Microtransformer / Microinductor on Silicon for Point-of-Load High Frequency Power Applications

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Overview

- Requirements on inductors and transformers
- Design of the microtransformer
- Fabrication
- Test results
- Conclusion

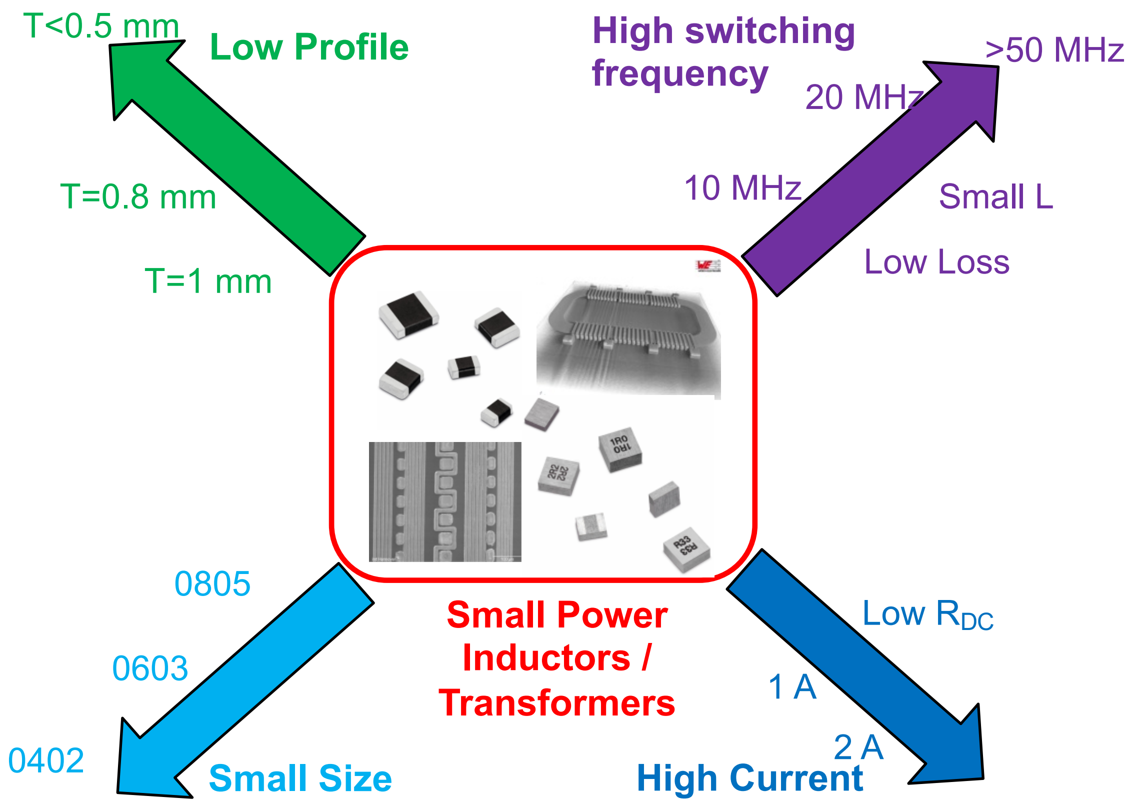
1. Requirements on Power Inductors and Transformers I

- Recent market requirements are driving Power Electronics towards higher level of integration (Power System in Package (PSiP) and/or Power System on Chip (PwrSoC))

- New PE devices require new magnetic components with following characteristics:
  - High switching frequency
  - Small size
  - Low profile
  - High saturation current

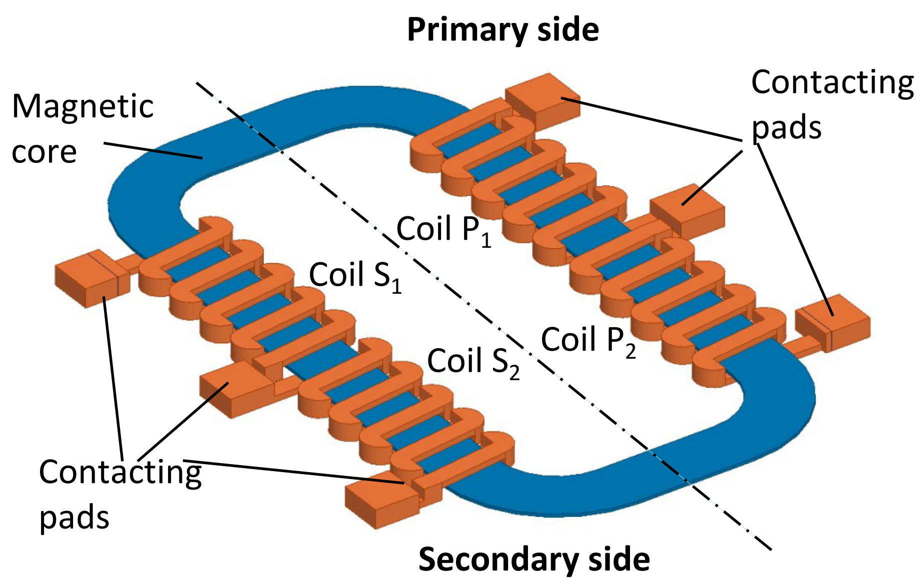
1. Requirements on Power Inductors and Transformers II

- High switching frequency: > 20MHz
- Small size: 1008, 0805, 0603
- Low profile: < 0.5mm
- High saturation current: Isat > 1A
- Inductance:
  - Inductor: 20nH – 200nH
  - Transformer: 50nH – 300nH
- All these requirements can be fulfilled by applying thin film technology (MEMS)
- Why MEMS:
  - Compatibility between MEMS and CMOS technology
  - Increasing of system integration



