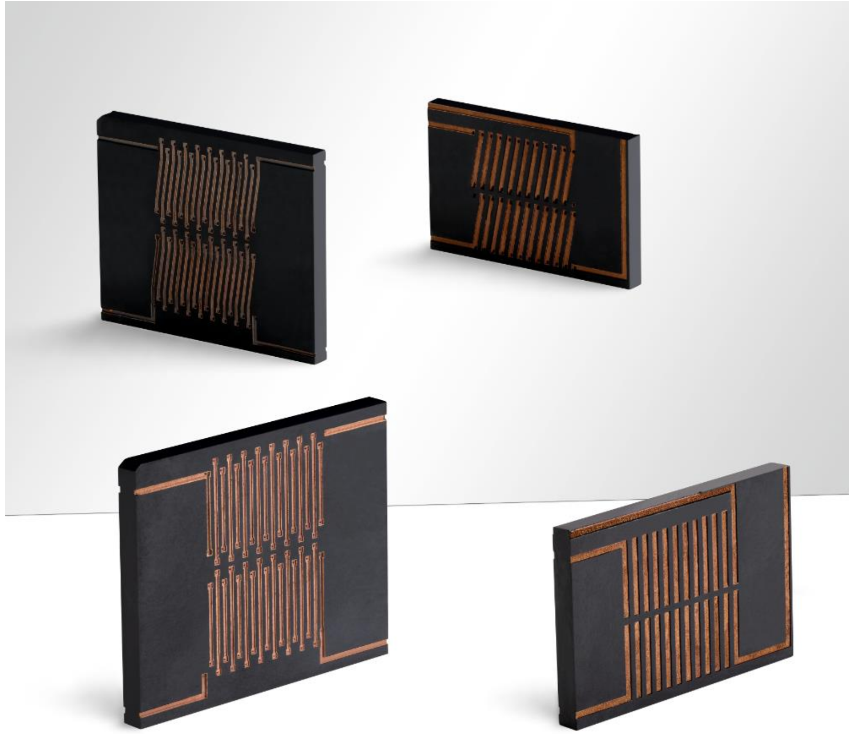


Fig. 1: MID Transformers

Manufacturing of Plastic-Based Inductors – a New Approach PWR SoC 2023

Ensinger Microsystems Technology - LDS-MID-Transformers

Engineering and Production Competence in High-Performance Plastics

Fig. a: Ensinger Nufringen, Germany

Fig. b: Ensinger Ergenzingen, Germany

Founded: 1966

Managing Directors:
Dr. Roland Reber, Ralph Pernizsak

Headquarters:
Nufringen, Baden-Württemberg

Employees:
appr. 2.600

Turnover:
appr. 500 Mio. Euro

Locations Worldwide: 35

Materials:
Engineering plastics and HT plastics

Content

Ensinger

- LDS MID Transformer
  - SoA and Benefits
  - Advantage “No Packaging" when Combined with LDS
  - Application Example LAN Transformer
- Concept
- Design
- Simulation
- Results Transformer 1
- Results Transformer 2
- Troubleshooting
- Discussion and Outlook

SoA and Benefits: SMD Coils/Transformers/Filters etc.

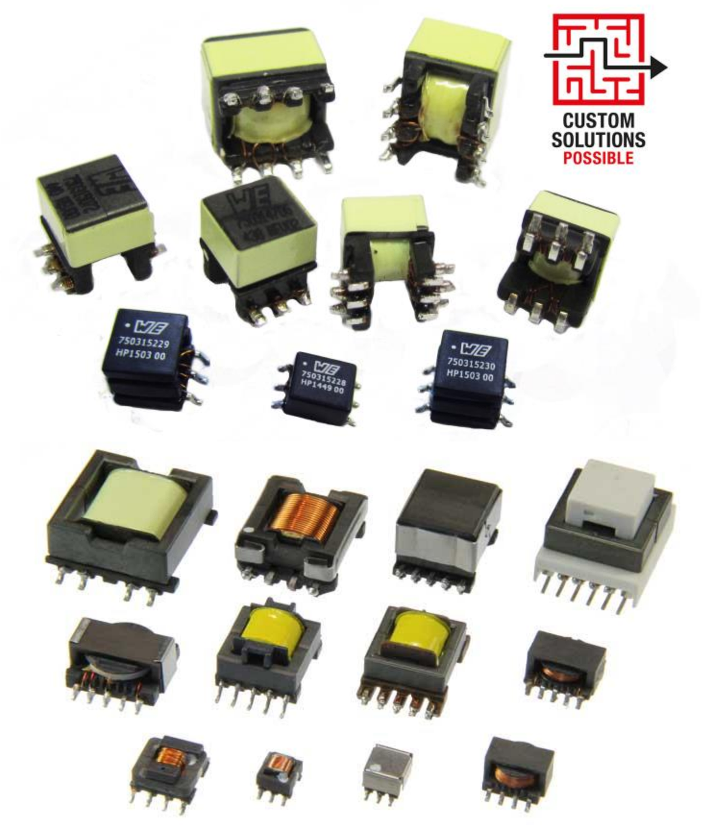


Fig. 2: Variety of SMD coil systems

Source: Würth Electronic

- Wound coils for transformers/inductors and filters are state of the art
- Winding technology is complex and cost-intensive
- Construction height is limited by winding technology and core
- Additional packaging increases volume
- Contacting via SMD package is usually challenging
- Laser-drilling of VIAs (Vertical Interconnect Access - VIA) through LDS technology
- Thus soldering of backside contacts possible
- **No winding technology**
- **No package necessary**
- Core integrated in MID component
- Winding of the conductor path via "daisy-chain" (LDS)

Advantage “No Packaging" when Combined with LDS

- Insertion of vias through LDS technology
- Thus "daisy-chain" windings and soldering of backside contacts possible
- **No winding** technology
- **No housing** necessary
- **Volume savings** of up to **80 %** possible
- **Weight savings** due to significantly lower copper content
- **Material savings** on core, housing and copper leads

