PCB embedding of Magnetic Material for Inductor-based Applications

Presenter: Gerald Weis

Morning session, June 11th

APEC®

June 2021 | Phoenix, AZ

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PCB embedding of Magnetic Material for Inductor-based Applications

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Introduction to AT&S

AT&S

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*

€ 1bn
revenue in FY 2019/20

Among the top
PCB producers worldwide

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

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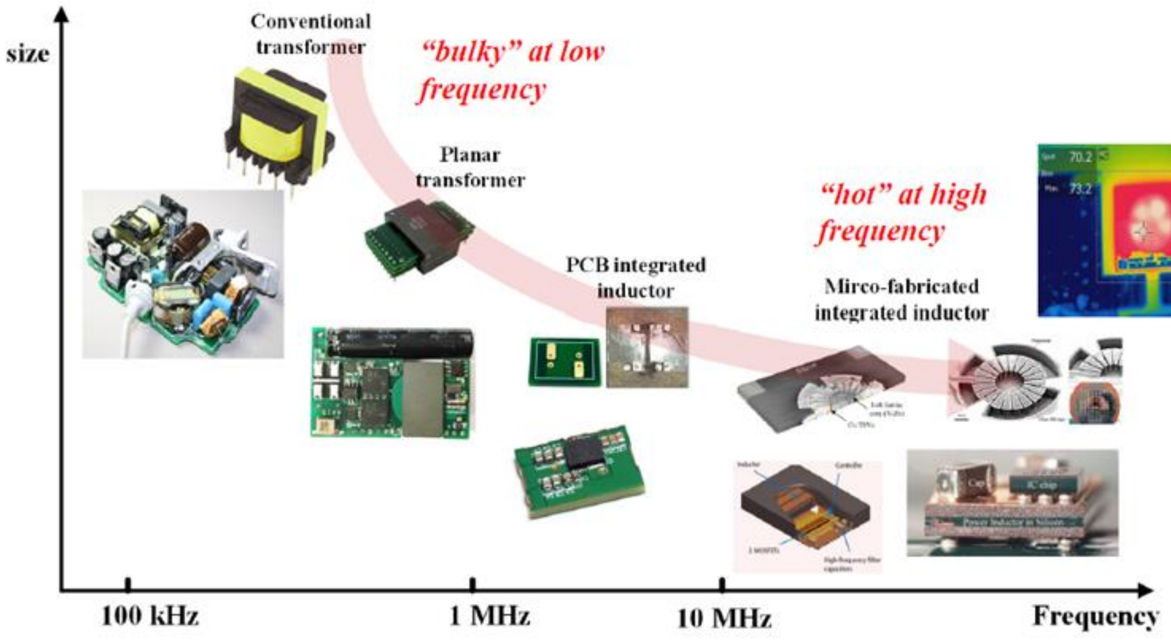
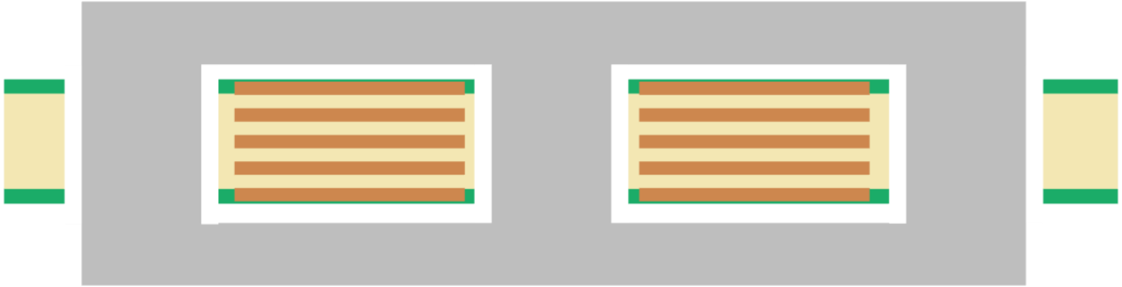
Evolution of PCB based Inductors or Transformers



Source: Zo Ouyang, "High Frequency Planar Magnetics for Power Conversion," ECPE Tutorial, Technical University of Denmark, Copenhagen, Sep. 2018.

