Application of the PCB-Embedding Technology to a 3.3 kW Power Factor Corrector

APEC 2019, Anaheim, California

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19 – 21 March 2019

Outline

Introduction

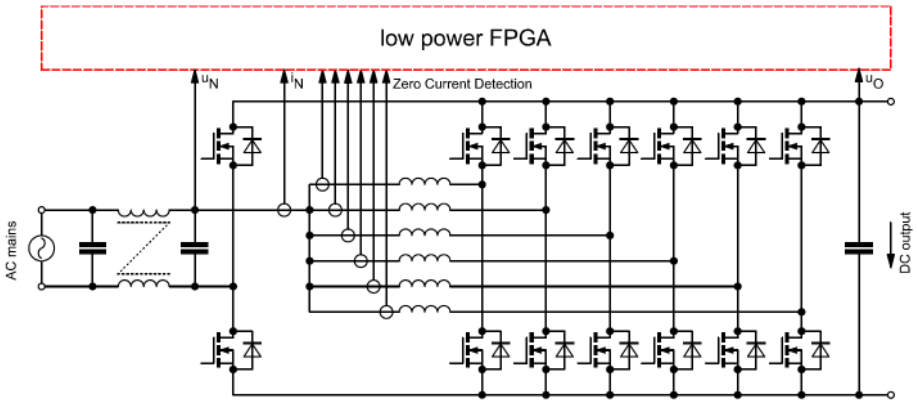
PCB Embedding Technology – A Review

Presentation of an embedded converter

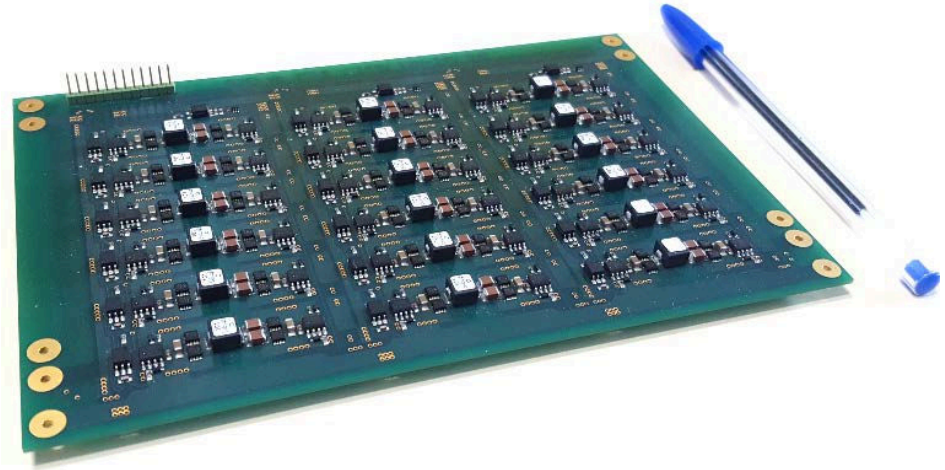
Conclusions

Outline

Power electronics – Areas for Progress



Source: Kolar et al. [1]

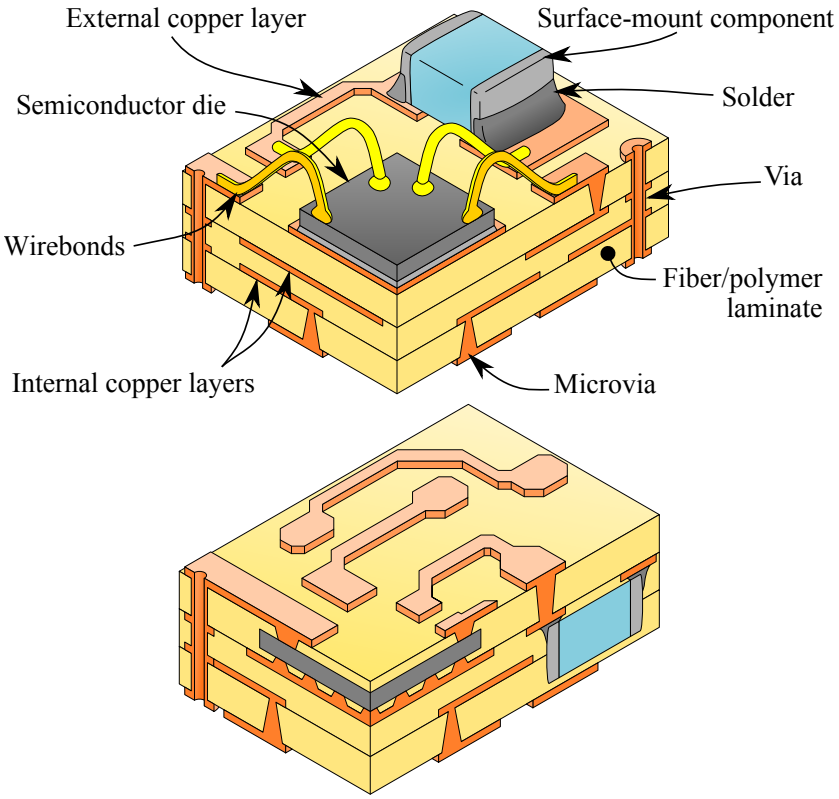


Source: Kerachev et al. [2]

- 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

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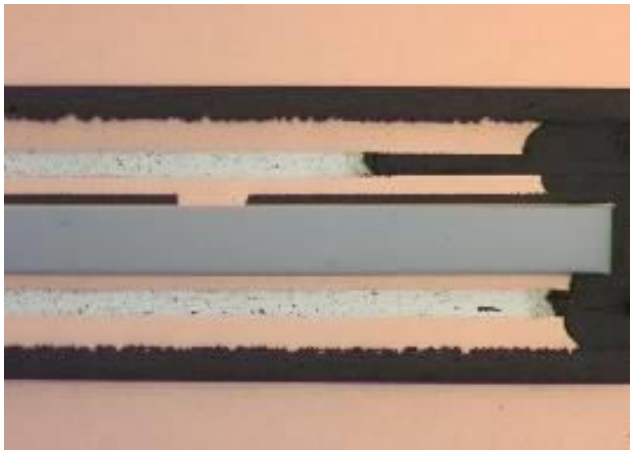
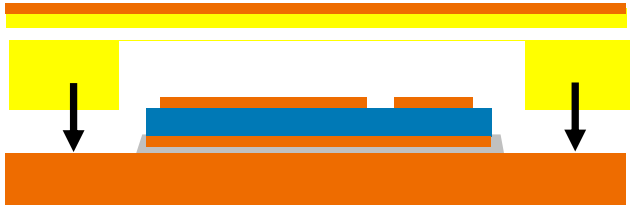


conductive chip attach



embedding by lamination

via drilling top, through-via

Cu plating and structuring

Left and above, source: Ostmann [6]

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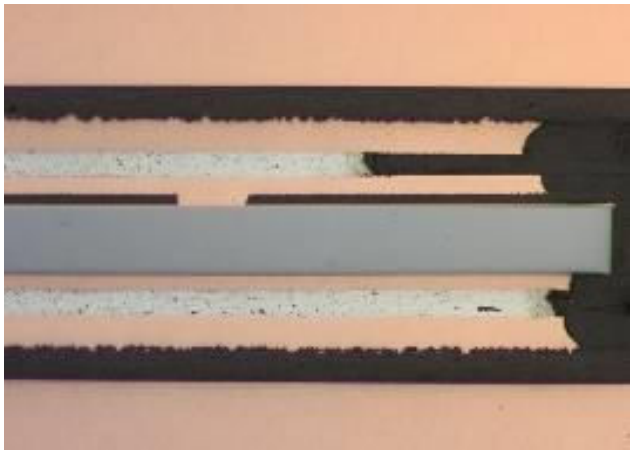

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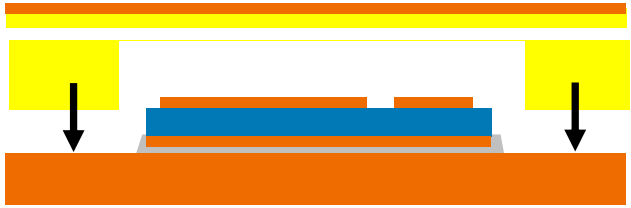

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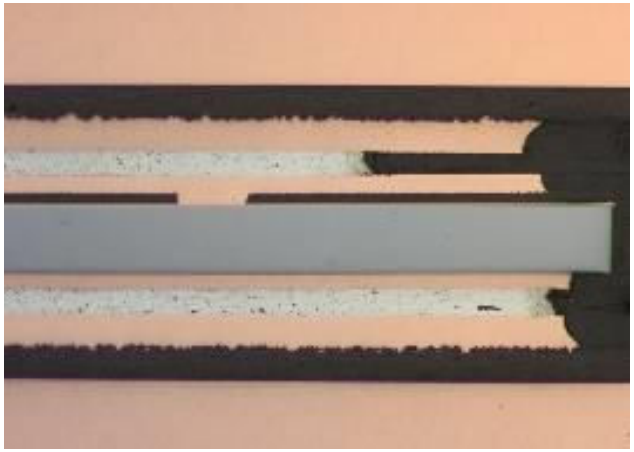

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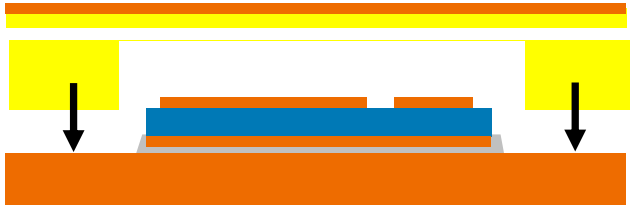

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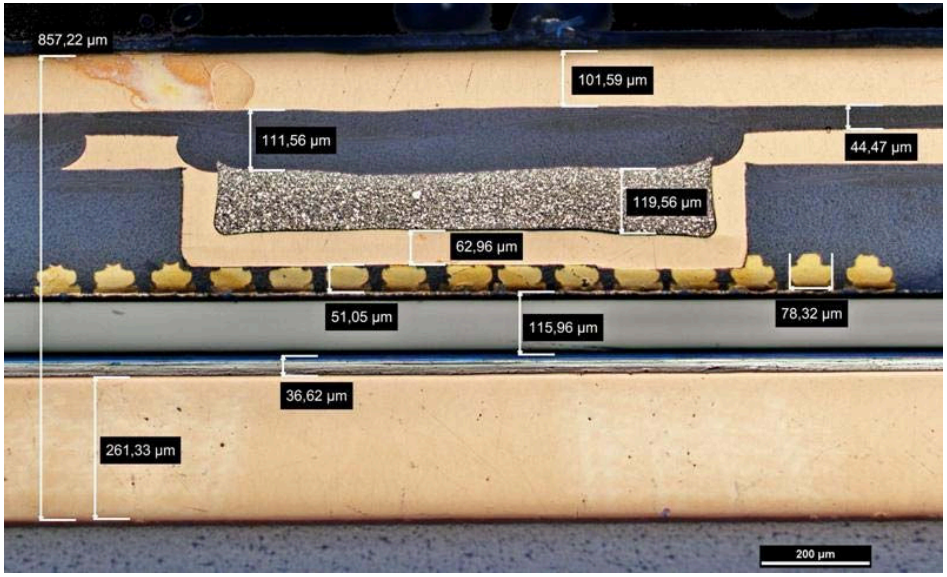
Embedding of Power Dies – 2

