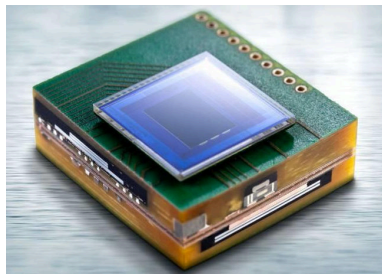
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For power electronics

- ▶ Embedding of “large” capacitors (1 μ F range)
- ▶ Embedding of gate driver ICs and peripheral components, control



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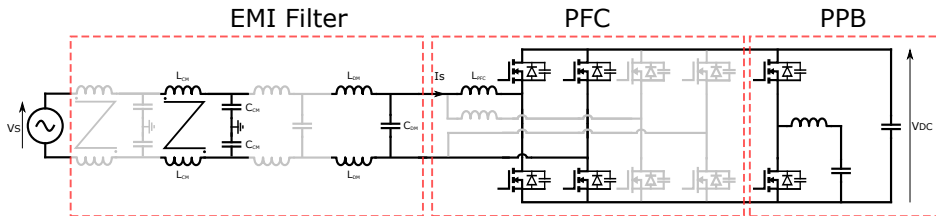
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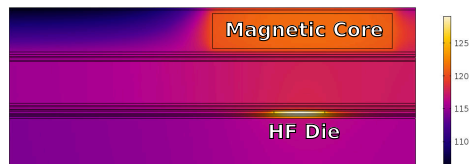
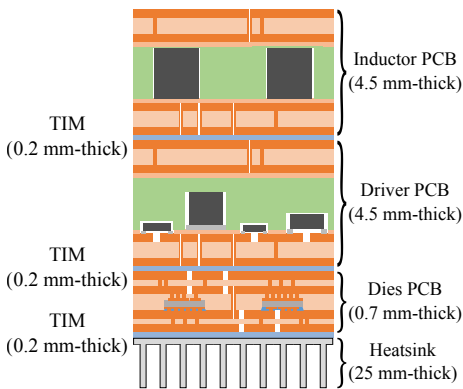
Conclusions

Converter topology



- ▶ Bidirectionnal, Power Factor Converter for 3 kW applications
- ▶ Designed through an optimization procedure [9, 10]
 - ▶ Based on SiC power devices
 - ▶ 180 kHz switching frequency
 - ▶ 4 interleaved cells
- ▶ Discussed here: EMI filter and PFC

Physical Structure



3-PCB structure

- ▶ Magnetic component on top
- ▶ Heatsink on bottom (natural convection)
- ▶ Power chips close to heatsink

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Thin PBC (1 mm)
for bare dies

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for SMT devices and inductors



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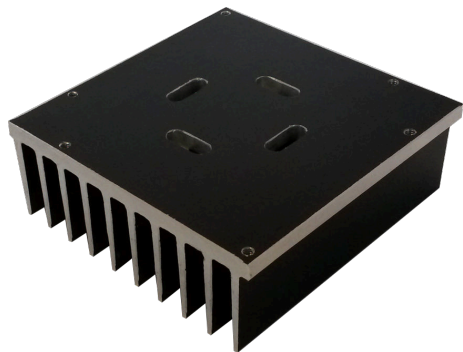


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Converter Cell Assembly

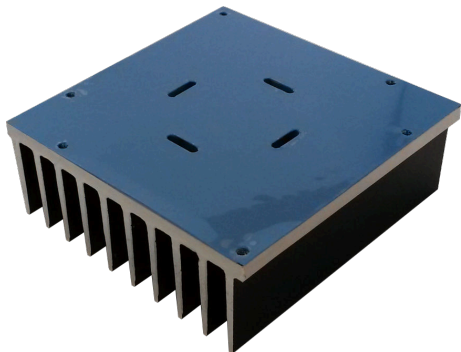
- ▶ PFC inductor (Thick)
- ▶ TIM
- ▶ Gate driver (thick)
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- ▶ Thermal Interface Material (TIM)
- ▶ Heatsink



- ▶ Board-to-board interconnects using wires soldered in through-holes
- ▶ Final cell dimensions: $7 \times 7 \times 3.5 \text{ cm}^3$