PCB embedding of Magnetic Material for Inductor-based Applications

Conventional vs. Embedded Solution

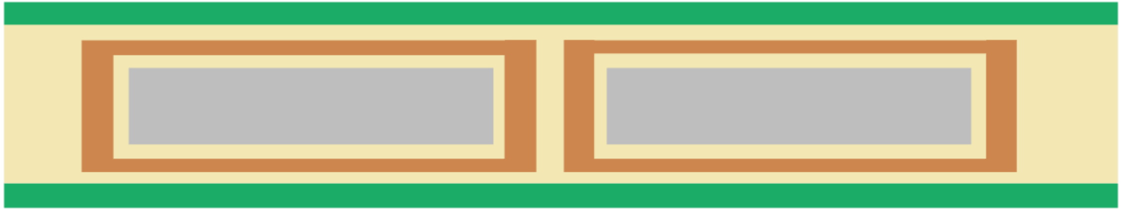


Conventional

- → Bulky
- → Best fit only with customized ferrite
- → Lower EMI performance

Optimization/Miniaturization

- ✓ Increasing power density
- ✓ Compatible to high frequency
- ✓ Comparably high inductance values



Embedded

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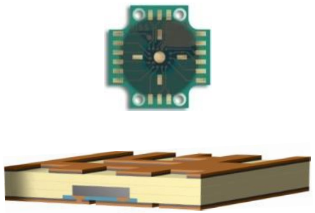
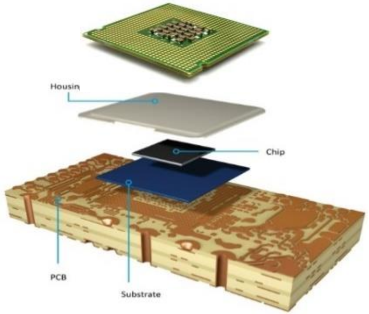
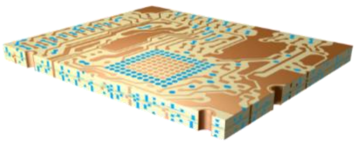
Part of AT&S Product Portfolio

ECP®: Embedded Component Packaging	IC substrates	Substrate-like printed circuit boards mSAP
 **Panel level packaging** (embedded component in laminate)		
Embedded Component Packaging allows to embed active/passive components (e.g. wafer level dies) within the layers of a PCB – contributes to miniaturization.	IC substrates serve as interconnection platform with higher density (Line/Space < 15 micron) between semiconductors (Chips) & PCBs .	Substrate-like PCBs (mSAP technology) are the next evolution of high-end HDI PCBs with higher density: Line/Space < 30 micron.
Production site Leoben, Shanghai	Chongqing	Chongqing, Shanghai
Applications Devices such as smartphones, tablets, digital cameras and hearing aids	High-end processors for Computer, Communication, Automotive, Industrial	Mobile applications like smartphones

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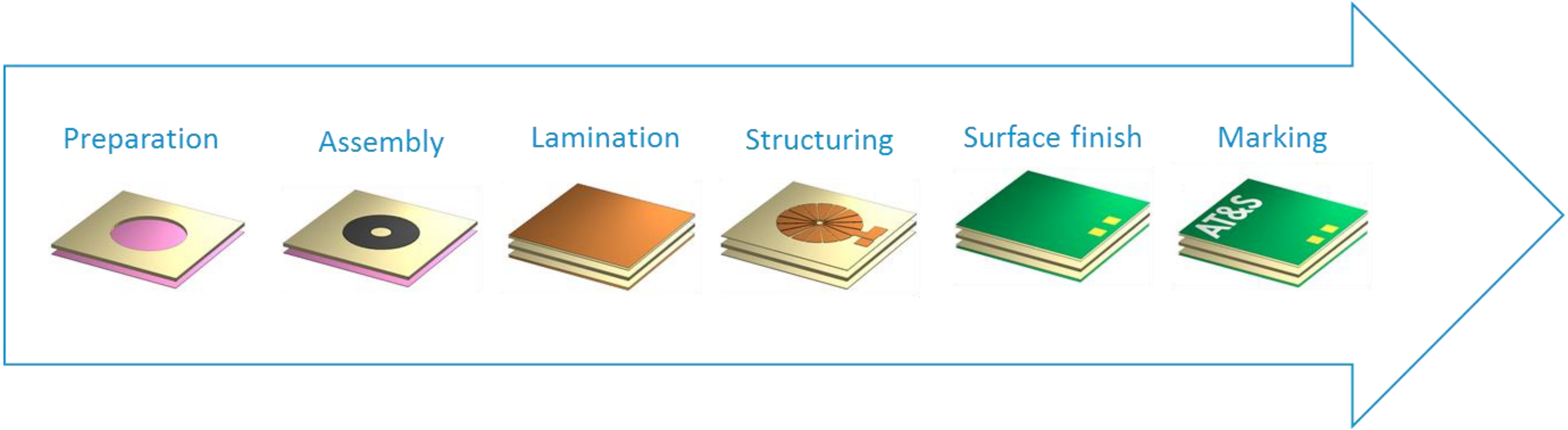
Embedding Process in Detail



