Novel packaging concepts and their potentials for generating energy efficient electronic based systems

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Outline

- Company introduction
- Integration of power semiconductors in PCB
  - Motivation
  - Embedding concept
  - 500 W demonstrator
  - Reliability test results
  - Summary power embedding
- Integration of magnetic materials in PCB
  - Objectives and features
  - Process flow
  - Automatic assembly of the inlays
  - Application: Inductor
  - Application: DC/DC converter
  - Application: Wireless charger
  - Application: Transformer
  - Summary magnetic embedding

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A world leading PCB & IC substrates company

High-end interconnect solutions
for
Mobile Devices, Automotive, Industrial, Medical Applications and Semiconductor Industry

Outperforming market growth
over the last decade

 # 2
high-end PCB producer worldwide*

Among the top
PCB producers worldwide

€ 1bn
revenue in FY 2019/20

Efficient global production footprint with
6
plants in Europe and Asia

~ 10,000
Employees**

*   For CY 2019
Source: Prismark
** For AT&S FY 2019/20

IEEE SSCS Electron Devices Society AT&S

Global footprint ensures proximity to supply chain & cost efficiency

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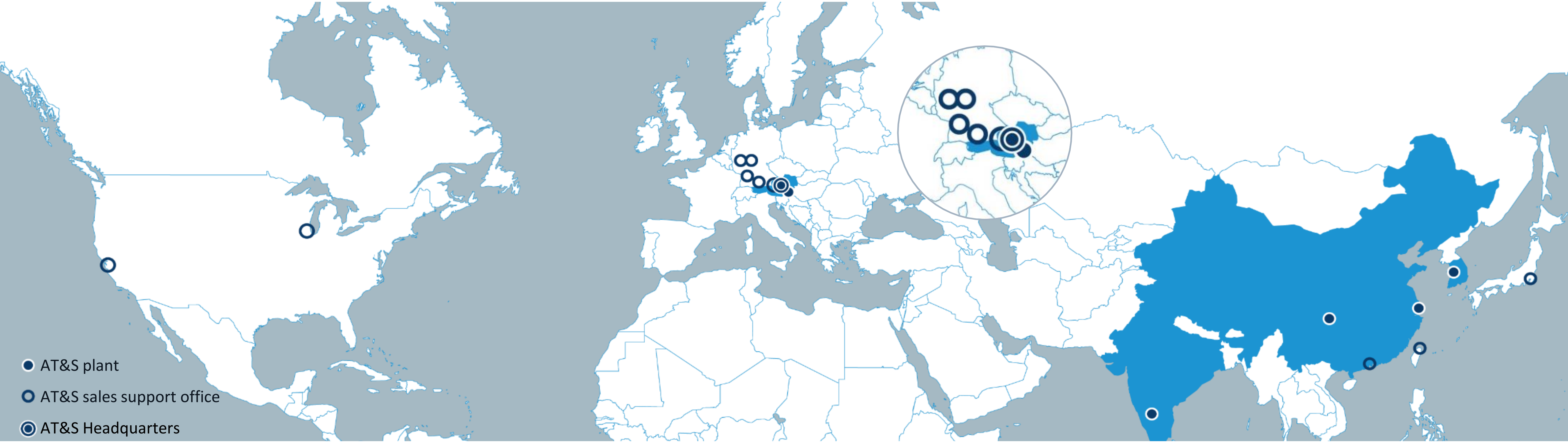
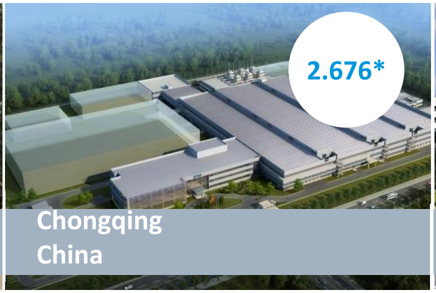




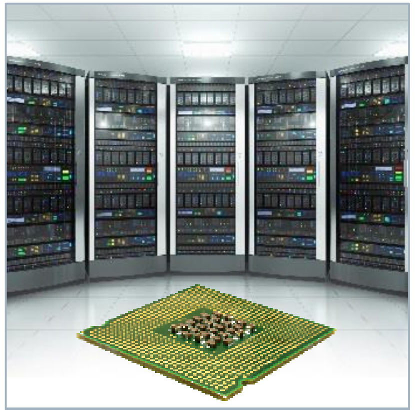
*Staff, Average, FTE, FY 2019/20; 75 employees in other locations

IEEE SSCS Electron Devices Society AT&S

Market segments and product applications

Computer, Communications, Consumer Appliances

Smartphones, Tablets, Wearables, Ultrabooks, Cameras



IC substrates

High Performance Computer, Microserver

Automotive

Advanced Driver Assistance Systems, Emergency-Call, X2X Communication

Industrial

Machine-2-Machine Communication, Robots, Industrial Computer, X2X Communication

Medical

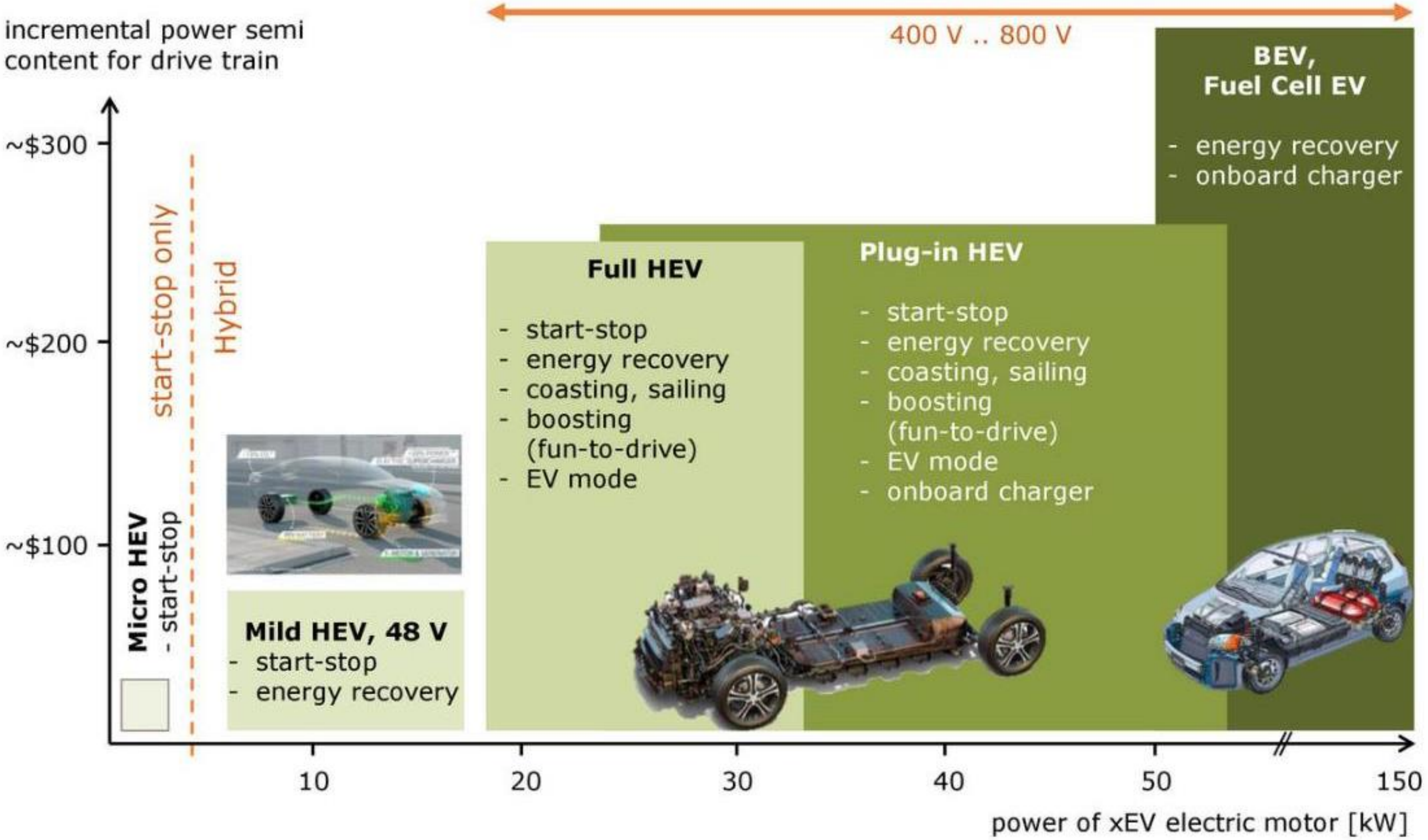
Patient Monitoring, Hearing Aids, Pacemaker, Neurostimulation, Drug Delivery, Prosthesis