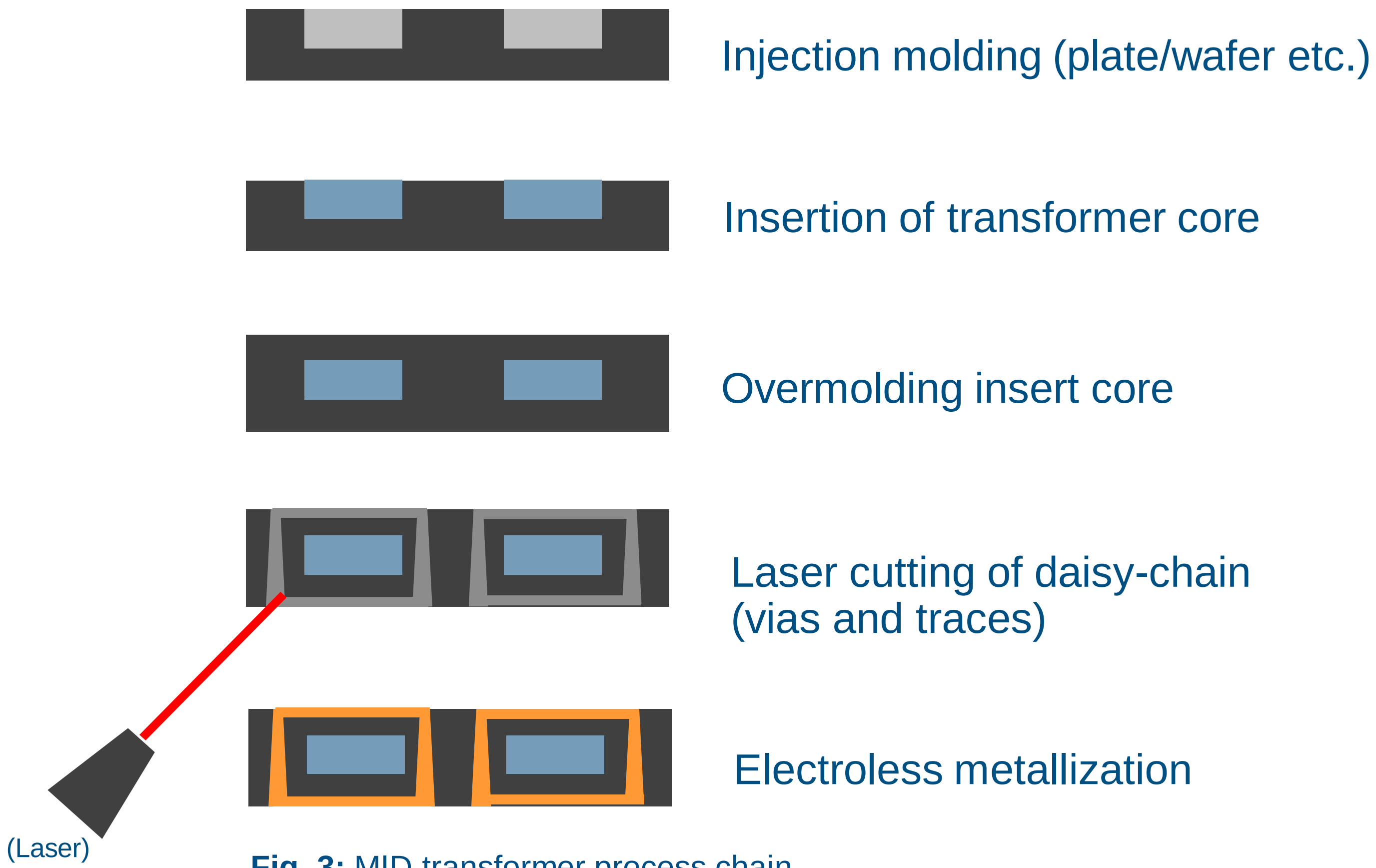


Fig. 3: MID transformer process chain

Application Example LAN Transformer

- Reduced number of production steps
- Requirements for plant technology and equipment significantly reduced
- Elimination of winding technology and packaging
- Short supply chain
- Example LAN transformer (component costs with winding technology between 5 - 12 € per component)

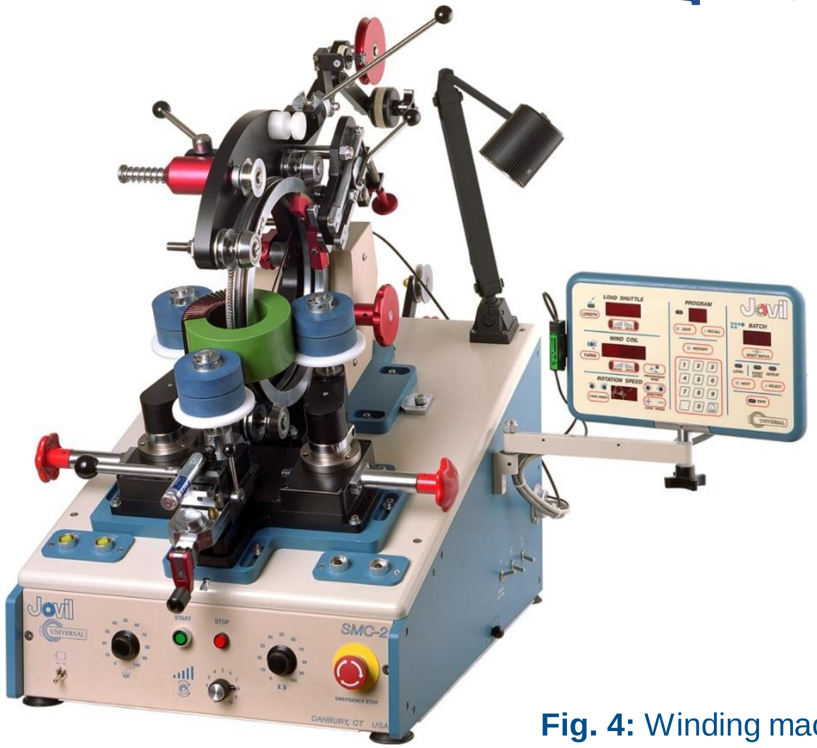


Fig. 4: Winding machine

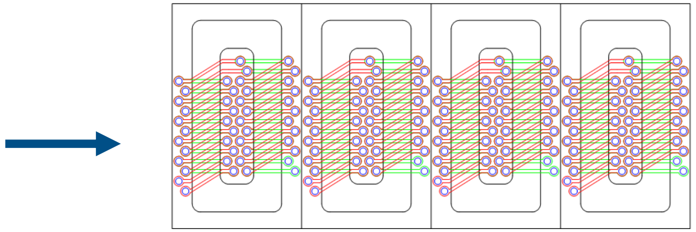


Fig. 5: LAN transformer SMD coil systems vs. Ensinger Transformer Design

Source: www.armaturewindingmachine.com

Concept

- Define core material (ferrites)
- LAN transformer Standard IEEE 802.3: minimum inductance 350 µH – difficult to reach!
- More windings and smaller core cross-section as previoius manufactured inductivities mandatory
- Problematic to find specific data for benchmarking
- Racetrack design to reach low resistance values and higher spaces for condcutive paths – mor windings