Some alternative techniques

- Stud bumps and machining
- Foam interposer
- Mechanical drilling



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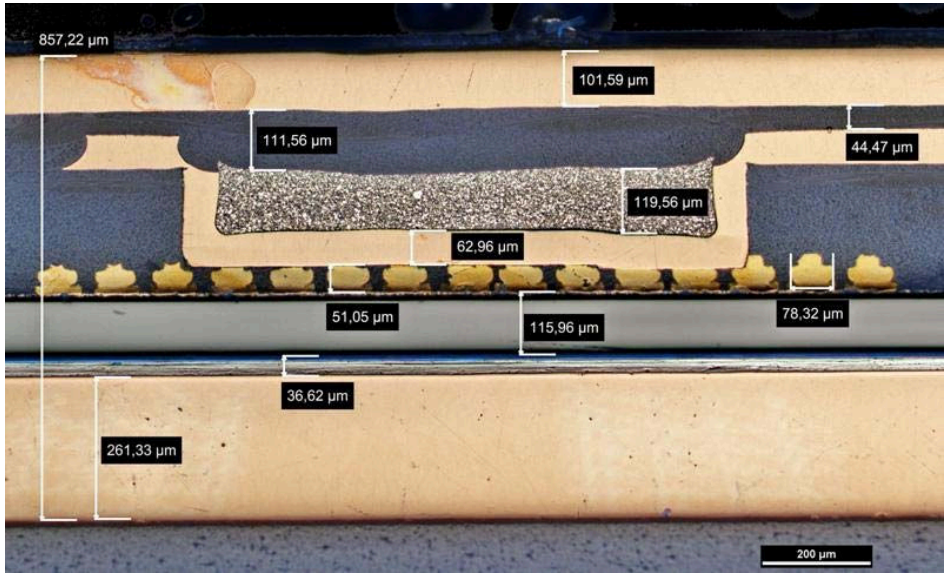

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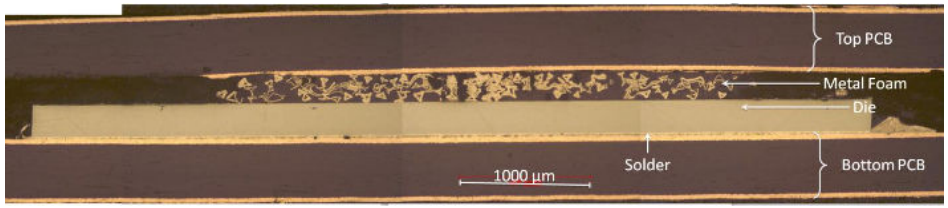

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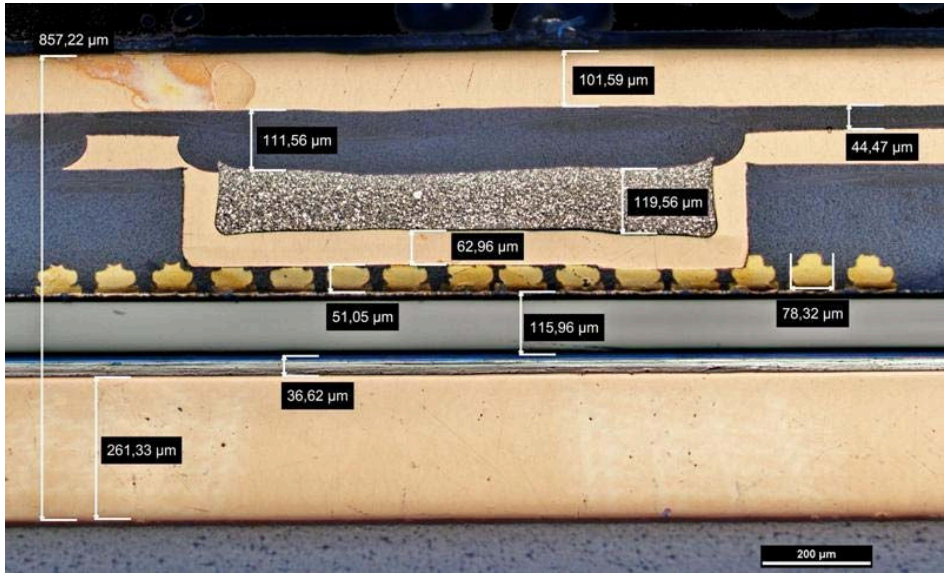

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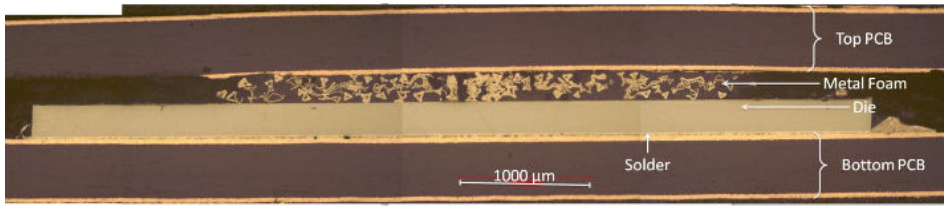

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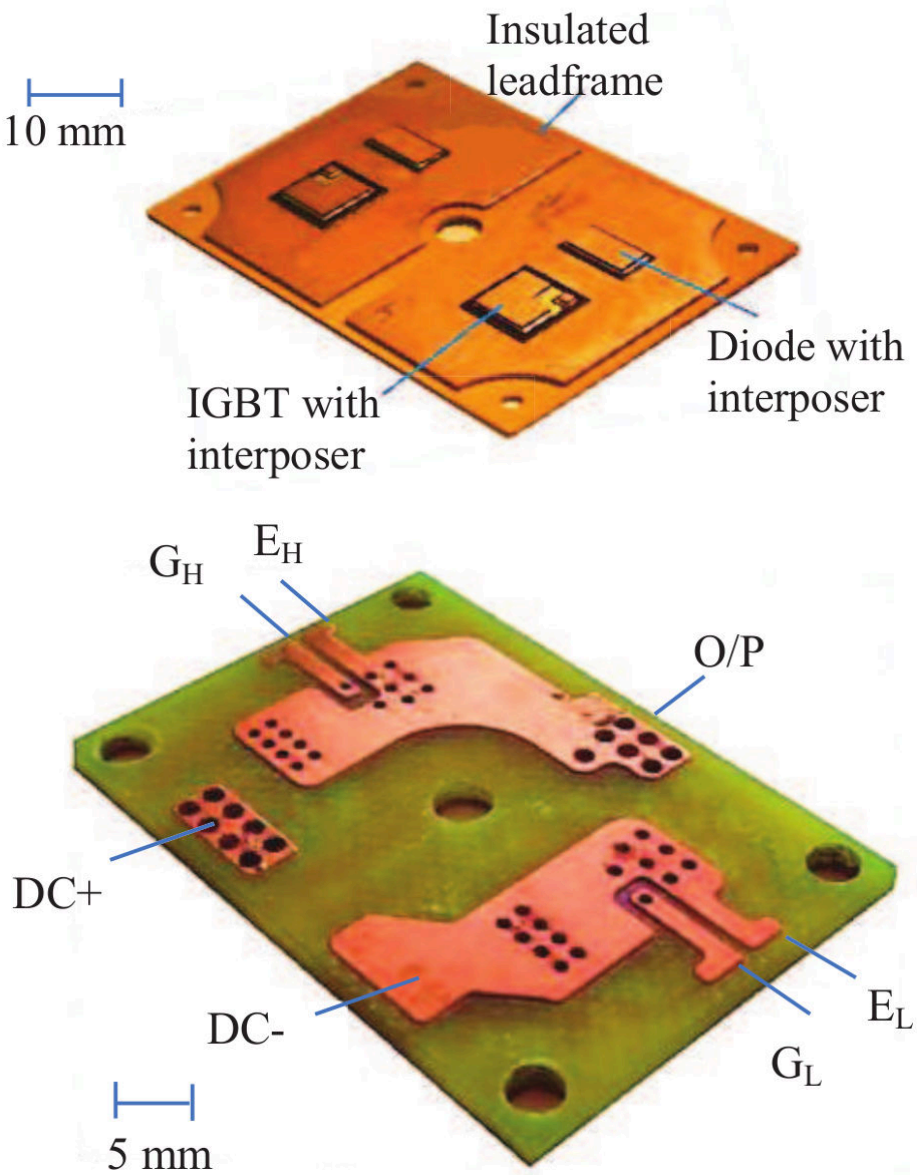
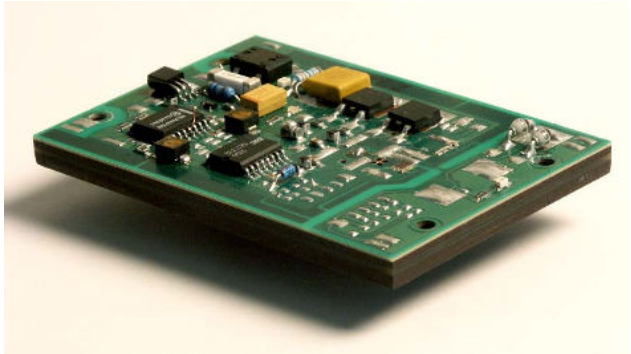


Source: Sharma et al. [9]

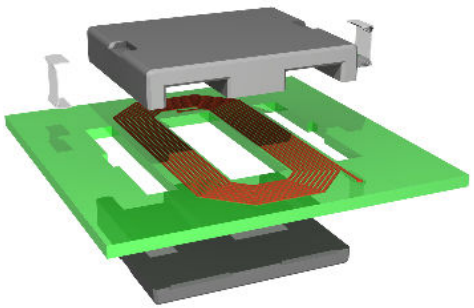
Embedding of Formed Components – Inductors

Magnetic Layer

- Relies on magnetic/polymer film ➜ Low μ_r
- Limited to 10 – 100 W



Source: Waffenschmidt et al. [10]

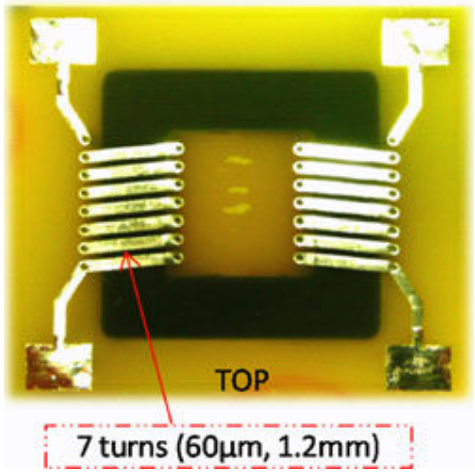


Planar magnetic components

- 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. [11]

