Evaluation of the PCB-embedding technology for a 3.3 kW converter

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24th of April, 2019

- Introduction
- Presentation of an embedded converter
- Technology Evaluation
- Operation of the PFC converter
- Conclusions

Outline

Introduction

Presentation of an embedded converter

Technology Evaluation

Operation of the PFC converter

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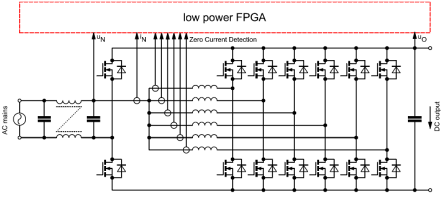
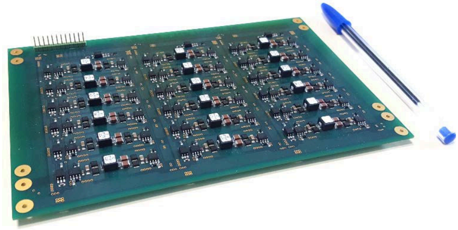
Power electronics – Areas for Progress



Source: Kolar et al. [1]



Source: Kerachev et al. [2]

- Excellent active devices are now available (SiC, GaN)
- Many topologies introduced over the years;
  - Recent changes: multi-cellular 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

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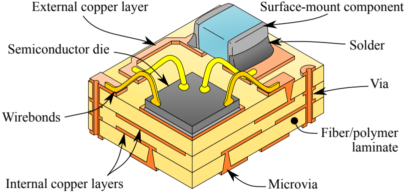
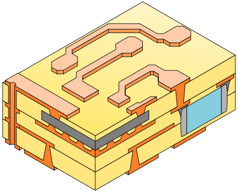
Why Embedding?

- 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
  - Take advantage of PCB design tools





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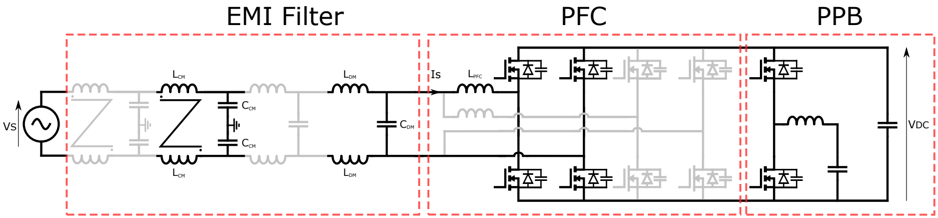
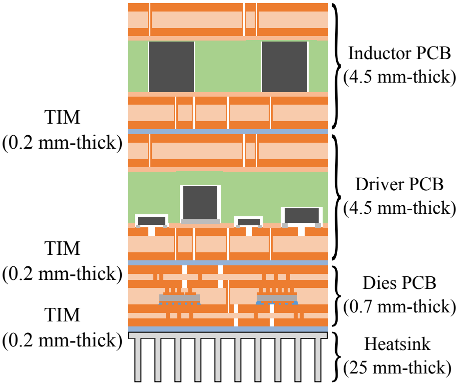
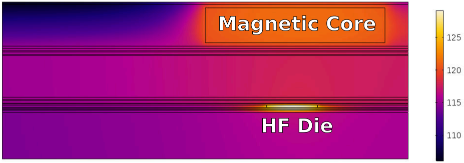
Converter topology



- Bidirectionnal, Power Factor Converter for 3.3 kW applications
- Designed through an optimization procedure [6, 7]
  - Based on SiC power devices
  - 180 kHz switching frequency
  - 4 interleaved cells
- Discussed here: PFC cell

Physical Structure





3-PCB structure

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

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Manufacturing of the PCBs

Two board structures are used:

Thin PBC (1 mm)
for bare dies

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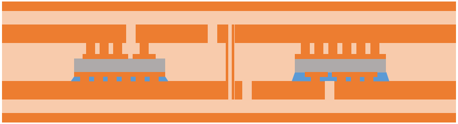

