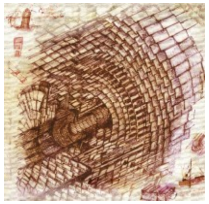


DC-DC Converter Development for the CMS Pixel Upgrade

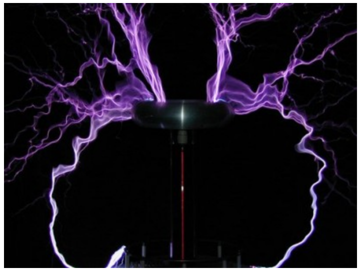
Katja Klein

RWTH Aachen University

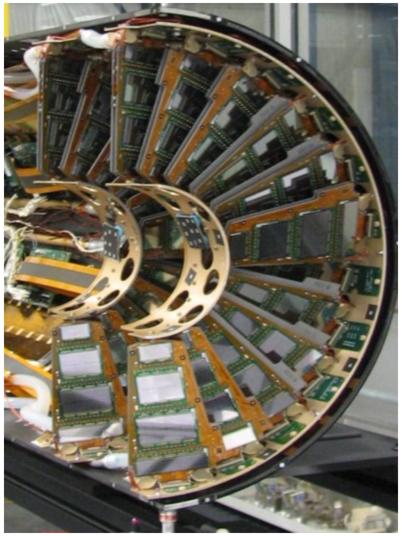
with input from: W. Bertl, A. Schultz von Dratzig, L. Feld, W. Karpinski, J. Merz, J. Sammet, M. Wlochal

ATLAS / CMS Power WG Meeting

March 8th, 2011



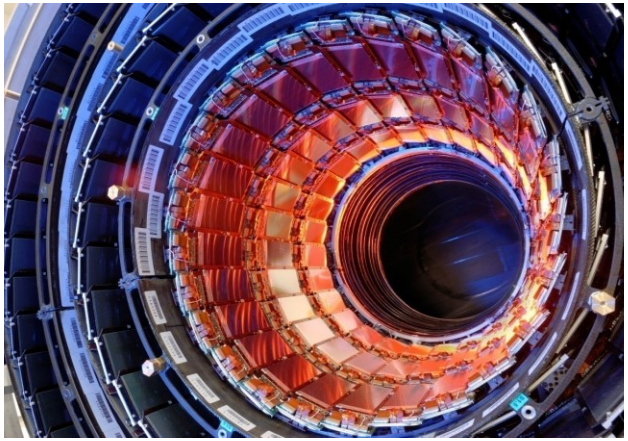
The CMS Tracker Upgrade



2017/2018: Exchange of the CMS pixel detector

- Less material, reduced data losses etc.
- Number of readout chips (ROCs) increases by factor 1.9
- Unacceptable power losses in cable trays
- Compatibility with existing power supply chain desirable

→ DC-DC buck converters with conversion ratio of 2-3



> 2020: Exchange of the CMS tracker

- Higher granularity → more readout channels
- Additional functionality (track trigger) needs power

→ DC-DC converters with conversion ratio of 8-10

DC-DC Converters for the Pixel Upgrade

- One buck converter powers 2-4 pixel modules
- Conversion ratio 2-3
- V_{out} = 2.5V & 3.3V
- I < 3A per converter
- Integration for pixel barrel onto supply tube

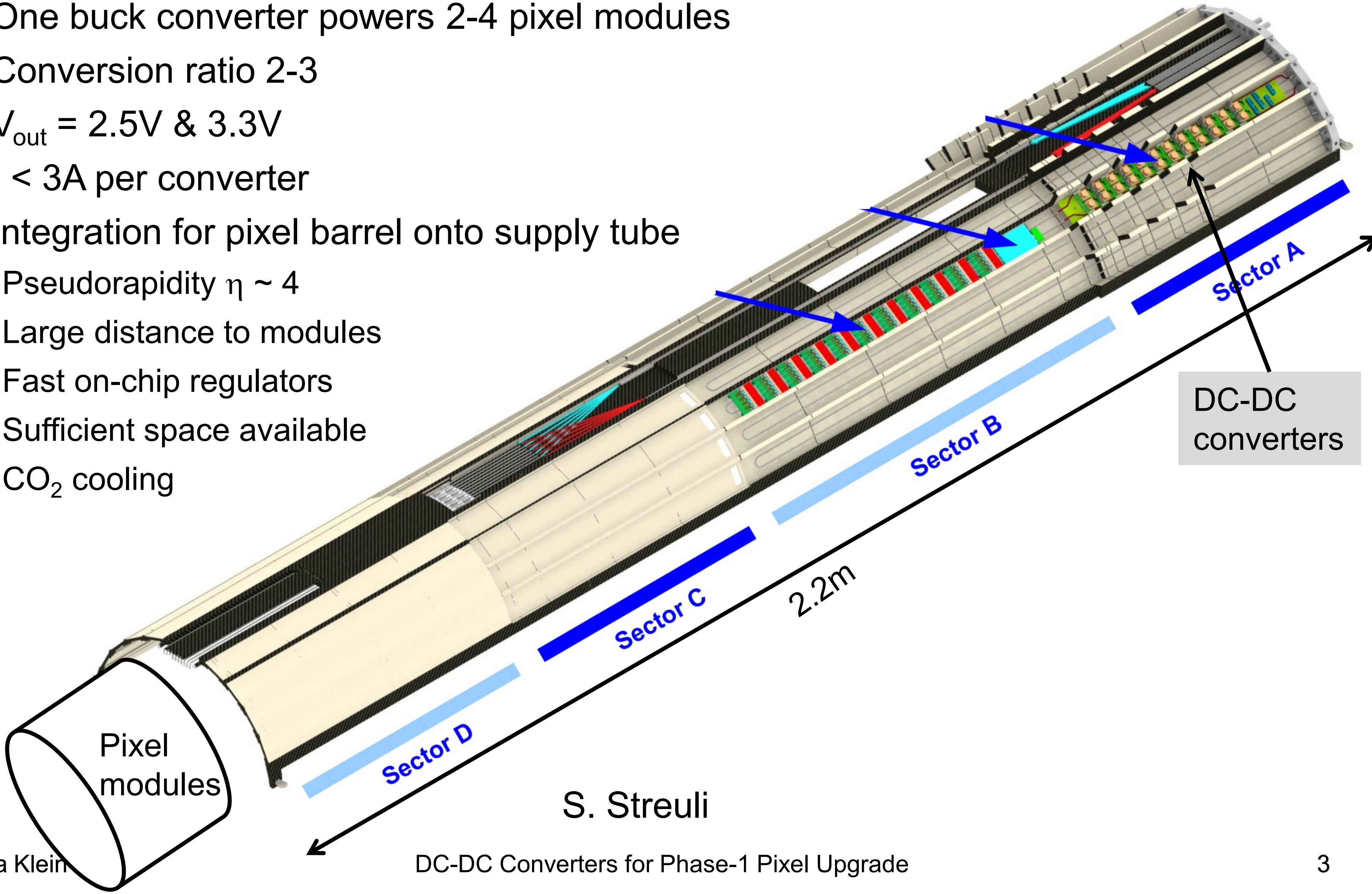
✓ Pseudorapidity η ~ 4

✓ Large distance to modules

✓ Fast on-chip regulators

✓ Sufficient space available

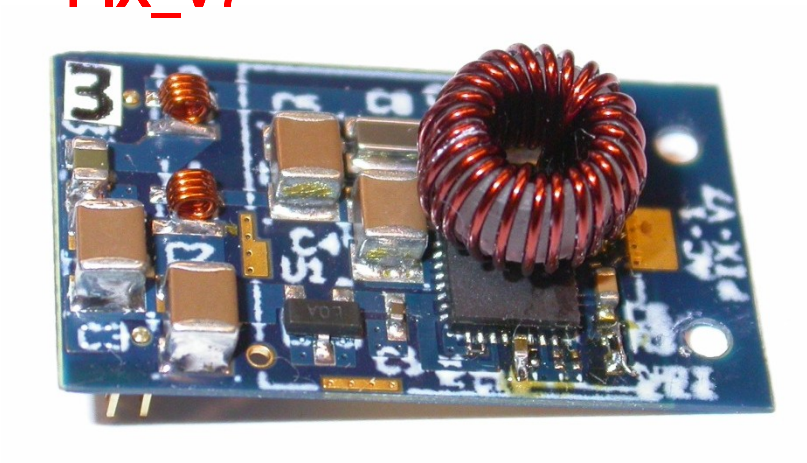
✓ CO_2 cooling



S. Streuli

DC-DC Buck Converter Development

PIX_V7



M = 2.3g
A = 28 x 16 mm^2

ASIC: AMIS2 by CERN
Iout < 3A
Vin < 12V
Vout configurable; 2.5V & 3.3V
fs configurable, e.g. 1.3MHz