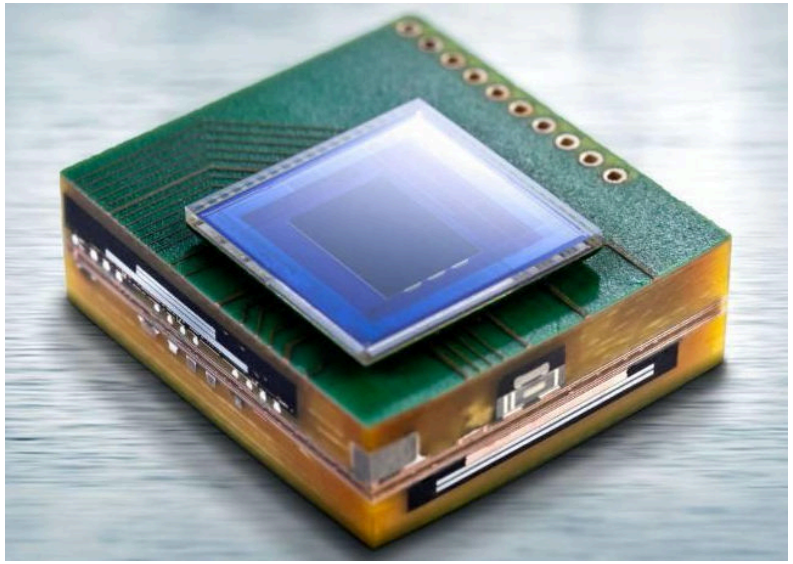
Embedding of Inserted Components

Soldered components:

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

Vias to components:

- Requires components with Cu finish
- More compact (vias on components)



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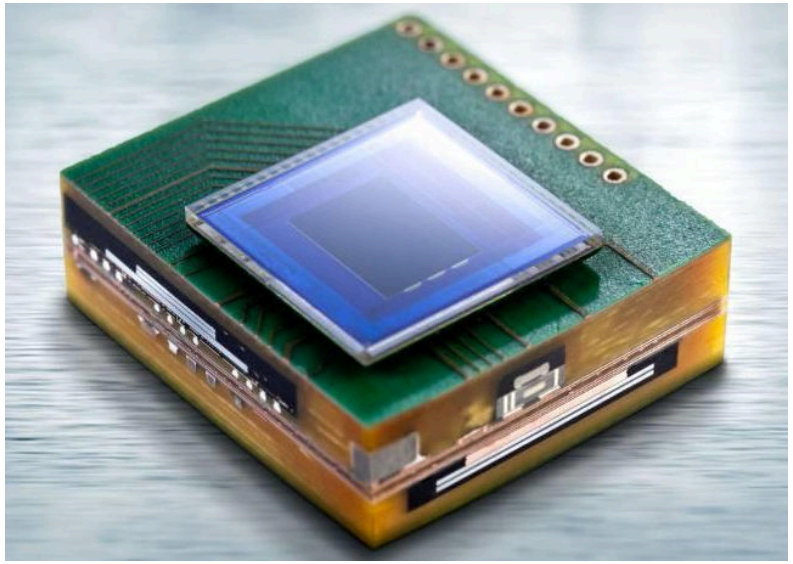

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For power electronics

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

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Thermal Management of Embedded Components

- Poor thermal conductivity of FR4 compared to ceramics (1–7 $\mathrm{W\,m^{-1}\,K^{-1}}$ vs 150 $\mathrm{W\,m^{-1}\,K^{-1}}$ for AlN)
- In theory better breakdown field ($\approx 50\,\mathrm{kV\,mm^{-1}}$ vs. $20\,\mathrm{kV\,mm^{-1}}$)

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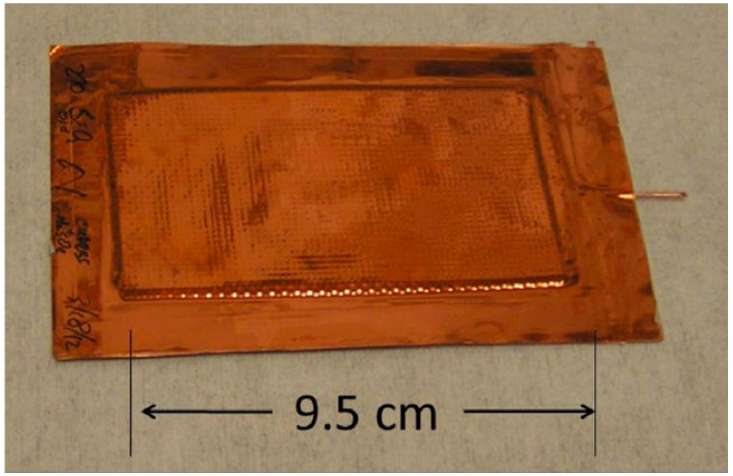
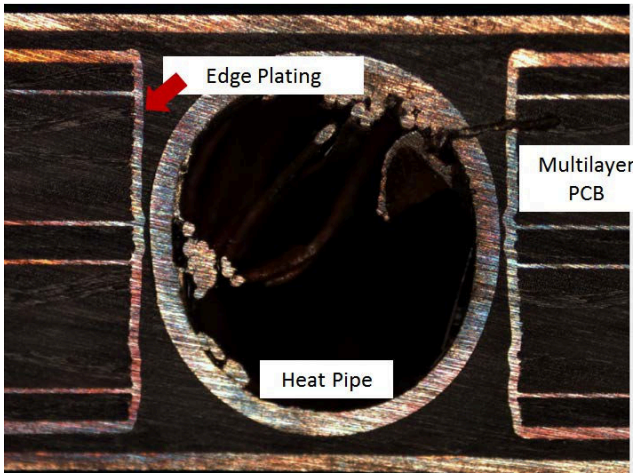
To increase in-plane heat conduction:

- Thicker copper, Anisotropic layers (Graphite), Dual-phase





Source: left: Liew et al. [12]; right: Silvano et al. [13]

Reliability of PCB with Embedded Components

- Temperature-related issues
  - Rapid degradation above 190 °C
  - Hydrocarbon, polyimide-based PCBs resistant up to 250 °C
- Thermal cycling issues
  - CTE of PCBs much higher than ceramic or semiconductor
  - Availability of low-CTE materials
  - ➜ lacks data on large components
- Other PCB-specific issues
  - moisture absorption,
  - conductive anodic filaments, ...

➜ No showstopper identified yet!

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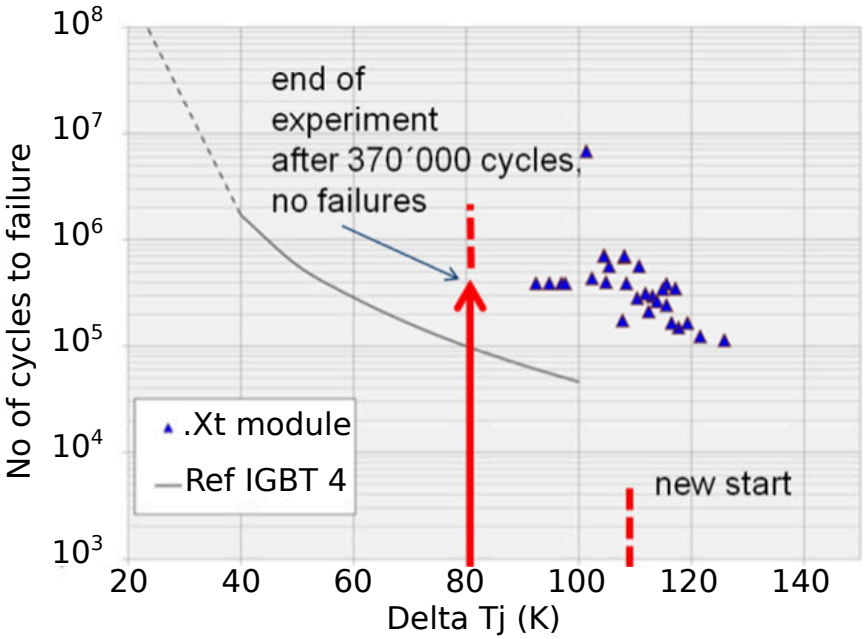

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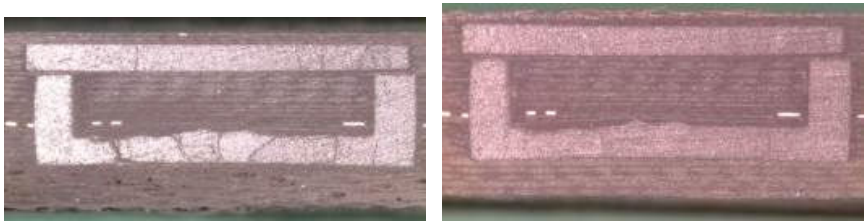

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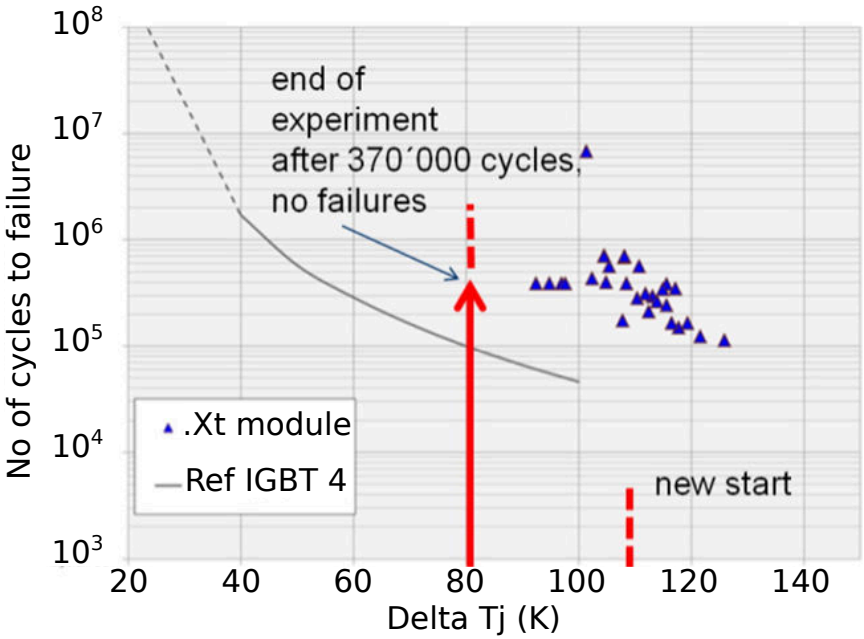

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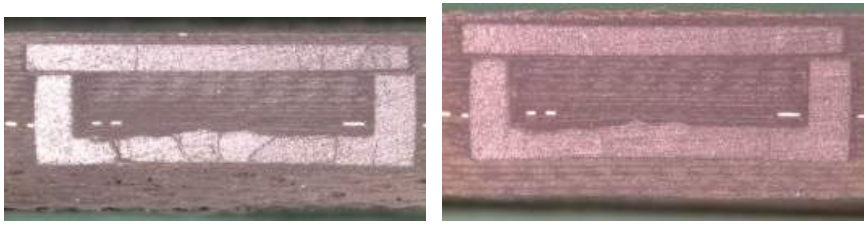

