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

Introduction to 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

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
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

Evolution of PCB based Inductors or Transformers

PCB embedding of Magnetic Material for Inductor-based Applications

Conventional vs. Embedded Solution

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

- Bulky
- Best fit only with customized ferrite
- Lower EMI performance
**PCB embedding of Magnetic Material for Inductor-based Applications**

Part of AT&S Product Portfolio

<table>
<thead>
<tr>
<th>ECP®: Embedded Component Packaging</th>
</tr>
</thead>
</table>
| **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. |

<table>
<thead>
<tr>
<th>Production site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leoben, Shanghai</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Devices such as smartphones, tablets, digital cameras and hearing aids</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IC substrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC substrates serve as interconnection platform with higher density (Line/Space &lt; 15 micron) between semiconductors (Chips) &amp; PCBs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substrate-like printed circuit boards mSAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate-like PCBs (mSAP technology) are the next evolution of high-end HDI PCBs with higher density: Line/Space &lt; 30 micron.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chongqing</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Chongqing, Shanghai</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-end processors for Computer, Communication, Automotive, Industrial</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile applications like smartphones</td>
</tr>
</tbody>
</table>
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

Embedding Process in Detail

- Qualified process based on the ECP® technology
- Circuit board layer count independent
- Compatible to nearly every PCB construction
PCB embedding of Magnetic Material for Inductor-based Applications

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
PCB embedding of Magnetic Material for Inductor-based Applications

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)

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner diameter</td>
<td>3</td>
<td>mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>10.5</td>
<td>mm</td>
</tr>
<tr>
<td>Total thickness</td>
<td>0.5</td>
<td>mm</td>
</tr>
<tr>
<td>Windings</td>
<td>16</td>
<td>turns</td>
</tr>
<tr>
<td>Outer diameter (blue circle)</td>
<td>12.3</td>
<td>mm</td>
</tr>
</tbody>
</table>

Demonstrator with visible X-Ray section
### PCB embedding of Magnetic Material for Inductor-based Applications

**Application Example: Inductor (II)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Without air gap</th>
<th>With 1 air gap</th>
<th>With 3 air gaps</th>
<th>Standard SMD (2)</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductance</td>
<td>L (1 MHz)</td>
<td>5.7 µH</td>
<td>2.2 µH</td>
<td>1.15 µH</td>
<td>1.2 µH</td>
<td>Equal</td>
</tr>
<tr>
<td>Saturation current</td>
<td>I&lt;sub&gt;sat&lt;/sub&gt; (1)</td>
<td>300 mA</td>
<td>1.5 A</td>
<td>3.6 A</td>
<td>3.8 A</td>
<td>Equal</td>
</tr>
<tr>
<td>Rated current (DC)</td>
<td>I&lt;sub&gt;R&lt;/sub&gt; (ΔT = 40 K)</td>
<td>2.0 A</td>
<td>1.9 A</td>
<td>Equal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC Resistance</td>
<td>R&lt;sub&gt;DC&lt;/sub&gt; (0.1 A)</td>
<td>79 mΩ</td>
<td>82 mΩ</td>
<td>Equal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-resonance fr.</td>
<td>f&lt;sub&gt;res&lt;/sub&gt;</td>
<td>30 MHz</td>
<td>40 MHz</td>
<td>80 MHz</td>
<td>75 MHz</td>
<td>Equal</td>
</tr>
<tr>
<td>Package size</td>
<td>D/D&lt;sub&gt;O&lt;/sub&gt;</td>
<td>3/10.5 mm</td>
<td>2.5 x 2 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air gap length</td>
<td>l&lt;sub&gt;g&lt;/sub&gt;</td>
<td>-</td>
<td>500 µm</td>
<td>3 x 170 µm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total thickness</td>
<td>h</td>
<td>500 µm</td>
<td></td>
<td>1 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Realization of ultra-thin constructions possible.

(1) Inductance drops 30% @ I<sub>sat</sub>
(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
PCB embedding of Magnetic Material for Inductor-based Applications

Application Example: DC/DC converter module (II)

Converter efficiency at 5V output, 2.1MHz
PCB embedding of Magnetic Material for Inductor-based Applications

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

- Antenna layers
- Magnetic material inlay
- Electronic circuit
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
PCB embedding of Magnetic Material for Inductor-based Applications