- Qualified process based on the ECP® technology
- Circuit board layer count independent
- Compatible to nearly every PCB construction

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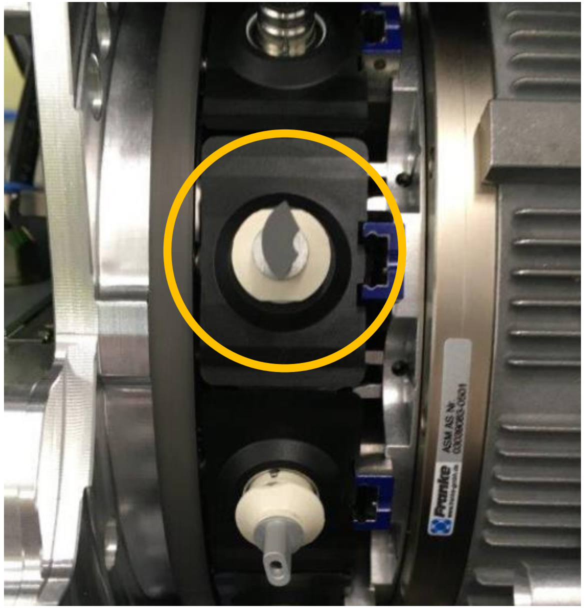
Automated Assembly of Inlays (I)

- Assembly process for high volume production
- Semi-automated setup for fast prototyping
- Assembly possible from **tape and reel** and **tray (small volume)**
- Inlay part: Ferrite particles mixed with resin
- Optimized pick-up nozzle for high-precision camera alignment



Pick up nozzle with inlay part
on assembly head

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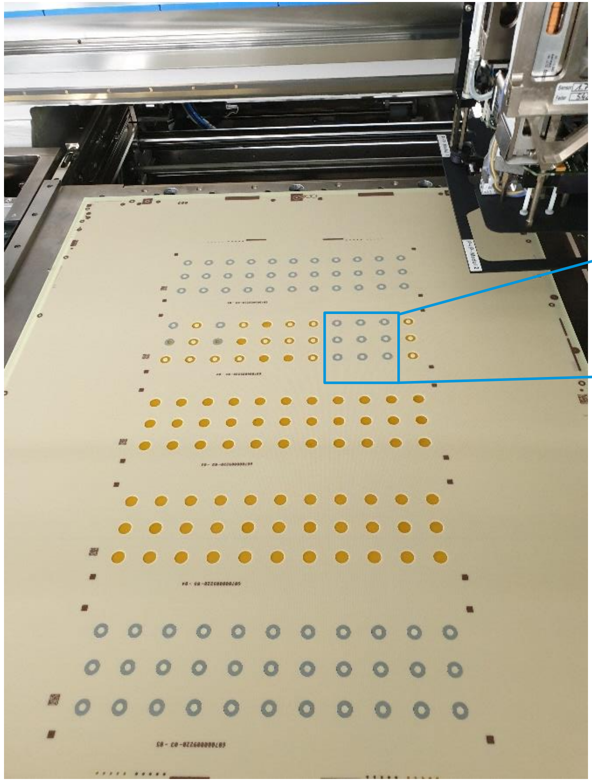
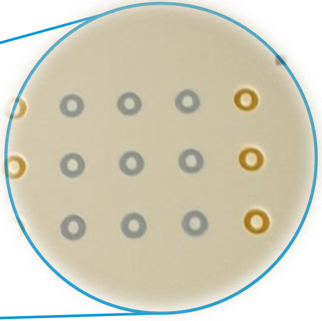
Automated Assembly of Inlays (II)





- Demonstrator assembly of inductor
- Optimized magnetic inlay geometry in combination with the part placement forms highly precise inductances

PCB embedding of Magnetic Material for Inductor-based Applications

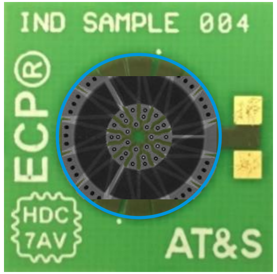
- Introduction
- Basics and Aim
- Embedding of magnetic material in FR4
- **Applications**
- Reliability
- Summary and Conclusion

PCB embedding of Magnetic Material for Inductor-based Applications

Application Example: Inductor (I)