Segment Mobile Devices & Substrates

Segment Automotive, Industrial, Medical

Motivation

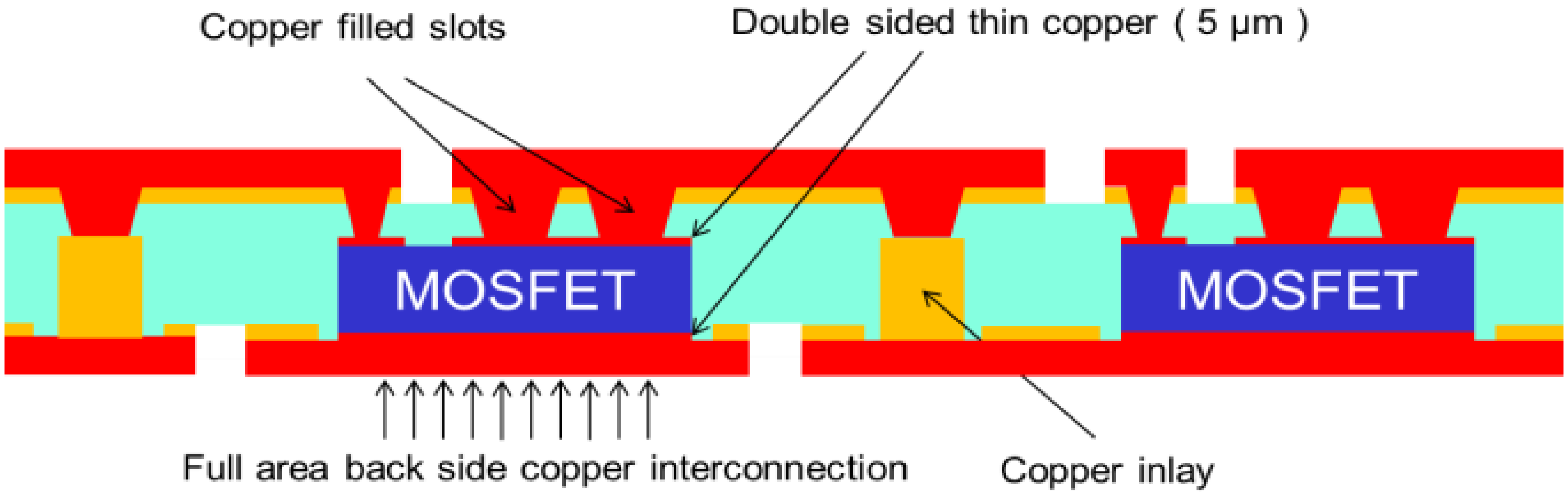
- Reduction of Fleet emissions and Fuel consumption
  - Higher efficiency of the ICE
    - Start-Stop
    - EPS
  - Energy efficiency of applications
    - Electric pumps
    - Electric fans
    - Power distribution
  - Drivetrain electrification
    - Inverter
    - Onboard charger
    - Battery management



Source: Infineon

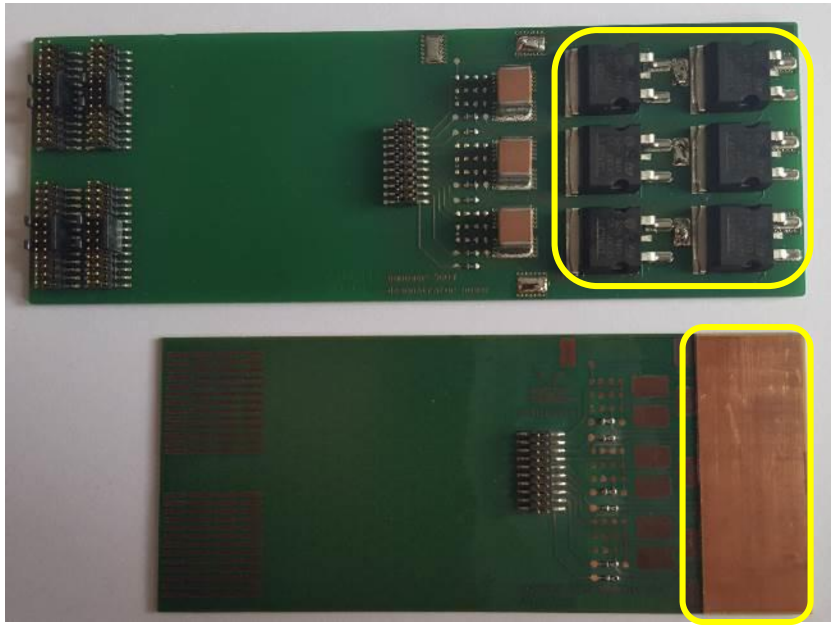
Embedding concept

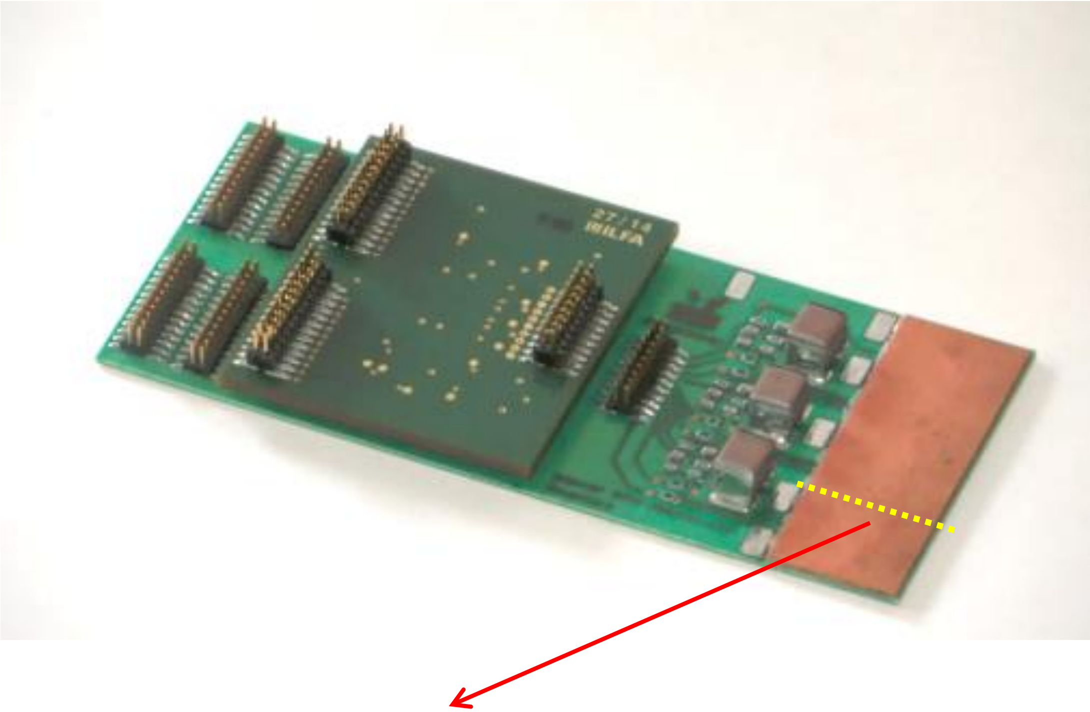
- Embedding concept – PARSEC (**P**l**A**na**R** **S**urface **E**mbedded **C**omponents)
  - Miniaturization in x, y, z
  - Embedded components positioned with backside directly into Cu-Layer of build up
  - Improved switching performance
  - Reduced inductance and improved of thermal resistance

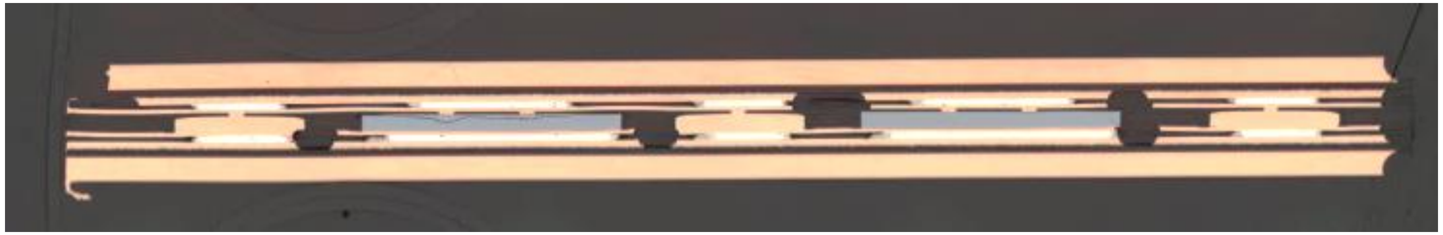


500 W Demonstrator

- Miniaturization x, y, z
  - Size reduction in x & y of 30% in power area
  - z – dimension of Power core around 350µm