Application Example: Transformer (II)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Turns ratio</td>
<td>10:11</td>
</tr>
<tr>
<td>( V_{\text{in}} )</td>
<td>Input voltage</td>
<td>24 V</td>
</tr>
<tr>
<td>( f_{\text{sw}} )</td>
<td>Switching frequency</td>
<td>1.6 MHz</td>
</tr>
<tr>
<td>( L_{\text{m}} )</td>
<td>Magnetizing inductance</td>
<td>3.5 µH</td>
</tr>
<tr>
<td>( L_{\text{leak}} )</td>
<td>Leakage inductance</td>
<td>0.5 µH</td>
</tr>
<tr>
<td>( I_{\text{prim}} )</td>
<td>Primary (rms) current</td>
<td>0.5 A</td>
</tr>
<tr>
<td>( I_{\text{sec}} )</td>
<td>Secondary (rms) current</td>
<td>0.5 A</td>
</tr>
<tr>
<td>( R_{\text{DC,1}} )</td>
<td>DR resistance</td>
<td>~ 60mOhm</td>
</tr>
<tr>
<td>( C_{\text{s}} )</td>
<td>Stray capacitance</td>
<td>6 pF</td>
</tr>
<tr>
<td>( h_{\text{mag}} )</td>
<td>Magnetic material height</td>
<td>0.5 mm</td>
</tr>
<tr>
<td>( h_{\text{PCB}} )</td>
<td>Total PCB height</td>
<td>0.92 mm</td>
</tr>
<tr>
<td>( V_{\text{iso}} )</td>
<td>Isolation (rms) voltage</td>
<td>&gt; 2.5kV</td>
</tr>
</tbody>
</table>

### Highlights

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

Magnetic material

Pre-preg/Glass

Winding

Shielding
PCB embedding of Magnetic Material for Inductor-based Applications

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
PCB embedding of Magnetic Material for Inductor-based Applications

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.

<table>
<thead>
<tr>
<th>Material</th>
<th>$\mu'$ Permeability 2MHz</th>
<th>Loss factor 2 MHz</th>
<th>$\mu'$ Permeability 10 MHz</th>
<th>Loss factor 10 MHz</th>
<th>Material type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>200</td>
<td>0,03</td>
<td>175</td>
<td>0,32</td>
<td>Resin sheet with metal particles</td>
</tr>
<tr>
<td>2</td>
<td>100</td>
<td>0,02</td>
<td>100</td>
<td>0,08</td>
<td>Resin sheet with metal particles</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>0,04</td>
<td>50</td>
<td>0,2</td>
<td>Resin sheet with ferrite particles</td>
</tr>
<tr>
<td>4</td>
<td>35</td>
<td>0,02</td>
<td>35</td>
<td>0,09</td>
<td>Resin sheet with ferrite particles</td>
</tr>
<tr>
<td>5</td>
<td>900</td>
<td>0,02</td>
<td>1</td>
<td>800</td>
<td>Sintered ferrite</td>
</tr>
</tbody>
</table>
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 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
PCB embedding of Magnetic Material or Inductor-based Applications

Reliability Testing – Applied test cycles & Measurement fixture

---

**EPT01**
Initial electrical parameter test

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

**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

**EPT03**
Electrical parameter test

**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

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

To be continued...
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

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

www.ats.net
Disclaimer

This presentation is provided by AT & S Austria Technologie & Systemtechnik Aktiengesellschaft, having its headquarter at Fabriksgasse 13, 8700 Leoben, Austria, or one of its affiliated companies (“AT&S”), and the contents are proprietary to AT&S and for information only.

AT&S does not provide any representations or warranties with regard to this presentation or for the correctness and completeness of the statements contained therein, and no reliance may be placed for any purpose whatsoever on the information contained in this presentation, which has not been independently verified. You are expressly cautioned not to place undue reliance on this information.

This presentation may contain forward-looking statements which were made on the basis of the information available at the time of preparation and on management’s expectations and assumptions. However, such statements are by their very nature subject to known and unknown risks and uncertainties. As a result, actual developments, results, performance or events may vary significantly from the statements contained explicitly or implicitly herein.

Neither AT&S, nor any affiliated company, or any of their directors, officers, employees, advisors or agents accept any responsibility or liability (for negligence or otherwise) for any loss whatsoever out of the use of or otherwise in connection with this presentation. AT&S undertakes no obligation to update or revise any forward-looking statements, whether as a result of changed assumptions or expectations, new information or future events.

This presentation does not constitute a recommendation, an offer or invitation, or solicitation of an offer, to subscribe for or purchase any securities, and neither this presentation nor anything contained herein shall form the basis of any contract or commitment whatsoever. This presentation does not constitute any financial analysis or financial research and may not be construed to be or form part of a prospectus. This presentation is not directed at, or intended for distribution to or use by, any person or entity that is a citizen or resident or located in any locality, state, country or other jurisdiction where such distribution, publication, availability or use would be contrary to law or regulation or which would require any registration or licensing within such jurisdiction.