R&D on Novel Powering Schemes at RWTH Aachen University - Plans and Status

Tracker Upgrade Power WG Meeting
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Our Working Group

- **Lutz Feld**: team leader
- **Waclaw Karpinski**: electronics engineer
  - plus electronics workshop team
- **Katja Klein**: HGF Fellow (4 years)
- Three diploma students:
  - **Jan Sammet**: *System test measurements with DC-DC converters*
  - **Rüdiger Jussen**: *Development and test of radiation hard magnetic field tolerant DC-DC buck converter* (in collaboration with CERN PH-ESE group, see later)
  - **Jennifer Merz**: *Simulation of material budget of various powering schemes*
• Contribute to the development & characterization of magnetic field tolerant and radiation hard DC-DC buck converters, in coll. with CERN PH-ESE group - *started*

• Investigation of system aspects of novel powering schemes
  – DC-DC conversion - *started*
  – Serial powering - *not started yet*

• Noise susceptibility measurements - *not started yet*
  – Noise injection into silicon strip modules
  – Noise injection into DC-DC converters

• Simulation of material budget of powering schemes - *started*

• R&D proposal submitted and approved (December)

• Funding via BMBF and special seed fund of RWTH Aachen university

→ In the following I go through above points and explain our plans and the current status
Development & Test of Buck Converter

• Collaboration with CERN PH-ESE group (Federico Faccio et al.)
• CERN group develops technology and converter chip - submitted
• Aachen develops and produces the converter PCB - started
• Aachen will contribute to the characterization of this custom converter
  – Test of magnetic field tolerance at up to 4 Tesla - set-up for 1.2T operational
  – Irradiation tests
  – EMI tests - set-up under preparation
• Test set-ups are also very useful to characterize commercial converters that we currently use for system tests (see later)
Test of Magnetic Field Tolerance

- Set-up with electro magnet of in-house solid state institute is **ready**
  - $B < 1.2T$ is enough for many applications
- Example: commercial converter EN5312QI (more details later)
  - MEMS technology: spiral inductor between magnetic plates
- Decrease of efficiency in magnetic field
- Total breakdown for fields below 1T (no surprise)
- Lower magnetic field tolerance for higher duty cycles $D = \frac{T_{on}}{T} = \frac{V_{out}}{V_{in}}$

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EMI Tests

- Standardized EMI test setup at CERN
- Standalone test of converter noise (common & differential mode) independent of power supply noise and load
- Different converters and PCB designs can be compared
- Example measurement of commercial converter EN5312QI → low noise
- Very useful → duplication of setup in Aachen is ongoing!
• Preparation of system test set-up with current strip tracker substructures (petals)
  – Set-up with 4 modules sufficient for many measurements - running
  – Upgrade to full petal set-up desirable - not yet done due to lack of time

• Operation of current (and future) strip tracker substructures with custom rad-hard & magnetic field tolerant DC-DC converters
  – Custom converters are being developed by CERN PH-ESE;
    expect converter chips to be available for system test not before Autumn

• Operation of current strip tracker substructures with of-the-shelf DC-DC converters
  – Market study of commercial devices - done
  – Integration into tracker structures using a custom adapter PCB - done
  – Investigation of noise behaviour, cross talk etc. - ongoing
  – Study combination of DC-DC converter with LDO regulator - ongoing
  – Study effect of external air-core coil - ongoing
  – …
• Market survey (W. Karpinski) with main criteria:
  – high switching frequency → small size of passive components
  – high conversion factor
  – sufficient current (~ 1A) and suitable output voltages (1.25V and 2.5V)

• Two devices identified and purchased:
  – Enpirion EN5312QI with 4 MHz switching frequency
  – Micrel MIC3385 with 8 MHz switching frequency

• All measurements shown are based on EN5312QI
  – since results with MIC3385 are still too fresh
Enpirion EN5312QI

- Small footprint: 5mm x 4mm x 1.1mm
- $f_s \approx 4$ MHz
- $V_{\text{in}} = 2.4V – 5.5V$ (rec.) / 7.0V (max.)
- $I_{\text{out}} = 1A$
- Integrated planar inductor with iron-manganese-zinc core

From data sheet

Inductor in MEMS technology

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Integration into CMS End Cap System

- 4-layer adapter PCB
- Plugged between Tracker End Cap (TEC) motherboard and FE-hybrid
- 2 converters provide 1.25V and 2.5V for FE-hybrid
- Input and output filter capacitors on-board
- Input power external or via TEC motherboard
Integration into CMS End Cap System

L-type:
Larger flat PCB, 1 piece

S-type:
Smaller inclined PCB, 2 pieces

Front-end hybrid

TEC motherboard (InterConnect Board, ICB)
Standalone Tests with Oscilloscope – L Type

Without load:

- $V_{in} = 6V$
- $V_{2.50}$
- $V_{1.25}$

With load ($I = 0.7A$):

- $V_{in} = 6V$
- $V_{2.50}$
- $V_{1.25}$

- High frequency ringing
- Ripple with switching frequency

$\Rightarrow 100mVpp$ high frequency ringing on input
$\Rightarrow 10mVpp$ ripple with switching frequency on output
System Test Setup

- TEC petal with InterConnect Board
- Four ring-6 modules powered & read out
- Petal housed in grounded metall box
- Optical readout
- Optical control communication
- Thermally stabilized at +15°C
- Final components (spares)
- Official DAQ software
• Since this meeting focuses on plans I will show only few results to indicate current status and lines of investigation
• This is work in progress – many aspects not yet fully understood
• A more comprehensive status report will be presented in the next meeting!
Effect of Converter (Position 6.4)