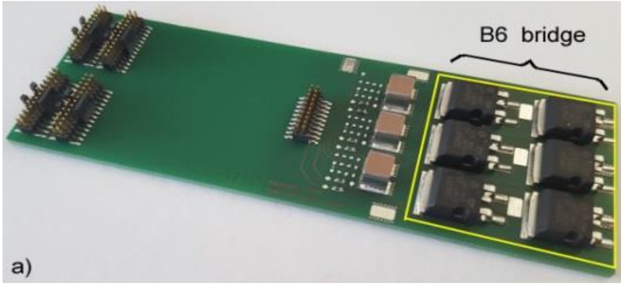




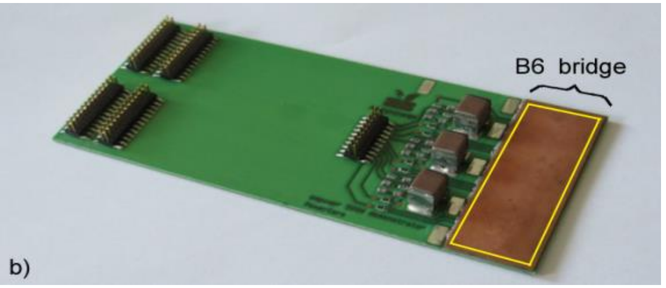


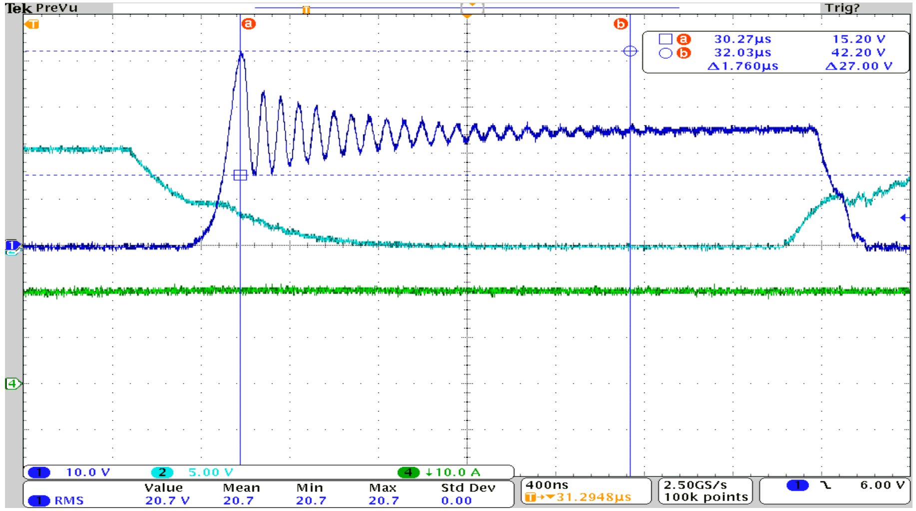
500 W Demonstrator

Switching performance

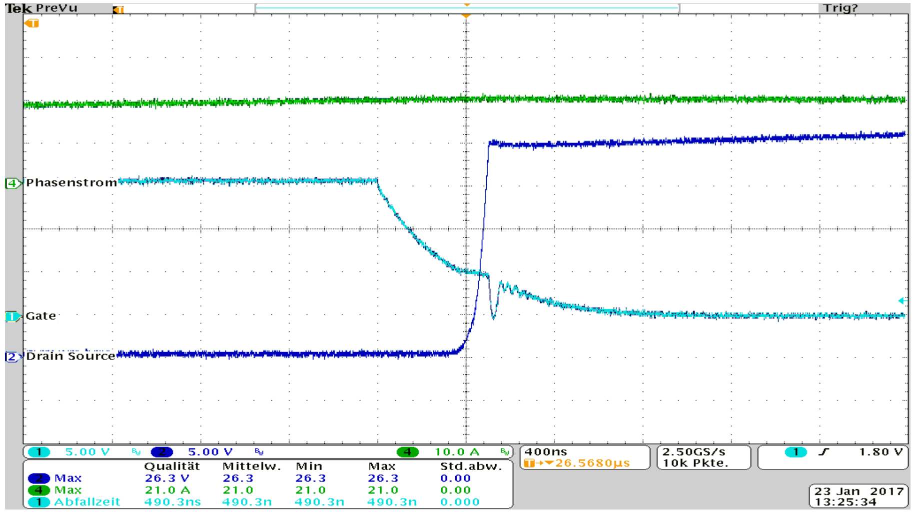


- **close positioning** of single components results in a minimization of inductance of the switching cell
- **reduction of the overvoltage** indicates less switching losses and finally **faster switching** is possible





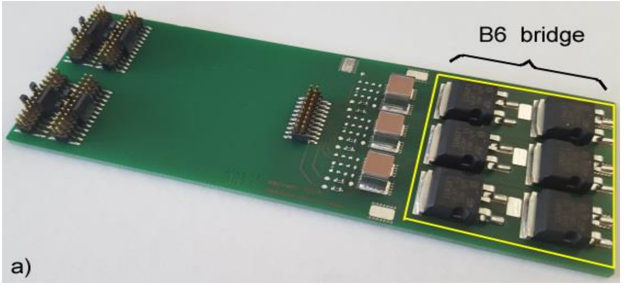
Switch off behavior of SMT benchmark module with a gate resistance of 51Ω. Green: Phase current (20A), Light blue: Gate voltage (5V), Blue: Drain Source voltage (24V)



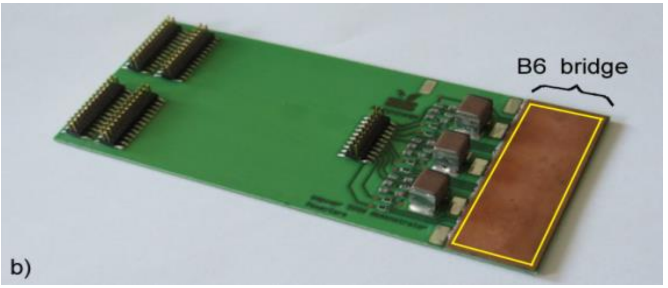
Switch off behavior of embedded module with a gate resistance of 51Ω. Green: Phase current (20A), Light blue: Gate voltage (5V), Blue: Drain Source voltage (24V)

500 W Demonstrator

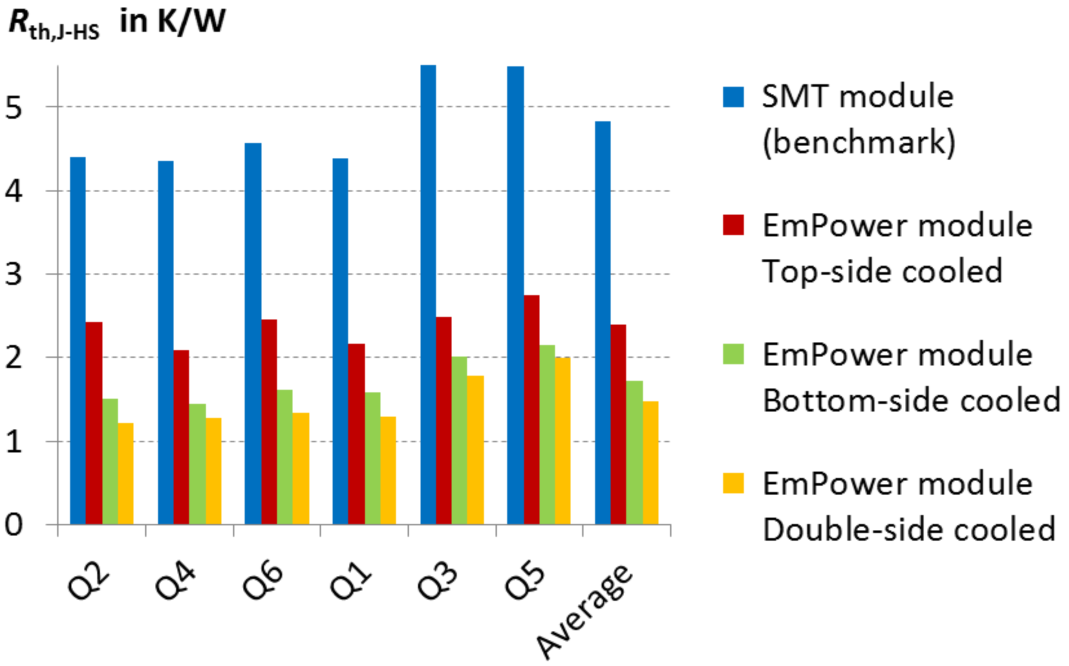
Thermal performance



Comparison of junction-to-heat sink thermal resistances of different cooling cases with those of a benchmark module fabricated in SMT.