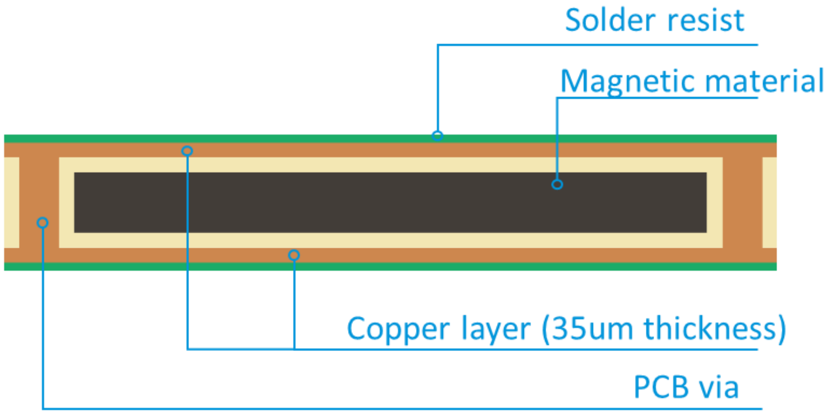
Highlights

- Two metal layer construction
- Different magnetic inlay 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



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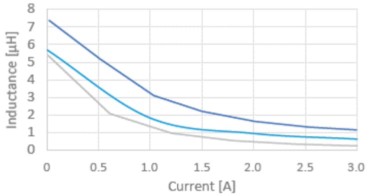
Application Example: Inductor (II)

Parameter	Symbol	Without air gap	With 1 air gap	With 3 air gaps	Standard SMD (2)	Benchmark
Inductance	L (@ 1 MHz)	5.7 µH	2.2 µH	1.15 µH	1.2 µH	Equal
Saturation current	I_{sat} (1)	300 mA	1.5 A	3.6 A	3.8 A	Equal
Rated current (DC)	I_R (@ ΔT = 40 K)		2.0 A		1.9 A	Equal
DC Resistance	R_{DC} (@ 0.1 A)		79 mΩ		82 mΩ	Equal
Self-resonance fr.	f_{res}	30 MHz	40 MHz	80 MHz	75 MHz	Equal
Package size	D_I/D_O		3/10.5 mm		2.5 x 2 mm	
Air gap length	l_g	-	500 µm	3 x 170 µm	-	
Total thickness	h		500 µm		1 mm	

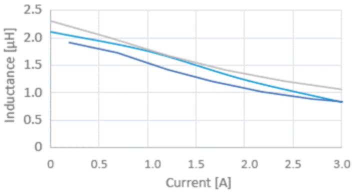
Embedding helps to optimize & customize inductors to meet complex product specifications.

Realization of ultra-thin constructions possible.