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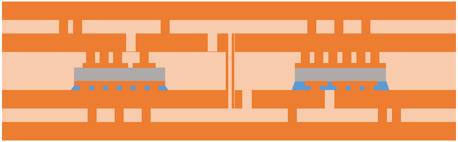

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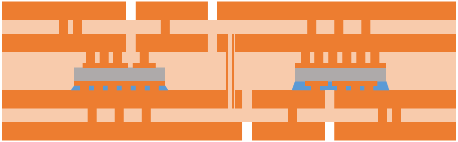

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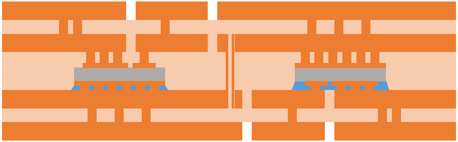

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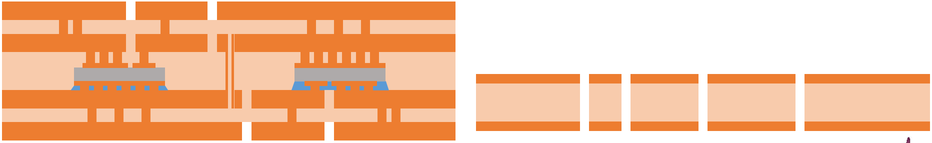

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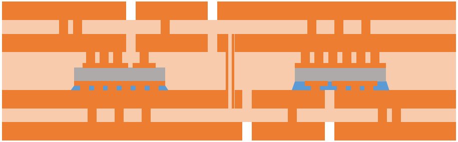

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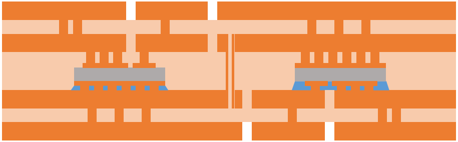

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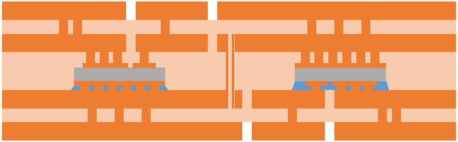

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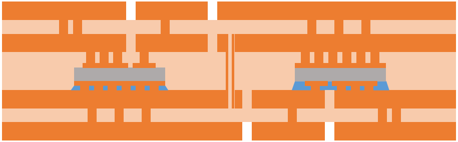

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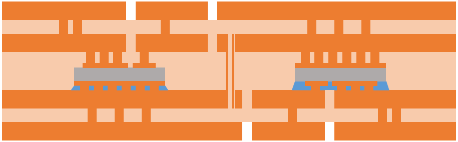

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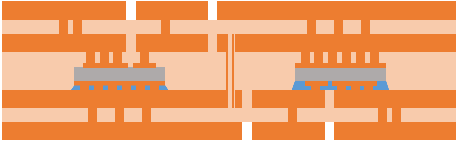

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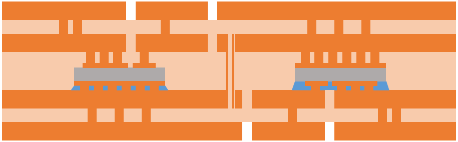

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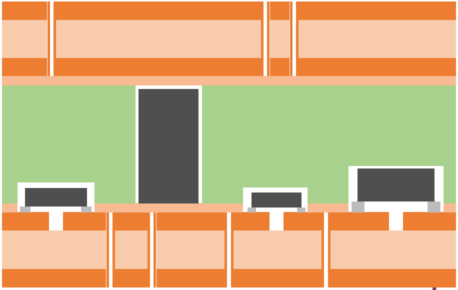

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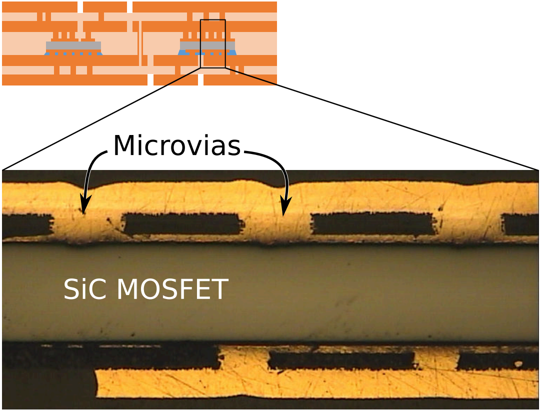
For SiC dies