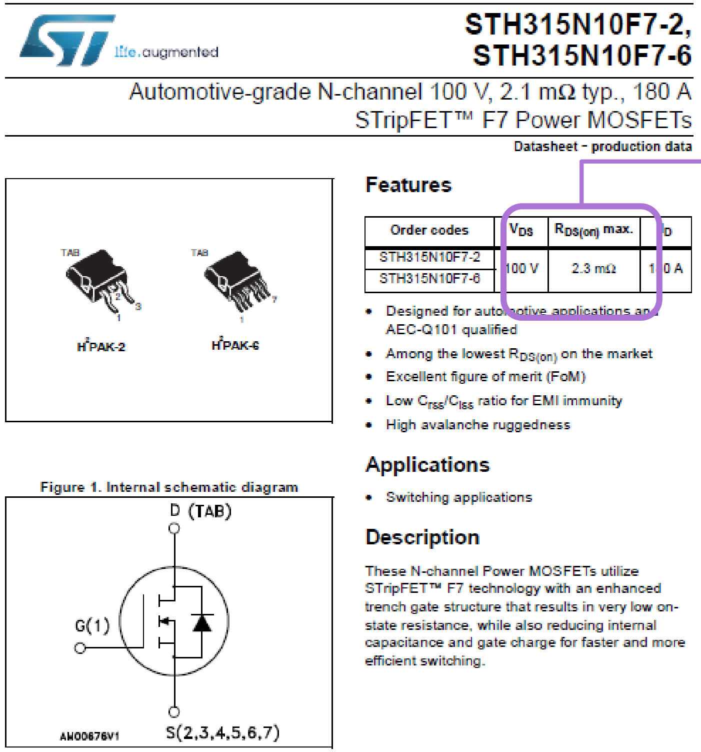


Transistor connection	Q2 A/L1	Q4 A/L2	Q6 A/L3	Q1 B/L1	Q3 B/L2	Q5 B/L3	Average
SMT module (benchmark)	4.40	4.35	4.57	4.39	5.79	5.49	4.83
EmPower Top-side	2.42	2.09	2.45	2.17	2.49	2.74	2.39
EmPower Bottom-side	1.50	1.45	1.61	1.59	2.01	2.15	1.72
EmPower Double-side	1.22	1.28	1.33	1.29	1.78	1.99	1.48



500 W Demonstrator

- $R_{DS(on)}$ measurement of embedded MOSFETs
  - Values are 0,4 mΩ below SMD-Package specification -> loss reduction of ~20%



STH315N10F7-2, STH315N10F7-6

Automotive-grade N-channel 100 V, 2.1 mΩ typ., 180 A STripFET™ F7 Power MOSFETs

Datasheet - production data

Features

Order codes	V_{DS}	$R_{DS(on)}$ max.	I_D
STH315N10F7-2 STH315N10F7-6	100 V	2.3 mΩ	1 0 A

- Designed for auto otive applications an AEC-Q101 qualified
- Among the lowest $R_{DS(on)}$ on the market
- Excellent figure of merit (FoM)
- Low C_{rss}/C_{iss} ratio for EMI immunity
- High avalanche ruggedness

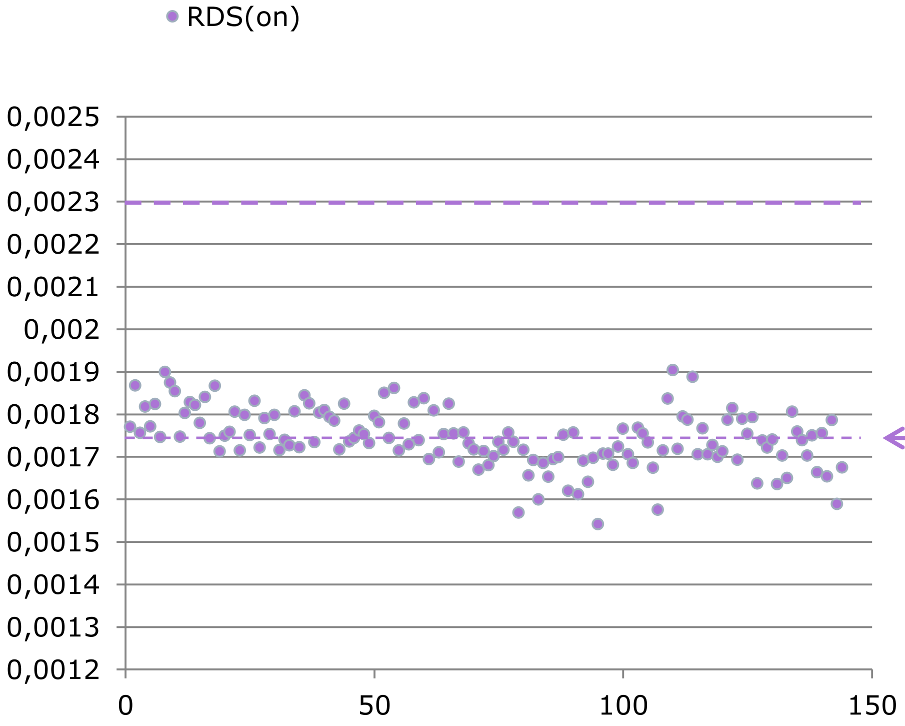
Applications

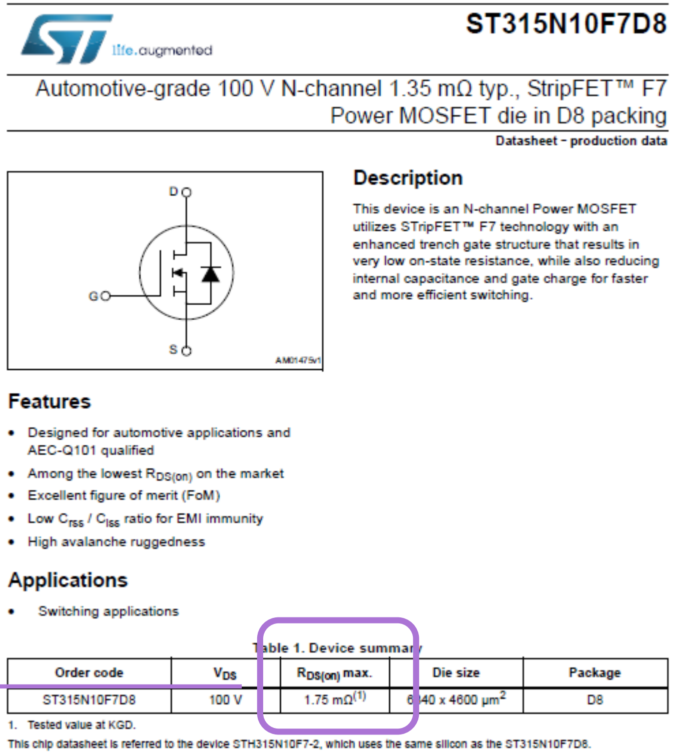
- Switching applications

Description

These N-channel Power MOSFETs utilize STripFET™ F7 technology with an enhanced trench gate structure that results in very low on-state resistance, while also reducing internal capacitance and gate charge for faster and more efficient switching.

Figure 1. Internal schematic diagram





ST315N10F7D8

Automotive-grade 100 V N-channel 1.35 mΩ typ., StripFET™ F7 Power MOSFET die in D8 packing

Datasheet - production data

Description

This device is an N-channel Power MOSFET utilizes STripFET™ F7 technology with an enhanced trench gate structure that results in very low on-state resistance, while also reducing internal capacitance and gate charge for faster and more efficient switching.

Features

- Designed for automotive applications and AEC-Q101 qualified
- Among the lowest $R_{DS(on)}$ on the market
- Excellent figure of merit (FoM)
- Low C_{rss} / C_{iss} ratio for EMI immunity
- High avalanche ruggedness

Applications

- Switching applications

Table 1. Device summary

Order code	V_{DS}	$R_{DS(on)}$ max.	Die size	Package
ST315N10F7D8	100 V	1.75 mΩ(1)	6 40 x 4600 µm²	D8

1. Tested value at KGD.

This chip datasheet is referred to the device STH315N10F7-2, which uses the same silicon as the ST315N10F7D8.