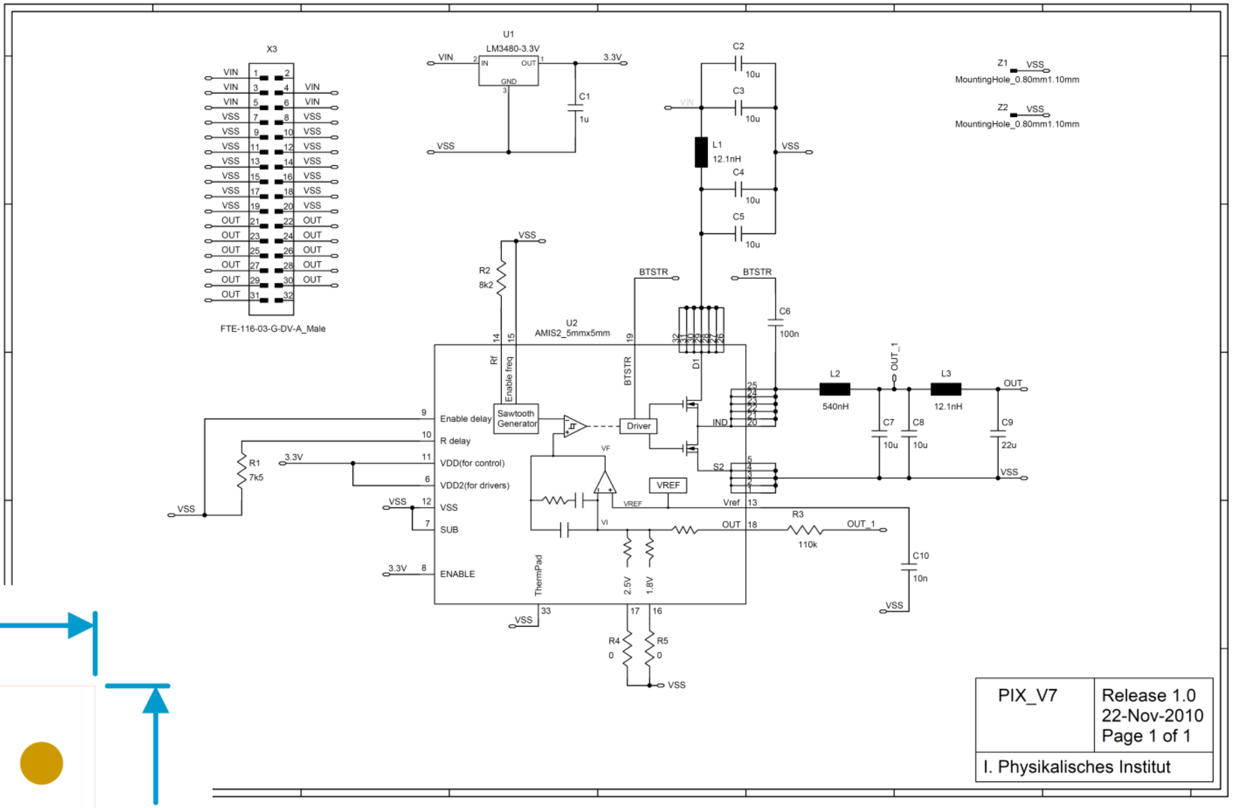
PCB:
2 copper layers a 35µm
0.3mm thick
Large metallic ground area on bottom for cooling

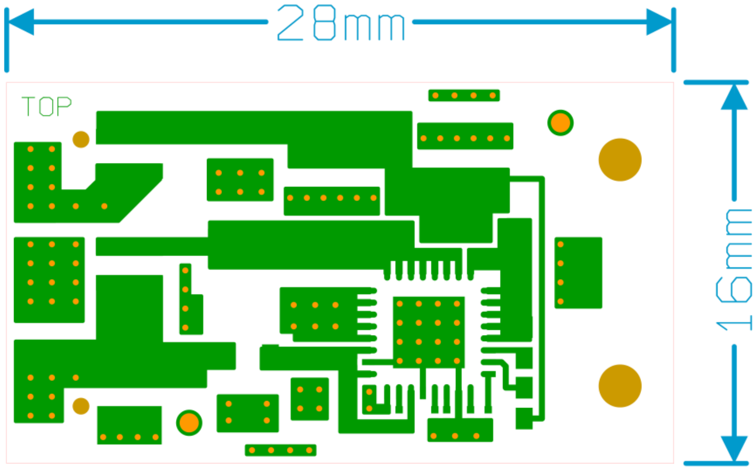
Toroidal inductor:
L = 450nH
R_{DC} = 40mΩ

Pi-filters at in- and output

Shield (soldered to GND pads of PCB):
e.g. 150µm Aluminium

DC-DC Buck Converter Development

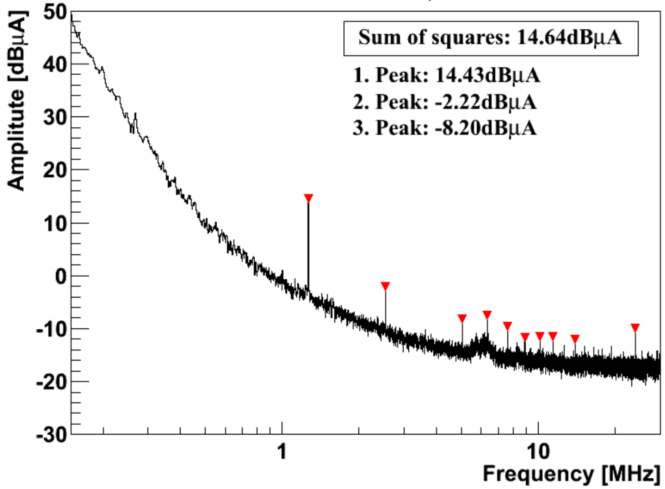




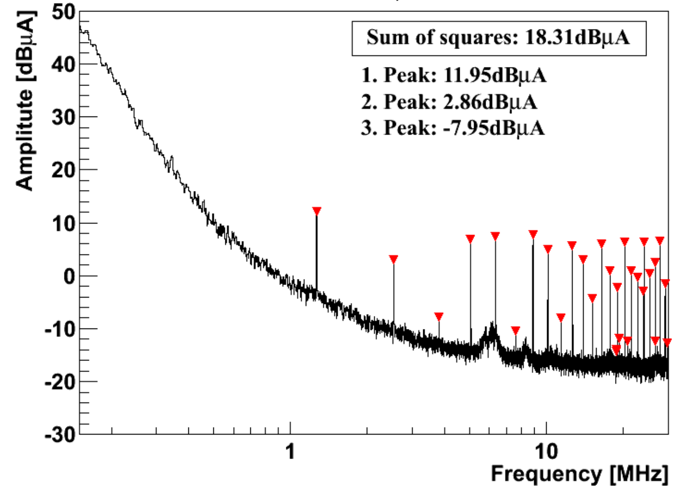
Design guidelines from CERN group have been followed.