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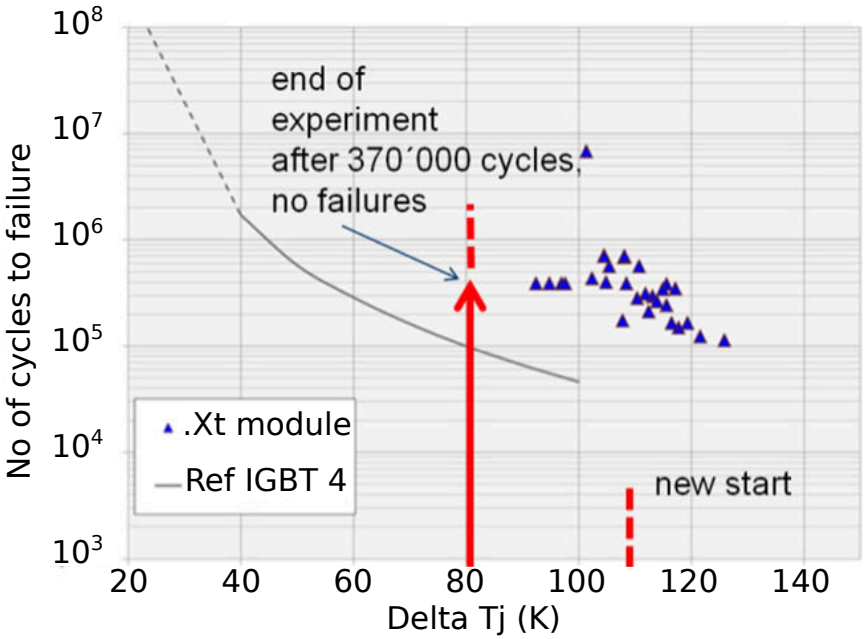

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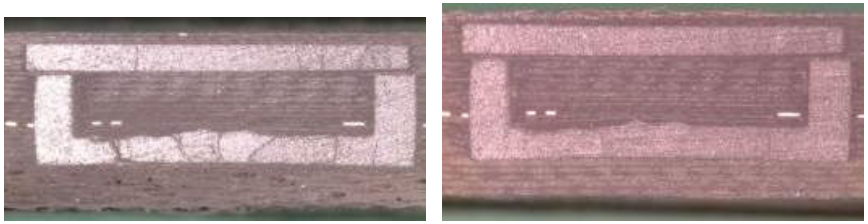

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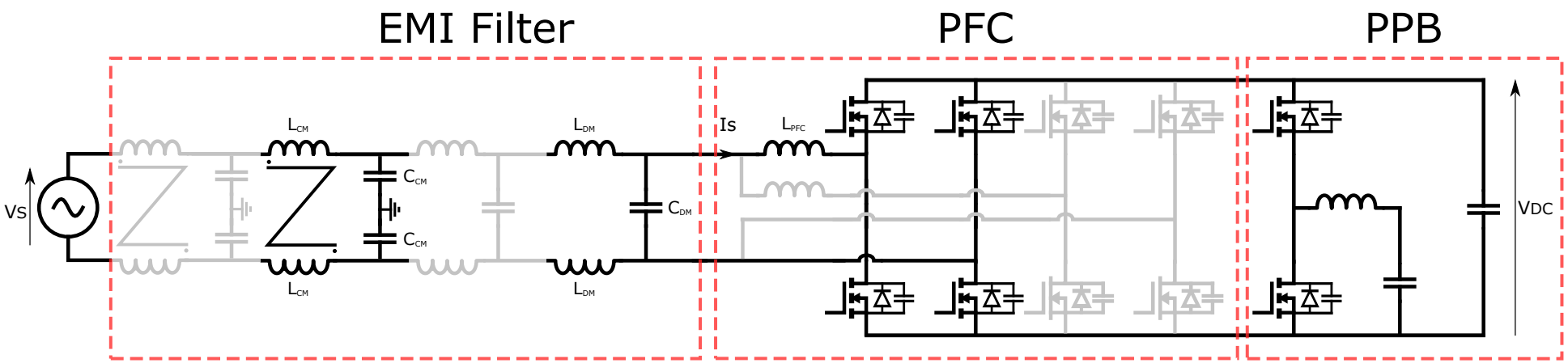
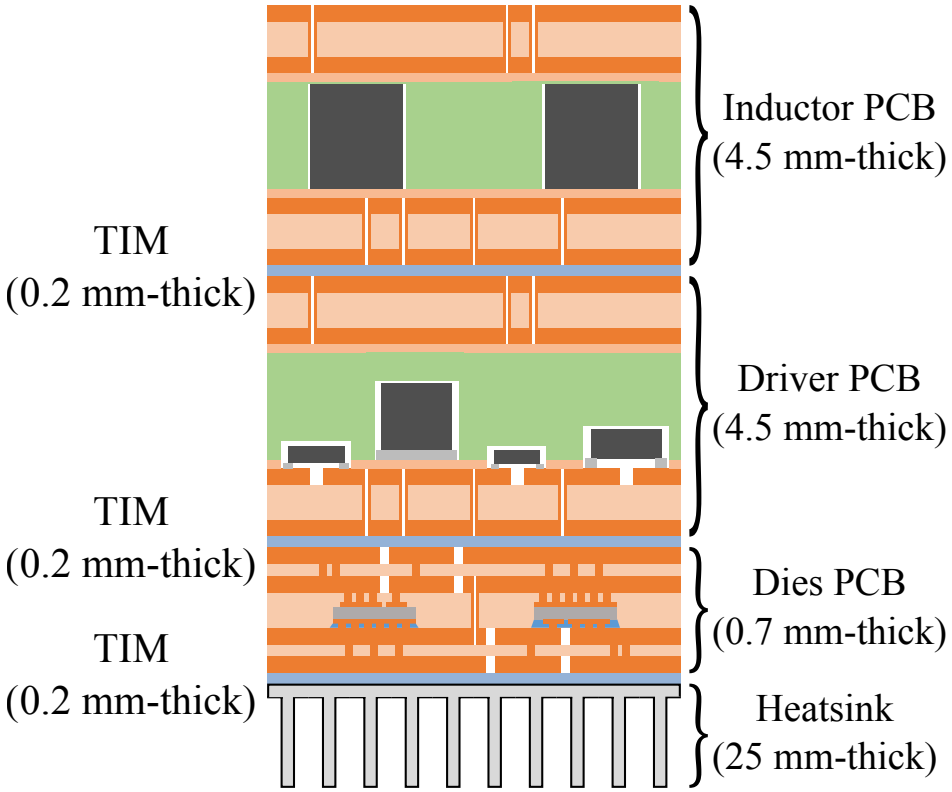
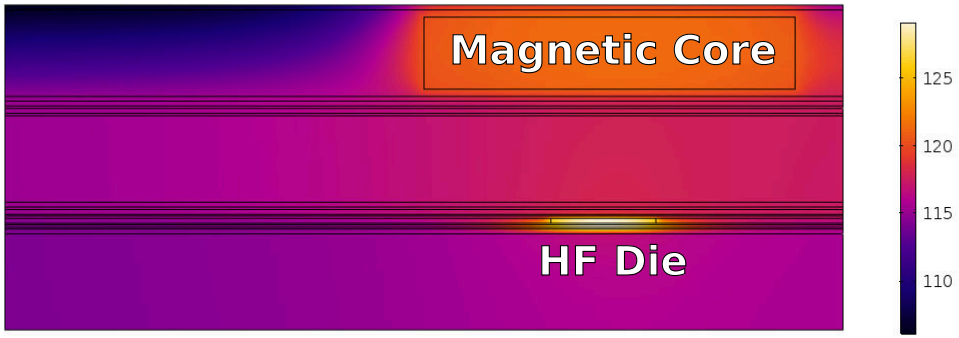
Converter topology



- Bidirectionnal, Power Factor Converter for 3.3 kW applications
- Designed through an optimization procedure [16, 17]
  - 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

Manufacturing of the PCBs

Two board structures are used:

Thin PBC (1 mm)
for bare dies

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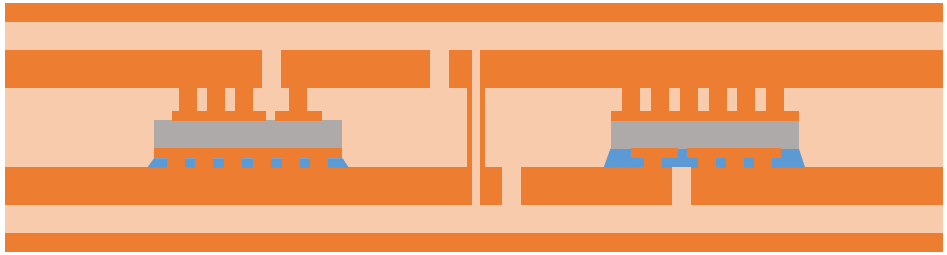

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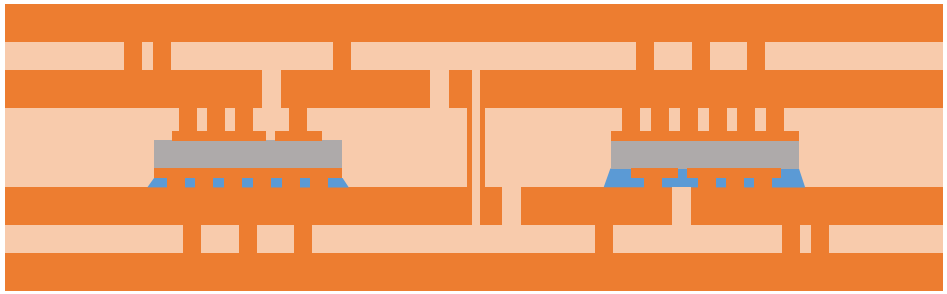

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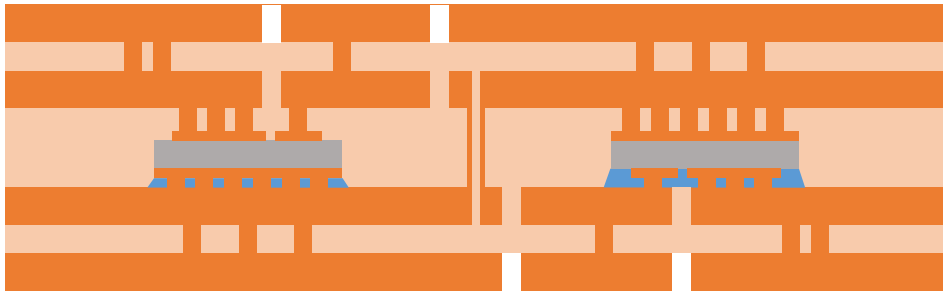

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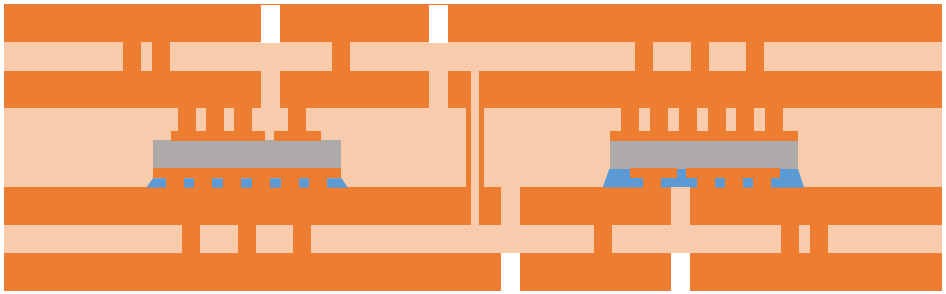

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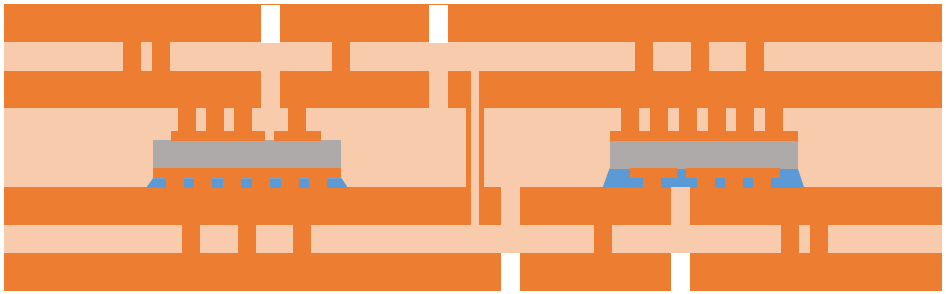