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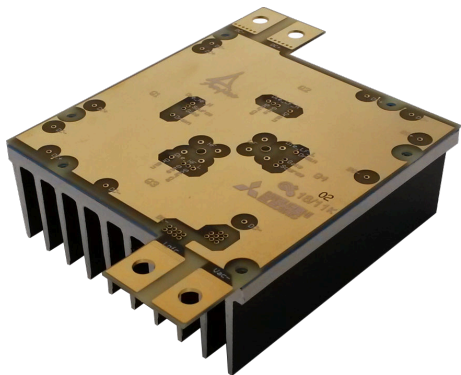
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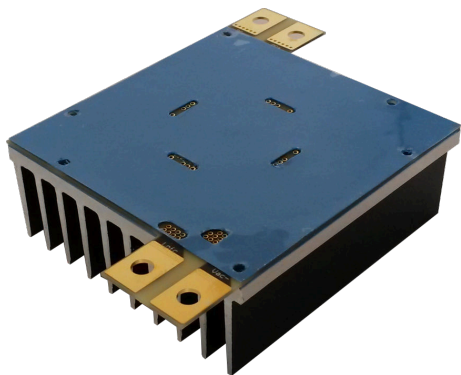
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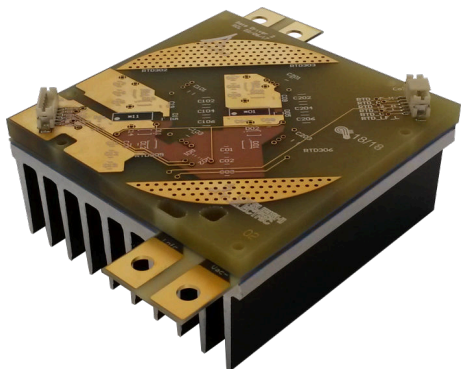
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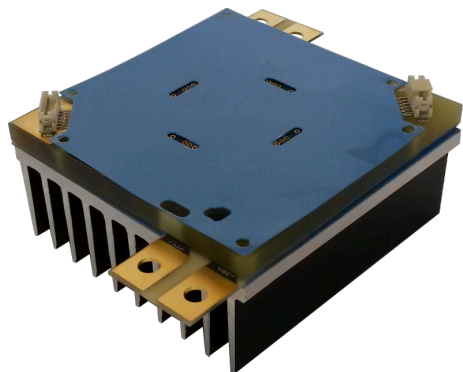
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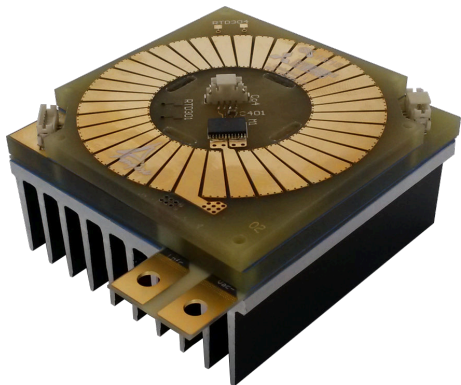
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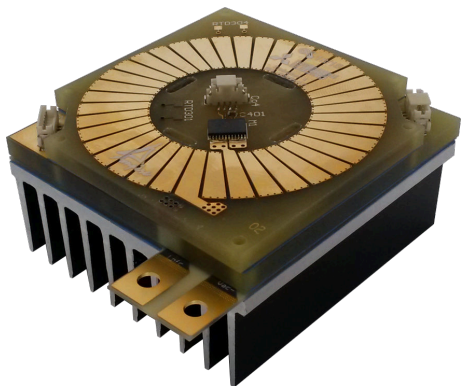
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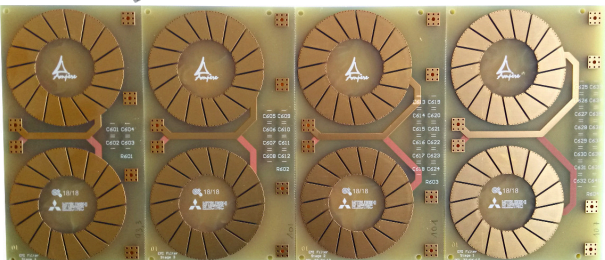
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Full converter assembly



- ▶ 4 PFC cells for a full converter
- ▶ DC capacitor bank for test only
- ▶ 4-stage EMC DM filter
- ▶ Very flat form factor
 - ▶ PFC: $28 \times 7 \times 5 \text{ cm}^3$
 - ▶ Filter: $28 \times 14 \times 0.4 \text{ cm}^3$



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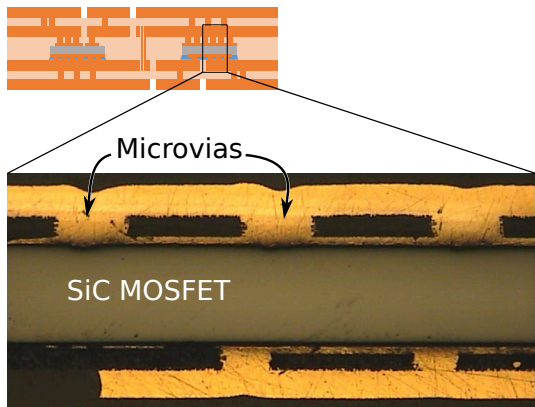
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Test Coupons – power devices