- Good quality of microvias
  - No damage to dies
  - Uniform thickness
- Good alignment
  - Gate contact $500 \times 800\ \mu m^2$
- Good electrical perf.
  - No change in V_{th}
  - Low leakage current (max 1.6 nA @ 1200 V)
  - Very good yield (97% on 44 dies)
  - Consistent $R_{DS_{on}}$ (80 mΩ)



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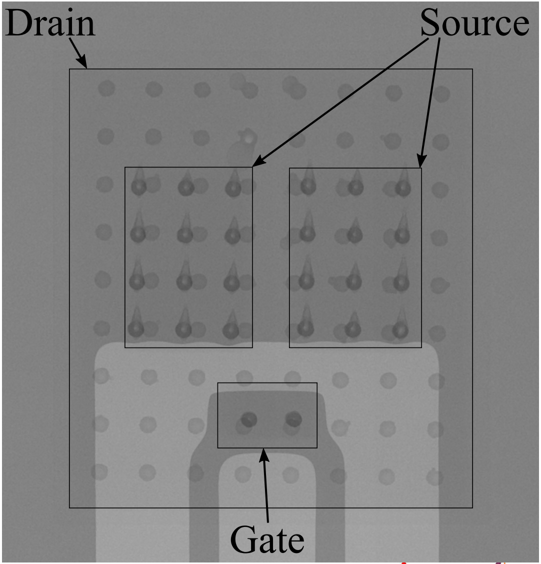

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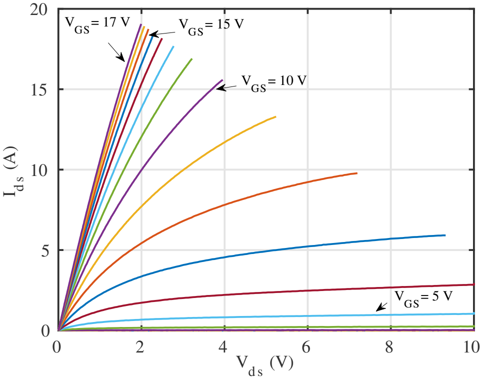

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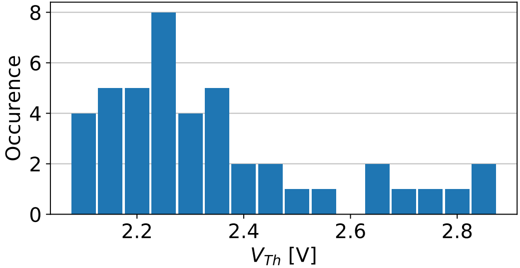

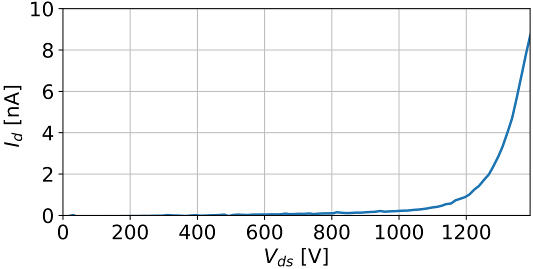

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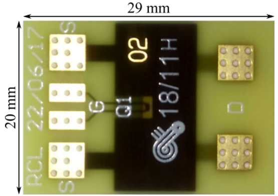
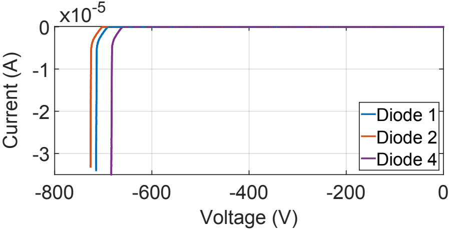
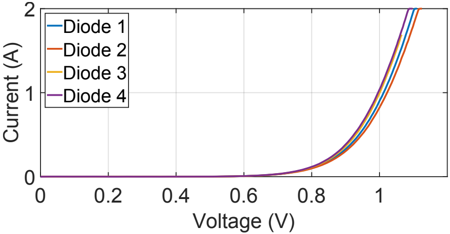