2. Design of the Microtransformer I

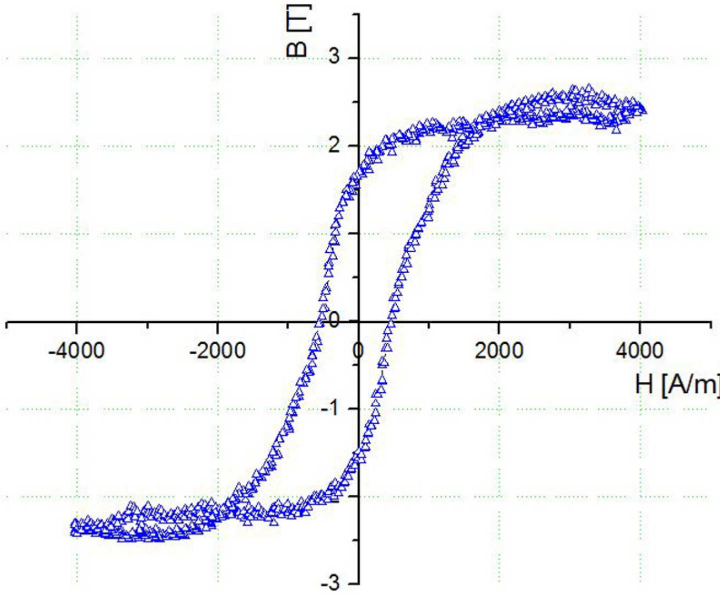
- Design of a microtransformer:
  - Closed magnetic core with more helix coils
  - Same number of coils on primary and on secondary side
  - Each coil can be separately powered
- Transformer ratio and inductivity of the device is adjustable
- Different transformer ratio (1:1, 1:2, 2:1, 2:2)
- Microtransformer can be also used as an inductor (max. inductance by 4 coils series connection)



- Aims for development of microdevice:
  - Flexible design
  - Device can be used as inductor, transformer, common mode choke
  - As transformer: variable turn ratio

2. Design of the Microtransformers II

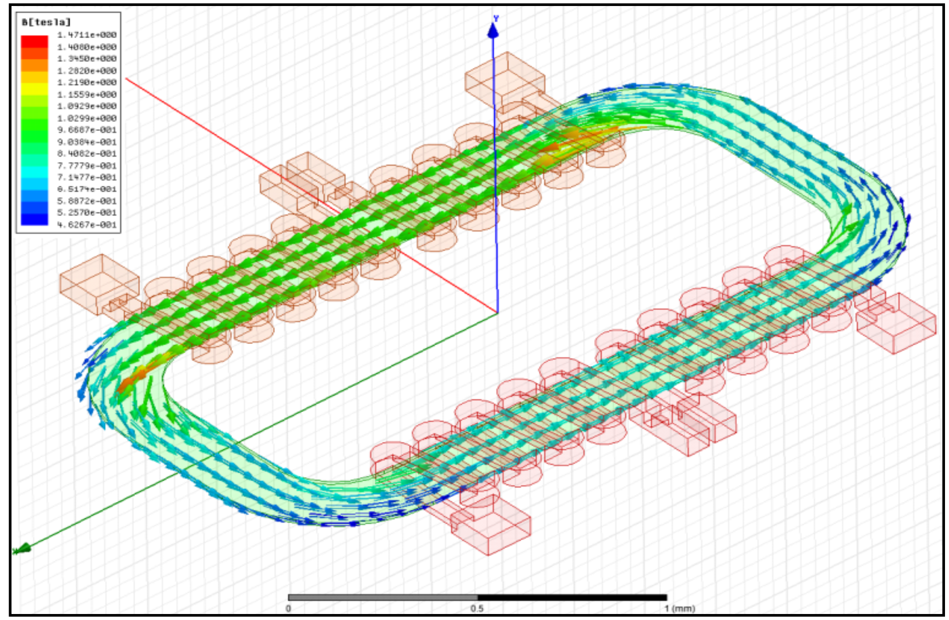
- Two design were developed
  - Design1: with 6 coils
  - Design2: with 4 coils
- Design data:
  - Device size: 1008 (2.5mm x 2mm)
  - Insulating material: Polyimide
  - Coil material: copper (electroplated)
- Magnetic material (electroplated)
  - CoFe and NiFe45/55 (Design1)
  - CoFe (Design1)



BH loop of applied Co-Fe alloy

2. Design of the Microtransformers III

- **The design was simulated and optimized using Finite Element Method (FEM)**
- **The software tool Ansys Maxwell® was applied**
- **Topics of simulation**
  - **Magnetic core design**
  - **Coil design**
  - **Inductance**
  - **Resistance**