For SiC dies

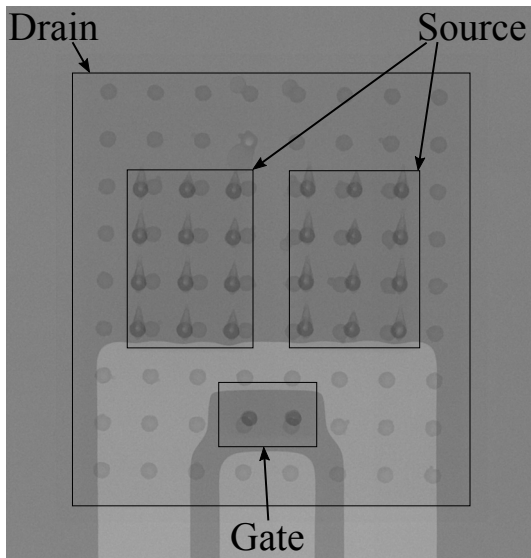
- ▶ good quality of microvias
 - ▶ No damage to dies
 - ▶ Uniform thickness
- ▶ Good alignment
 - ▶ Gate contacts
 - ▶ $500 \times 500 \mu\text{m}^2$
- ▶ Good electrical perf.
 - ▶ Consistent $R_{\text{DS(on)}}$ (80 mΩ)
 - ▶ No change in V_{GS}
 - ▶ Low leakage current (max 1.0 nA @ 1200 V)
 - ▶ Very good yield (97% on 44 dies)



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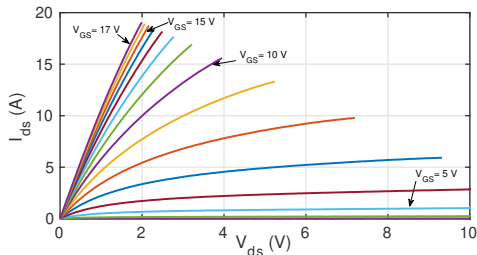
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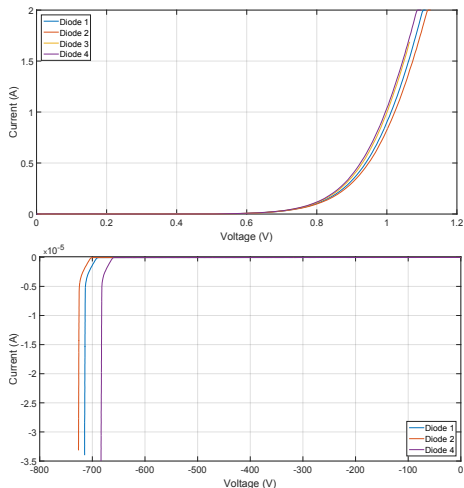
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Test Coupons–2



Example: 600V diodes for bootstrap driver

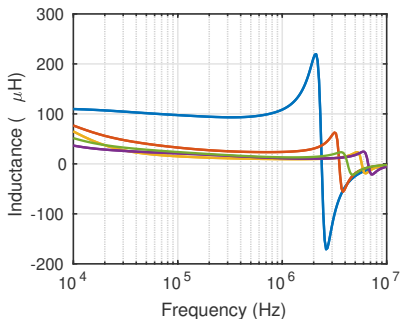
For SMD components:

- ▶ Test on:
 - ▶ Ceramic capacitors (3.3 μ F, 25 V up to 330 nF, 500 V)
 - ▶ Packaged diodes (4.7 V Zener up to 600 V rectifier)
- ▶ Characterization:
 - ▶ No failure detected