Reliability

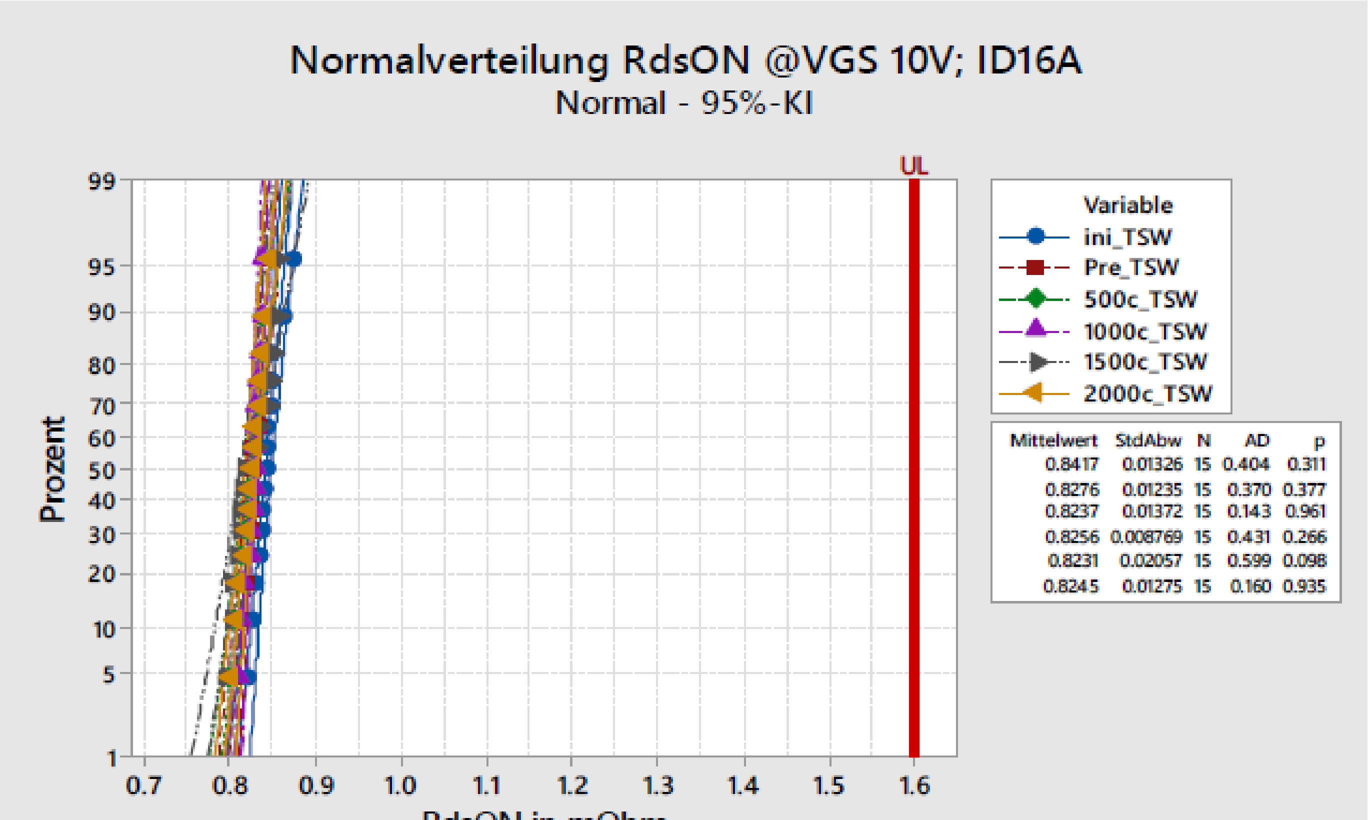
- $R_{DS(on)}$ during TCT (AEC-Q101)
  - TCT – test according AEC-Q101
    - -40 / 140 °C
    - 2000 cycles

Electrical characteristics

(T_C = 25 °C unless otherwise specified)

Table 4: On /off states

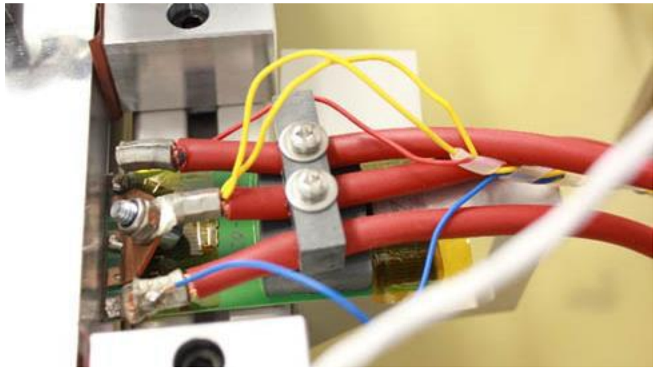
Symbol	Parameter	Test conditions	Min.	Typ.	Max.	Unit
$V_{(BR)DSS}$	Drain-source breakdown voltage	V_{GS} = 0 V, I_D = 250 µA	40			V
I_{DSS}	Zero gate voltage drain current	V_{GS} = 0 V V_{DS} = 40 V			1	µA
I_{GSS}	Gate-body leakage current	V_{GS} = 20 V, V_{DS} = 0 V			100	nA
$V_{GS(th)}$	Gate threshold voltage	V_{DS} = V_{GS}, I_D = 250 µA	2		4	V
$R_{DS(on)}$	Static drain-source on-resistance	V_{GS} = 10 V, I_D = 16 A		1.3	1.6	mΩ



TCT cycles (15 samples)

Reliability

- Power cycling
  - Project 500W Demonstrator:
    - dT= 100K, 3sec. on, 3sec. off → 300.000 cycles passed
  - Project Power X:
    - dT= 80K → 850.000 cycles passed
  - Project Power Y:
    - 5sec. on, 5sec. off (8600 cycles per day)
    - 2 types of stress
      - dT=120K
      - dT=140K
    - 1.100.000 cycles passed



Summary power embedding

- 30% footprint reduction
- High robustness
- Improved switching performance
- Improved thermal performance
- Increased power density
- System cost reduction

Objectives

Develop DC-DC converters for

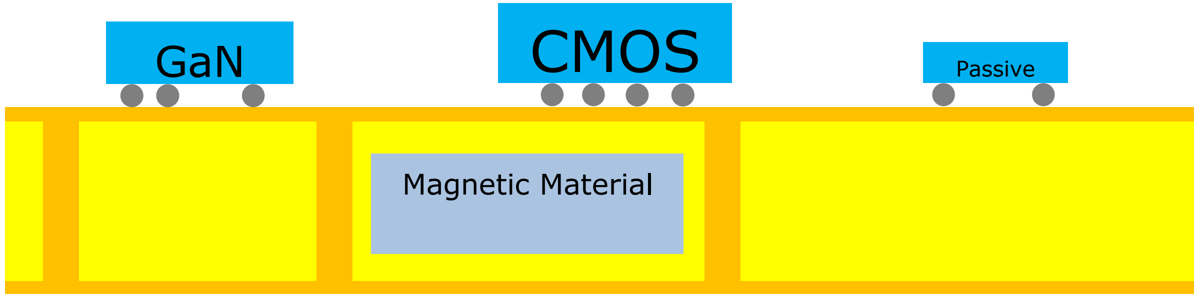
- Automotive
- Industrial
- Server applications

Our tasks:

- embed magnetic material
- packaging of GaN switches
- design of the magnetic components (inductor / transformer)

