Radiated Electromagnetic Emissions of DC-DC Converters

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DC-DC conversion

V_{in} I_{in}

DC-DC converter

Switching Network

Energy buffer

Reduced voltage: $V_{out} = V_{in}/r < V_{in}$

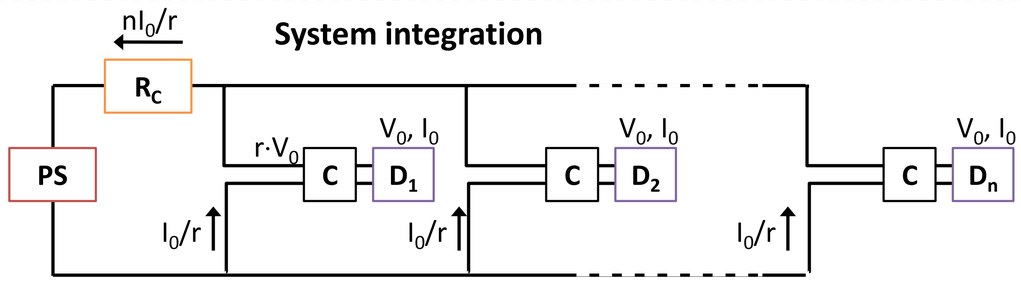
Increased current: $I_{out} = r \cdot I_{in} > I_{in}$

Motivation: the CMS tracker – from LHC to SLHC

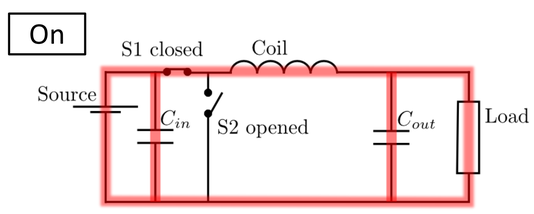
- Luminosity: 10^{34} cm^{-2}s^{-1} → 5^{34} cm^{-2}s^{-1}
  - ⇒ Up to 10 times more particles per collision in the tracker
  - ⇒ More channels, track information in level-1 trigger
  - ⇒ Faster and more complex electronics
- Smaller feature size front-end electronics (helps to save power)
  - ⇒ Larger currents for same amount of power
- More/thicker cables are not an option (material budget, services cannot be accessed)

⇒ **New tracker with a new powering scheme**

System integration



- n detector modules D_i powered in parallel, one converter C per detector
- Detectors are operated at $V_0 = V_{out}$ while $V_{in} = r \cdot V_0$
- Power losses are reduced by factor of r^2



- Converter switches between "On" and "Off" state
- Inductor is used as energy buffer
- Conversion ratio r is given by duty cycle D (for lossless converter: $r = 1/D = T/t_{on}$)

Advantages

- V_{out} is programmable via the duty cycle
- Large currents (~A) can be provided
- High efficiency is feasible (~70% - 80%)

Topology of choice: buck converter

Challenges

- Radiation-hard ASIC (switches)
- Efficient and light design
- **Switching noise**
- **Air-core coil** (due to 3.8T field in CMS)

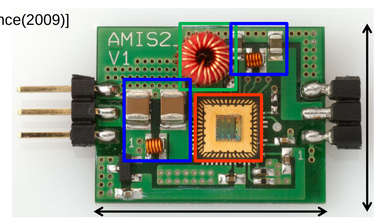
→ **risk of radiated noise**

Implementation:

- Chip: AMIS2 developed by S. Michelis, CERN

[S. Michelis et al., ASIC buck converter prototypes for LHC upgrades, TWEPP-09, Paris, France(2009)]

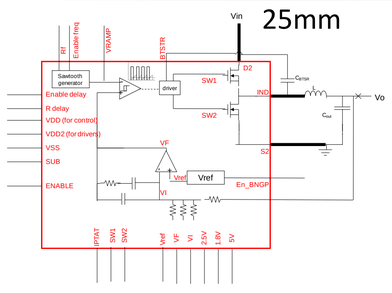
- V_{IN} = 6-12V
- $I_{OUT} \leq$ 3A
- V_{OUT} = 1.2V and 2.5V
- $f_S \approx$ 1…4MHz (1MHz)