Coupon	$R_{DS_{on}}$
#1	88.7 mΩ
#2	77.9 mΩ
#3	82.2 mΩ
#4	83.3 mΩ
#5	86.3 mΩ
#6	89.1 mΩ
#7	88.9 mΩ
#8	84.2 mΩ

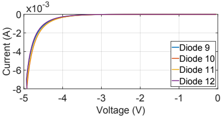
Test Coupons – SMD Diodes

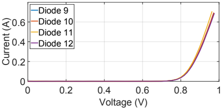


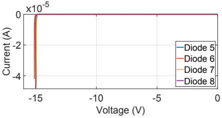


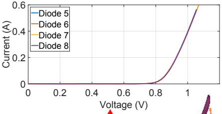
Test on packaged diodes:

- 600 V, 1 A diode for bootstrap supply rectifier, SMF case
- 4.7 V and 15 V zener diodes for voltage regulation, SOD123 case
- No failure detected









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Test Coupons – SMD Capacitors

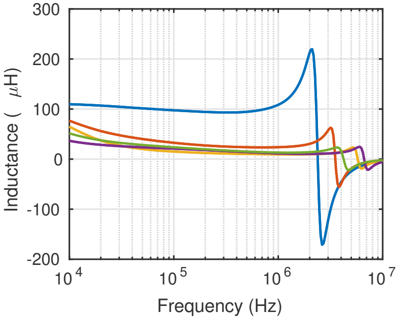
Ceramic capacitors :

- 330 nF, 500 V, X7R, 1812 case (decoupling)
- 56 pF, 500 V, C0G, 1206 case (increase C_{oss})
- Leakage current used as indicator of health (would increase with cracks)

Capacitor type	**Leakage current** (@500 V)	
330 nF non embedded (ref)	107.0	nA
330 nF embedded (#1)	83.0	nA
330 nF embedded (#2)	96.0	nA
330 nF embedded (#3)	106.0	nA
56 pF non embedded (ref)	1.02	nA
56 pF embedded (#1)	2.64	nA
56 pF embedded (#2)	0.81	nA
56 pF embedded (#3)	0.86	nA

Large diffs in inductance values

- Some cores broken (3/8)
- No clear correlation between elec. behav. and core condition



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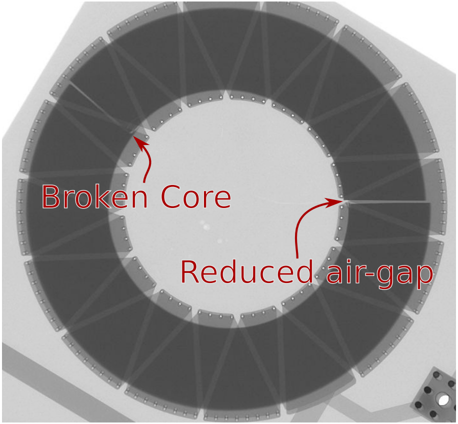

Embedded inductors

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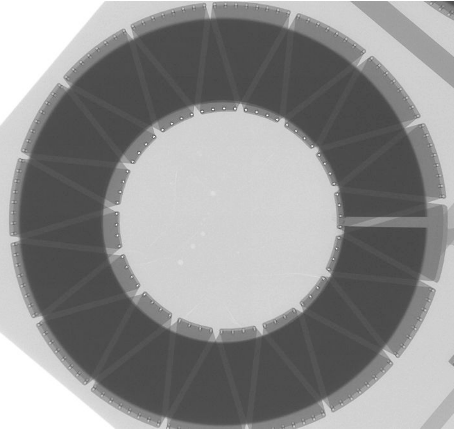
Good perspectives on process