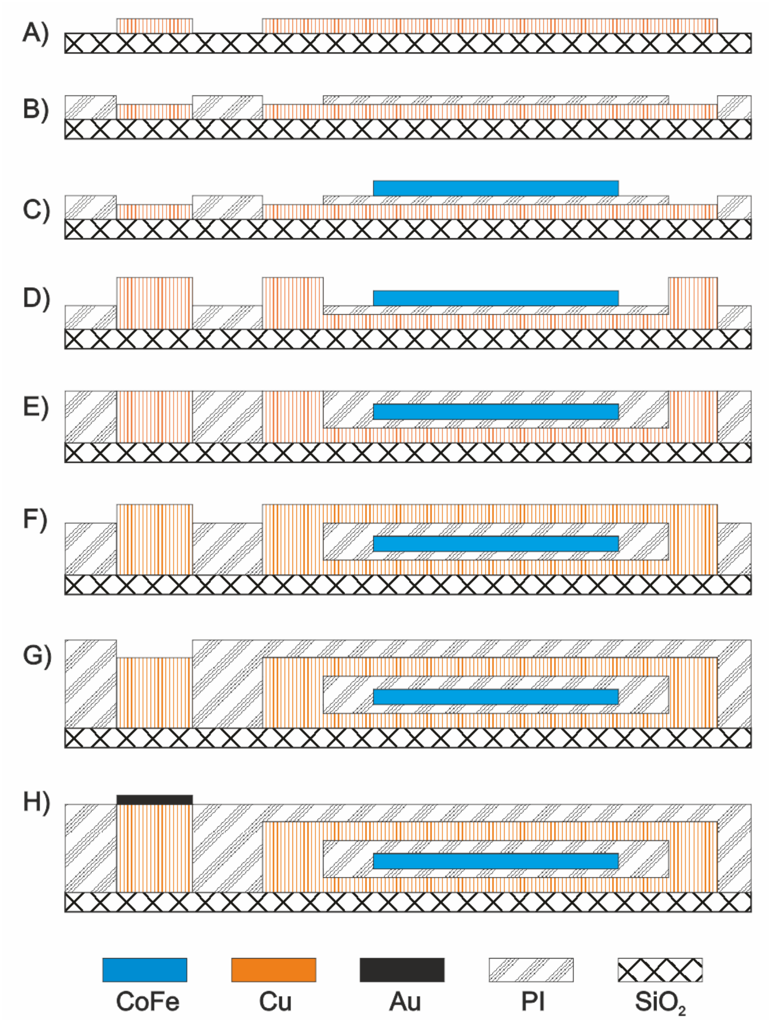
Magnetic flux density of the microtransformer

2. Design of the Microtransformers IV

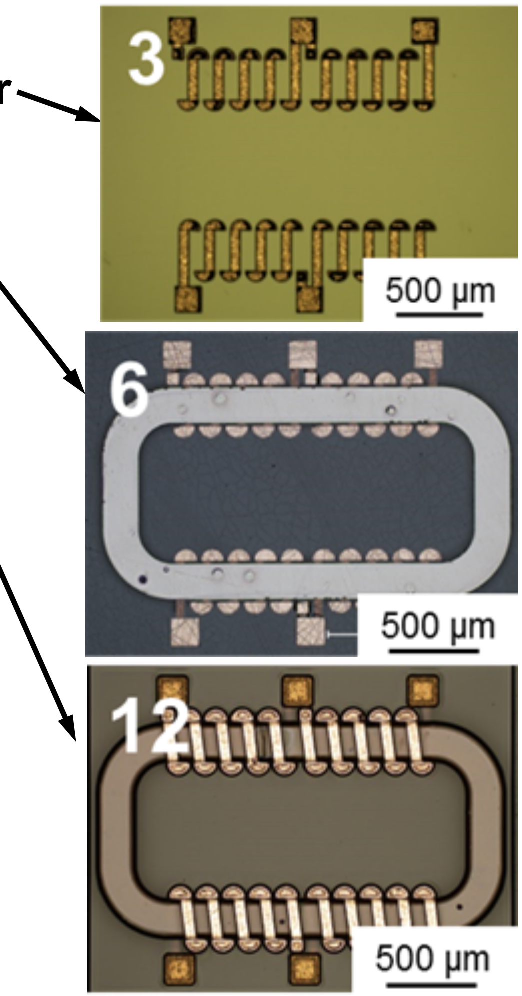
- Chip size: 1008 (EIA): 2,5mm x 2mm
- Same magnetic core design with core track width of 200µm
- Same insulation material: Polyimide

Parameter	Design1	Design2
Core thickness [µm]	5	5, 10
Core material	CoFe, NiFe45/55	CoFe
Coils	2 x 3	2 x 2
Turns (per coil)	9	5
Turn thickness [µm]	15	20
Turn width [µm]	20	60
Insulation coil-to-core [µm]	10	10

3. Fabrication Steps I

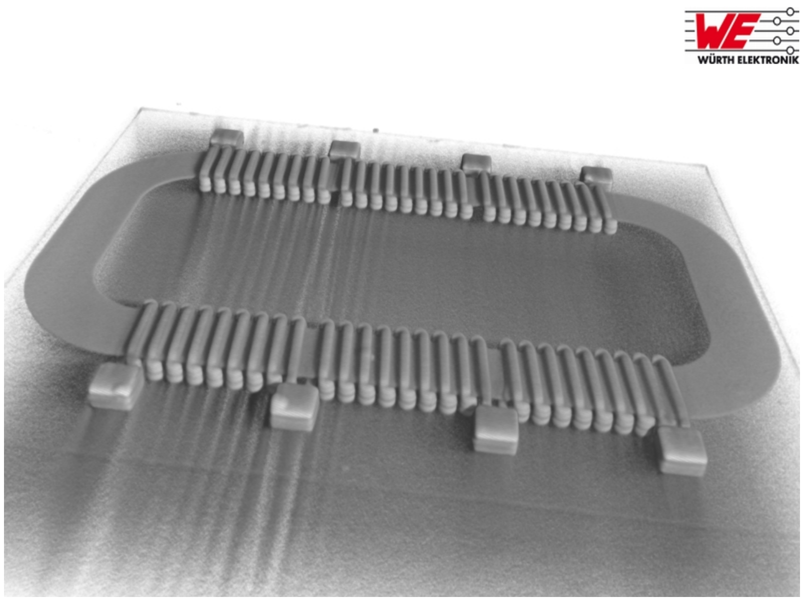


- **Fabrication steps:**
  1. **Bottom coil layer**
  2. **Insulation**
  3. **Magnetic core**
  4. **Insulation**
  5. **Vias**
  6. **Top coil layer**
  7. **Insulation**