Conductive Noise at Converter Output

Differential Mode, no shield

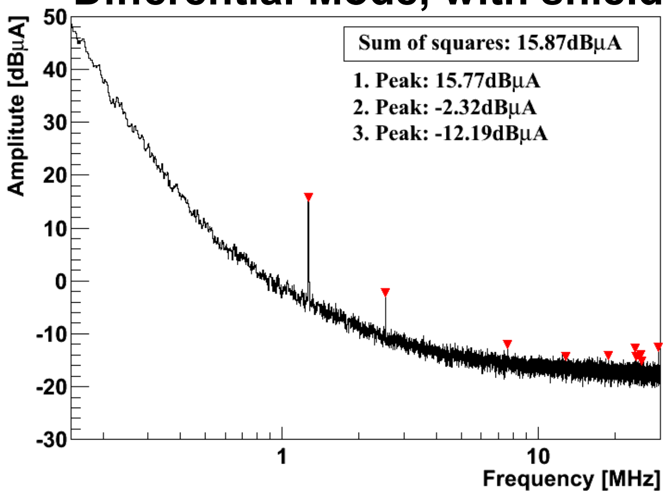


Common Mode, no shield

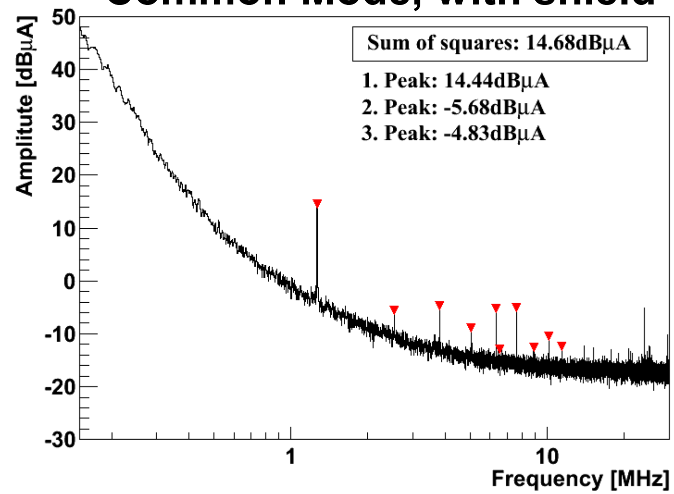


PIX_V7
Vout = 3.3V
Vin = 10V
fs = 1.3MHz
L = 450nH

Differential Mode, with shield



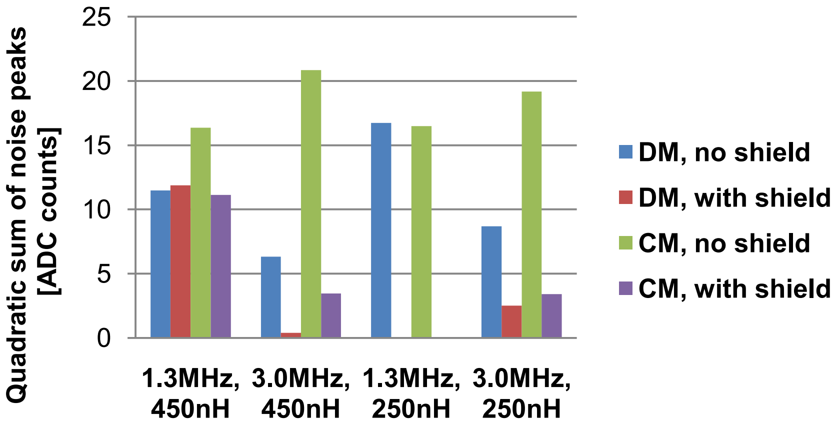
Common Mode, with shield



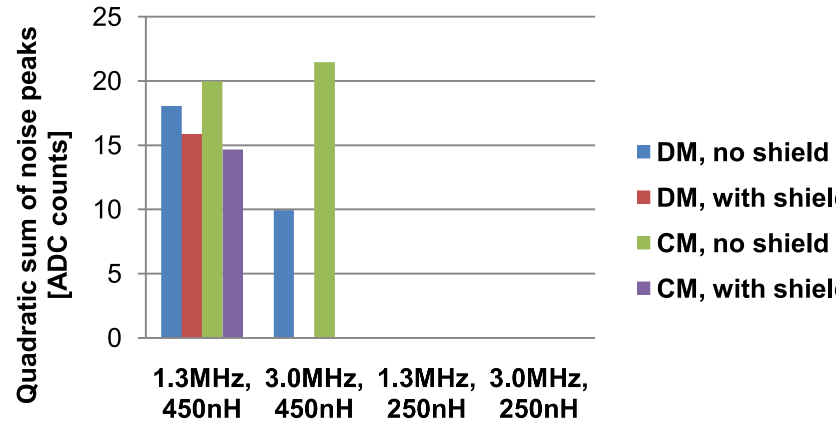
Shield most effective above ~ 2-3 MHz → large reduction of CM, less red. for DM

Conductive Noise

2.5V, output noise



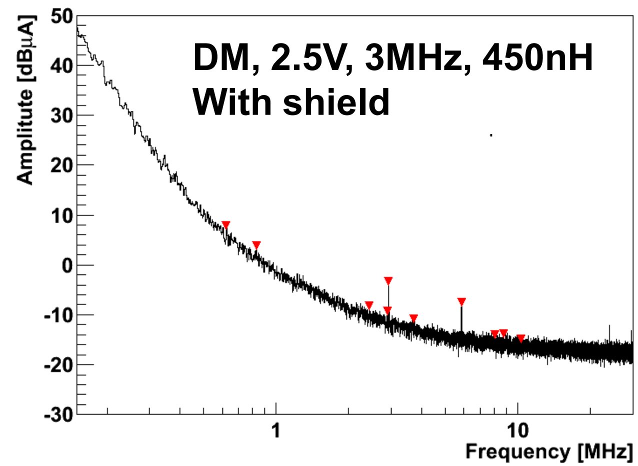
3.3V, output noise



The conductive noise at the input and output has been studied under various conditions:

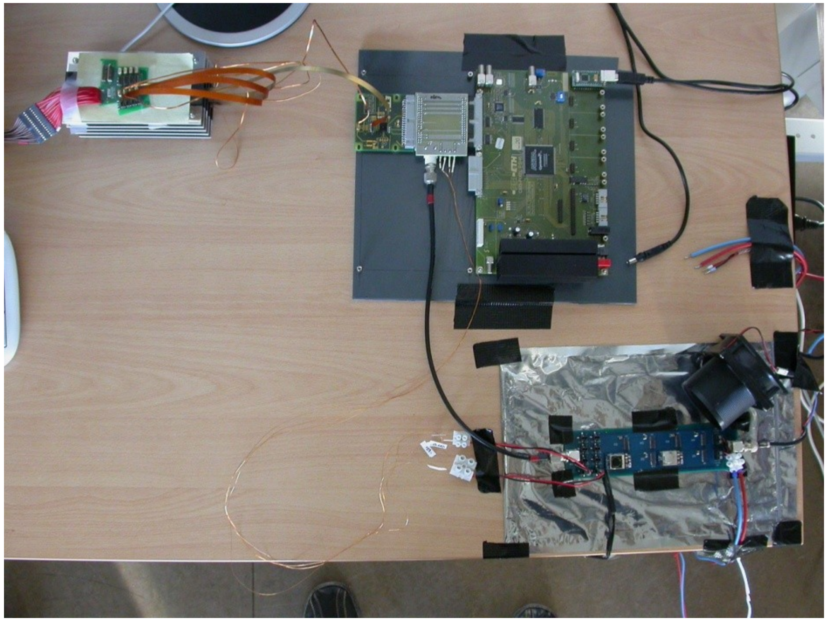
→ Shield is more effective for switching frequency of (e.g.) 3MHz

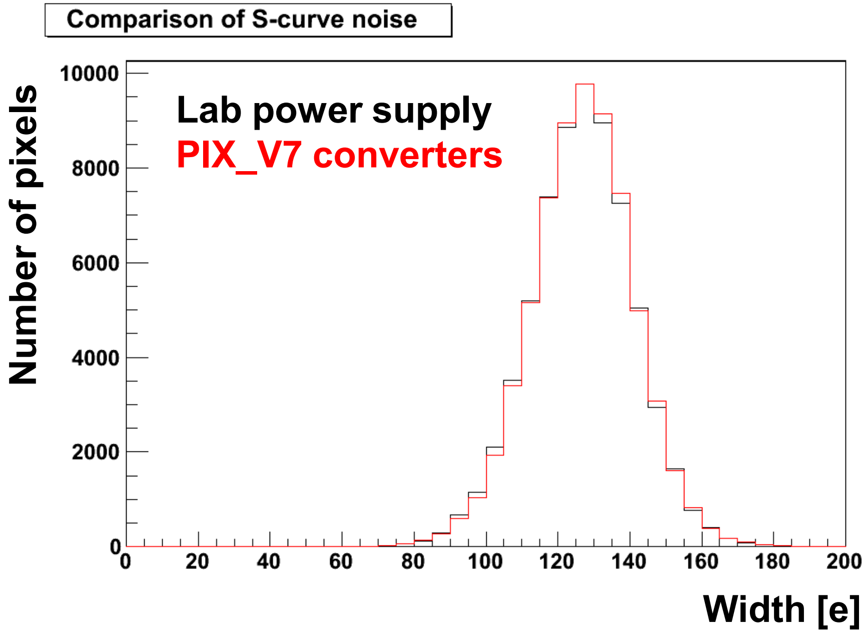
→ Larger DM noise for lower inductance



Conductive Noise

- Tests with pixel modules have to tell if noise is acceptable & what frequency is preferred!
- Measurement of S-curve with and without DC-DC converters
- Width of S-curve is taken as noise figure
- Pixel modules seem to be rather insensitive to ripple from V7 converters
- Work in progress ...





Radiated Noise Emissions

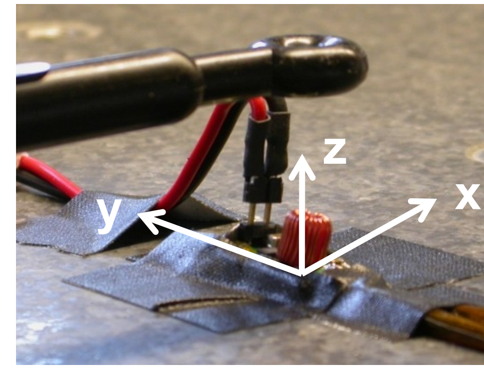
Field measured with pick-up probe ~ 1.5mm above coil

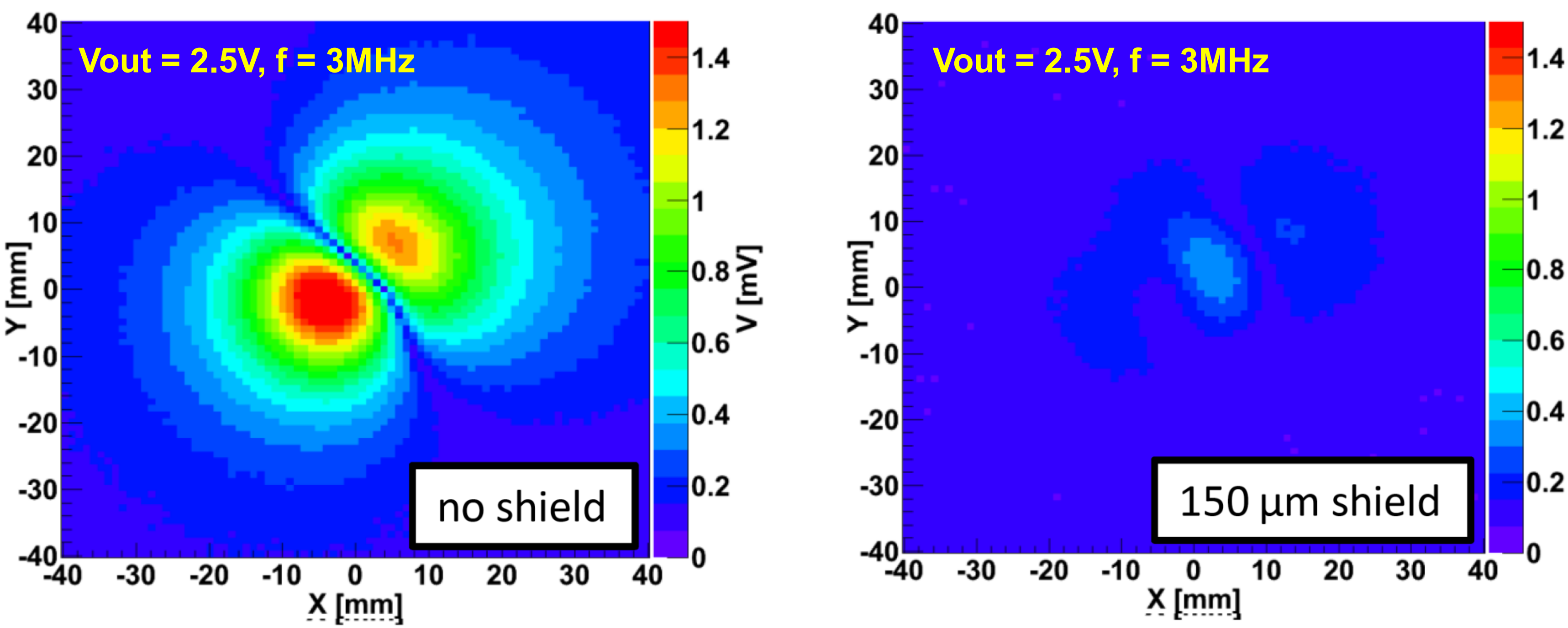
→ Both 150µm & 50µm Aluminium shields are very effective