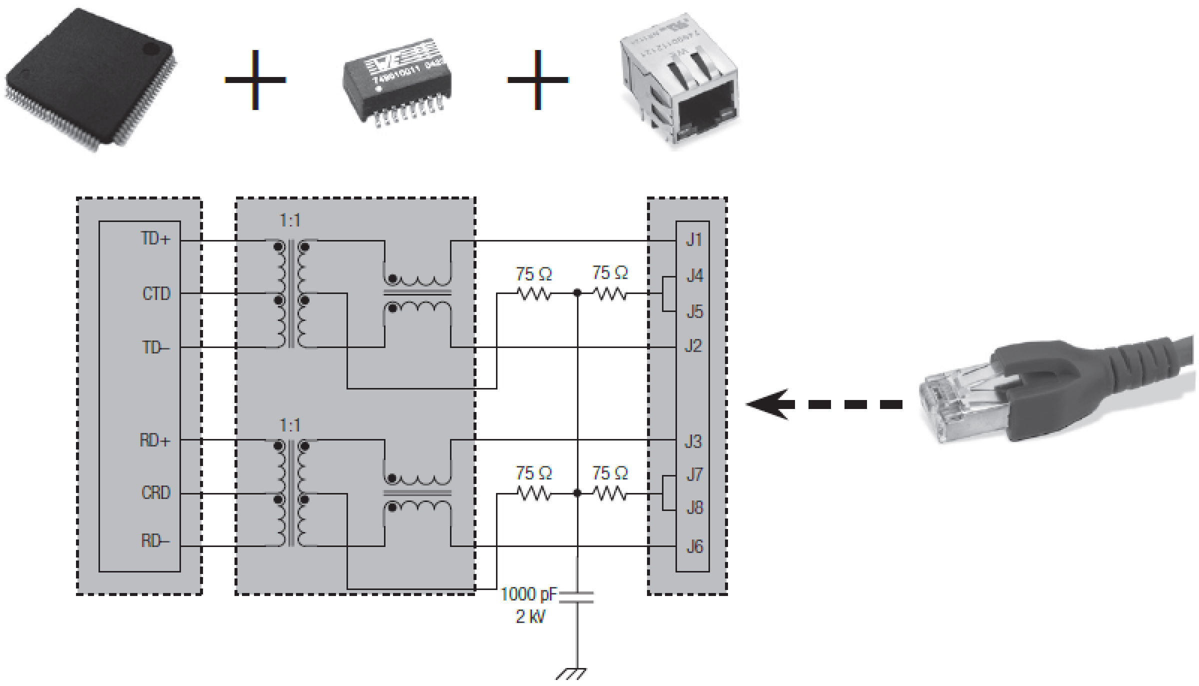


Fig. 6: Ethernet transformer with connectors

Source: https://www.we-online.de

Design

- Footprint: 31 mm x 13.5 mm x 2,5 mm
  - Housing standard: e.g. CDIP JW (Texas Instruments)
- Core height: 1,5 mm
- Core material: *Tridelta MF106, MF143, MF199*
- Permeabilties between 1000 and 2000
- VIA diameter: 400 µm
- Laser Direct Structuring using *LPKF Fusion 3D 1100 and Keyence Laser System*