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



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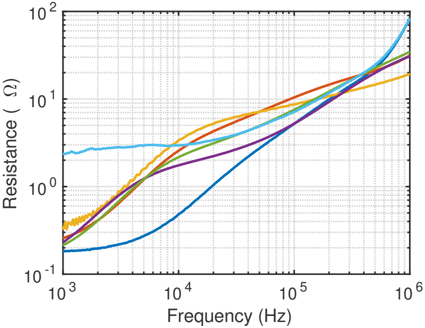
Unexpected increase in resistance

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



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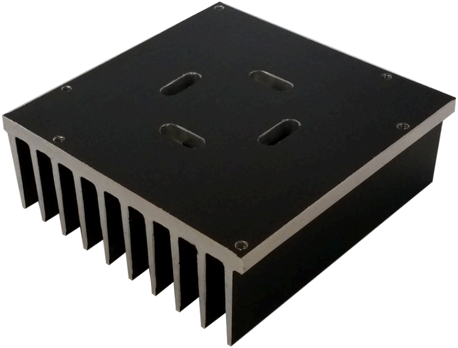
- PFC inductor (Thick)
- TIM
- Gate driver (thick)
- TIM
- Power devices PCB (thin)
- Thermal Interface Material (TIM)
- Heatsink



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

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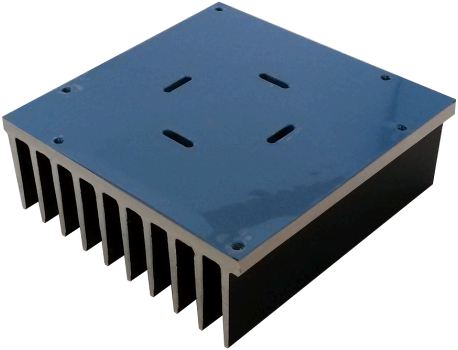

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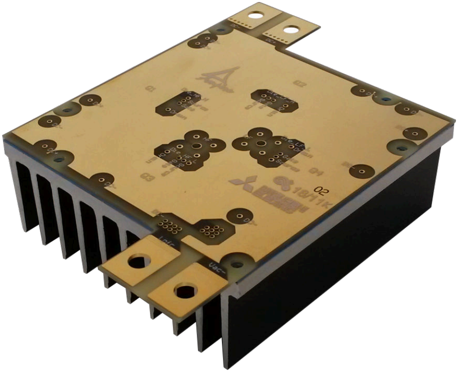

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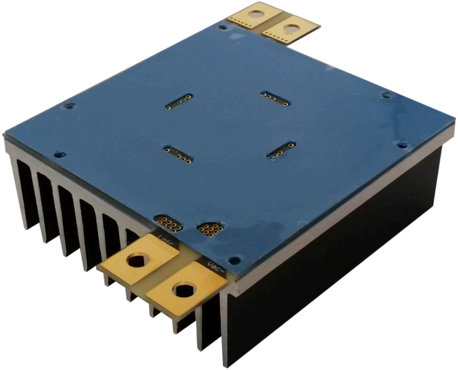

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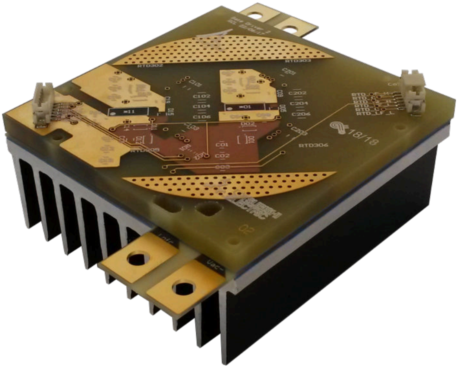

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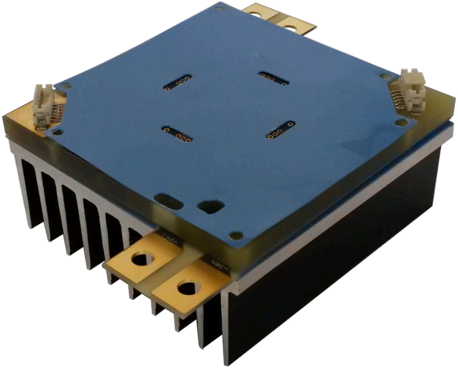