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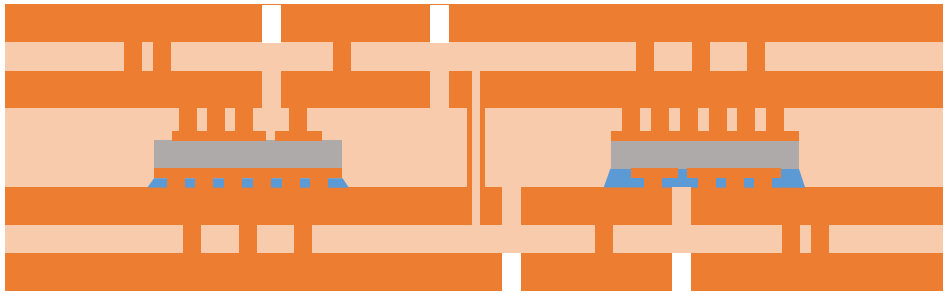

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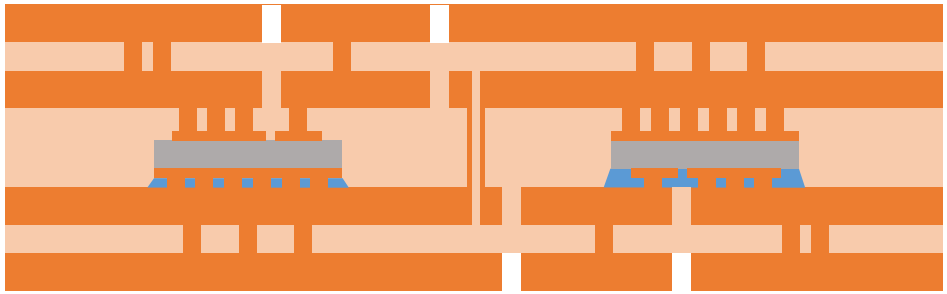

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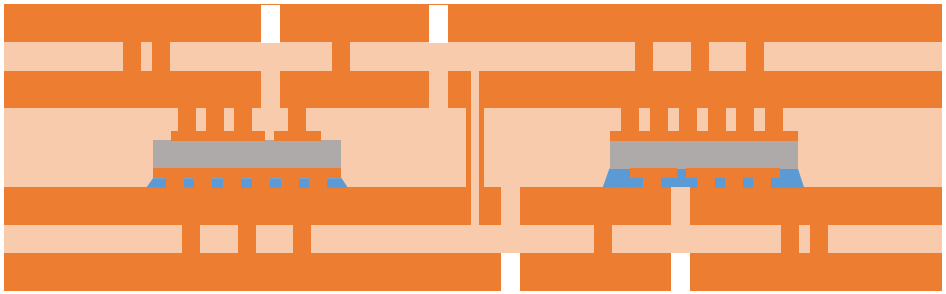

Manufacturing of the PCBs

Two board structures are used:

Thin PBC (1 mm)
for bare dies

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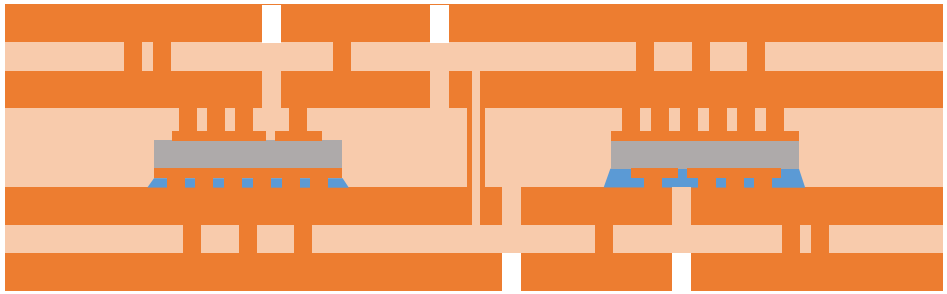

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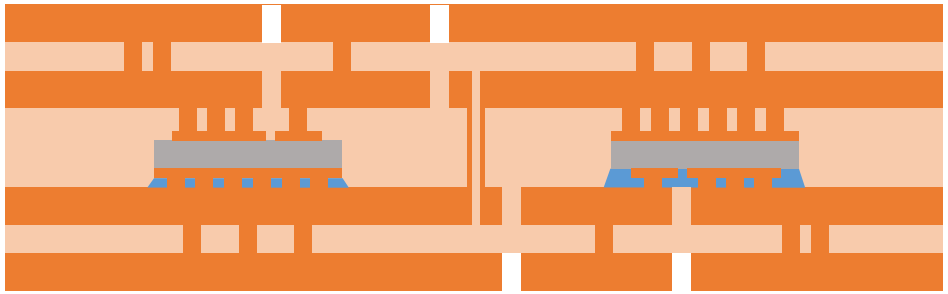

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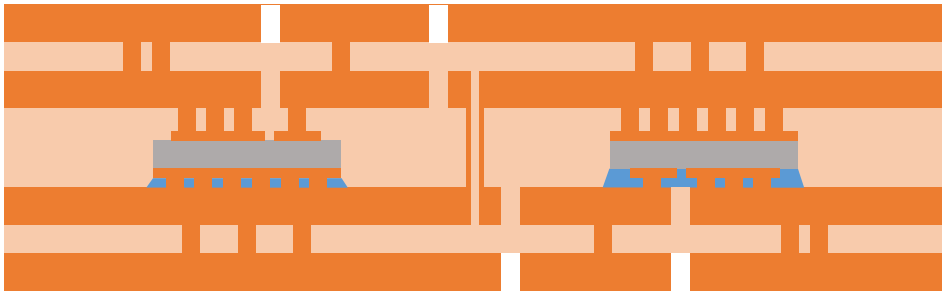

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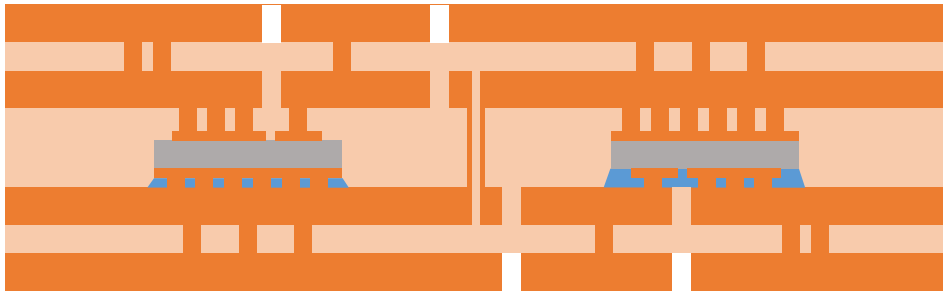

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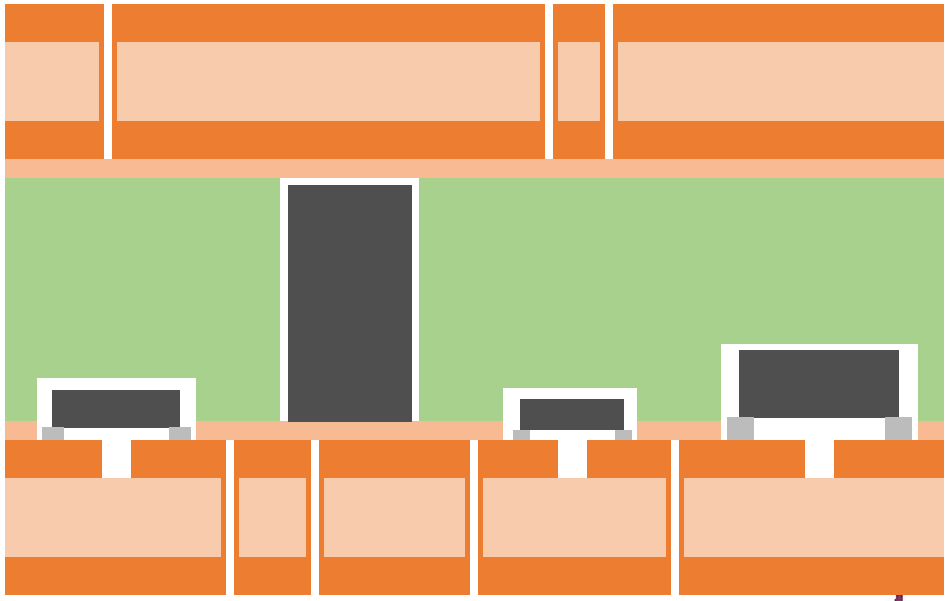
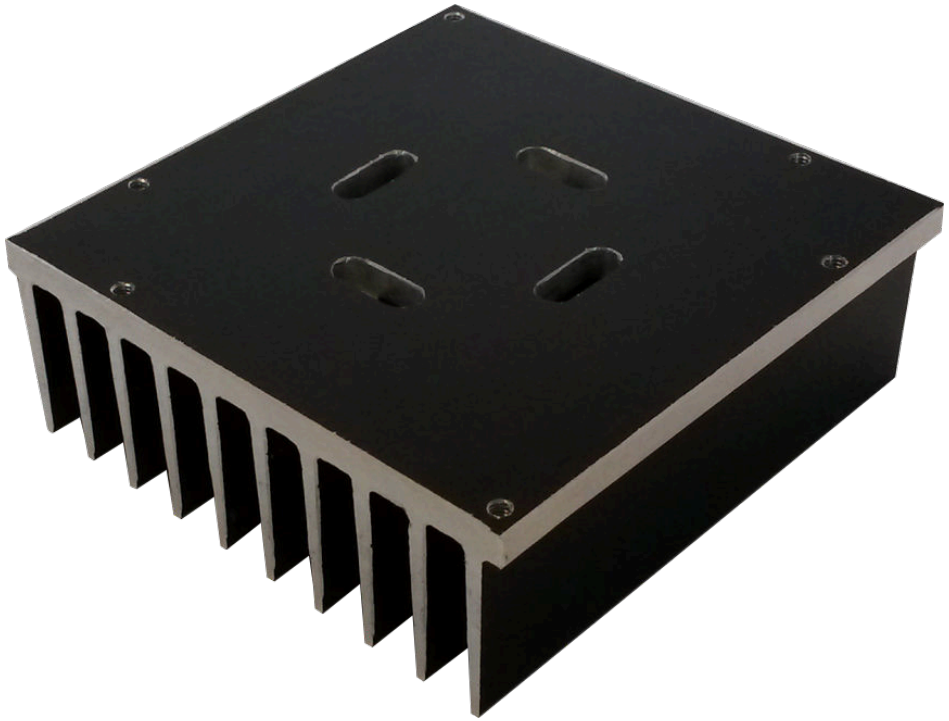