→ Plastic shields coated with ~ 20µm Alu or Cu less effective

→ Larger emissions for lower inductance (250nH)

→ Larger emissions with higher switching frequency (but can be shielded)

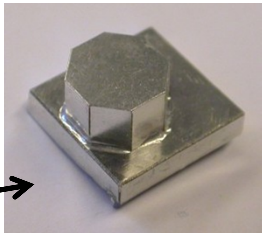




More on Shields

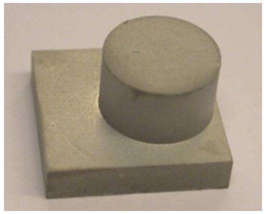
The shield has three functions:

1) to shield radiated emissions
2) to reduce conducted noise by means of segregation between noisy and quiet parts of board
3) to provide cooling contact for coil through its solder connection to PCB, since cooling through contact wires not sufficient (see later)



We are currently investigating several technologies:

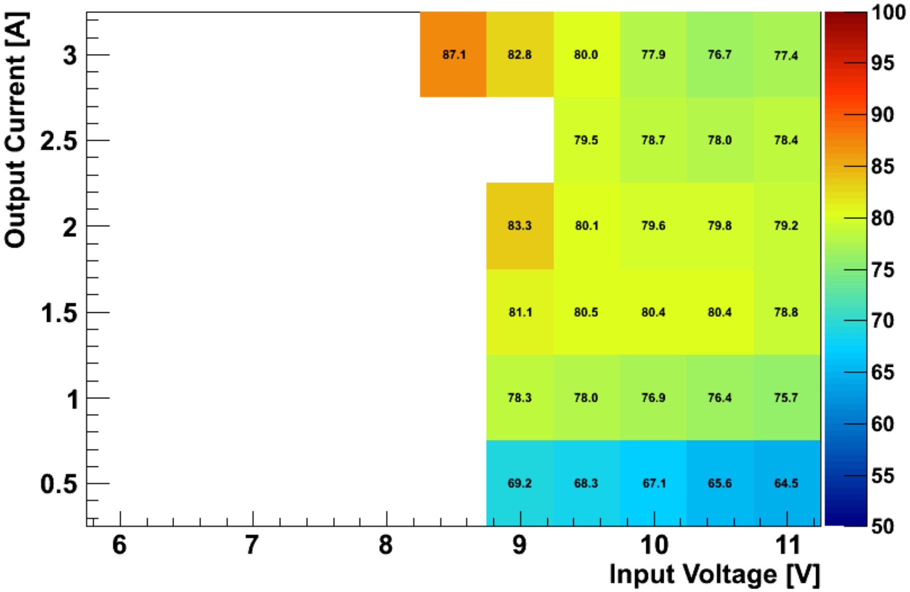
- Aluminium shields of various thicknesses
- Plastic shields (PEEK) coated with a metall layer (outside, inside & outside)
  - Aluminium sputtered (5 or 10μm)
  - Copper/tin sputtered (5 or 10μm)
  - Copper, galvanic deposition (20μm)
  - Parylene coating of whole PCB ...



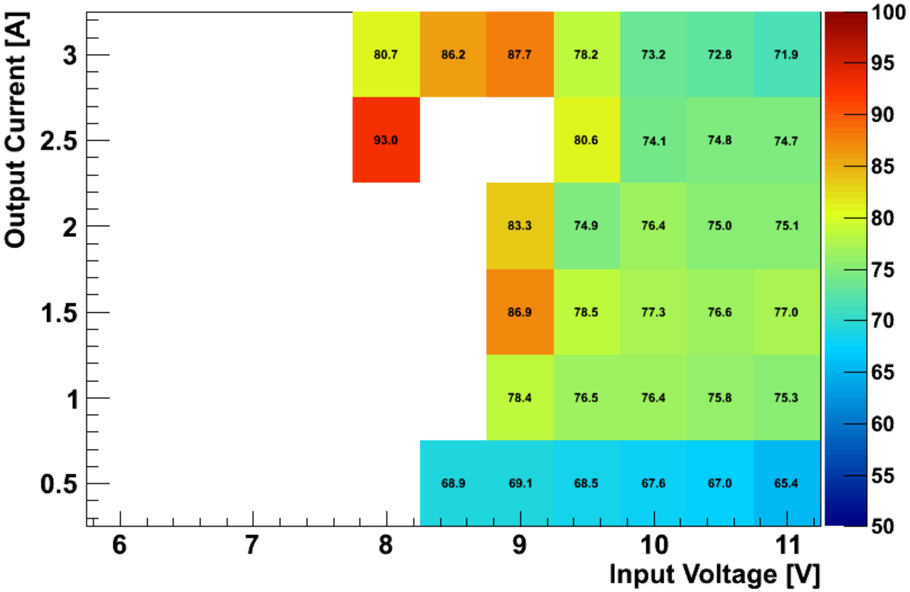
We are also in contact with industry to find industrial affortable solutions (deep drawing, forming with water pressure, ...)

Efficiency

Vout = 3.2V, 1.3MHz, 437nH



Vout = 2.5V, 1.3MHz, 450nH



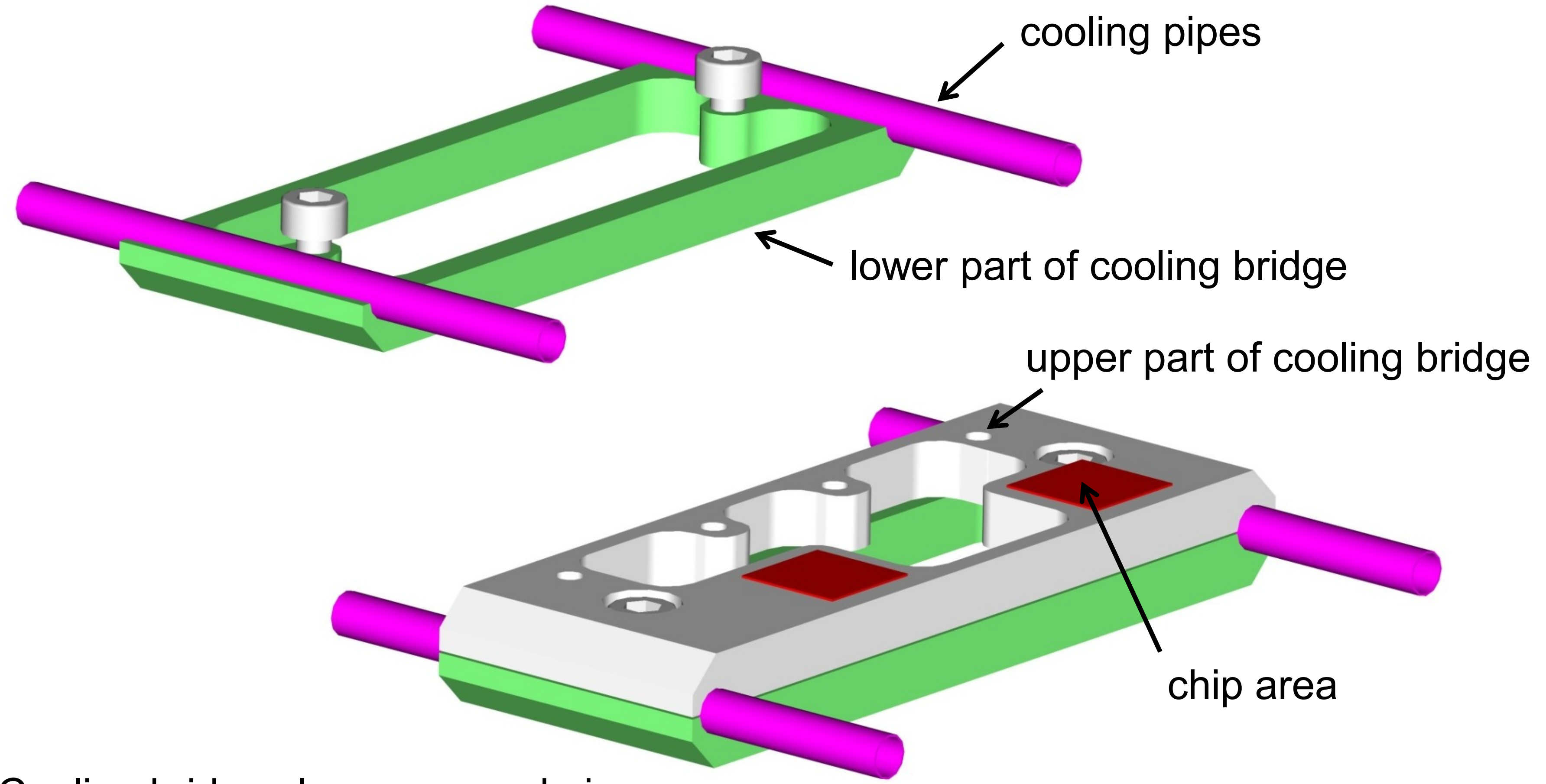
→ **Efficiencies are around 75%** (expected to increase for AMIS4 ASIC)