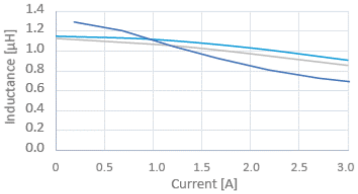
Without air gap



With one air gap



With three air gaps

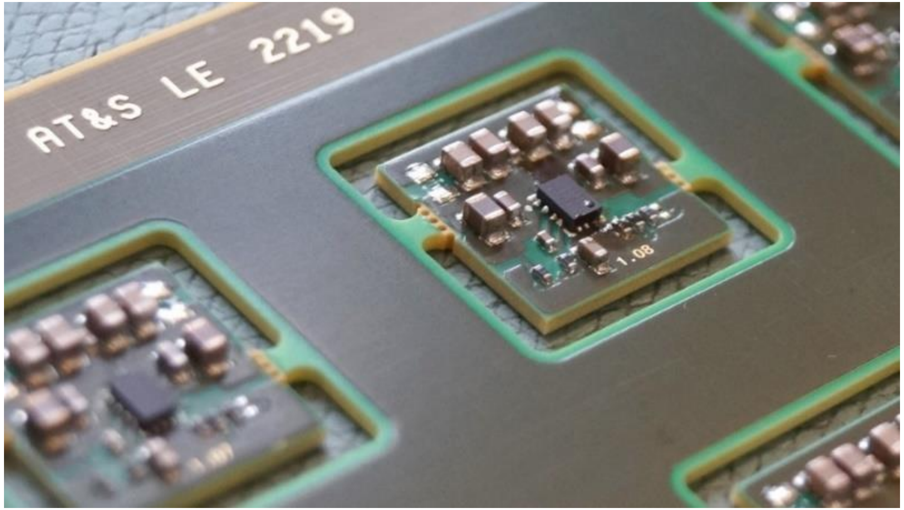


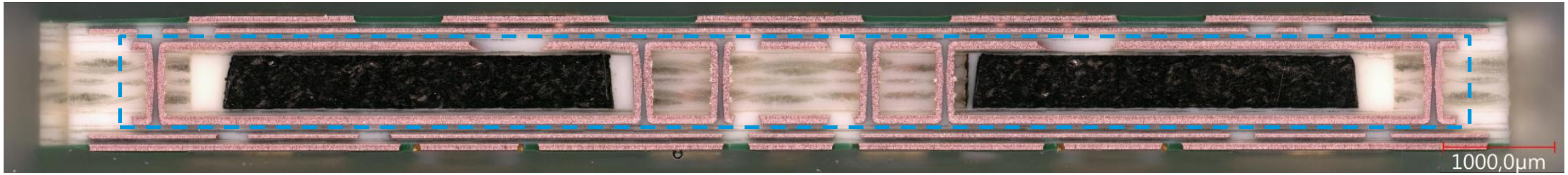
(1) Inductance drops 30% @ Isat
(2) Würth Electronics (74438323012)

PCB embedding of Magnetic Material for Inductor-based Applications

Application Example: DC/DC converter module (I)

- Conversion from 12V to 3.3V with buried inductor
- Target inductance: 2 µH @ a current of 3 A
- Module size: 13.3 x 14 mm
- Based on 6 metal layers
- Overall board thickness: 1.4 mm
- Single IC solution (LMR33630)
- No additional components embedded
- Functional Demonstrator
- Good magnetic inlay performance





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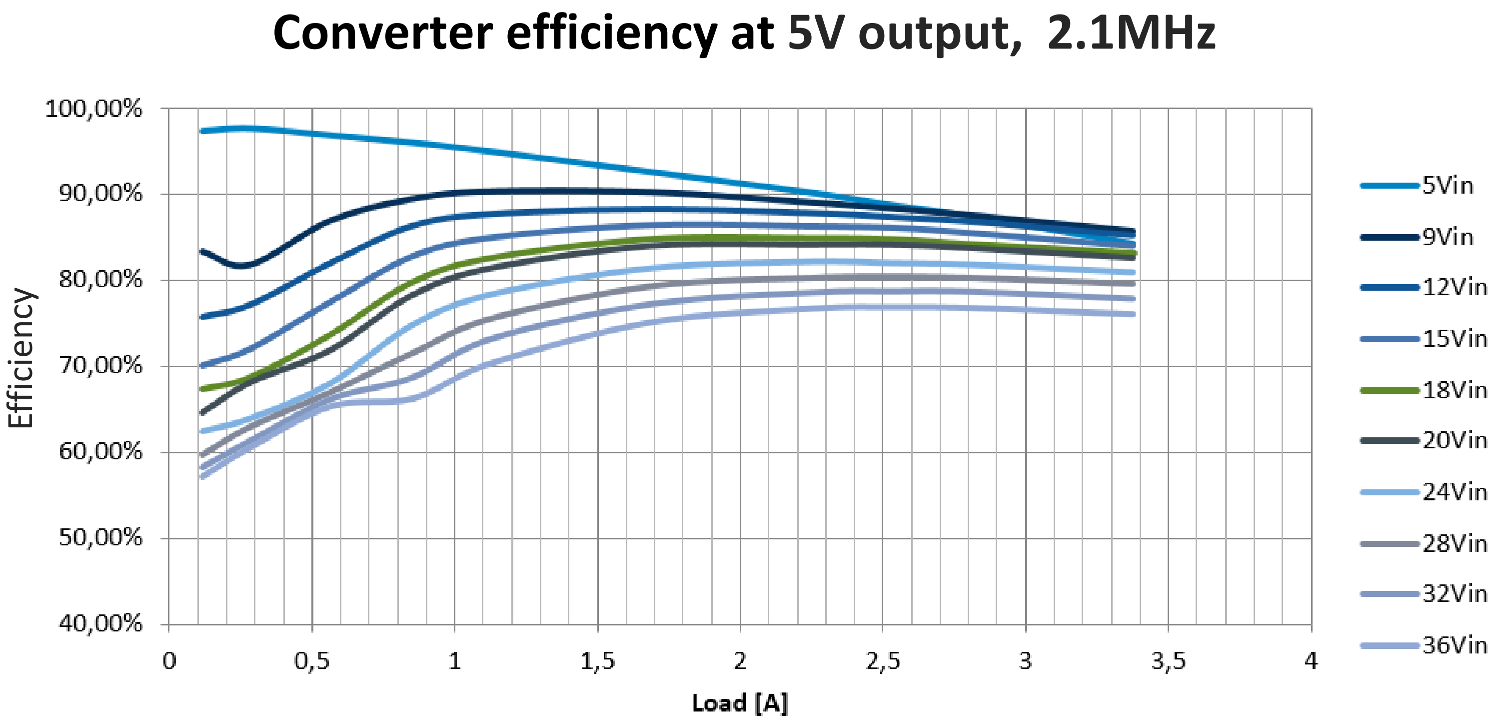
Application Example: DC/DC converter module (II)