1st step: Embedded inductor

2nd step: DC/DC converter with embedded inductor

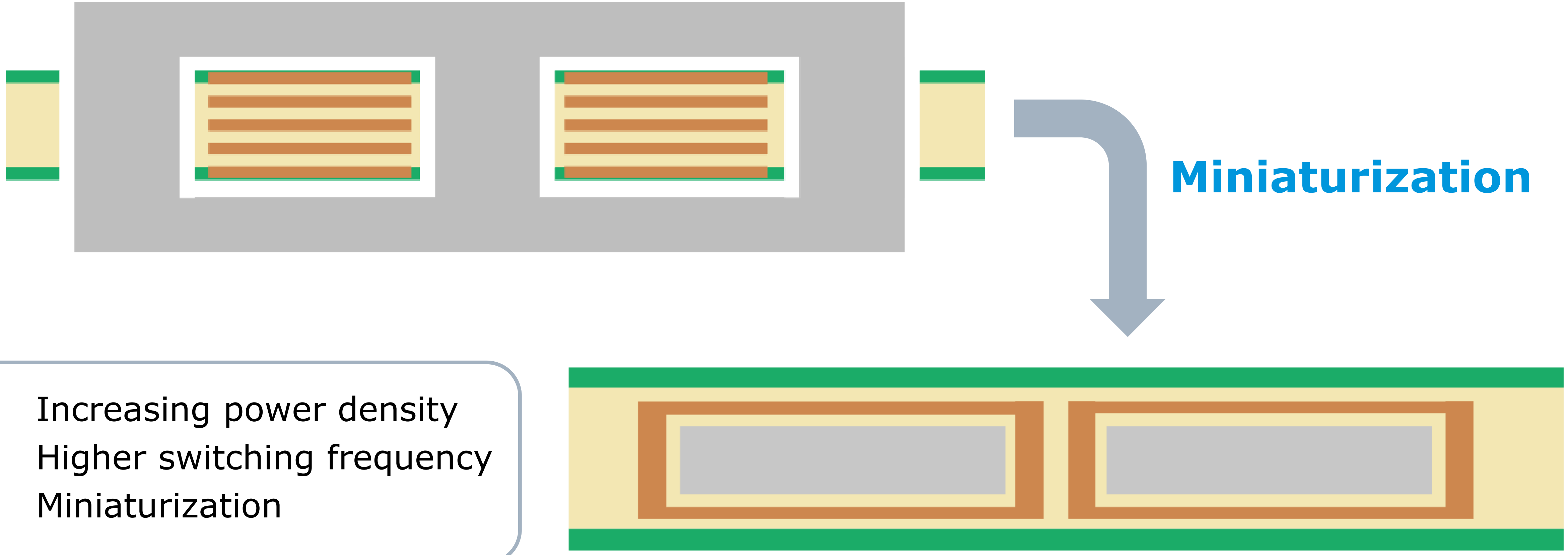


Project demonstrators

Demonstrator	V_{in} [V]	V_{out} [V]	I_{out} [A]	$f_{switching}$ [MHz]
#1	12	1	2	5
#2	12	1	30	5
#3	48	12	10	5

Features

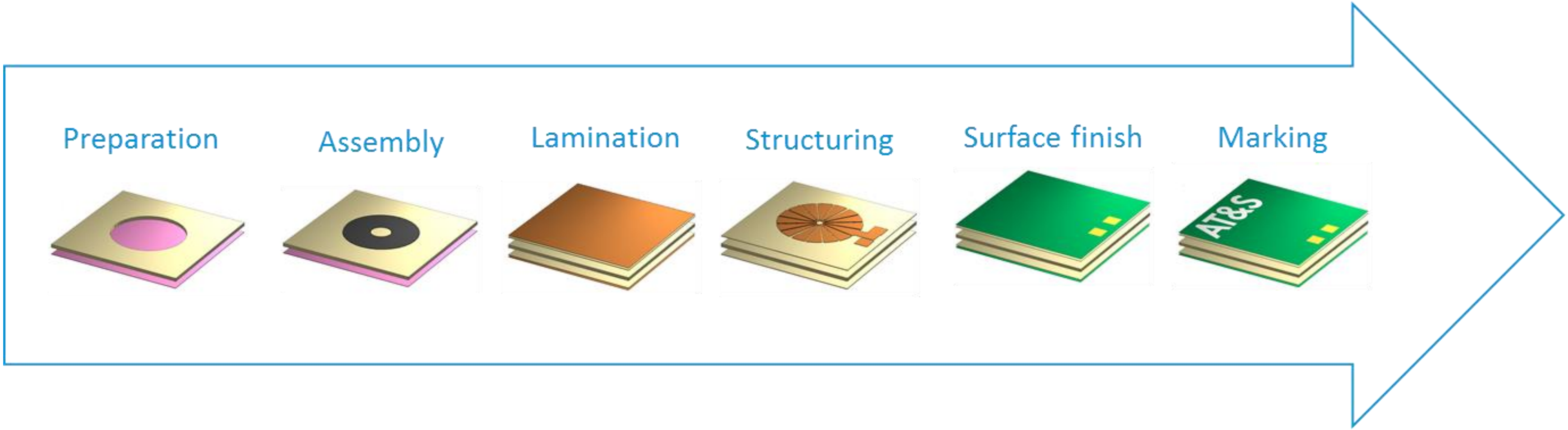
Why – What is the advantage of this technology?



- Increasing power density
- Higher switching frequency
- Miniaturization

Process flow

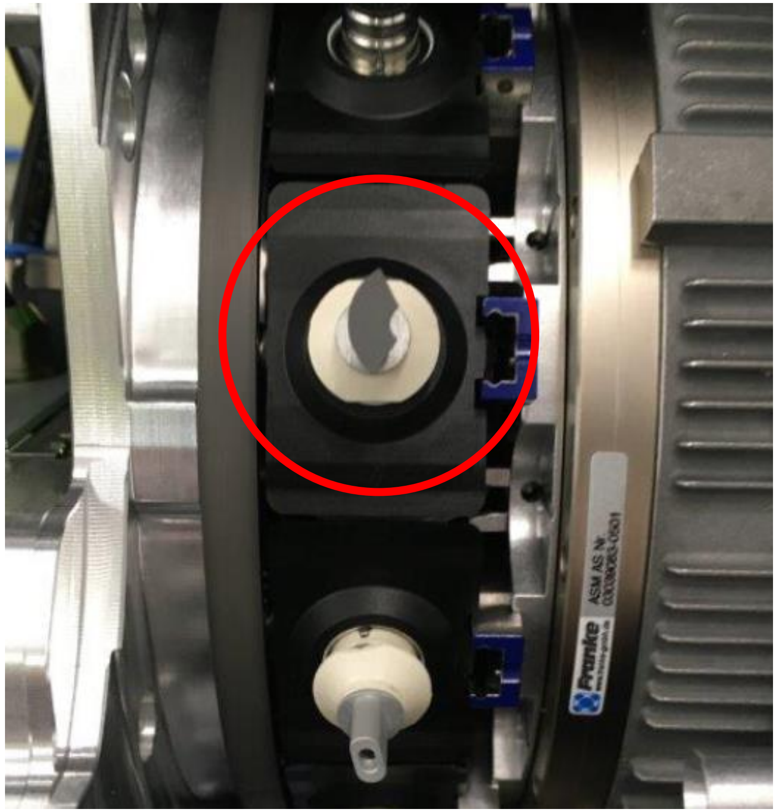
Embedding Process in Detail



- Qualified process based on the ECP® technology
- Independent from layer count
- Can be applied to every PCB construction

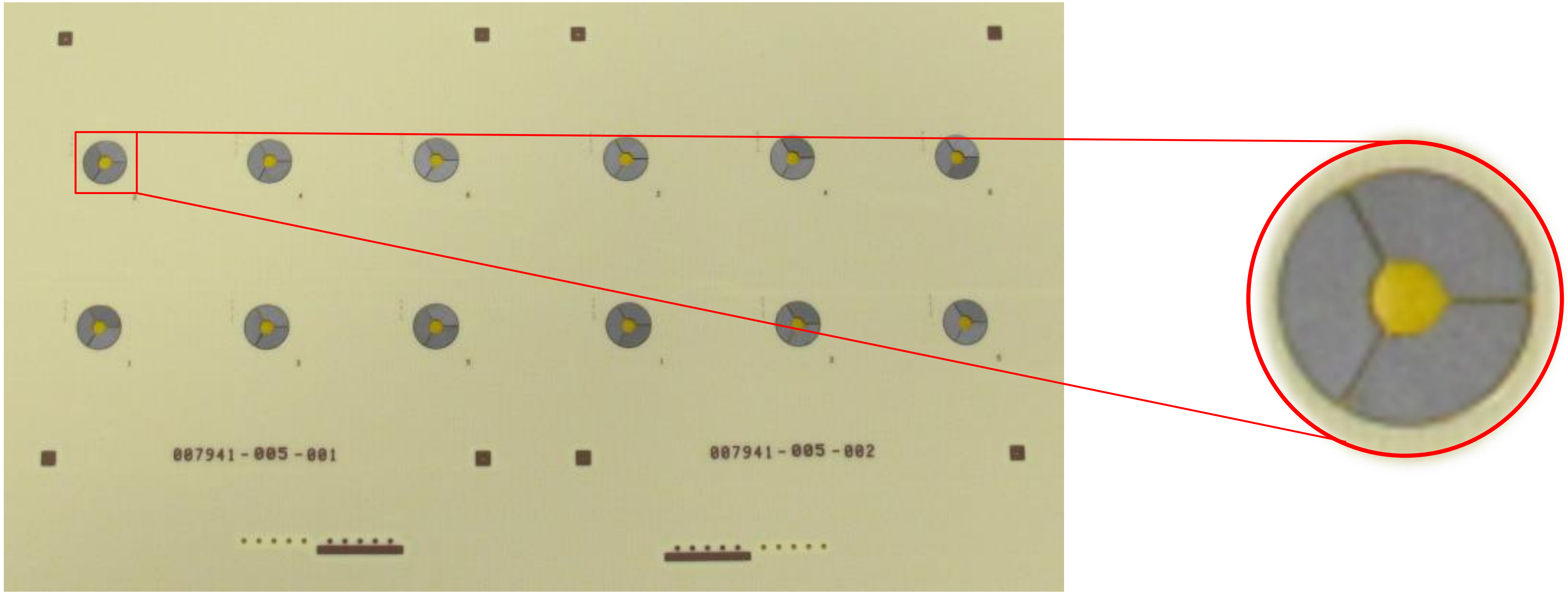
Automatic assembly

- Fully automated assembly for high volume production
- Semi-automated setup for fast prototyping
- Assembly from tape and reel as well as tray
- Special nozzle to optimize camera alignment and position accuracy