→ 5 -10% higher efficiency with 1.3MHz wrt 3MHz (for 450nH)

→ For lower inductance (250nH), 5-30% lower for 1.3MHz, 0-10% lower for 3MHz

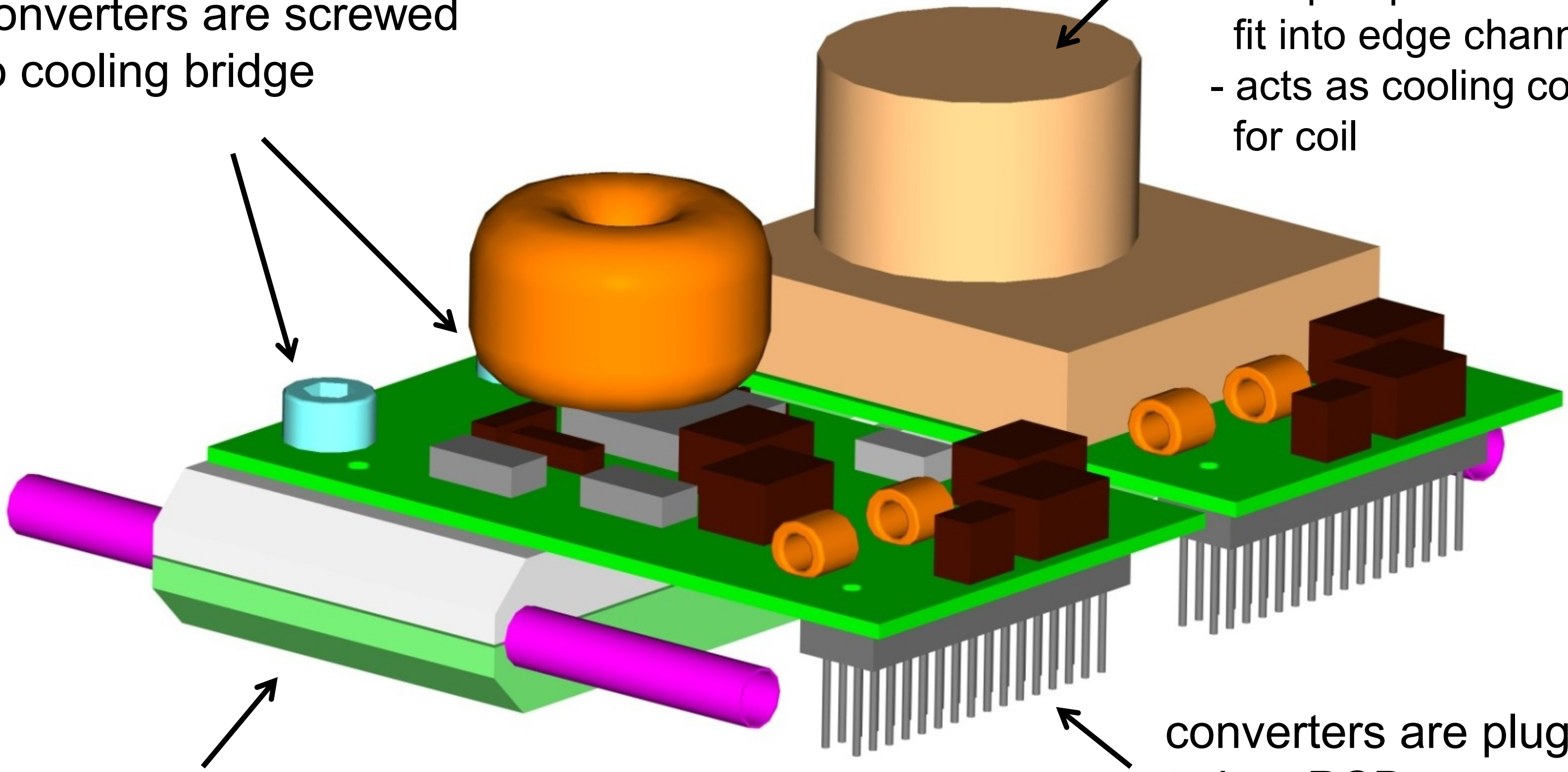
➔ suggests to stay with 1.3MHz if noise acceptable to pixel system;
to be studied again with AMIS4

Mechanical & Thermal Integration



- Cooling bridge clamps around pipe
- Area reduced to reduce material
- Aluminium (could be Graphite, but gain for material budget is low)

Mechanical & Thermal Integration



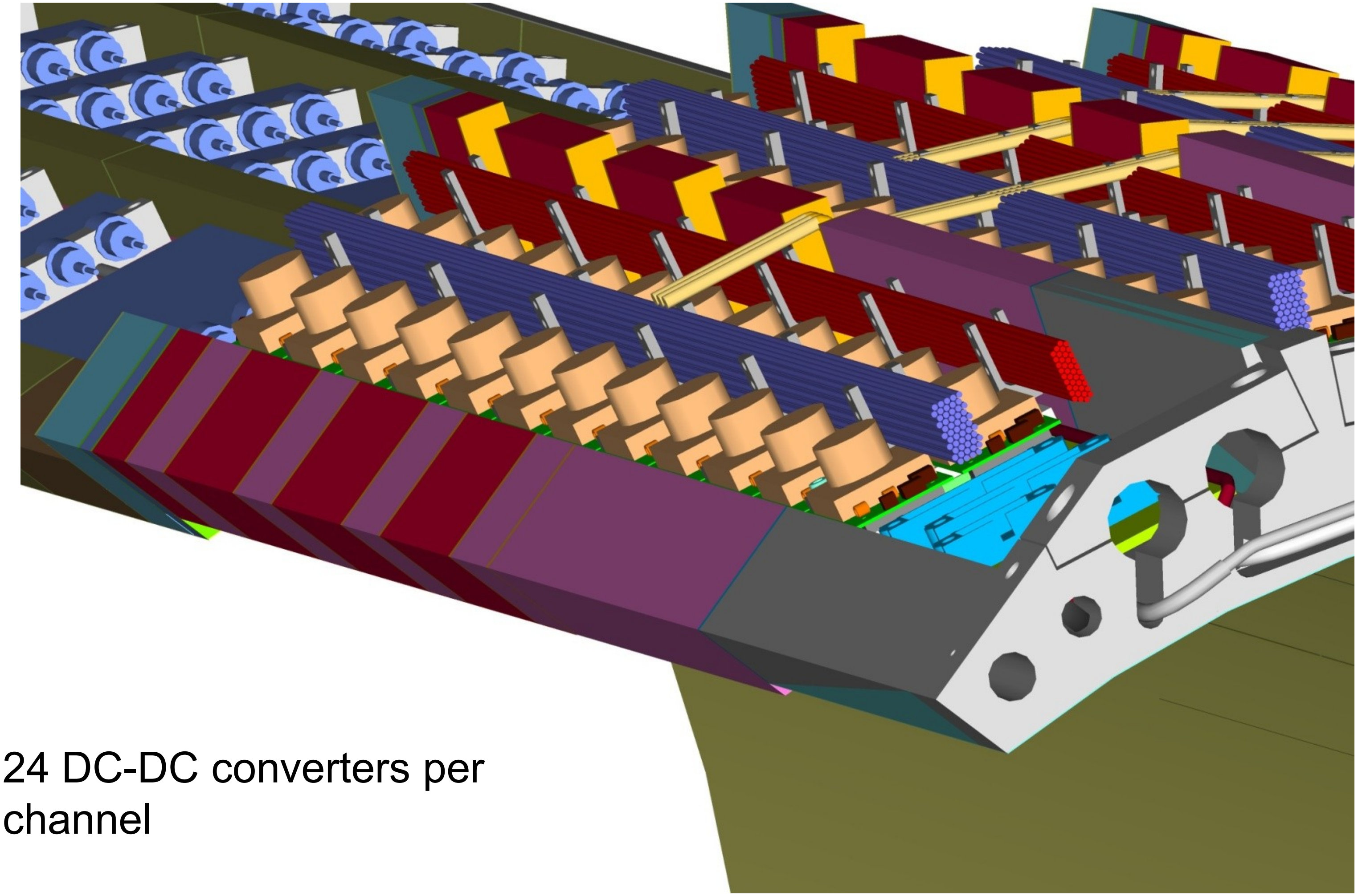
Electrical shielding
- shape optimized to fit into edge channels
- acts as cooling contact for coil

converters are screwed to cooling bridge

cooling bridge is glued to bus PCB (on a jig)