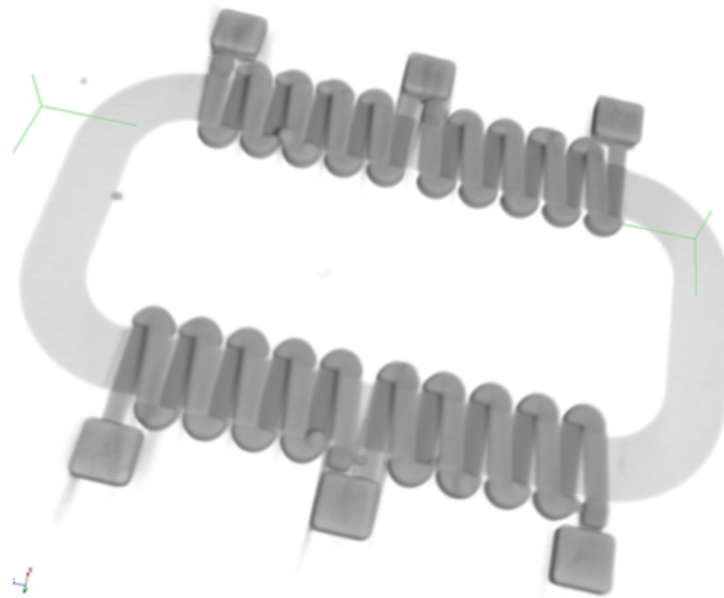


3. Fabrication Steps II

- **Fabricated microtransformers**



CT micrograph of microtransformer Design1



CT micrograph of microtransformer Design2

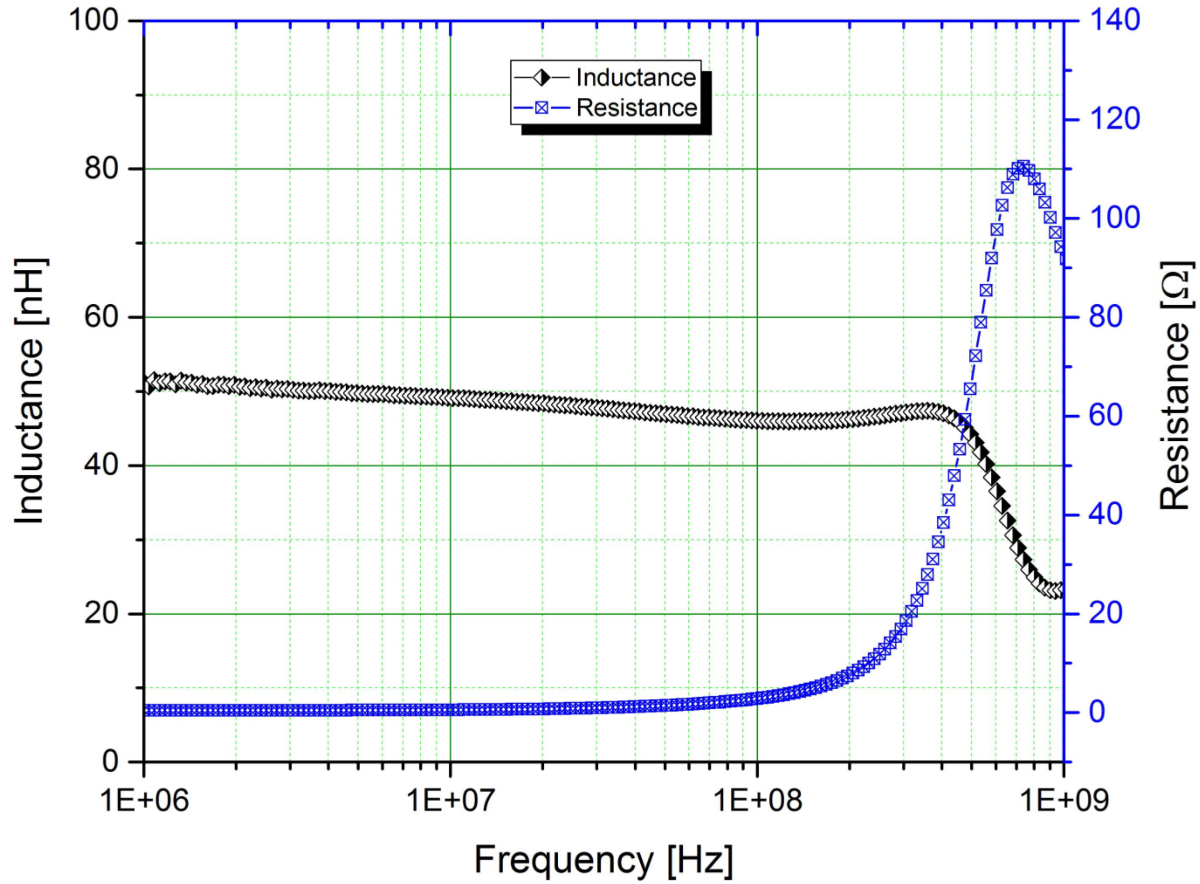
4. Test Results I – Comparison

- **For Design1 the inductance is stable up to frequencies higher then 30MHz**
- **For Design2 the inductance is stable up to frequencies higher then 50MHz**