PCB:
FR4 1mm, 2 copper layers a 35µm
m = 2.5g, V = 19x25mm² x 1mm

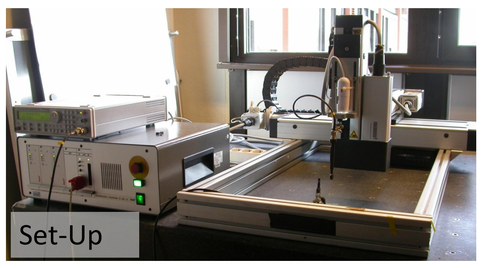
Input and output π-filters
L = 12.1nH, C = 22µF, f_{cut} = 0.34MHz

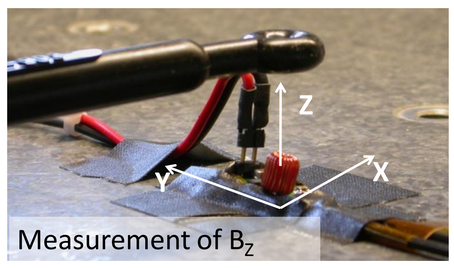
External air-core inductor:
Custom-made toroid, ∅ ≈ 6mm,
height = 7mm, L = 600nH, R_{DC} = 80mΩ

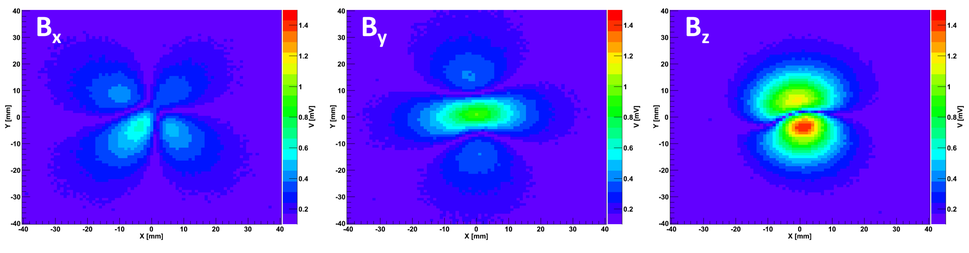


Coil Optimization

Measurement





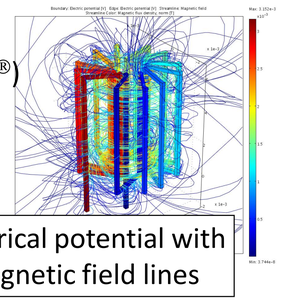


Measured components of magnetic field in x-y-plane (1.5 mm above coil)

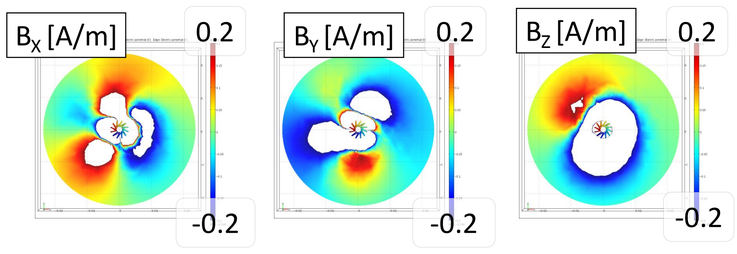
Simulation

DC Simulation (COMSOL Multiphysics®)

- Simulated toroid:
  - 12 turns
  - R_{in} = 1.1mm
  - R_{out} = 2.5mm
  - L_{sim} = 206nH