converters are plugged to bus PCB

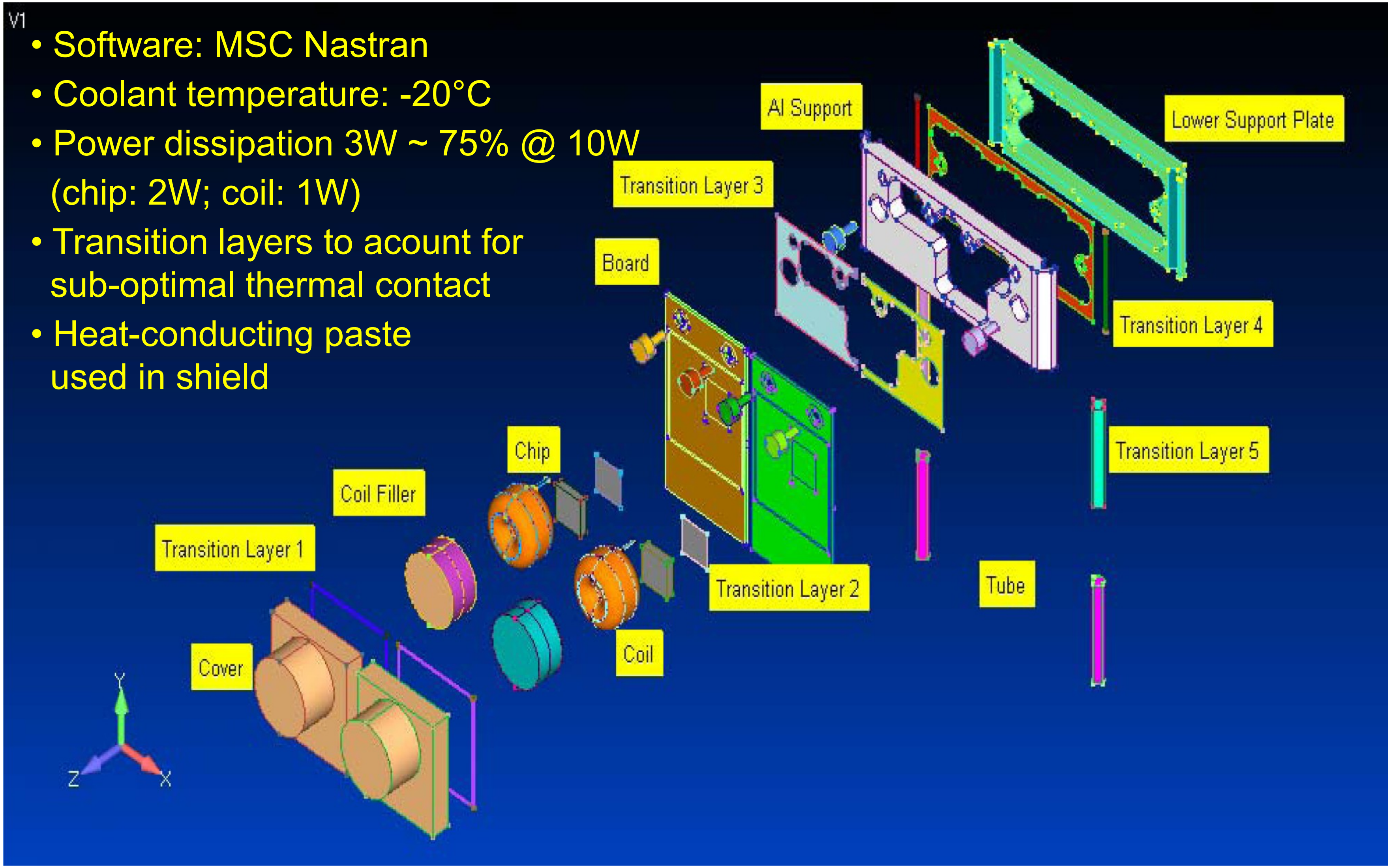
Mechanical & Thermal Integration



24 DC-DC converters per channel

Thermal FE-Simulation

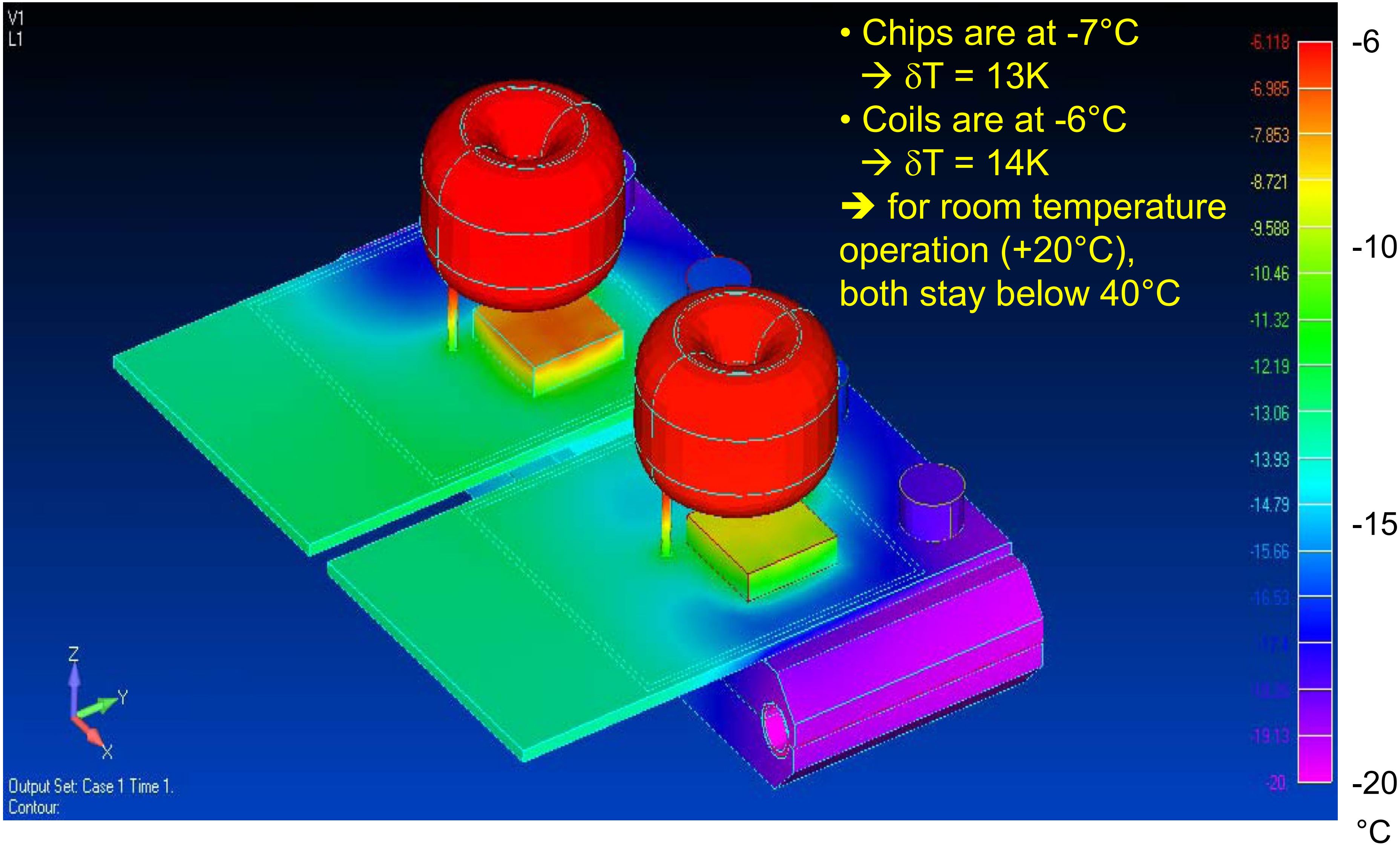
- Software: MSC Nastran
- Coolant temperature: -20°C
- Power dissipation 3W ~ 75% @ 10W (chip: 2W; coil: 1W)
- Transition layers to acount for sub-optimal thermal contact
- Heat-conducting paste used in shield