Parameter (only one side)	Design1 (NiFe)	Design1a (CoFe)	Design2 (10µm core)	Design2a (5µm core)
Inductance [nH]	35	33	25	13
Resistance [Ω]	0.8	1	0.35	0.25
Q-factor	3 at 20MHz	3 at 20MHz	11 at 70MHz	11 at 70MHz

4. Test Results I – Design2

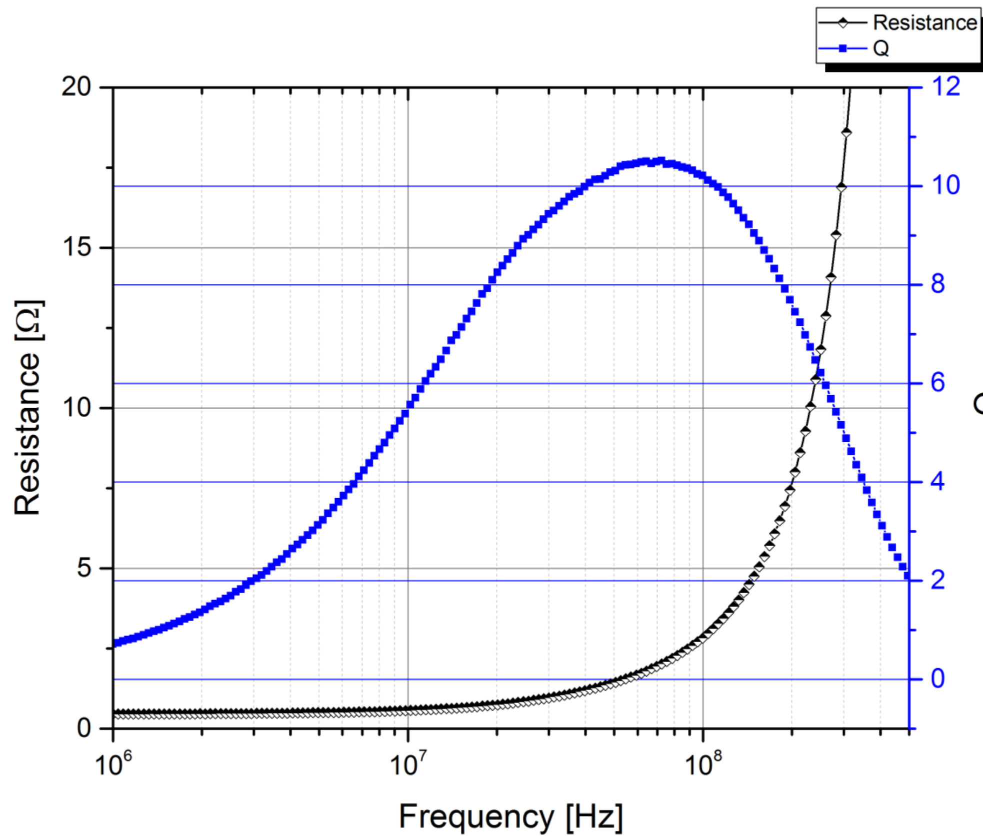
- **Inductance is stable up to frequencies higher then 50MHz**
- **The measured electrical resistance of whole system is about 350 mΩ**
- **Maximal Q-factor is 11 at frequency of 70 MHz.**



L and *R* characteristics over the frequency

4. Test Results II – Design2

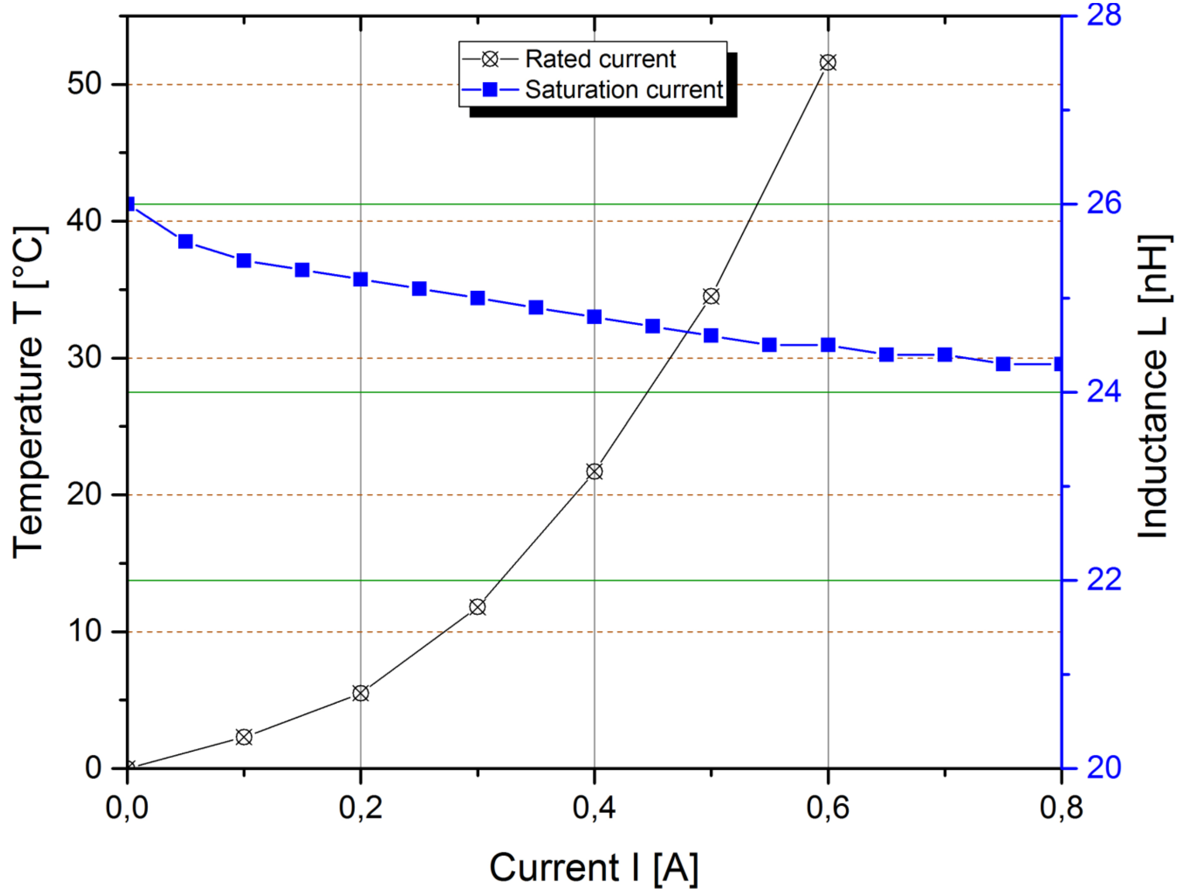
- **Maximal Q-factor is 11 at frequency of 70 MHz.**