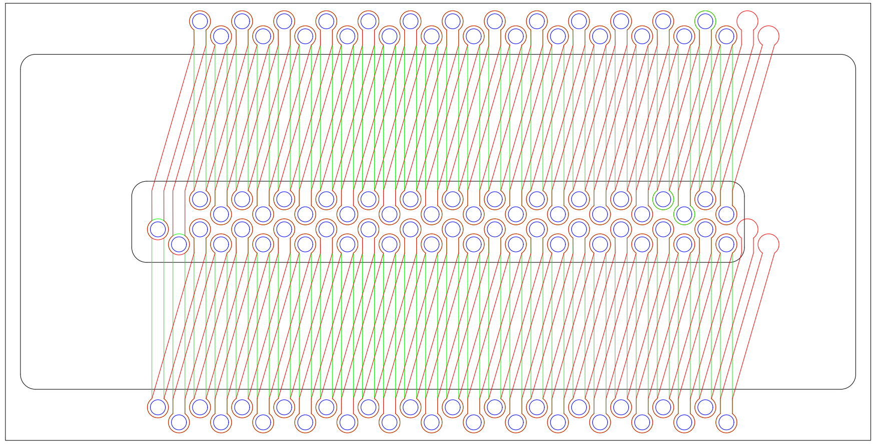


Fig. 7: Transformer 1: 1 core and 2 windings

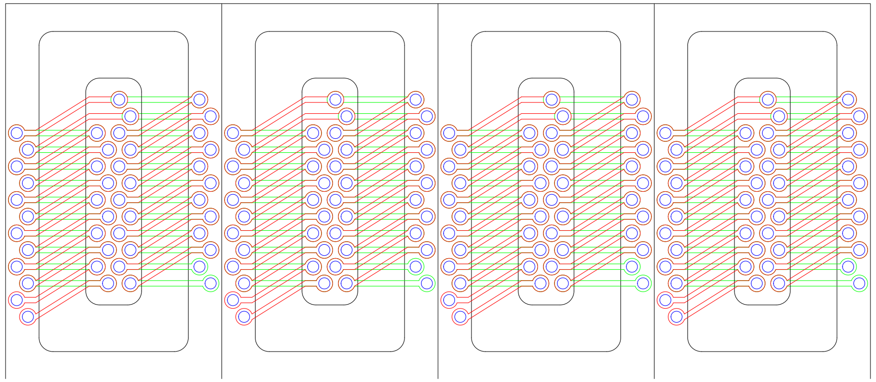
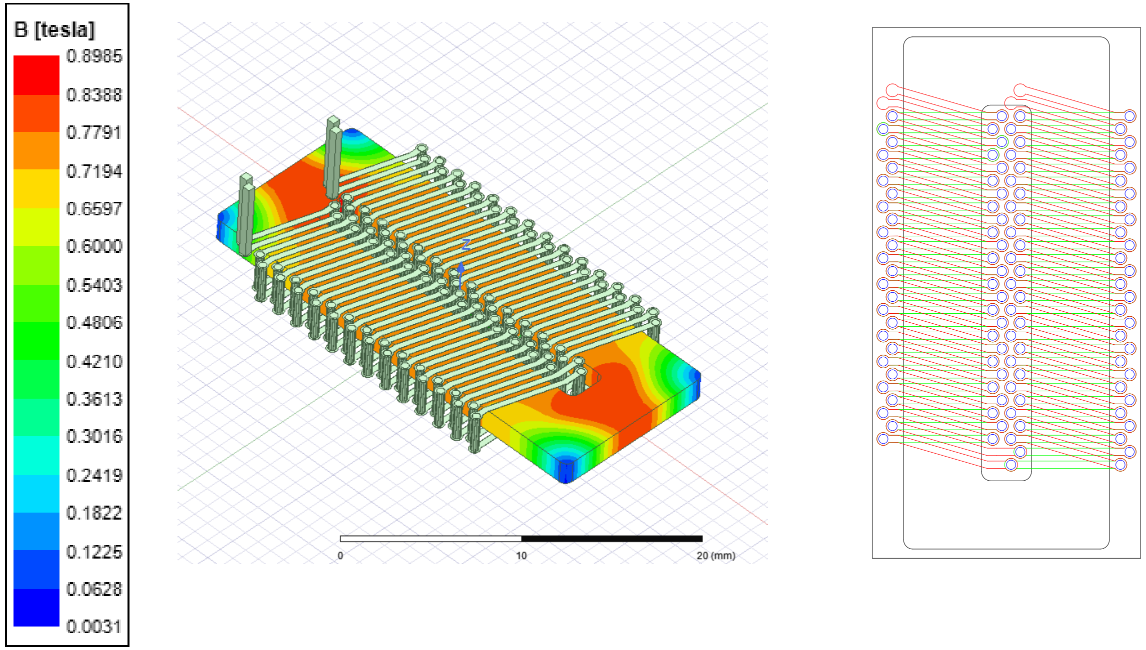
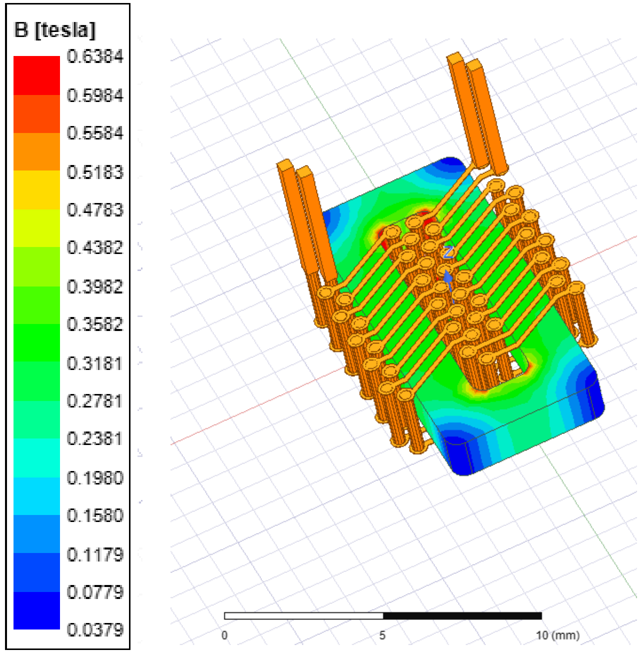


Fig. 8: Transformer 2: 4 cores and 8 windings

Simulation





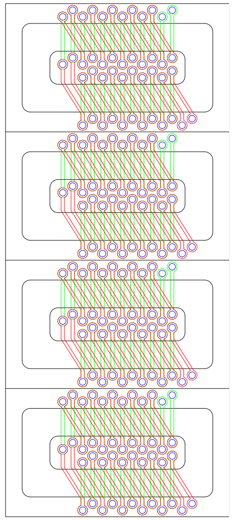


Fig. 9: Simulation results

- 2 Racetrack cores:
  - Core diameter: 2,6 mm²
- Coils: 2
- Windings : 40:40 (1:1)
- Current : 400mA

- Inductivity: 35 µH
- Resistance: 906 mΩ

- 4 Racetrack cores:
  - Core diameter: 2,5 mm²
- Windings: 12:12 (1:1)
- Current: 500 mA

- Inductivity: 30 µH
- Resistance: 342 mΩ
- Comparable for LAN applications
  - TMS61518CS (2)
  - PLC-002 (1)

Results Transformer 1 I

- MID transformer production successful
- Successfully produced transformers 10 out of 13 (77%)
- 10 of them tested with LCR meter

Tab. 1: Simulated data of transformer 1

Transformer 1	
Air Gap	500 µm
Current	2 A
Primary inductivity	35,0 µH
Secondary inductivity	35,0 µH
Primary resistance	3,3 Ω
Secondary resistance	3,3 Ω
Coupling factor	**Up to 99,6 %**