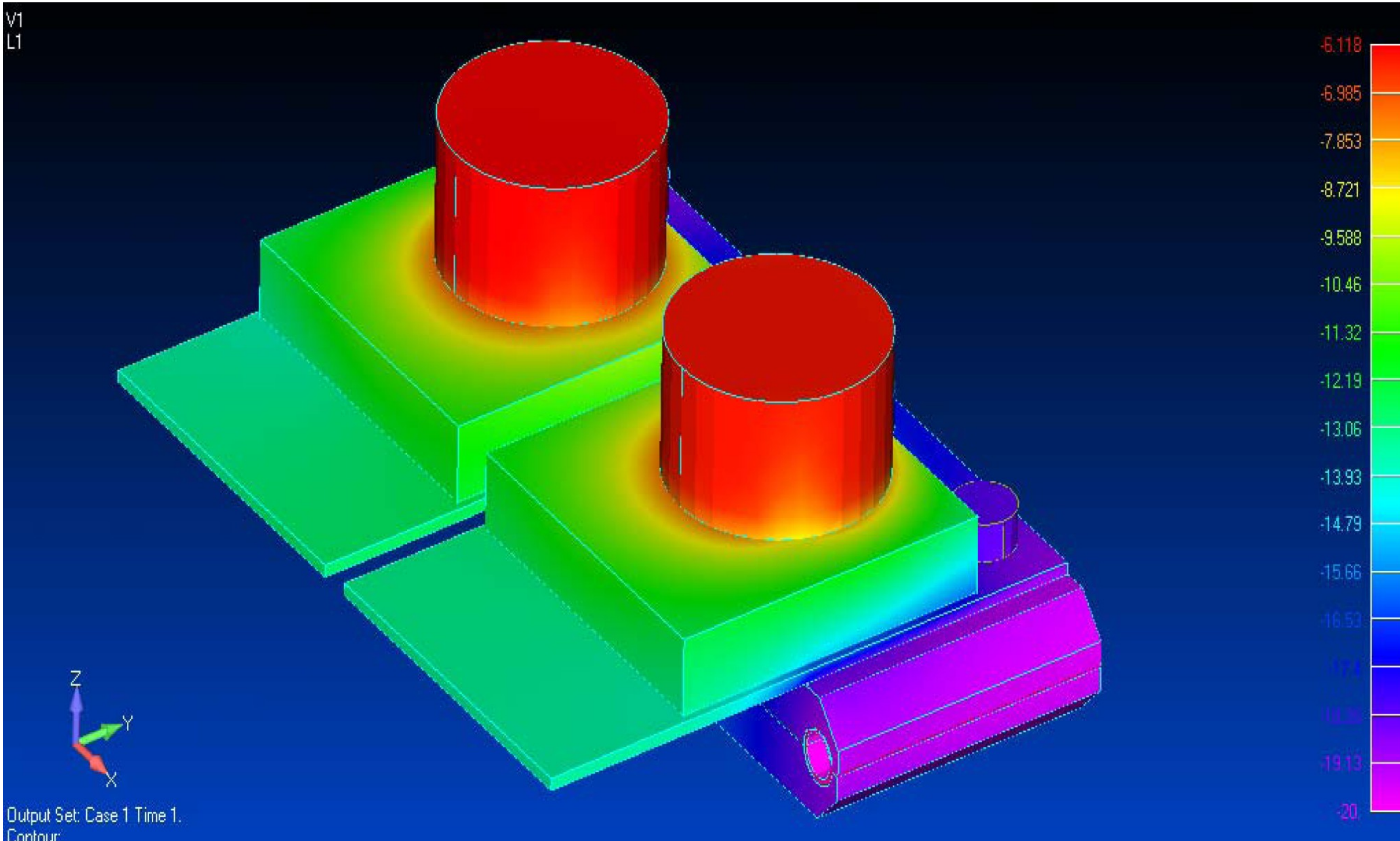
Thermal FE-Simulation

- Chips are at -7°C
  → δT = 13K
- Coils are at -6°C
  → δT = 14K

→ for room temperature operation (+20°C), both stay below 40°C

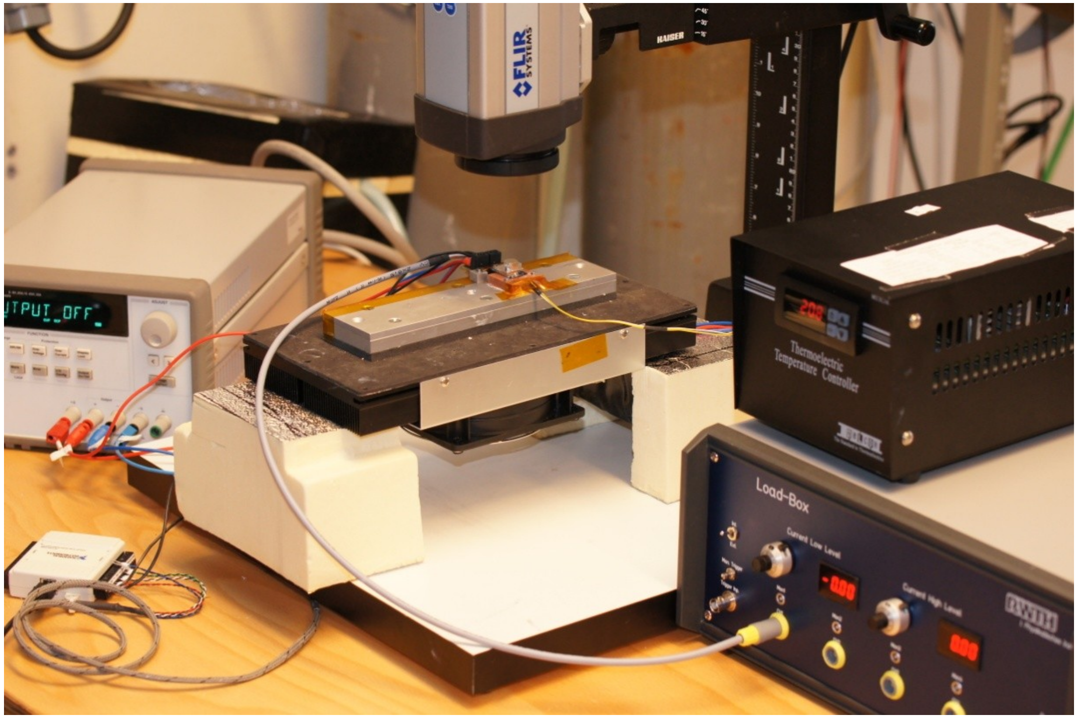


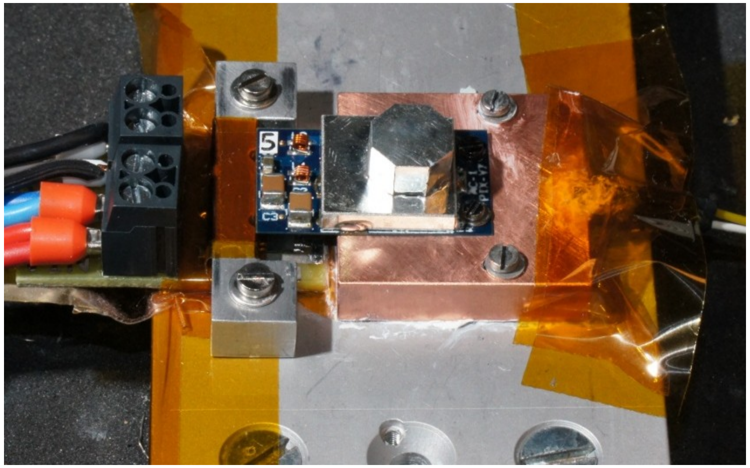
Thermal FE-Simulation



-6
-10
-15
-20
°C

Thermal Measurements



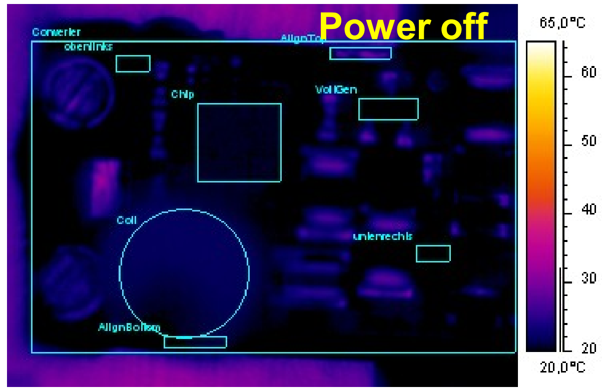


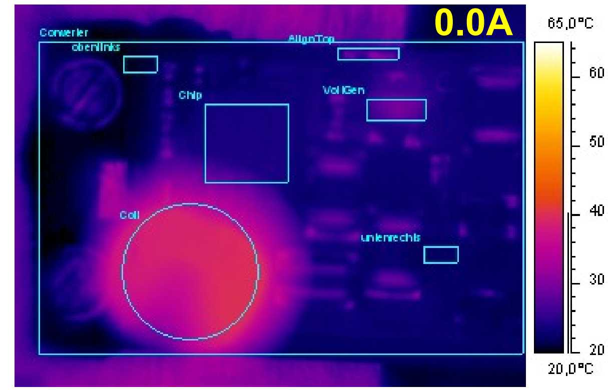
- To cross-check simulations
- Peltier element set to +20°C
- Peltier regulates on external sensor that is fixed to copper block

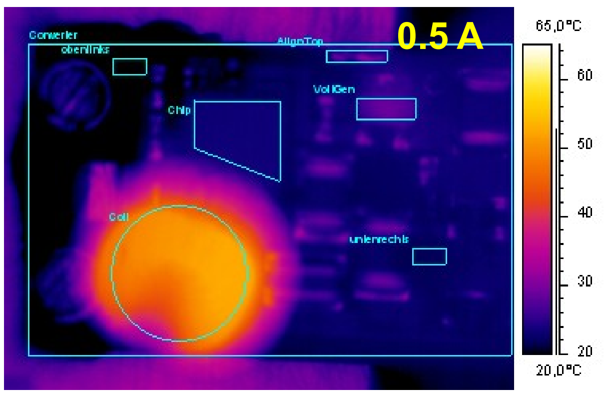
Thermal Measurements

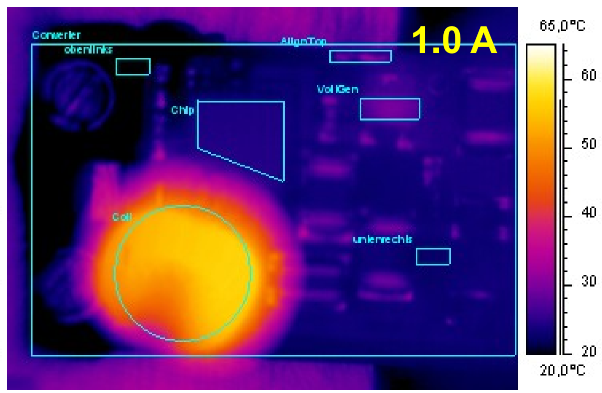
Temperate of coil, chip and PCB versus output current