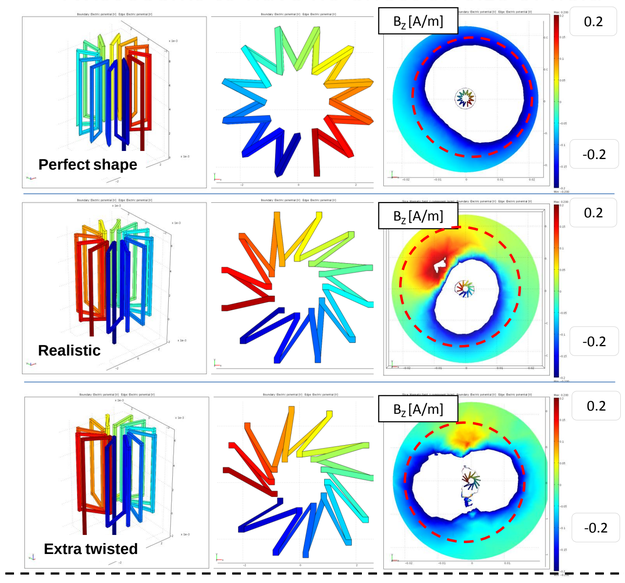


Electrical potential with magnetic field lines

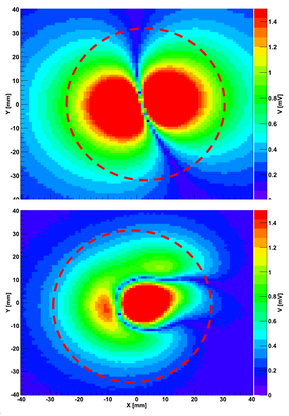


Simulated components of magnetic field in x-y-plane (1.5 mm above coil, white areas = under/over flow)

- Simulation confirms shape of field
- Effect is related to a slight twist of the coil
- Twist seems to have no effect on size of field

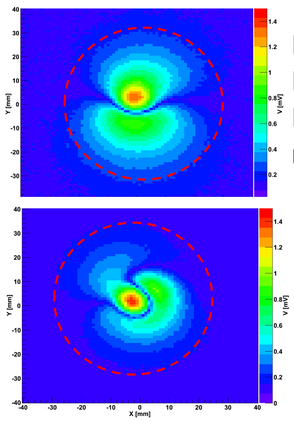


Comparison of different coils



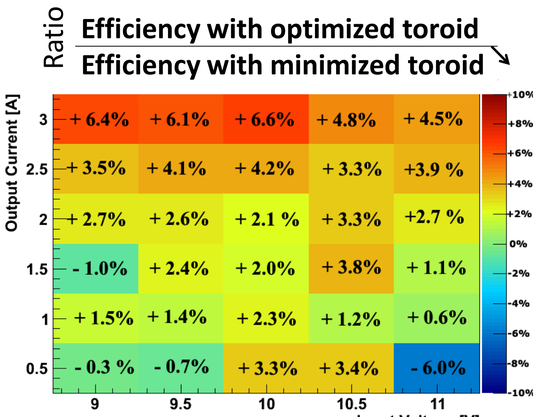
Solenoid
L = 540nH
R_{DC} = 90 mΩ
m = 245 mg

Large Toroid
L = 600 nH
R_{DC} = 104 mΩ
m = 783 mg



Minimized toroid
L = 500 nH
R_{DC} = 80 mΩ
m = 330 mg

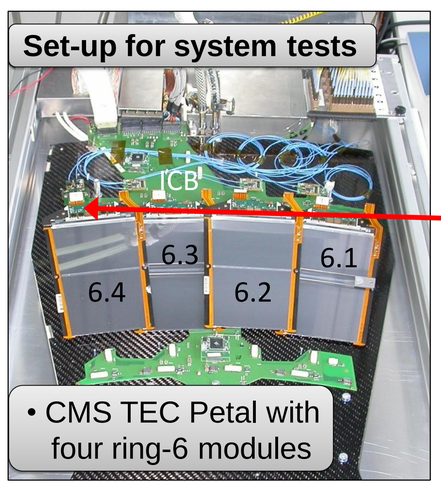
Optimized Toroid
L = 600 nH
R_{DC} = 40 mΩ
m = 660 mg