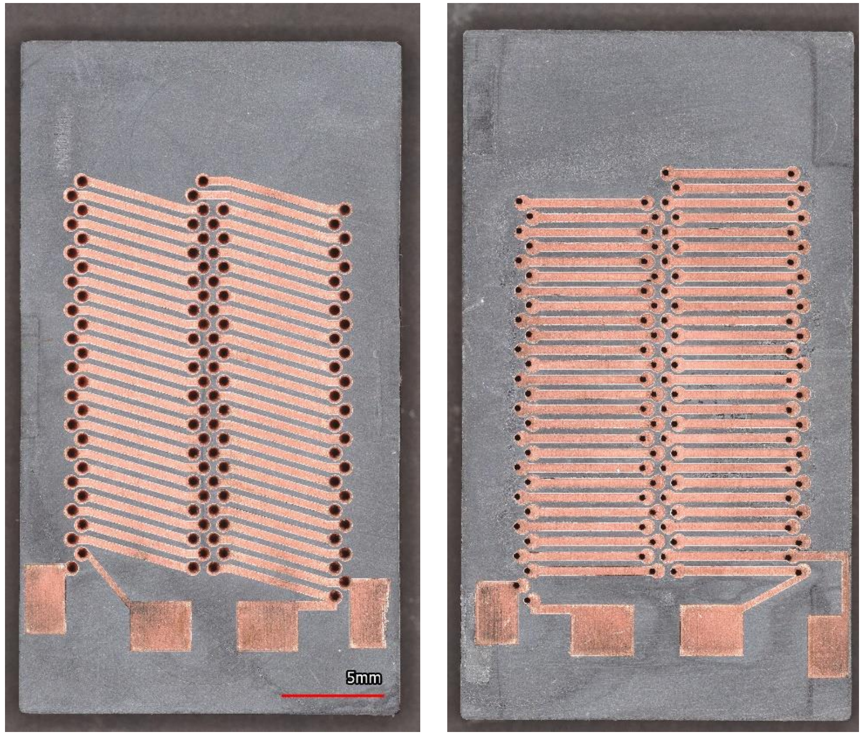


Fig. 10: Front- and backside of transformer 1

Results Transformer 1 II

Inductivity Values and Coupling Factor

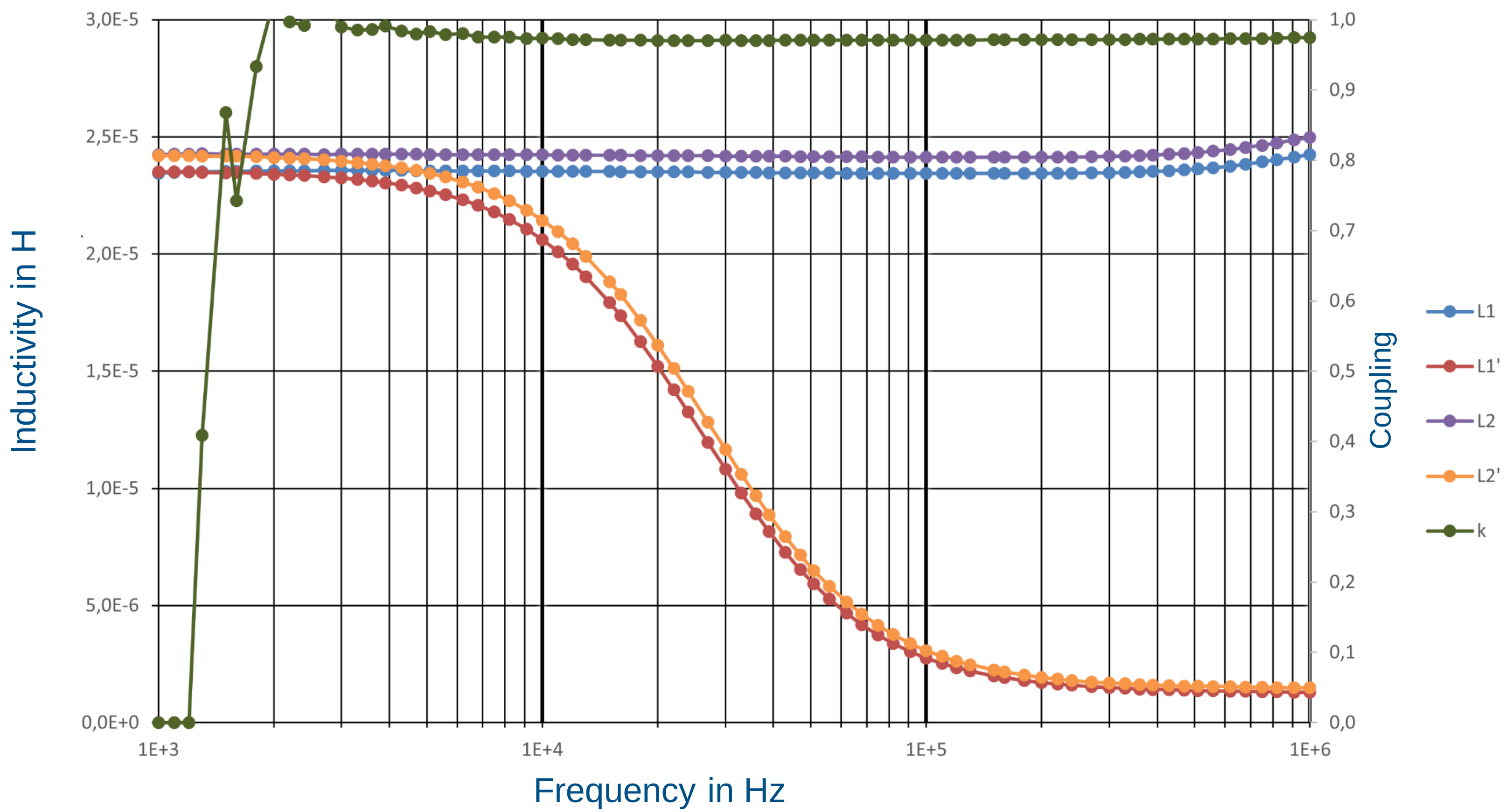


Fig. 11: inductivity values and coupling factor

Results Transformer 1 III

- 9 out of 10 manufactured transformers are within the tolerance of 15 %.
- Resistances vary from 1.5 Ω to 4 Ω
- Current carrying capacity still needs to be tested
- Coupling factor at over 95%
- Production chain with reproducible values is in place