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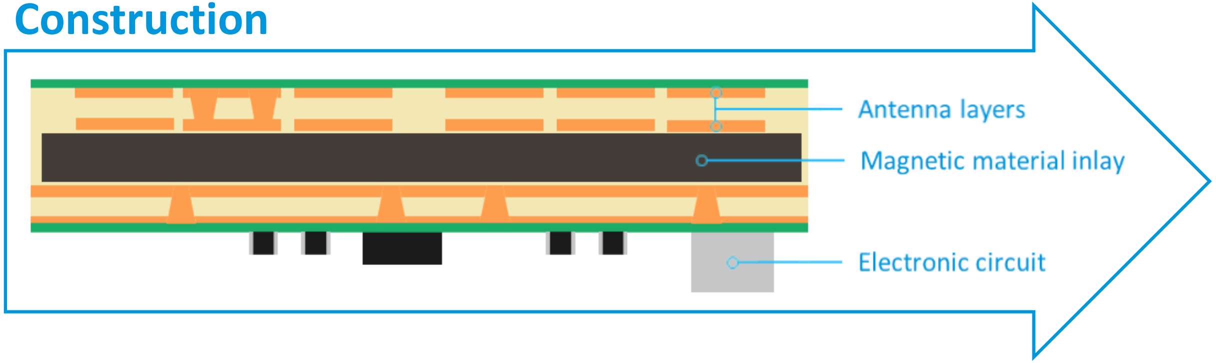
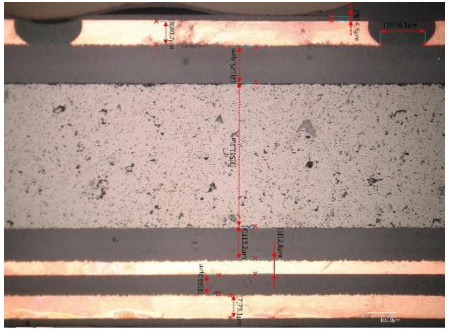
Application Example: Wireless transmitter pad

Highlights

- 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

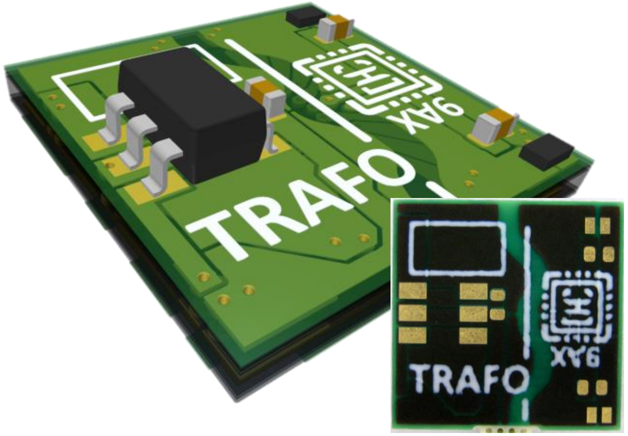
Construction

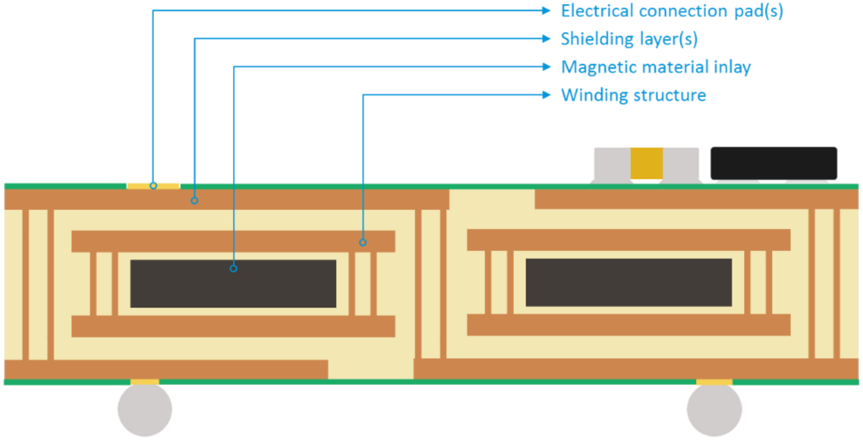




PCB embedding of Magnetic Material for Inductor-based Applications

Application Example: Transformer (I)