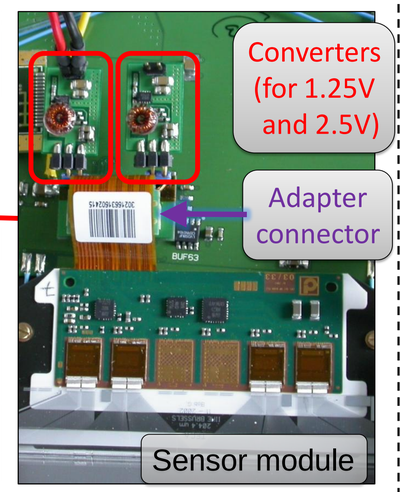


→ Improvement of about 5 %

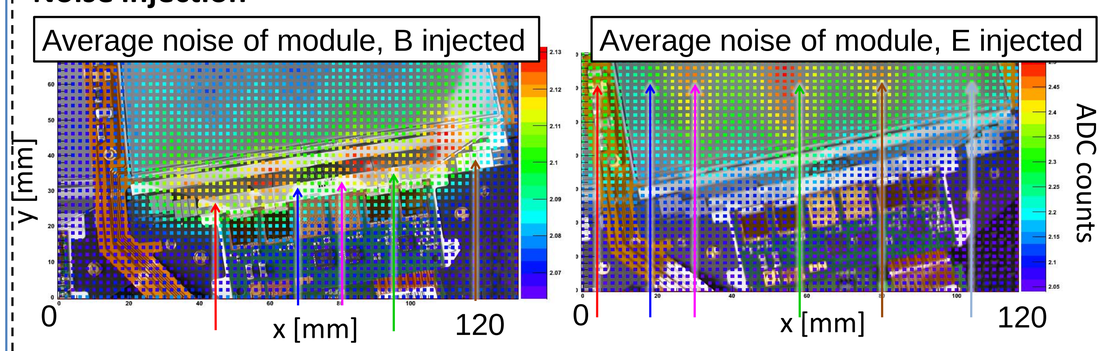
(V_{out} = 3.3V)

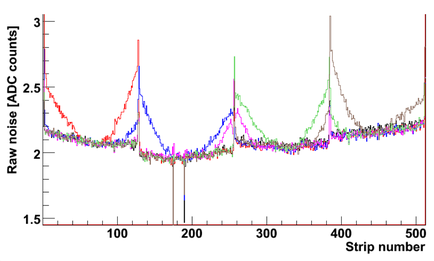
System test measurements

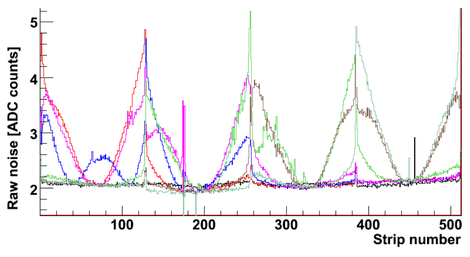




Noise injection

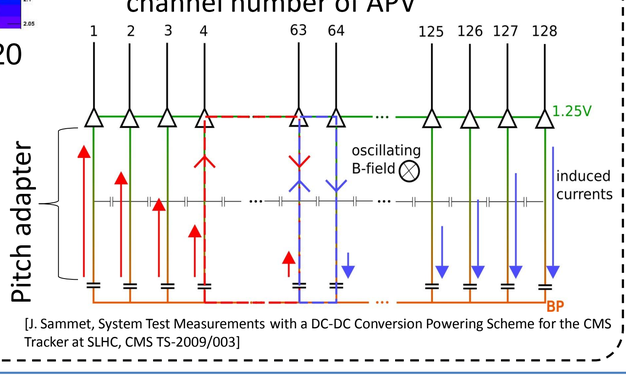






- Sensor connects pitch adapter to backplane capacitively
- 127 loops of different sizes connected to each pre-amplifier
- B_Z couples into pitch adapter
- Inner loops cancel out

→ Resulting current depends linearly on channel number of APV



[J. Sammet, System Test Measurements with a DC-DC Conversion Powering Scheme for the CMS Tracker at SLHC, CMS TS-2009/003]