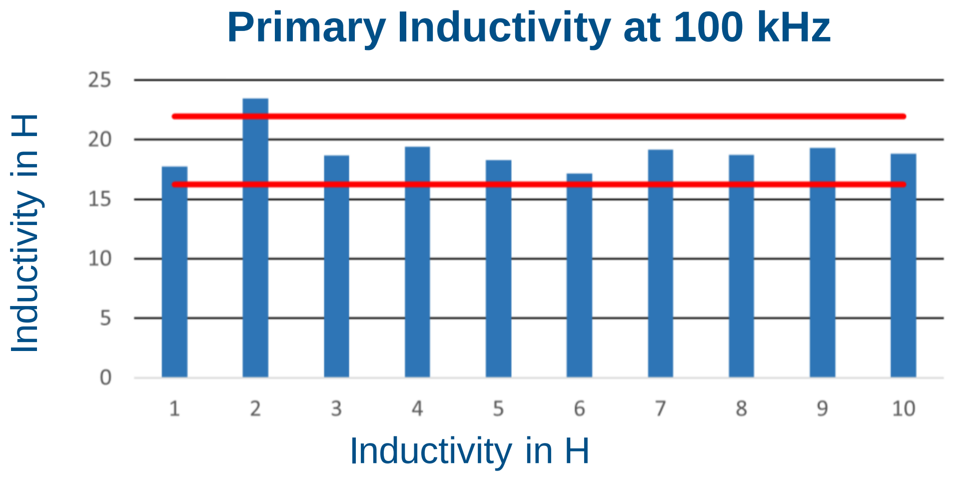


Fig. 12: inductivity at 100 kHz

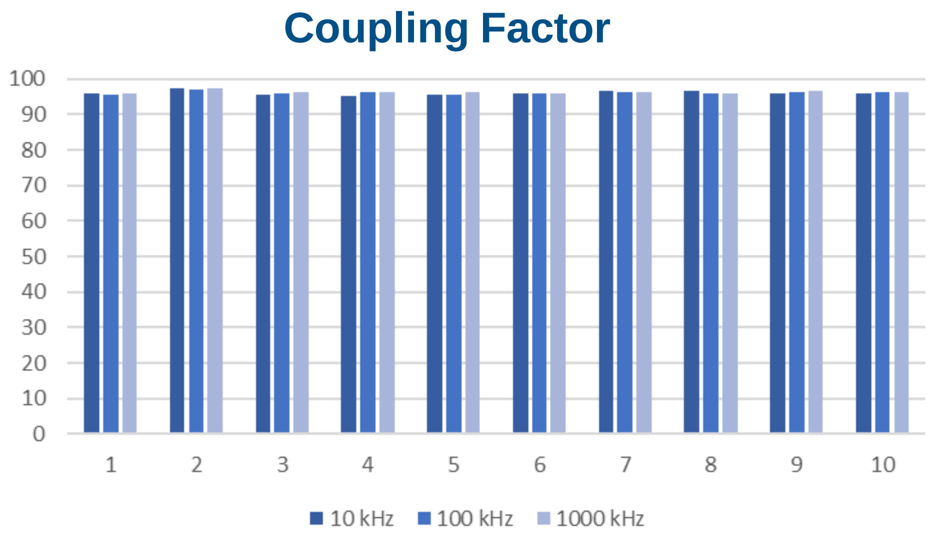


Fig. 13: Coupling factor

Results Transformer 2 I

- Production of MID transformers successful
- Successfully produced transformers 37 out of 40 (92.5%)
- tested with LCR meter

Tab 2: Simulated data of transformer 2

Lan Transformator	
Air Gap	none
Current	100 mA
Primary inductivity	30 µH
Secondary inductivity	30 µH
Primary resistance	0,34 Ω
Secondary resistance	0,34 Ω
Coupling factor	**Up to 99,9 %**

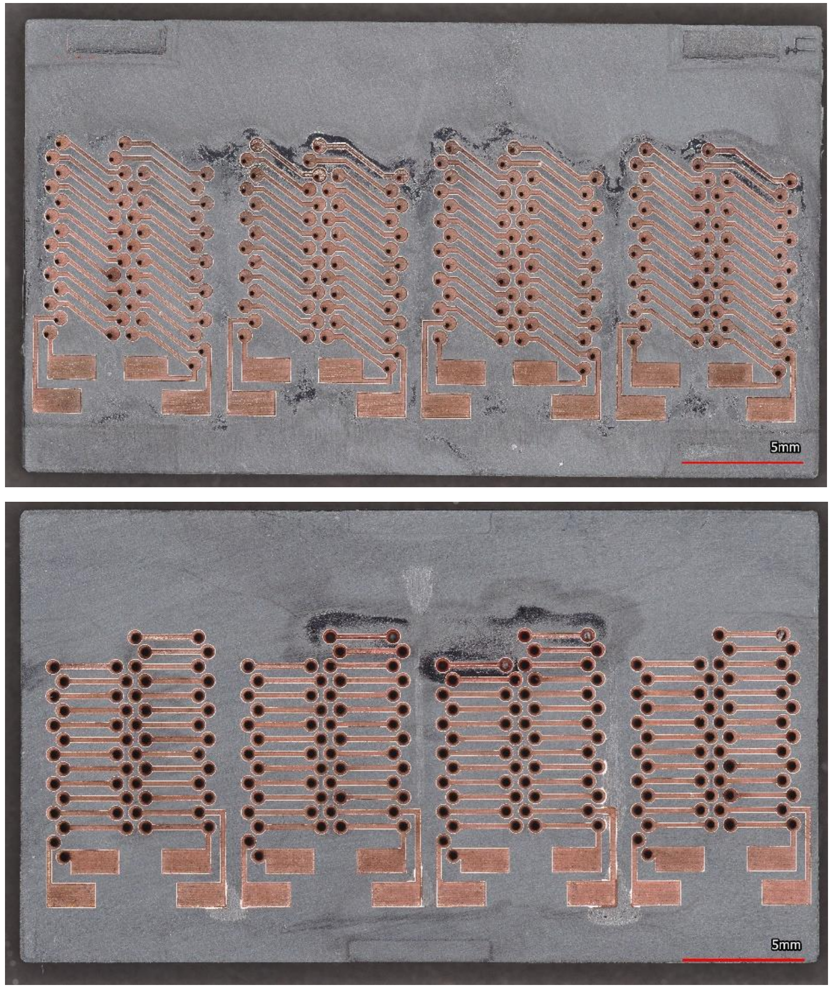


Fig. 14: Front- and backside of transformer 4

Results Transformer 2 II

- Successfully manufactured transformers 37 out of 40 (92.5 %)
- High tolerances between transformers even on a single PEEK chip
- Resistances vary from 1 Ω to 5 Ω
- High coupling factors up to 99 %.
- High quality in the manufacturing process