Embedded inductors

Large diffs in inductance values

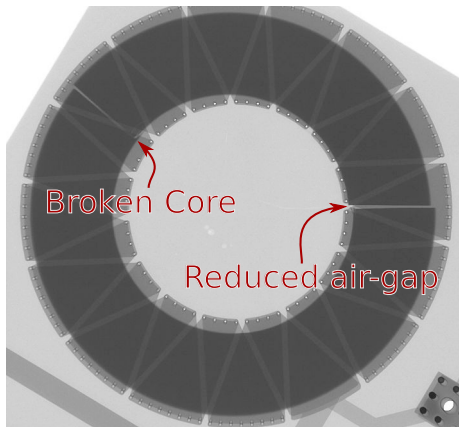
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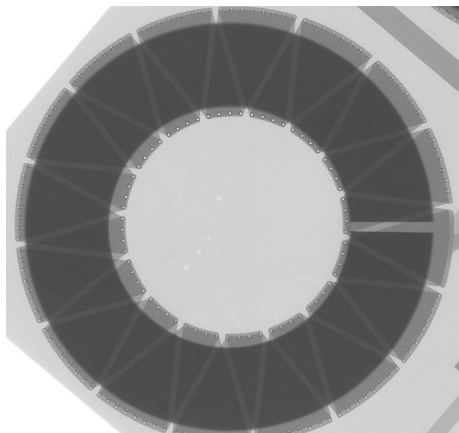
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Good perspectives on process

- ▶ Many cores intact
- ▶ Good cavity filling
- ▶ Reducing cavity size may improve yield and centering



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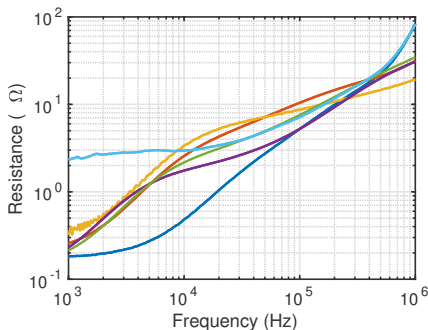
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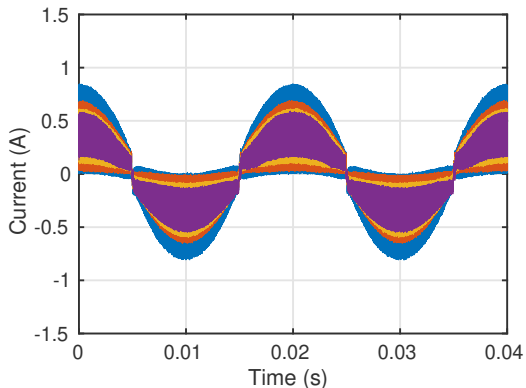
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Unexpected increase in resistance

- ▶ R_{AC} at 180 kHz is $10 \times R_{DC}$
- ▶ Analysis ongoing



Operation of the PFC converter



- ▶ 4 interleaved PFC cells (target power $4 \times 750 \text{ W} = 3 \text{ kW}$)
- ▶ Operation at reduced power because of losses in inductors
 - ▶ Current imbalance because of differences in inductor values

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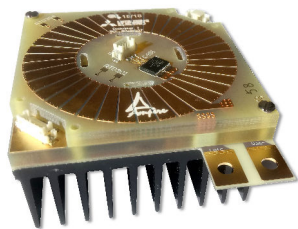
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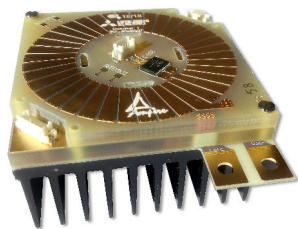
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- ▶ “All-embedded”, interleaved PFC designed
 - ▶ includes dies, driver, inductors
 - ▶ Very good production yield
 - ▶ Only issue: embedded inductors
- ▶ Full power tests ongoing
 - ▶ Tested at 400 V with planar inductors
 - ▶ Resistance increase in embedded inductor must be investigated
 - ▶ Thermal validation not yet complete
- ▶ Next step: better use of embedding
 - ▶ Keep some components on the surface
 - ▶ Improve design for manufacturing
 - ▶ Improve design tools



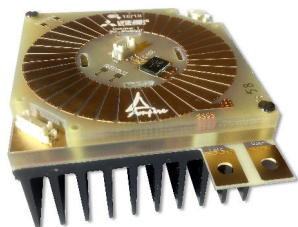
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 - ▶ Improve design for manufacturing
 - ▶ Improve design tools



Conclusions – Exploiting the PCB Embedding

- ▶ “All-embedded”, interleaved PFC designed
 - ▶ includes dies, driver, inductors
 - ▶ Very good production yield
 - ▶ Only issue: embedded inductors
- ▶ Full power tests ongoing
 - ▶ Tested at 400 V with planar inductors
 - ▶ Resistance increase in embedded inductor must be investigated
 - ▶ Thermal validation not yet complete.
- ▶ **Next step: better use of embedding**
 - ▶ **Keep some components on the surface**
 - ▶ **Improve design for manufacturing**
 - ▶ **Improve design tools**



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Thank you for your attention.

cyril.buttay@insa-lyon.fr

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