Converter Cell Assembly

- 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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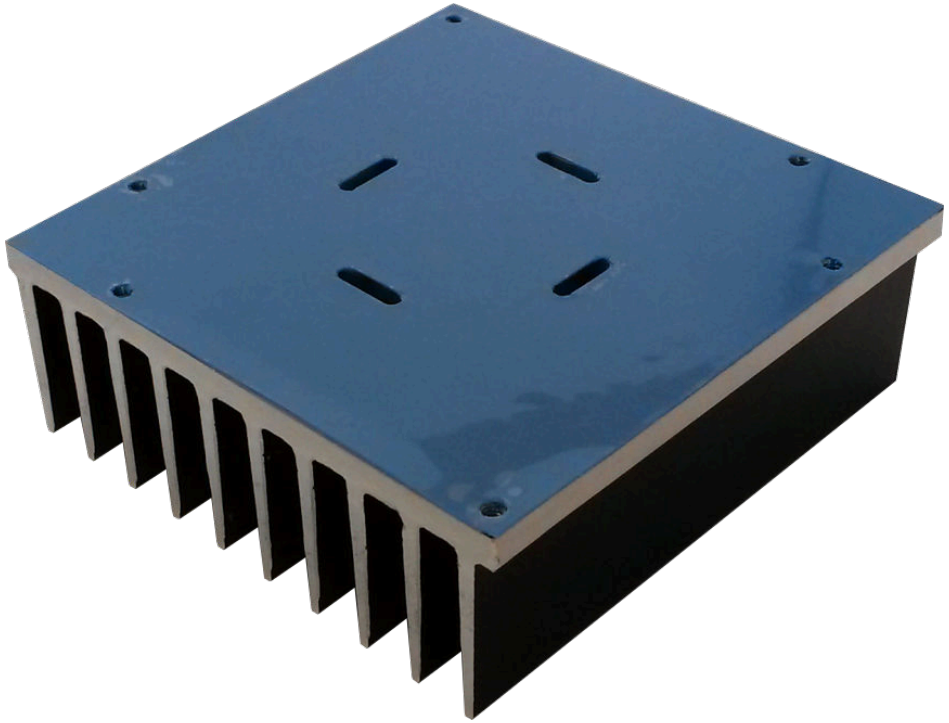

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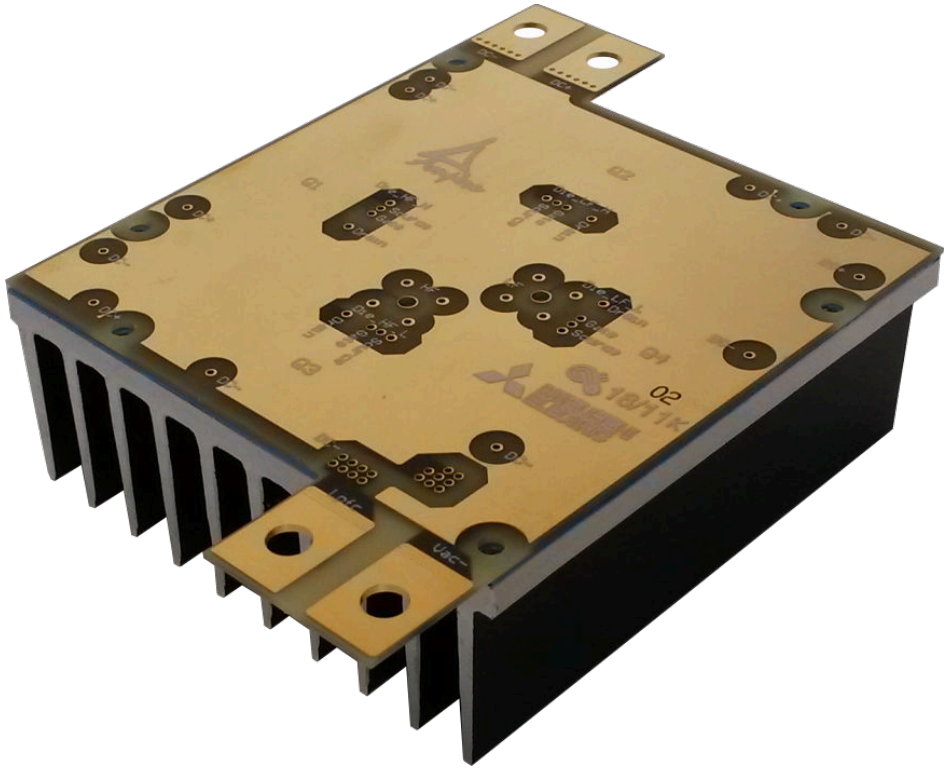

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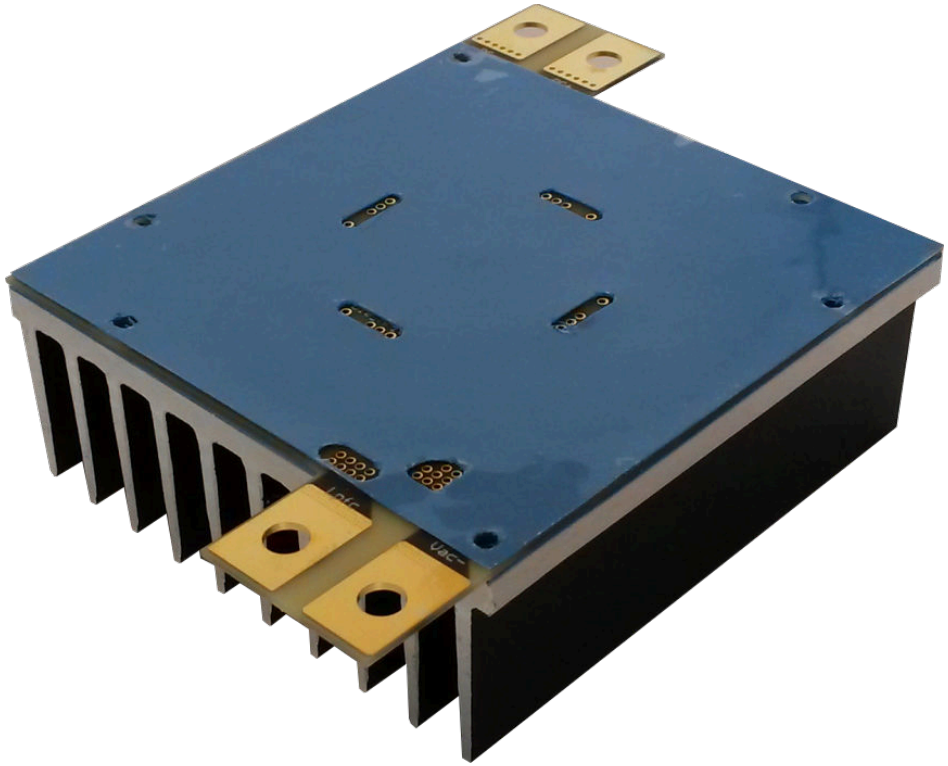

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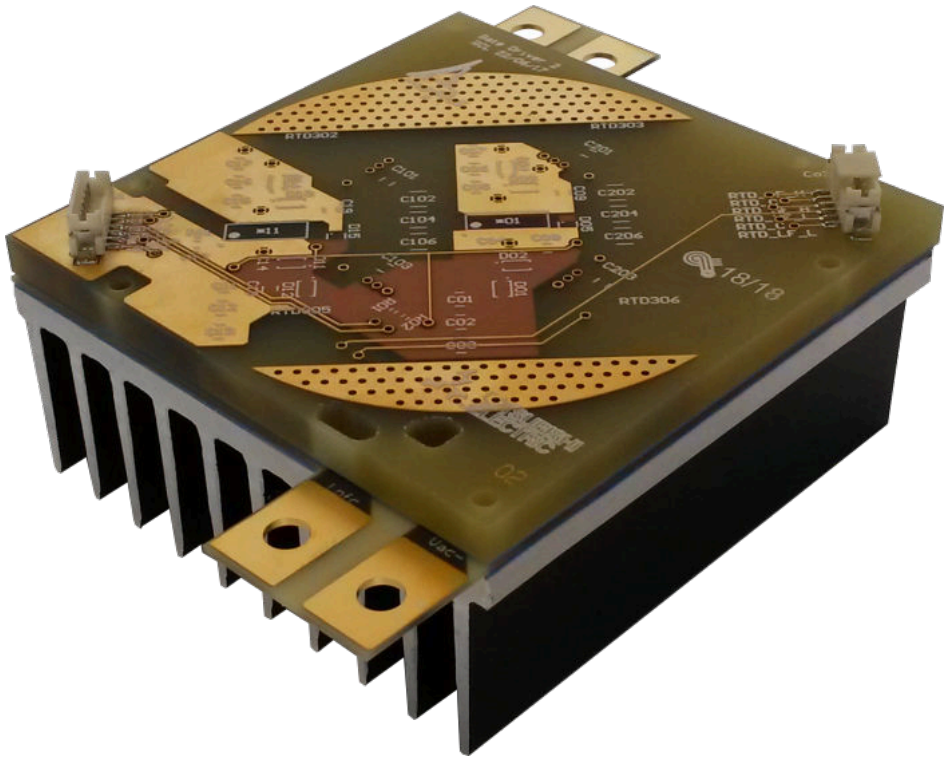

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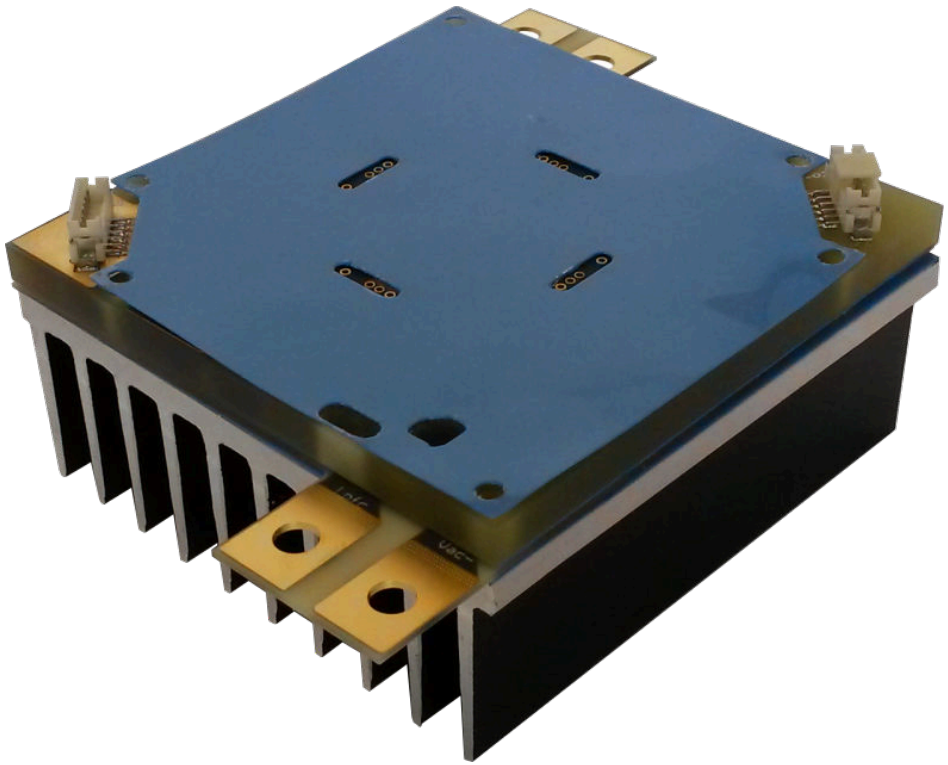