Pick up nozzle with inlay part on assembly head

Automatic assembly

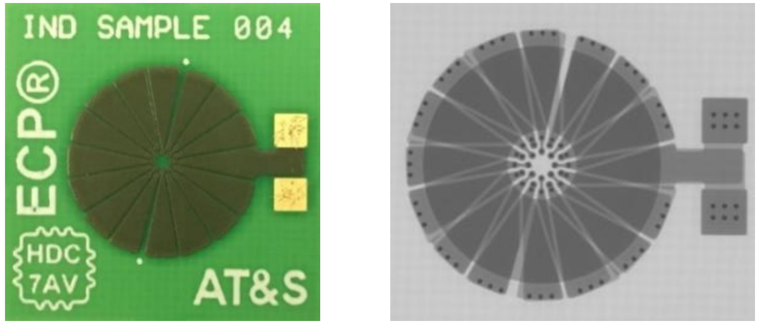


- Inductor demonstrator assembly
- Three parts of magnetic material as well as three air gaps to optimize magnetic behaviour

Application: Inductor I

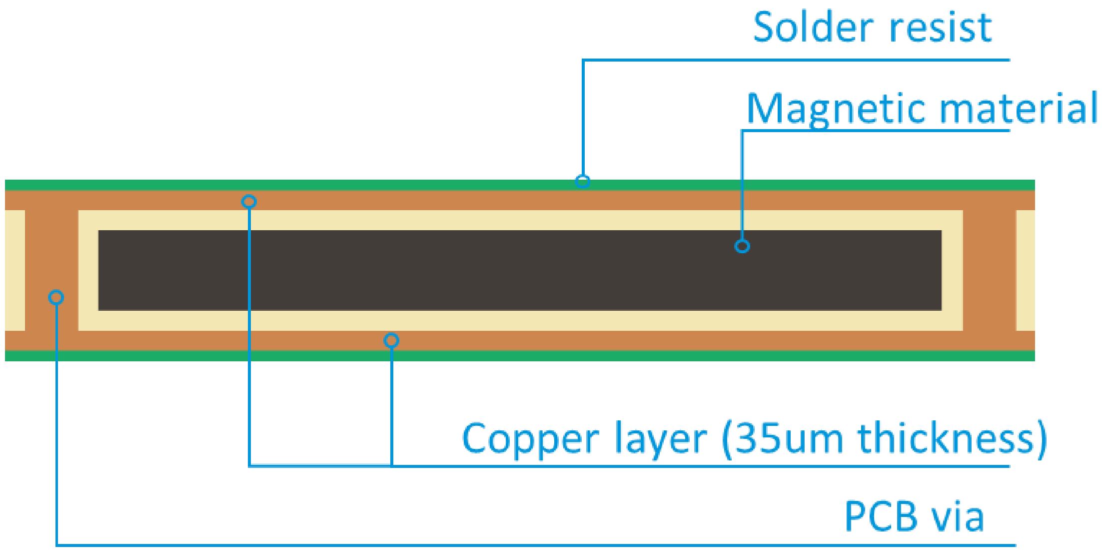
Facts

- Two layer construction
- Different thicknesses possible (used: 300 µm)
- Flexible copper height (used: 35 µm)



Demonstrator with visible X-Ray section

Geometry	Value	Unit
Inner diameter	3	mm
Outer diameter	10.5	mm
Total thickness	0.5	mm
Windings	16	turns
Outer diameter (blue circle)	12.3	mm



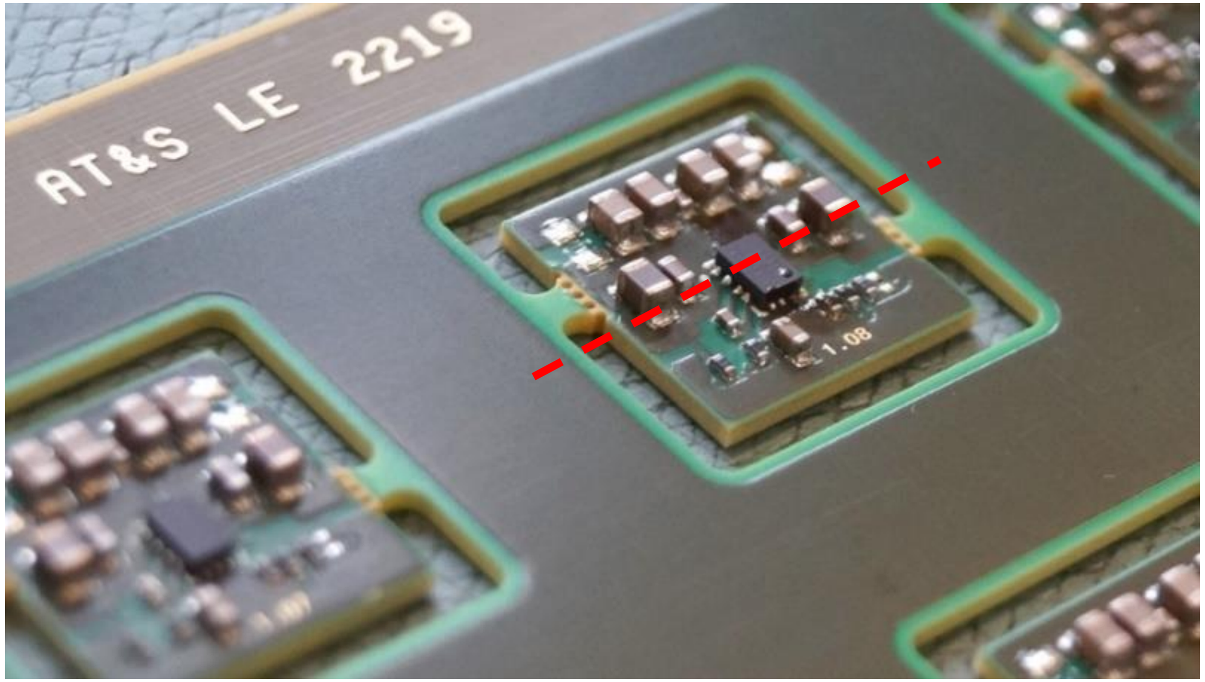
Application: Inductor II

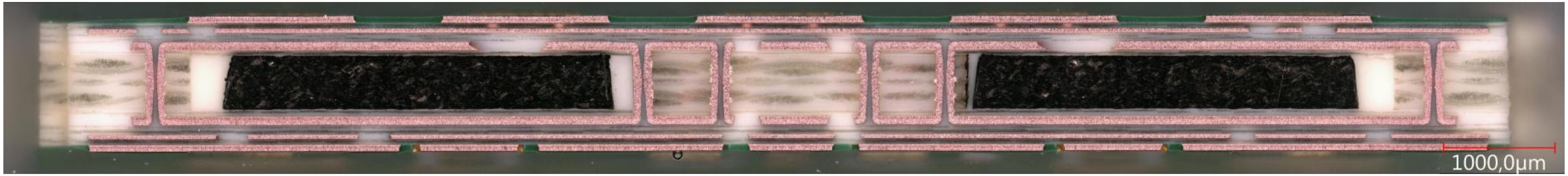
Parameter	Symbol	Without air gap	With 1 air gap	With 3 air gaps
Inductance	L (@ 1 MHz)	5.7 µH	2.2 µH	1.15 µH
Saturation current	I_{sat} (1)	300 mA	1.5 A	3.6 A
Rated current (DC)	I_R (@ ΔT = 40 K)	2.0 A		
DC Resistance	R_{DC} (@ 0.1 A)	79 mΩ		
Self-resonance frequency	f_{res}	30 MHz	40 MHz	80 MHz
Package size	D_I/D_O	3/10.5 mm		
Air gap length	l_g	-	500 µm	3 x 170 µm
Total thickness	h	500 µm		