Transformer Demonstrator

- Wiring board dimensions: 10 mm x 10 mm x 920 µm
- Embedded magnetic inlay shape: ring
- Ideal for miniaturized isolated power supplies and high side gate drive applications
- Application configurable footprint & isolation performance

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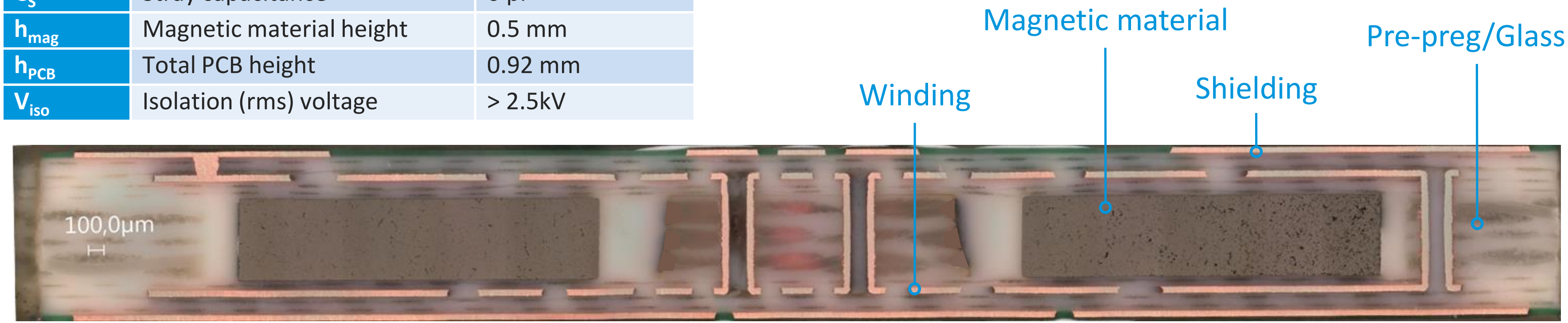
Application Example: Transformer (II)

Symbol	Parameter	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	0.5 A
I_{sec}	Secondary (rms) current	0.5 A
$R_{DC,1}$	DR resistance	~ 60mOhm
C_S	Stray capacitance	6 pF
h_{mag}	Magnetic material height	0.5 mm
h_{PCB}	Total PCB height	0.92 mm
V_{iso}	Isolation (rms) voltage	> 2.5kV

Highlights

- Based on push-pull converter concept
- Application optimization possible
- Variable inlay thicknesses
- Module design or PCB integration feasible



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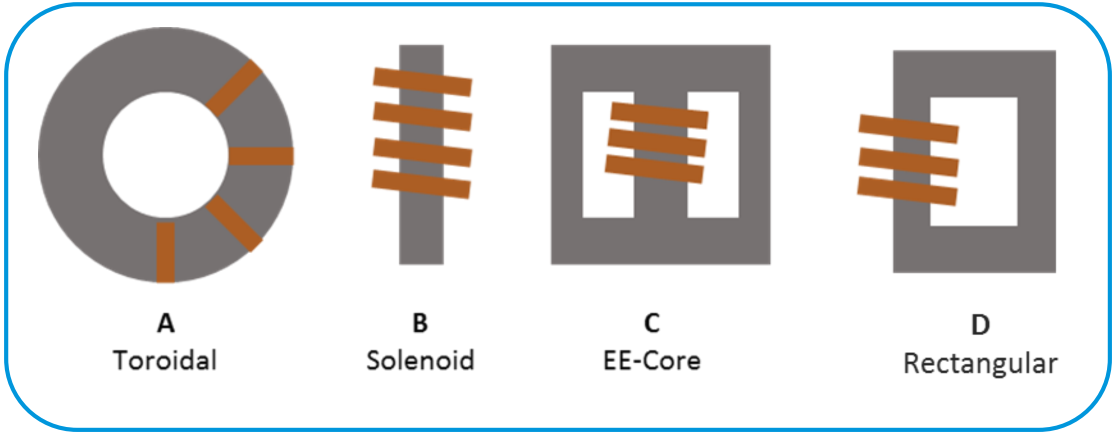
Magnetic Material Inlay - Possible Shape

- Processed performs with many different core shapes
- Actual limitations:
  - VIA count per area
  - Line/Space requirements @ demanded copper height
  - Current carrying capability



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Magnetic Material Inlay - Materials

- The following table shows a list of different materials available.
- Permeability and loss factors are nominal values.
- Please note that materials optimized for higher frequencies are not mentioned on this slide.