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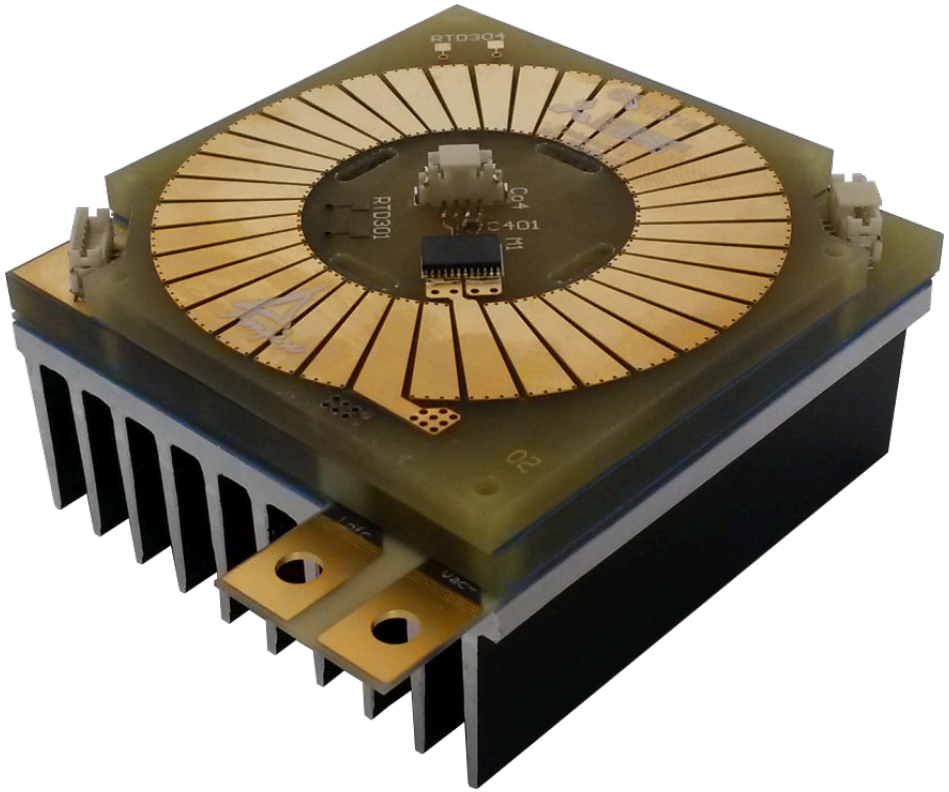

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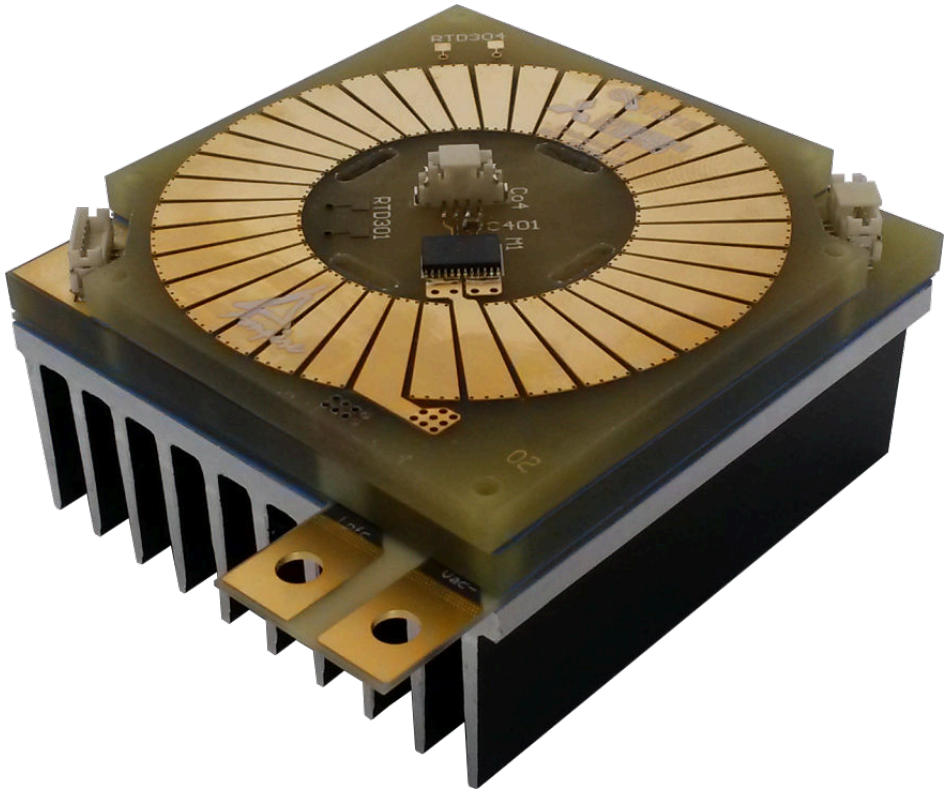

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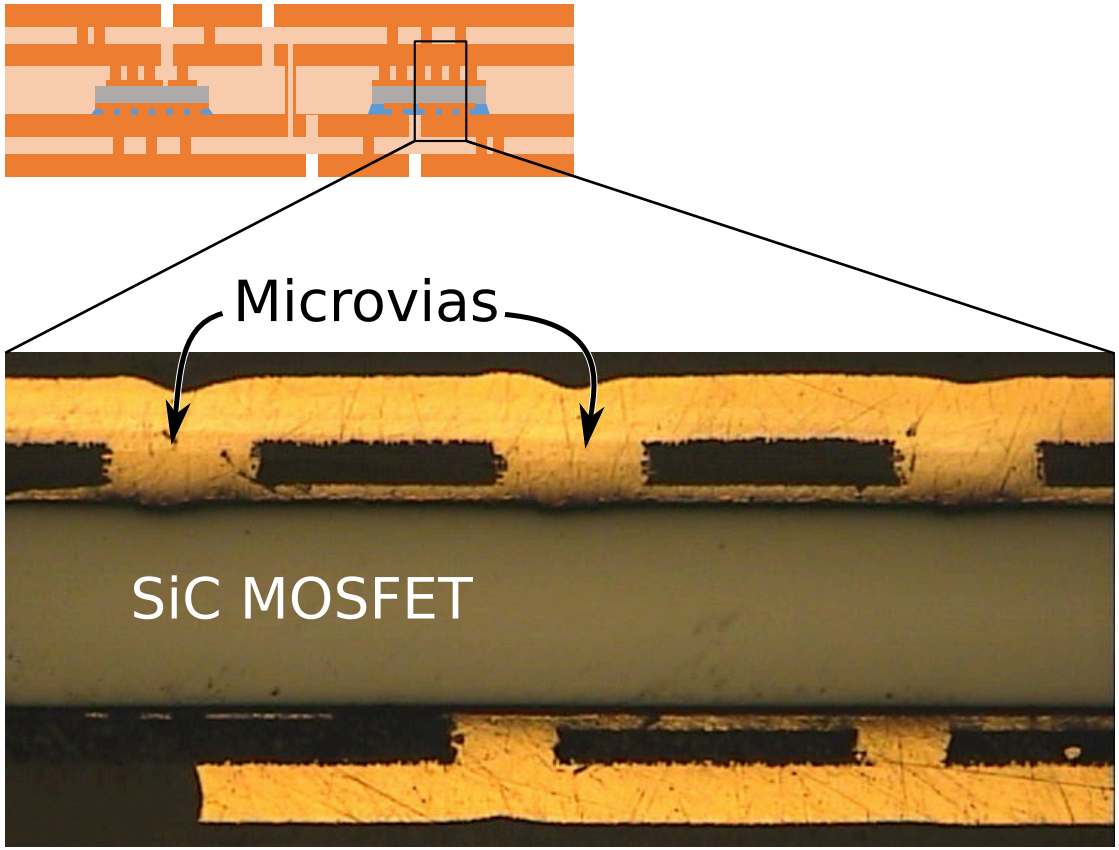
Full converter assembly

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

Test Coupons – power devices

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.
  - Consistent $R_{DS_{on}}$ (80 mΩ)
  - No change in V_{th}
  - Low leakage current (max 1.6 nA @ 1200 V)
  - Very good yield (97% on 44 dies)



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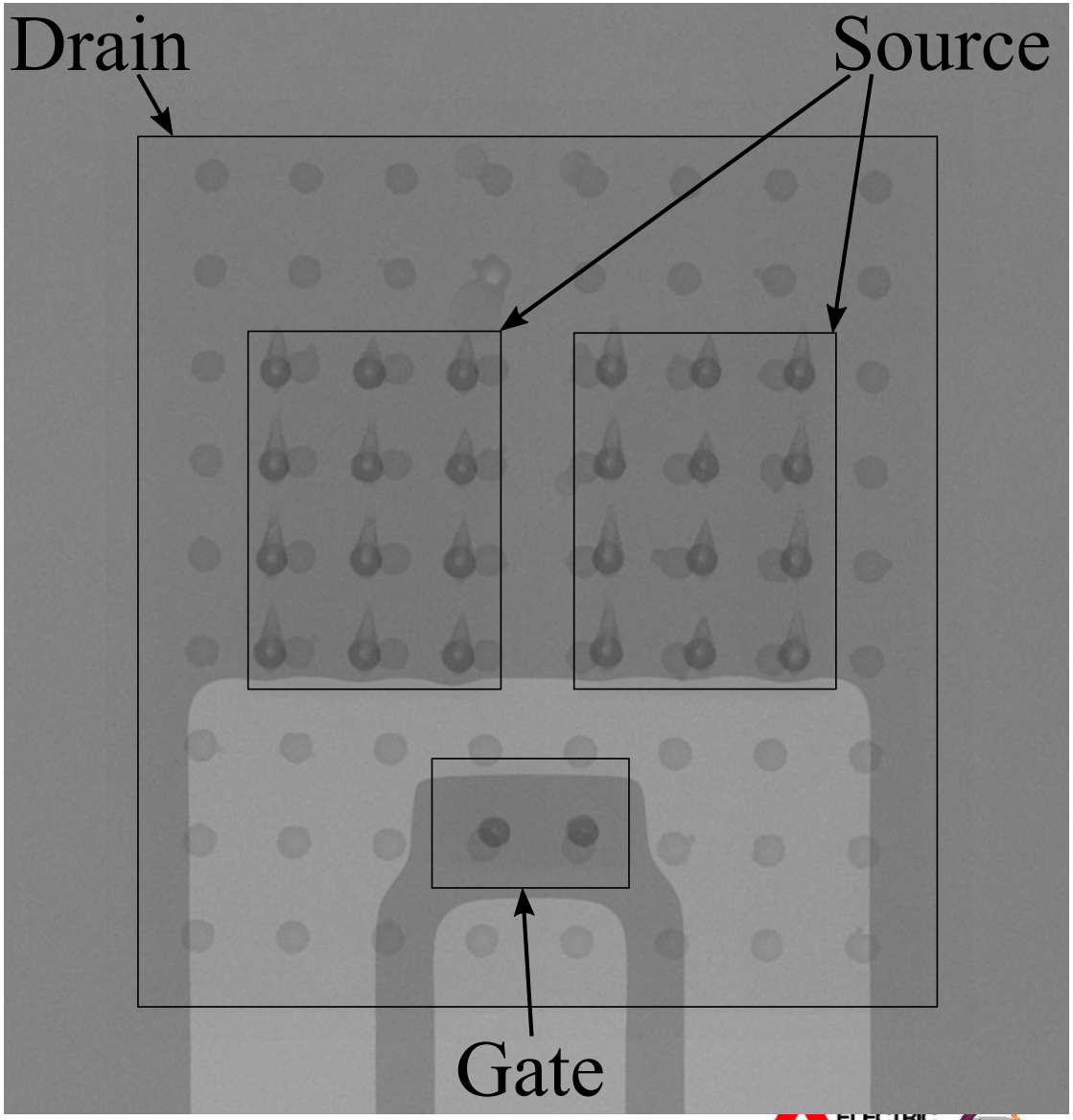