1) Inductance drops 30% @ I_{sat}

Application: DC/DC Converter

- Conversion from 12V to 3.3V with embedded inductor
- 2 µH inductance at a current of 3 A
- Module size: 13.3 x 14 mm
- Based on 6 layers
- Overall board thickness is 1.4 mm
- Single IC solution (LMR33630)



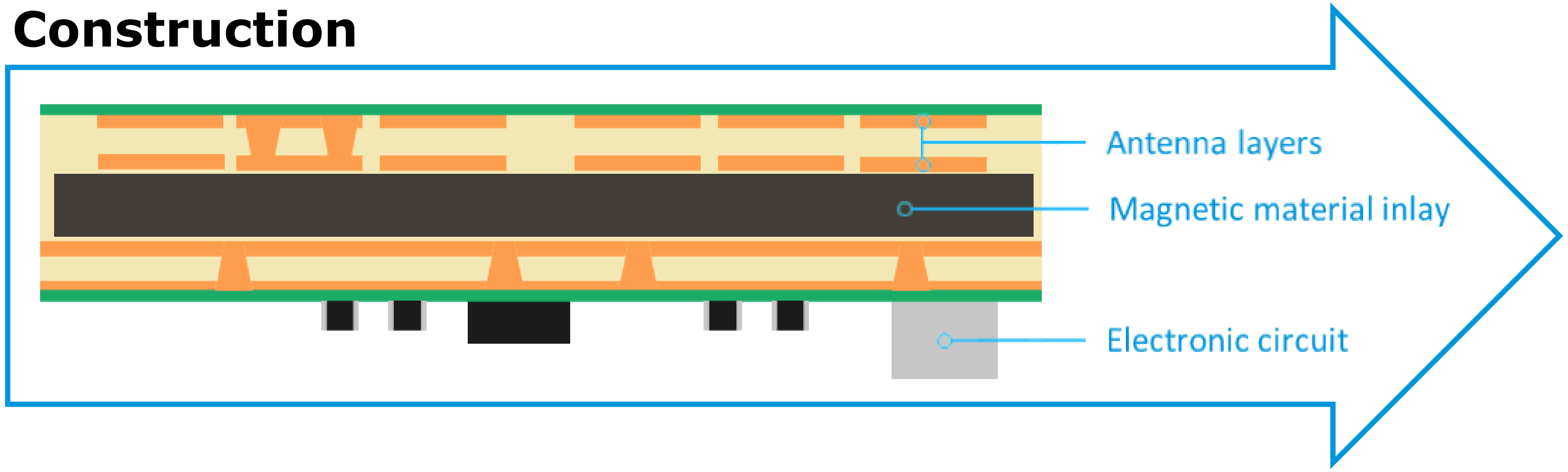


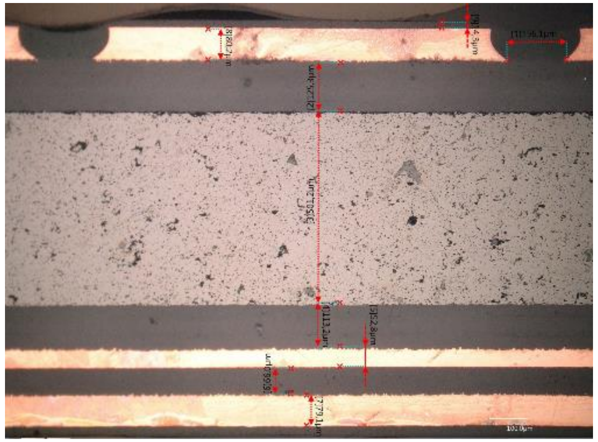
Application: Wireless charger

Facts

- Handles up to 10W wireless charging power
- Proof of concept for large inlay size (50 mm x 50 mm x 500 µm)
- Optimized temperature distribution
- Coil DC-Resistance: 200 mΩ
- Overall construction height: 1 mm

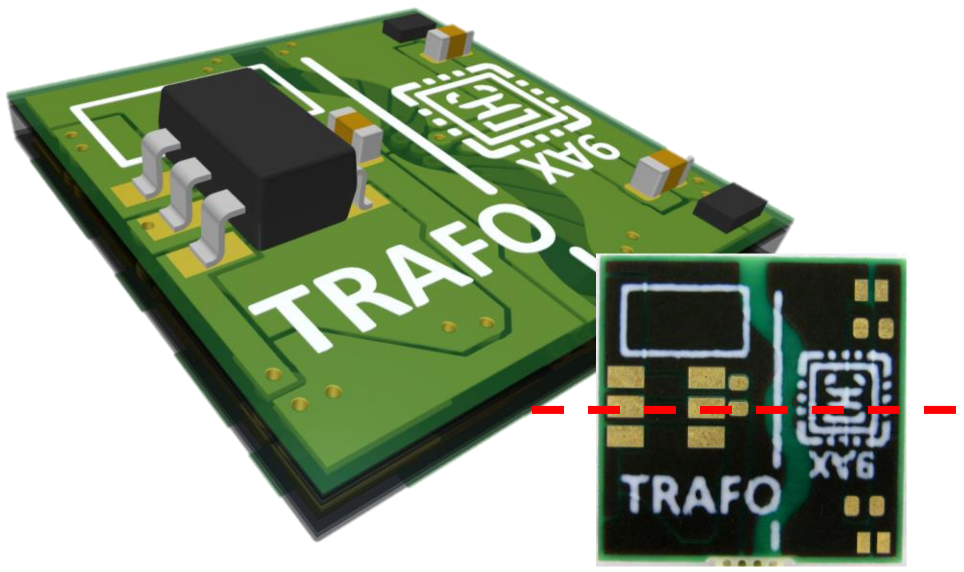
Construction

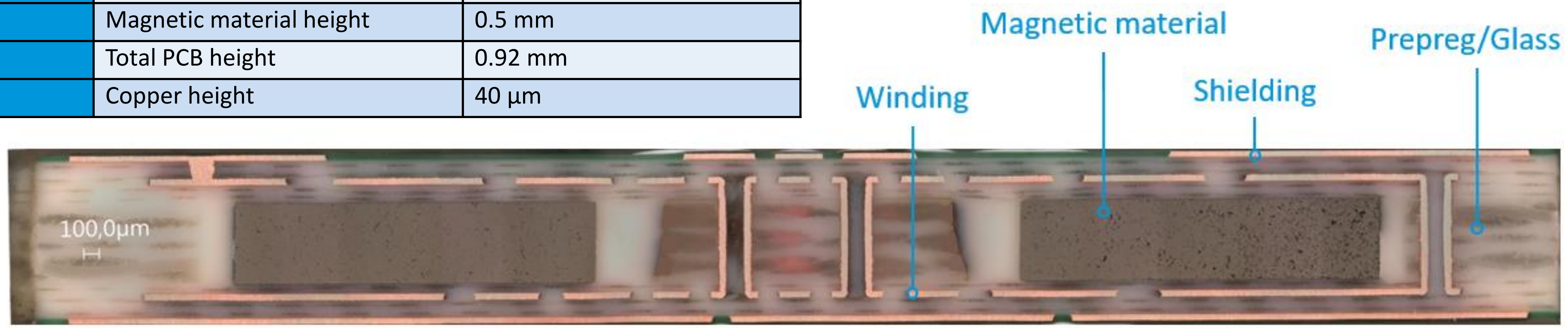




Application: Transformer

Symbol	Parameter	AT&S value
a	Turns ratio	10:11
V_{in}	Input voltage	24 V
f_{sw}	Switching frequency	1.6 MHz
L_m	Magnetizing inductance	3.5 µH
L_{leak}	Leakage inductance	0.5 µH
I_{prim}	Primary (rms) current	0.4 A
I_{sec}	Secondary (rms) current	0.4 A
$R_{DC,1}$	Primary DC resistance	57 mΩ
$R_{DC,2}$	Secondary DC resistance	68 mΩ
C_S	Stray capacitance	6 pF
A_{PCB}	Total PCB area	10 mm x 10 mm
A_{mag}	Magnetic material area	D_{out} = 8 mm; D_{in} = 4 mm
h_{mag}	Magnetic material height	0.5 mm
h_{PCB}	Total PCB height	0.92 mm
h_{Cu}	Copper height	40 µm





Summary magnetic embedding

- Flexible solution
- Further miniaturization of power electronics
- Ultra thin concepts possible
- Different materials (and behavior) available
- Can be used for transformers, inductors, shielding and charging applications
- Technology can be combined with PCB processes

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Thank you very much for your attention!

For further questions and more details please do not hesitate to contact me.

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