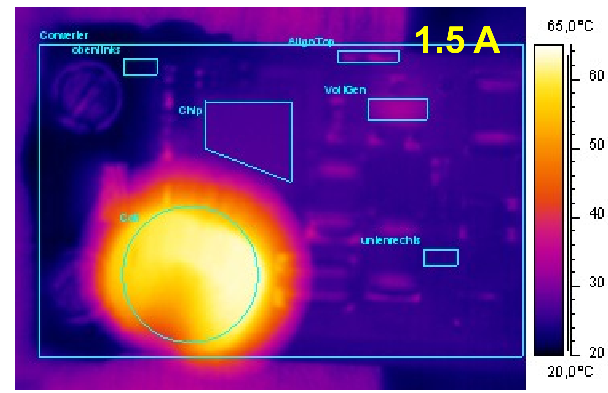
PIX_V7, 450nH, 1.3MHz
Vin = 10V, Vout = 3.3V

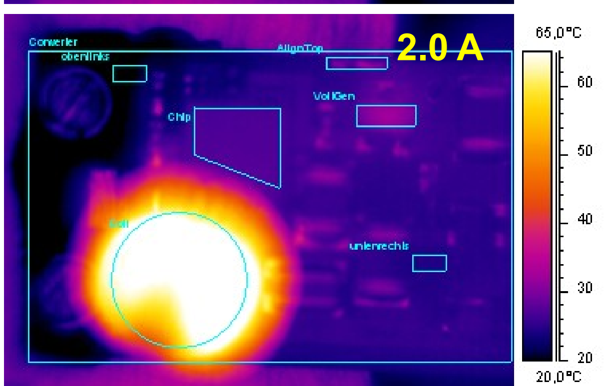


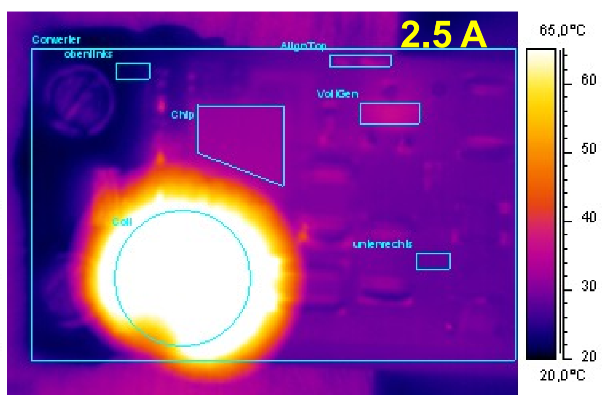


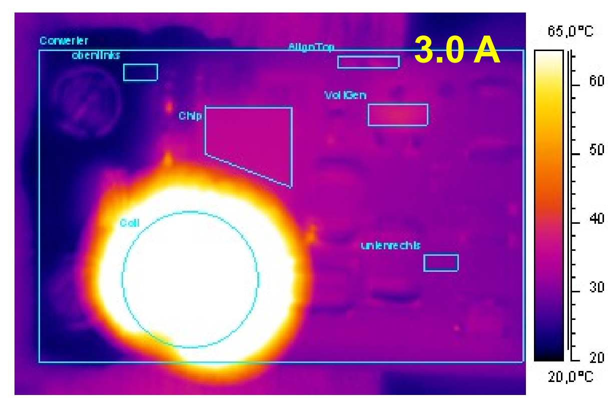




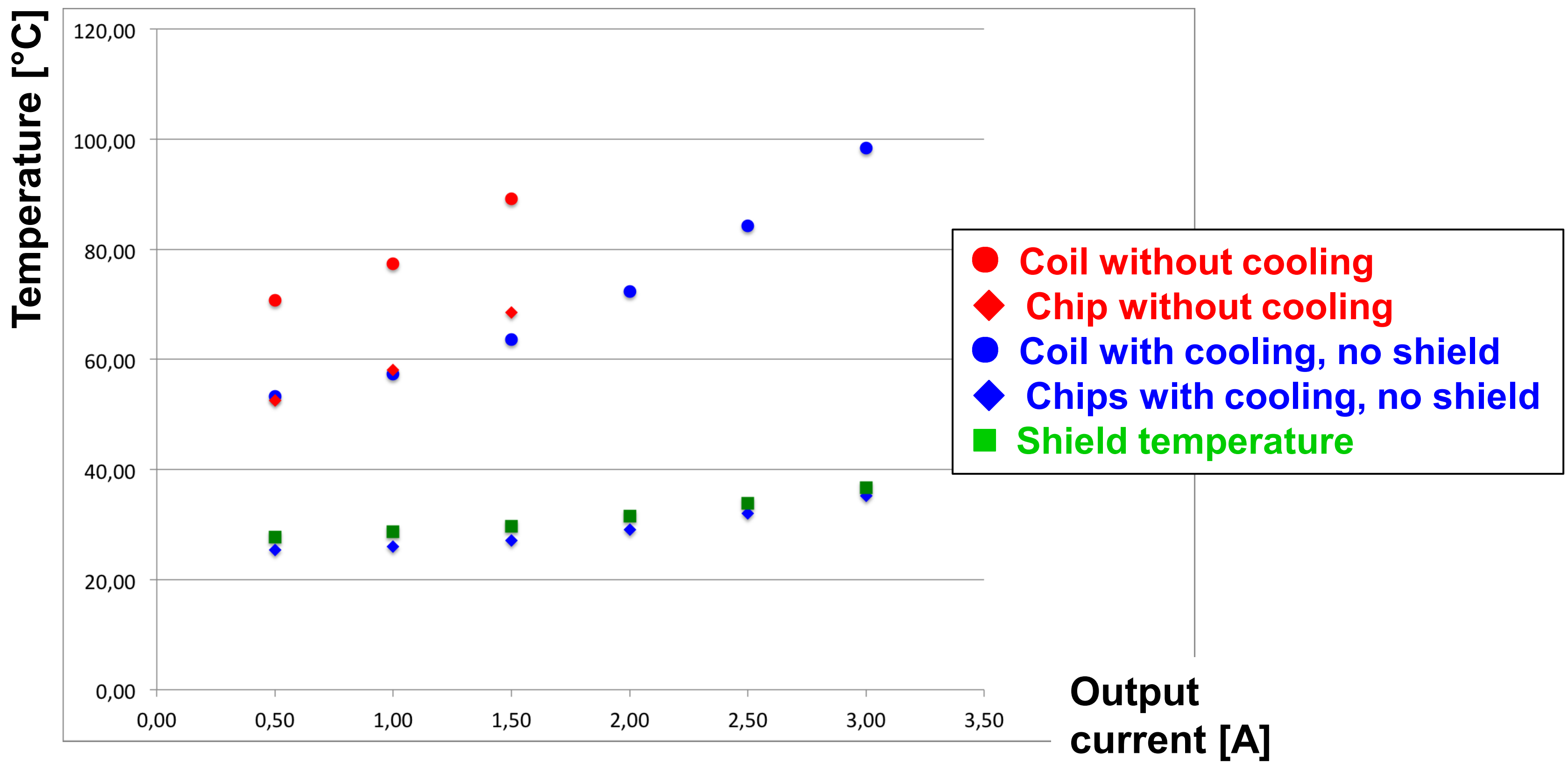








Thermal Measurements



→ Converters need to be cooled

→ Cooling of chips via backside of PCB is very effective

→ Coil needs to be connected to cooling contact (shield)

→ Temperatue of coil inside shield measured with thermistor → very similar to shield temp.

→ Good agreement with FE-simulations

Summary & Outlook

- Low noise converters with reasonable efficiency in hands
- Large progress with mechanical, electrical and thermal integration
- Cooling of converters (chip and coil) under control

- Industrialization of coil and shield production
- Further study of sensitivity of pixel modules to ripple from DC-DC converters
- Production and test of bus PCB, thermal tests with cooling bridge, ...
- Turn next ASICs (AMIS3, AMIS4) into converters

Back-up Slides

Thermal FE-Simulation

- Support Plates: Aluminum **200 W/m/K**
- Tubes: Stainless Steel (316L) **18.8 W/m/K**
- Coils: Copper **390 W/m/K**
- Chips: Silicon **20 W/m/K**
- Screws: Stainless Steel **13 W/m/K**
- Coil Filler: Conductive Glue: **22 W/m/K**

- Transition Layer Between Support Plates: Assumed 50 % Contact **100 W/m/K**
- Transition Layer Around Tubes: Assumed 95 % Contact **190 W/m/K**
- Transition Layer Underneath Boards: Some Conductive Plastic **20 W/m/K**
- Transition Layer Underneath Chips: 32 Contacting Strips (**0.25 mm** Dia) and a Ø**2 mm** Solder Patch resulting in **4.1 W/m/K**
- Transition Layer Underneath Cover: At 4 Locations Solder **3 mm** Wide, **1.5 mm** High, **1.4 W/m/K**

- Boards:
  The Board Consists of a Glass Fiber Composite Coated with two Layers of Copper Foil. The Thickness of the Composite is **0.3 mm** and of the Foil **0.035 mm**. At Several Locations there are Feedthroughs from the Upper to the Lower Foils. The Upper Foil covers 70 % of the Total Area and the Lower 100 %. The Fraction of the Feedthroughs is 1 % of the Total Area.

  in plane: 63W/m/K
  accross plane: 5W/m/K

- Plastic Cover:
  The Cover Consists of a Plastic Body coated with Layers of Aluminum Foil. The Thickness of the Plastic is **0.3 mm** and of the Foil **0.05 mm**. The Foils Cover the Plastic Totally. This leads to

  in plane: 55W/m/K
  accross plane: 0.2W/m/K

Thermal Measurements

Temperature of shield; temperature of coil inside shield measured with thermistor