Material	µ‘ Permeability 2MHz	Loss factor 2 MHz	µ‘ Permeability 10 MHz	Loss factor 10 MHz	Material type
1	200	0,03	175	0,32	Resin sheet with metal particles
2	100	0,02	100	0,08	Resin sheet with metal particles
3	50	0,04	50	0,2	Resin sheet with ferrite particles
4	35	0,02	35	0,09	Resin sheet with ferrite particles
5	900	0,02	1	800	Sintered ferrite

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- **Reliability**
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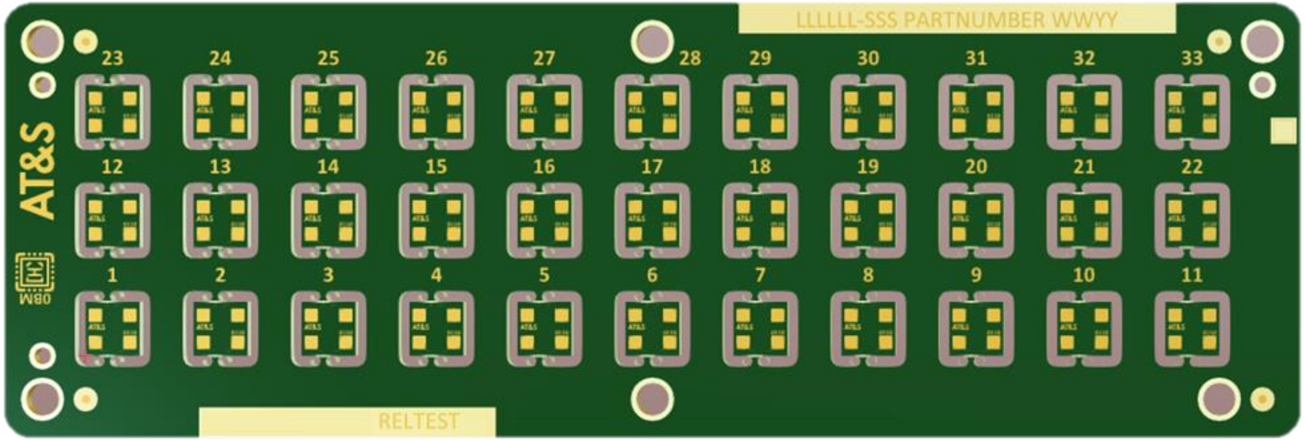
PCB embedding of Magnetic Material or Inductor-based Applications

Reliability Testing

Facts

- 33 samples/test panel
- 10 different magnetic materials embedded & tested
- Semi-automated electrical test fixture measures primary & leakage inductance

Reliability test panel



PCB embedding of Magnetic Material or Inductor-based Applications

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Reliability Testing – Applied test cycles & Measurement fixture

EPT01 Initial electrical parameter test

PreCon
Drying for 24h @ 125°C
MSL3a 40 h @ 60°C /60% RH
after 15min…max 4h: 3x reflow cycle

Max. 48h

EPT02 Electrical parameter test

RelTest
HAST: 96h, 130°C/85%RH or
TC: -55°C to 125°C or
LTS: 1000h, -55°C or
HTS: 1000h, 125°C or
THB: 1000h, 85°C / 85%RH

Max. 48h

EPT03 Electrical parameter test

Electrical measurement fixture

Semi-automated measurement includes test fixture and impedance analyser to gain results.

Note

During test of LTS, HTS and THB additional electrical tests are performed at 100h and 500h.

Legend

LTS	Low temperature storage
HTS	high temperature storage
TC	thermal cycling test
HAST	highly accelerated stress test
THB	temperature humidity bias test

To be continued…

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PCB embedding of Magnetic Material for Inductor-based Applications

Conclusion

- Flexible and scale-able solution
- Further miniaturization of power electronics
- Ultra thin concepts possible
- Different materials for application optimization available
- Technology useful for transformers, inductors, shielding and wireless power applications
- Embedding process compatible to almost all PCB technologies
- *Future:* Integration in interposers, substrates and modules
- *Ongoing:* Reliability

AT&S – First choice for advanced applications

AT & S Austria Technologie & Systemtechnik Aktiengesellschaft
(Headquarters)
Fabriksgasse 13,
8700 Leoben, Austria
Tel.: + 43 3842 200-0

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www.ats.net

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