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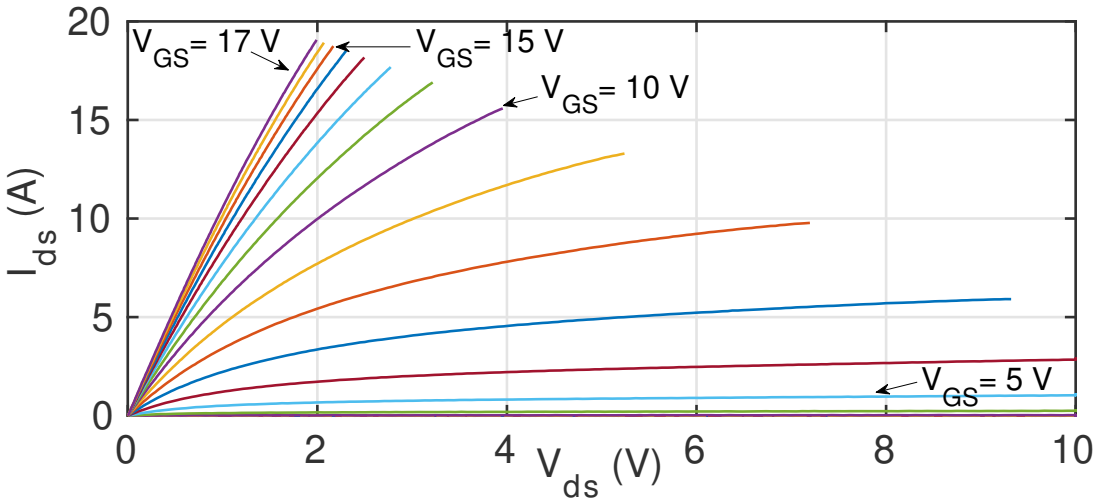
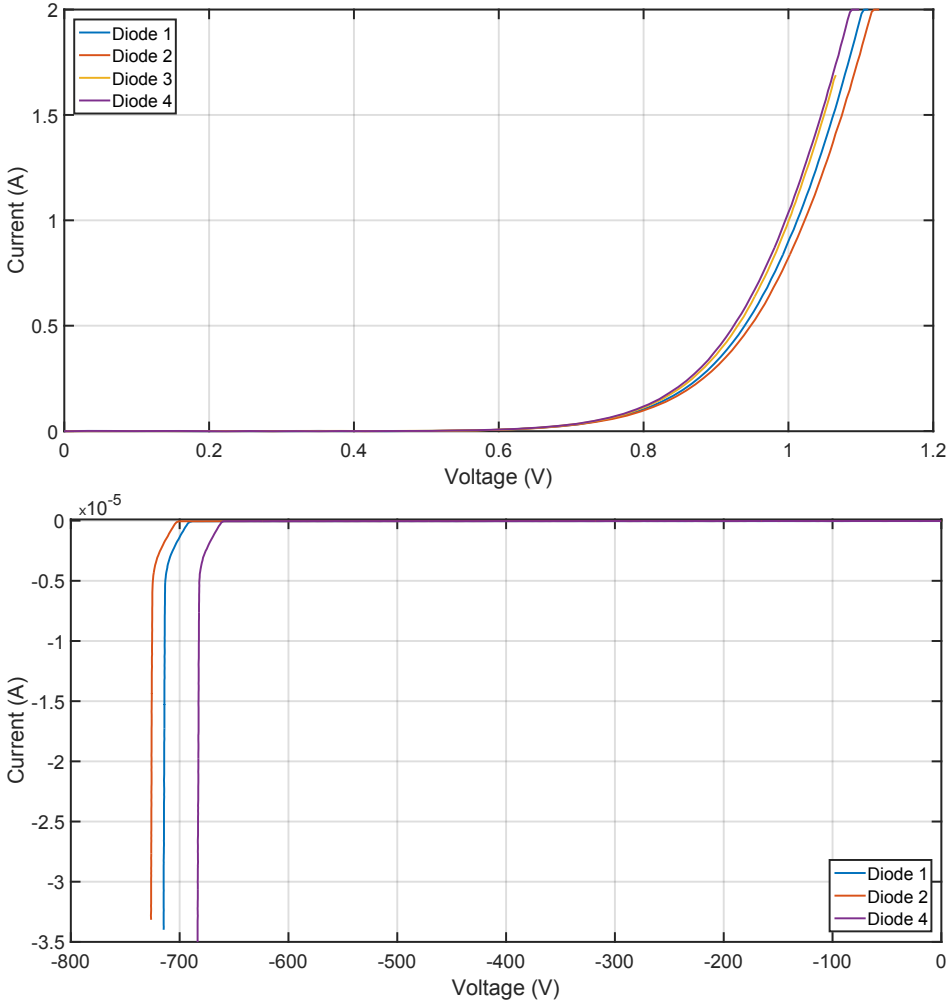


Test Coupons – 2

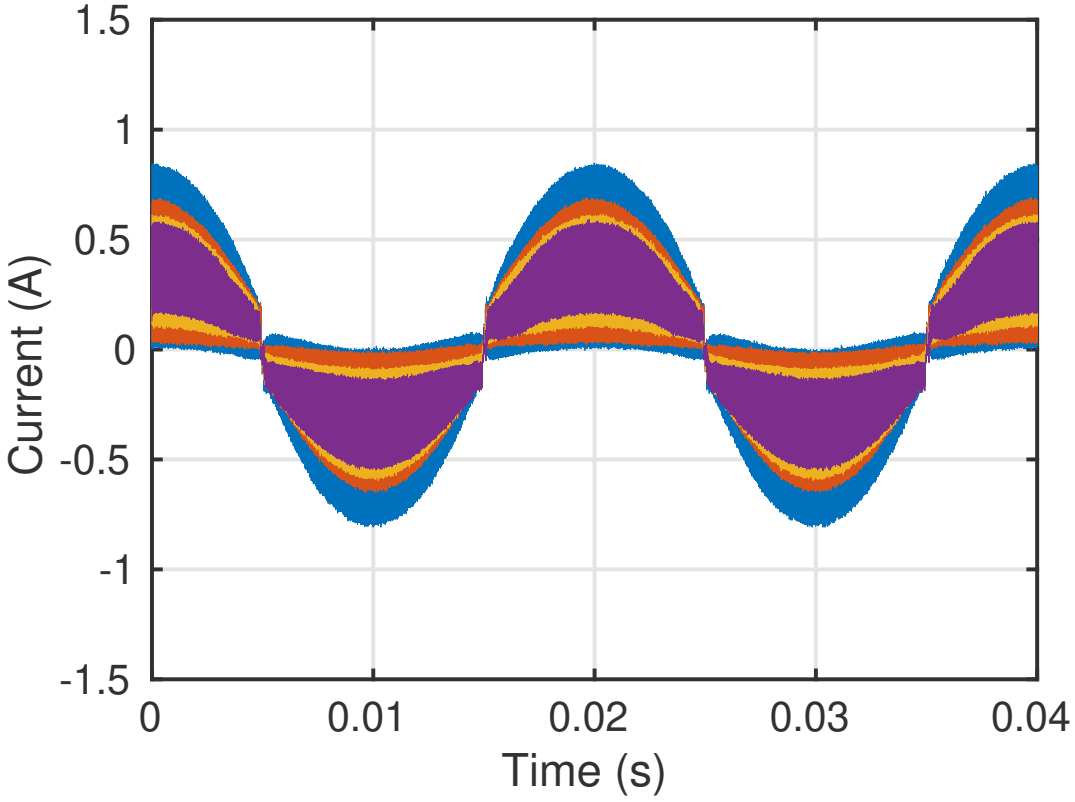


Example: 600 V diodes for bootstrap driver

For SMD components:

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

Operation of the PFC converter

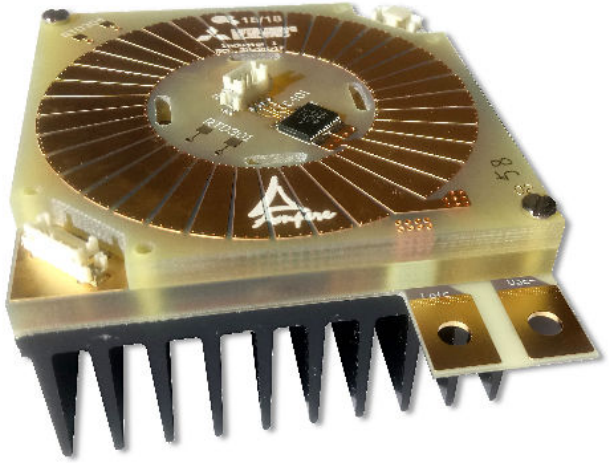


- 4 interleaved PFC cells (target power $4 \times 825\,\mathrm{W} = 3.3\,\mathrm{kW}$)
- Operation at reduced power because of losses in inductors
  - Current unbalance because of differences in inductor values

Outline

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
  - 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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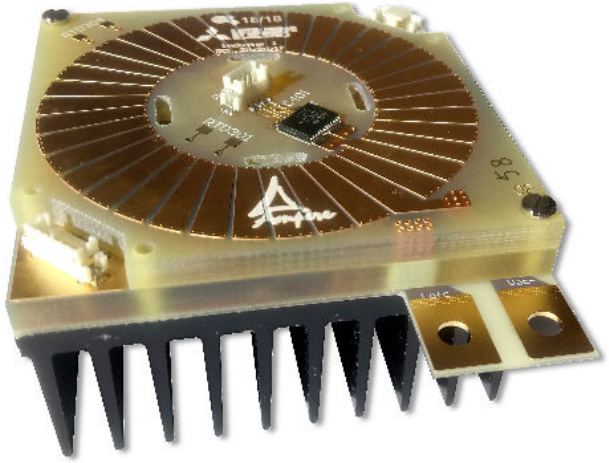

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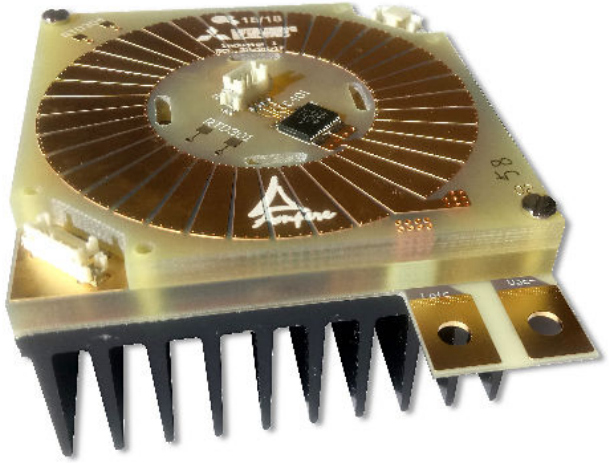

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Thank you for your attention.

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