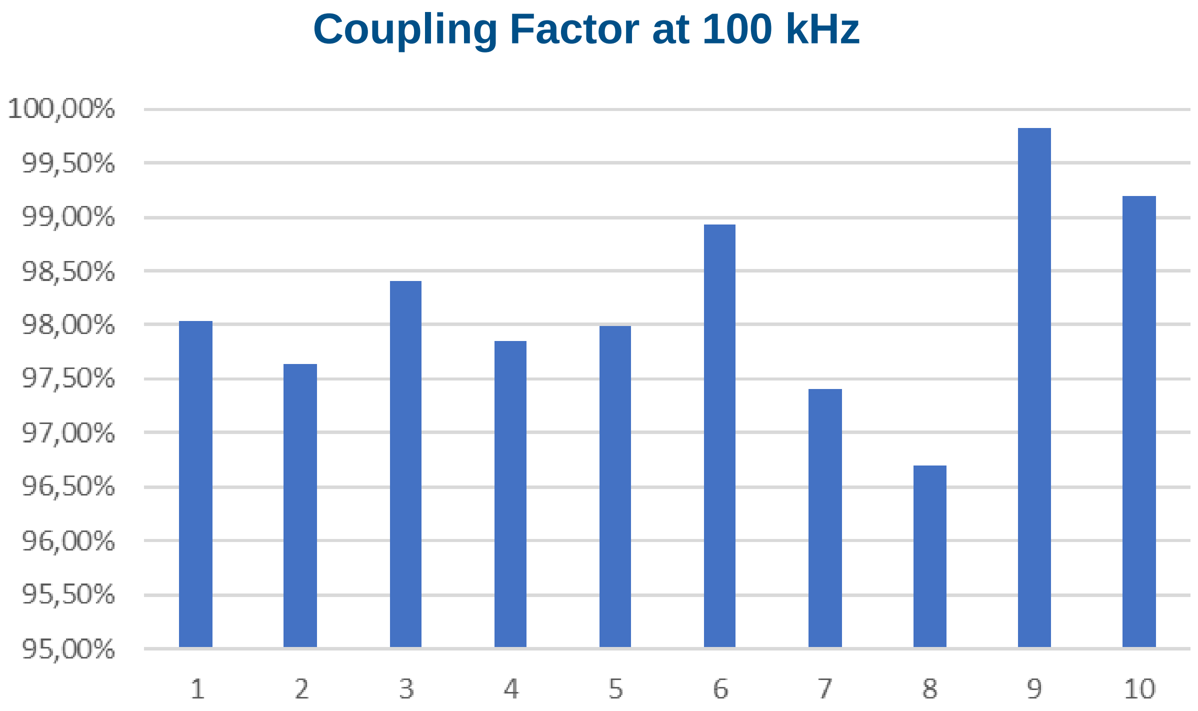


Fig. 16: coupling factor at 100 kHz

Results Transformer 2 III

- Successfully manufactured transformers 37 out of 40 (92.5 %)
- High tolerances between transformers even on a single PEEK chip
- Resistances vary from 1 Ω to 5 Ω
- High coupling factors up to 99 %.
- High quality in the manufacturing process

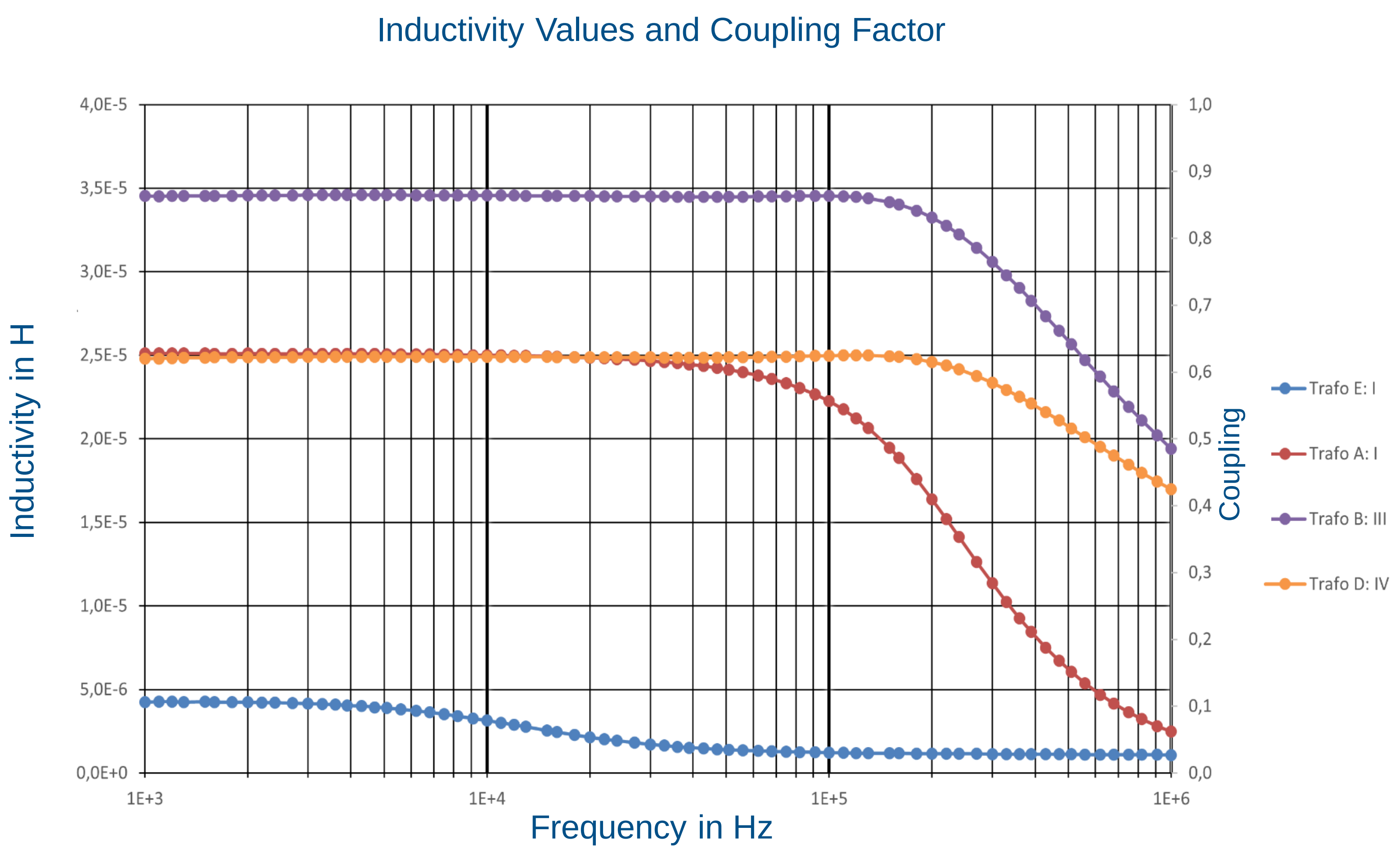


Fig. 17: inductivity values and coupling factor

Troubleshooting

- Finest cracks form on the longitudinal parts
- Toroid geometry could be more efficient
- Cracks at similar positions
- Cracks form differently
- Difficult to determine the number per core
- Small cracks of <10 µm visible
- Simulation with an additional air gap of 3 µm and 7 µm (total 10 µm) results in an inductance of 24 µH
- Corresponds to real conditions