Q and *R* characteristics over the frequency

4. Test Results III – Design2

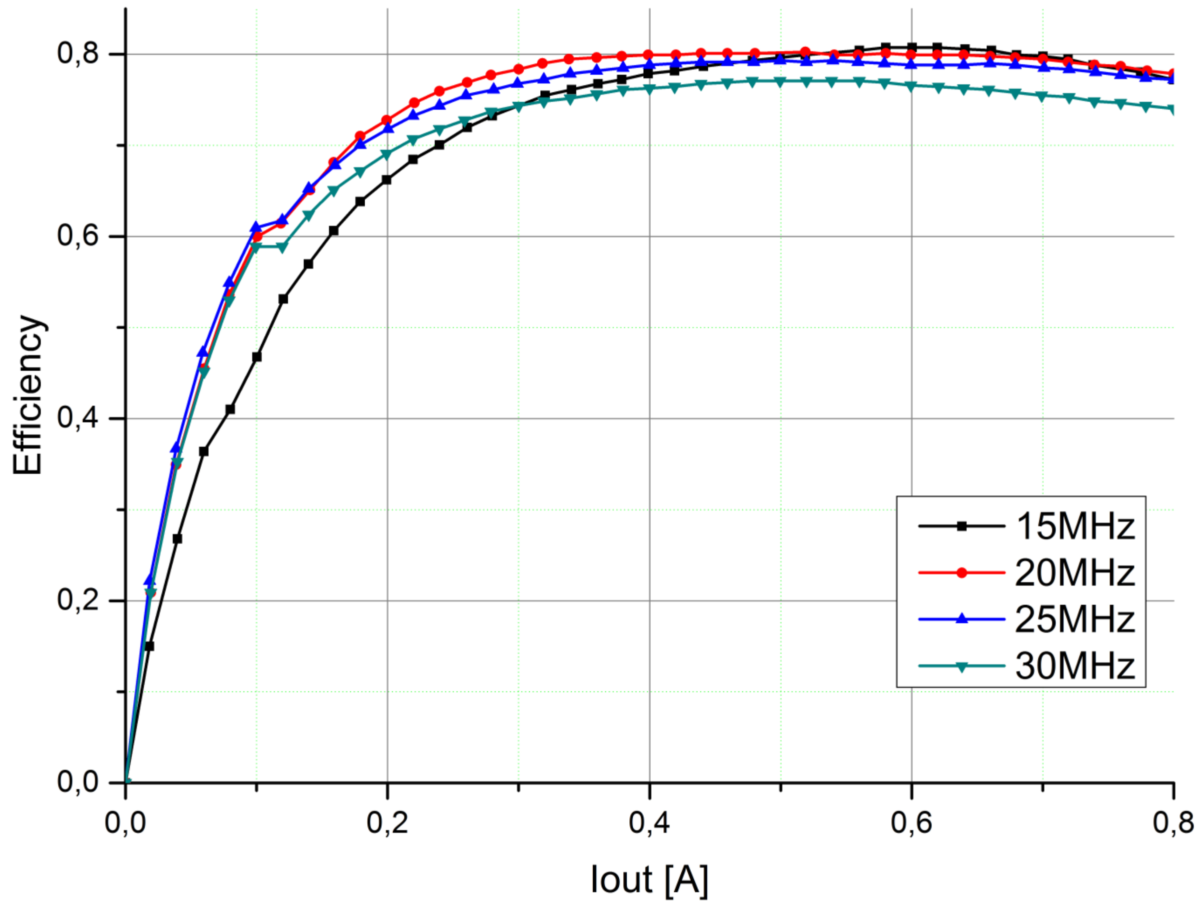
- At DC-Bias of 800 mA decrease the initial inductance for under 10% of the initial inductance (ΔL/L<10%).
- At current of 550 mA the microtransformer heats up to 40°C degrees above the ambient temperature.



Rated and saturation current of microtransformer

4. Test Results IV – Design2

- Microtransformer samples were tested in HF buck DC-DC converter
- Microtransformer device used only as inductor
- Efficiency of almost 80% is measured at switching frequencies between 15 MHz and 30 MHz.
- Core loss of micro-transformer shows the value of about 100 mW.