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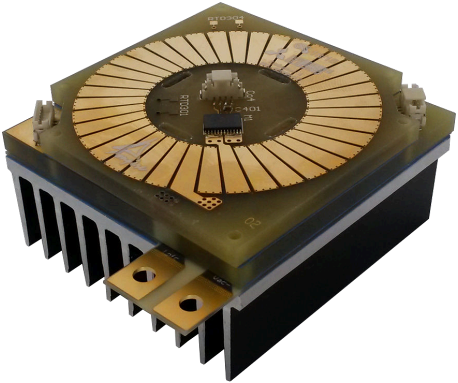

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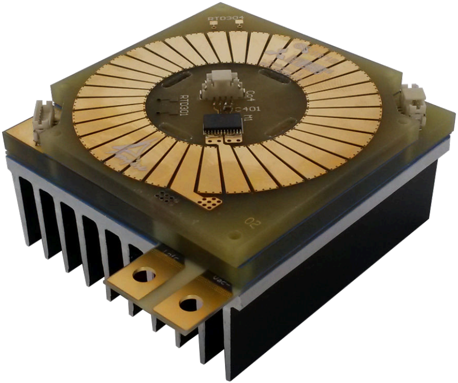

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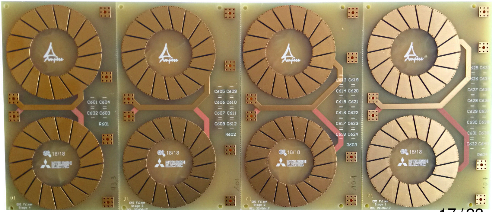
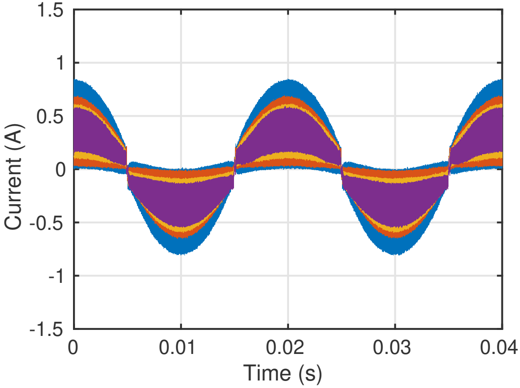
Full converter assembly

- 4 PFC cells for a full converter
- DC capacitor bank for test only
- 4-stage EMC DM filter
- PFC: 28x7x5 cm^3
- DM filter: 28x14x0.5 cm^3



Operation of the PFC converter



- 4 interleaved PFC cells (target power 4×825 W=3.3 kW)
- Operation at reduced power because of losses in inductors
  - Current unbalance because of differences in inductor values

Introduction

Presentation of an embedded converter

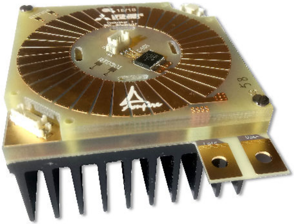
Technology Evaluation

Operation of the PFC converter

Conclusions

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 higher power with planar inductors
  - Frequency behavior of embedded inductor under investigation
- Next step: better use of embedding
  - Keep some components on the surface
  - Improve design for manufacturing
  - Improve design tools



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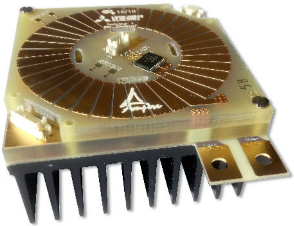

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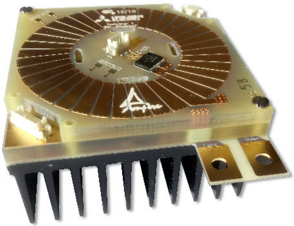

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Thank you for your attention.

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