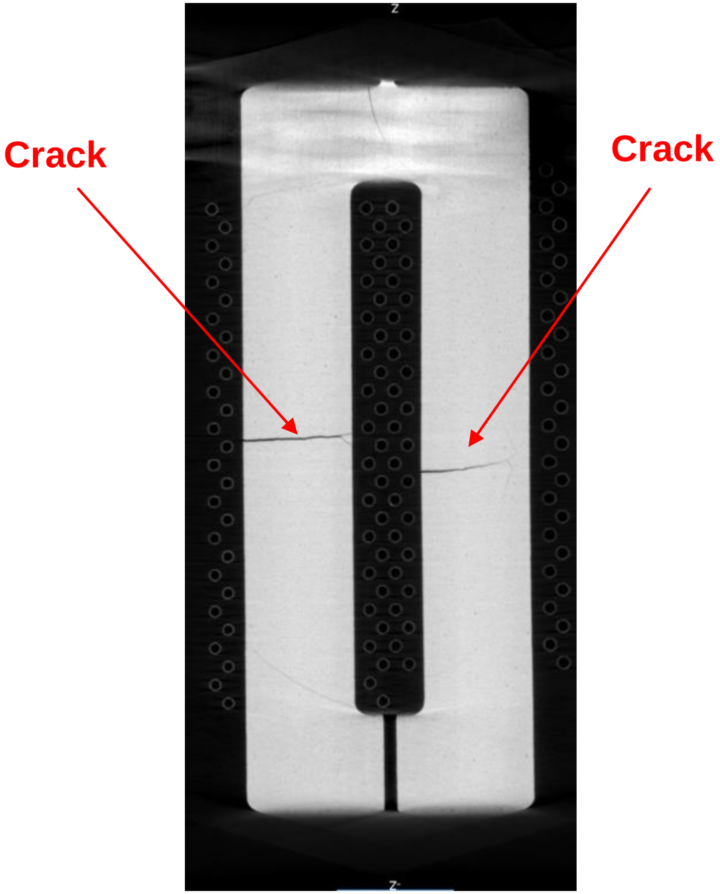


Fig. 18: Core of transformer 1

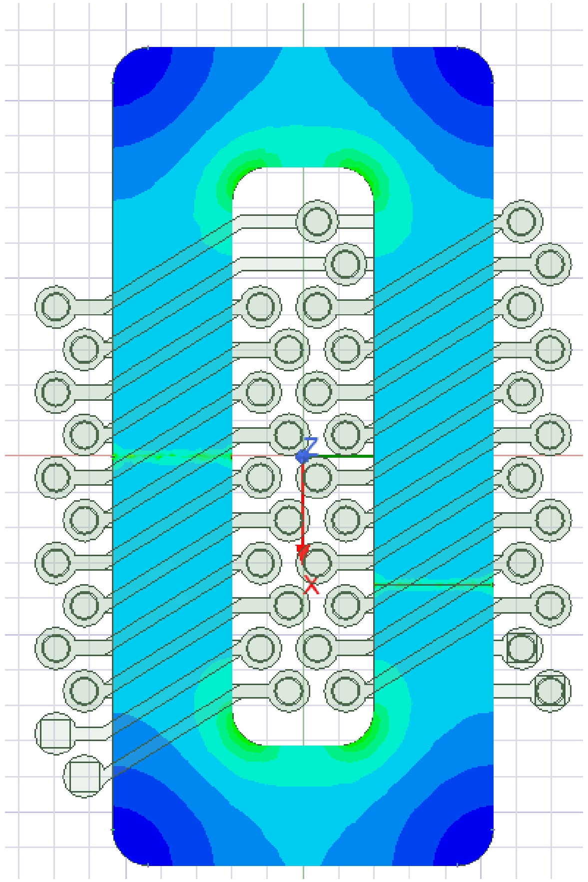


Fig. 19: Simulation with two air gaps

Discussion and Outlook

- **MID transformers** in cooperation of Ensinger and IMPT could be **manufactured**
- **Low failure rate** especially with Lan transformers
- Optimization of electroless deposition by better controlled circulation
- Inductance values do not reach the simulated values
- In the Lan transformer, different drop of inductances with increasing frequency
- Possible solutions: Core data from manufacturer not sufficient - VSM analysis at IMPT does not indicate variances
- Core material not homogeneous over the plate?
- Microcracks in core due to injection molding seem to interfere with simulation results
- **High coupling factors** in the functional transformers
- **Production chain developed** even in high volumes

  - **Outlook**
    - **Preventing the cracks**
    - Geometry changes: toroid should be more stable
    - Optimize injection molding tool
    - Protective layer: makes system larger overall

Special thanks to:

IMPT
Hahn Schickard
Tridelta Weichferrite

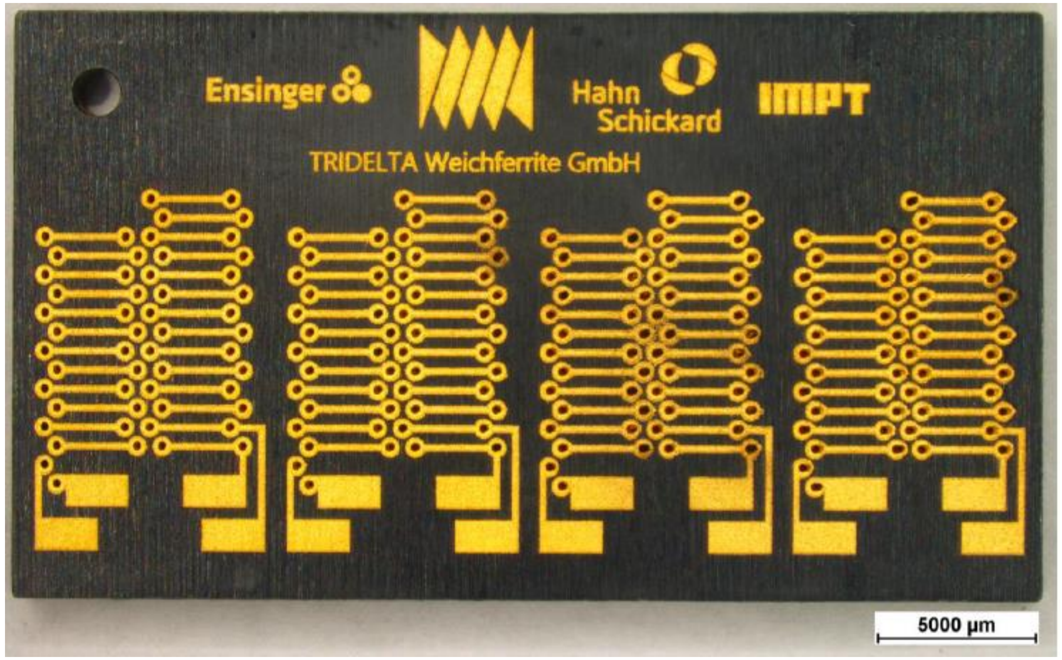


Fig. 20: Final Transformer