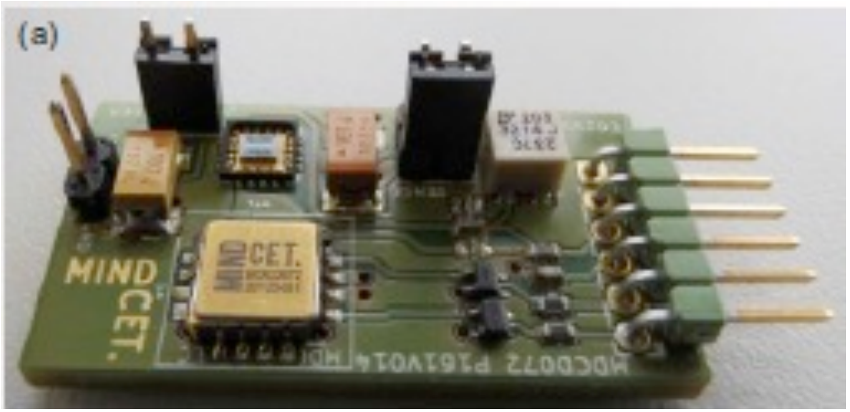


Efficiency measurement for input voltage 3.6 V and output voltage 2.5 V

4. Test Results V

- **MDCD073 a dual 7V half bridge with pre-drivers in 180 nm SOI technology is developed and applied**

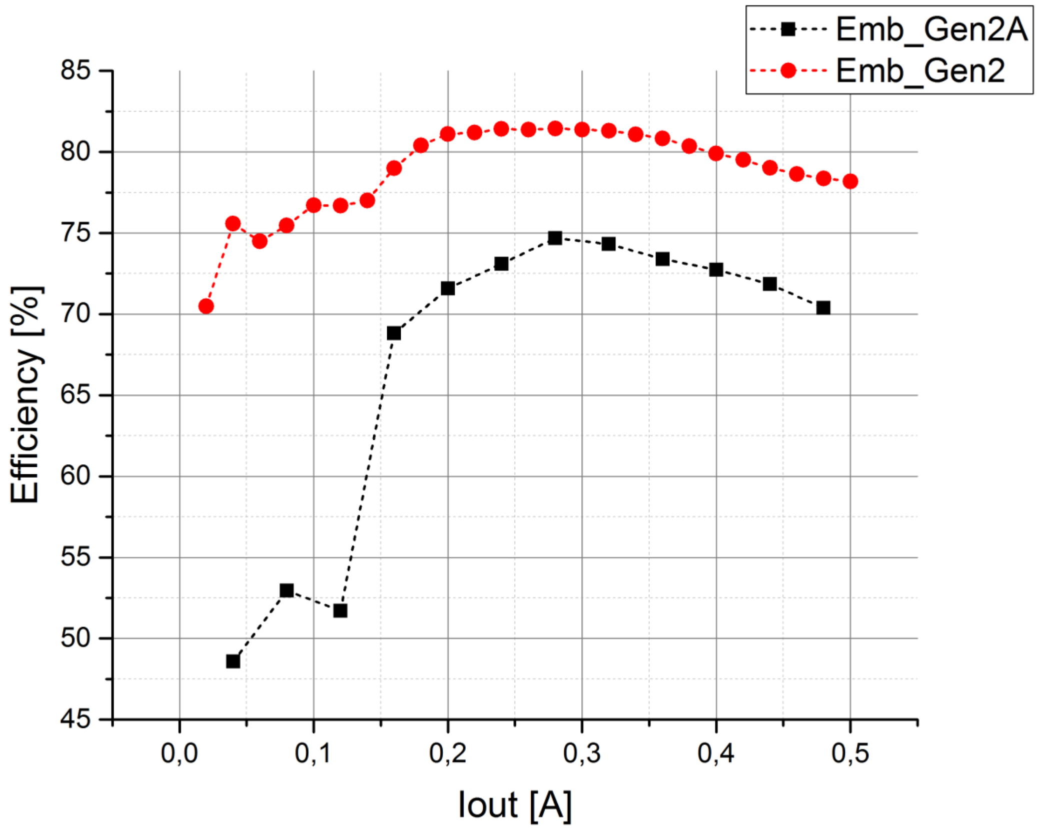
ASIC chip used for efficiency measurements (b)



MCDC073 DC-DC Buck controller

4. Test Results VI

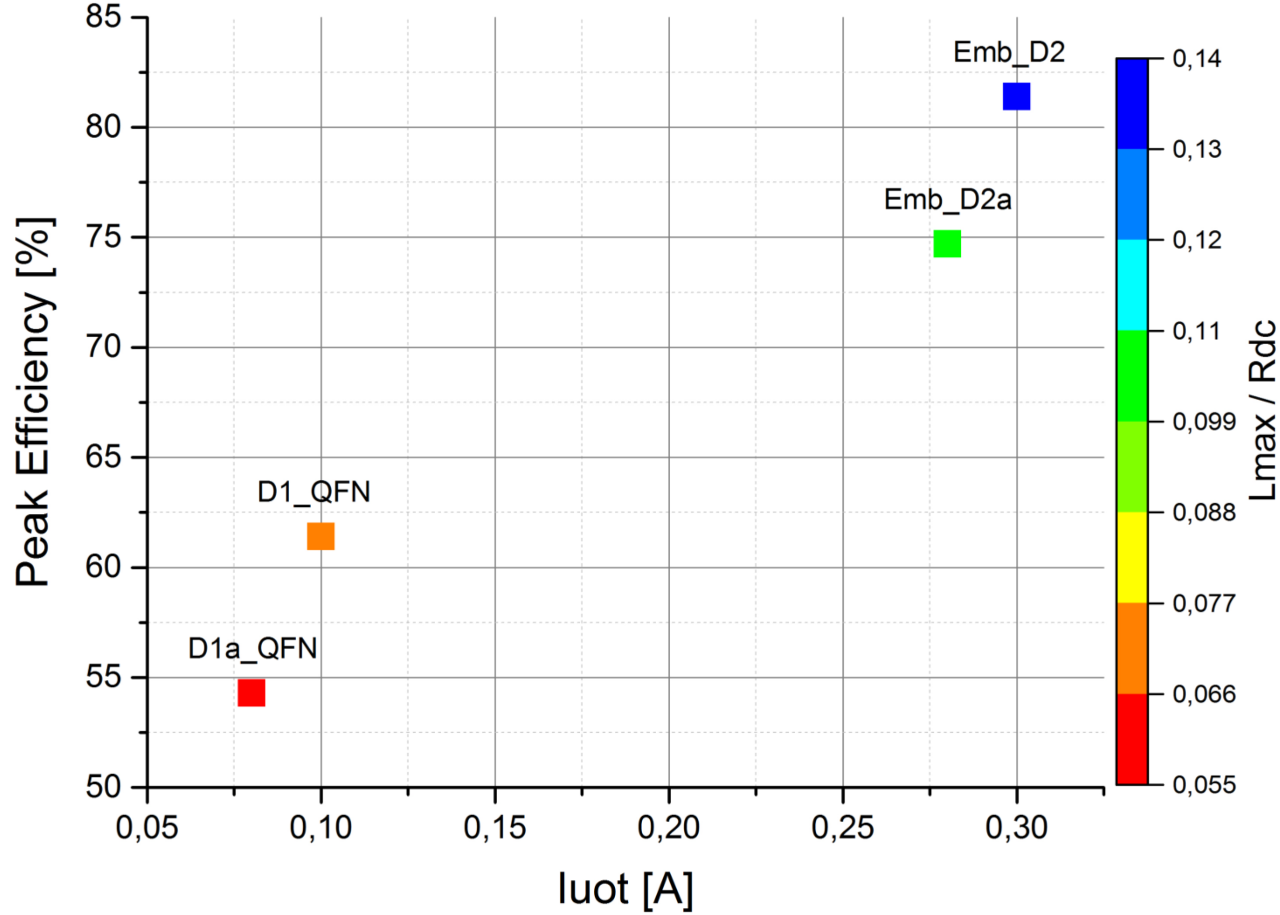
- **Efficiency measurements using Semtech SC220 20MHz step-down regulator**
- **Best results shows the design2 with 10µm core thickness**
- **These parts are embedded in FR4**



Efficiency measurement for input voltage 3.3 V and output voltage 2 V

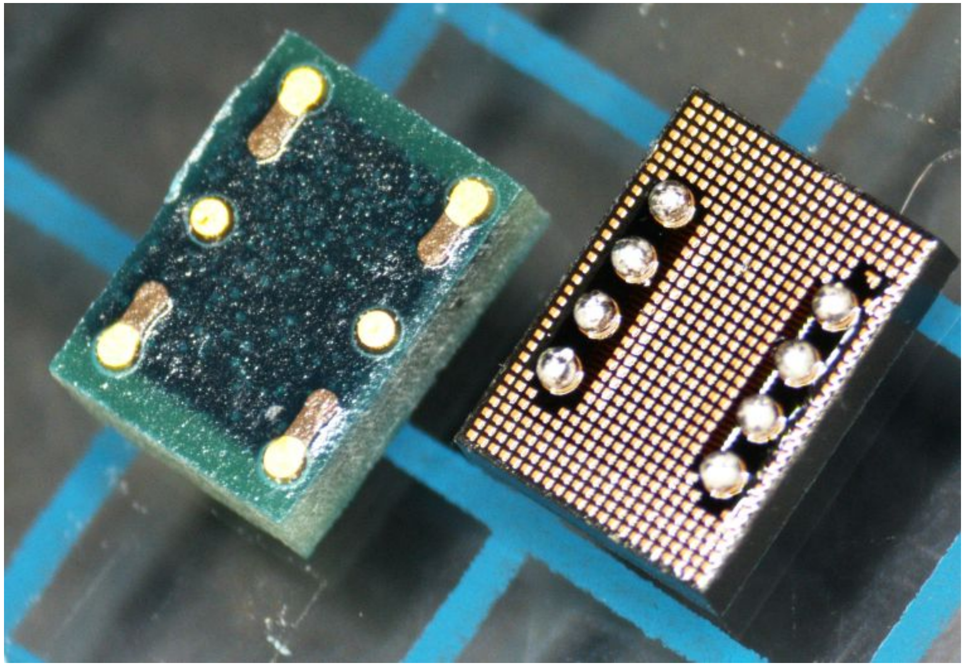
4. Test Results VII

- **Comparison of different design regarding to the efficiency**
- **Same regulator is used (Semtech SC220 20MHz step-down regulator)**



5. Packaging

- **Two packaging approach were already tested**
  - **WLP (eWLB)**
  - **Embedding in PCB**



6. Conclusion

- Two microtransformers were completed using thin-film technology.
- The device shows stable inductance characteristic up to frequencies higher
- than 50 MHz.
- The maximal inductance of device is about 50 nH
- Efficiency of almost 80% was realized with microtransformer device and MCDC073 ASIC in DC-DC Buck application at frequencies between 15MHz and 30 MHZ.
- Recent developments are focused on packaging of the transformer and integration with the ASIC chip.