- No converter
- L type
- S type
Powered via ICB

⇒ Raw noise increases by 5-10%
⇒ Design of PCB has significant impact
⇒ Further optimization seems possible
Effect of Converter (Position 6.4)

Pos. 6.4

- No converter
- L type
- S type

Powered via ICB

⇒ Broader common mode distribution
⇒ Huge increase of noise at module edges, APV edges and “bad“ strips

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Edge strip noise increased only if sensor is present
Capacitive coupling seems to be crucial
Further investigations are needed
Cross Talk

Effect of cross talk - position 6.4

- No converter
- Converter on all positions
- Converter on 6.4 only

L Type

\[ \Rightarrow \text{Performance with converter does not depend on \# of modules operated with converter} \]

\[ \Rightarrow \text{A converter on position 6.4 does not spoil the performance of modules without converter (e.g. 6.3)} \]

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Effect of Low DropOut Regulator

Linear technology VLDO regulator LTC3026 after DC-DC converter

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Effect of Low DropOut Regulator

- No converter
- L type without LDO
- L type with LDO, dropout = 50mV
- L type with LDO, dropout = 100mV

⇒ LDO reduces voltage ripple and thus noise significantly
⇒ Indicates that noise is differential mode
⇒ Can efficiency penalty be accepted?
Enpirion **EN5382D** (similar to EN5312QI) operated with external inductor:

- Air-core inductor Coilcraft 132-20SMJLB; L = 538nH
- Ferrite-core inductor Murata LQH32CN1R0M23; L = 1μH
Effect of External Air-Core Inductor

Effect of different inductors on position 6.4

- No converter
- Internal inductor
- External ferrite inductor
- External air-core inductor

$$\Rightarrow$$ Huge noise induced by air-core inductor
$$\Rightarrow$$ Radiated noise leads to cross talk between modules

Pos. 6.4

Pos. 6.3
(Converter is on 6.4)
• Integration of serial powering scheme into (current) petal structure
  – Much more complicated than for DC-DC converters
  – Needs development of new InterConnect Board - not started
  – Generic chip (SPI) developed at Fermilab (Marcel Trimpl);
    can probably be used for CMS tracker but integration not completely trivial;
    Marcel has agreed to provide us with these chips - available not before autumn?

• System test measurements

⇒ Activity has not yet started since priority is on DC-DC converters
⇒ Significant engineering man power needed
⇒ Help of other groups is very welcome!
• Noise injection tests have been performed in the past
  – On level of APV – Mark Raymond
  – On level of petal – Fernando Arteche together with Aachen group
  – …

• We want to inject noise into a single module to measure noise susceptibility vs. frequency
  – Interesting to know critical frequency range for future DC-DC converter development
  – Set-up needs same components as EMI set-up (e.g. current probes)
  – Can use converter PCB for injection

• We want to inject noise into input of DC-DC converters
  – Check sensitivity to power supply noise and pick-up noise in cables

⇒ Not yet started - awaiting components!
Simulation Study of Material Budget

- **Simulation of material budget for various powering schemes**
  - Based on current CMSSW tracker geometry
  - Relative comparison only
  - Aim to understand in a more quantitative way what we can gain

- **Activity has started, but we are still in the learning phase**
• We will investigate DC-DC converters and serial powering schemes with emphasis on system aspects
• We have started with system test measurements based on commercial buck converters
• Noise increases by 5-10%
• Noise on edge and bad strips increases drastically
• Conductive noise can be controlled with LDO regulator
• External air-core coil radiates noise

• We will continue these tests with custom converters, when available
• In the longer term, we have to answer some basic questions:
  – Can radiative noise of air-core inductor be controlled?
  – How many conversion steps do we want?
  – CMOS or/and discrete implementation?
  – How close to the silicon modules do we want/need to place those converters?
Back-up
Output Voltage (e.g. 2.5V)

DCU read out 1000 times per converter (caveat: sensitivity to low frequ. variations only)
⇒ Some variation between converters, but RMS of each single converter is small
⇒ No significant difference between L and S
⇒ No correlation between mean or RMS of voltage and mean module noise
Influence of PCB Design

No converter

L type

S type

⇒ Some variation within types, but L and S are clearly different

Mean = 1.92548
σ = 0.0314997

Mean = 2.08891
σ = 0.0340944

⇒ Indication that difference comes from inductance of “bridge“ connector
Common Mode Subtraction

- Raw noise without converter
- Raw noise with converter
- CM calculated per APV (128 strips)
- CM calculated for 32 strips
- Linear CM subtraction

L Type
Powered externally

\[\Rightarrow \] Additional noise completely subtractable with proper common mode algorithm
\[\Rightarrow \] Noise increase due to higher common mode

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Mean noise increases with input voltage or conversion ratio $g \ (g = V_{\text{in}}/V_{\text{out}})$.
Different Methods of Powering

Different Methods of Powering

--- No converter
--- L/S type powered externally
--- L/S type powered via ICB; many filter capacitors

⇒ Sensitivity to input voltage ripple to be studied, but sensitivity seems to be small
Effect of Output Filter Capacitance

Different output filter capacitances

Pos. 6.4
L type

No converter
L3: standard output filter capacitors
L1*: add. 22 μF
L2*: add. 100 μF

Pos. 6.4
S type

No converter
S2: standard output filter capacitors
S1*: add. 100 μF

⇒ Noise can be reduced further by larger output filter capacitances

---- No converter
---- Standard output filter capacitors
---- Additional 22 μF capacitor
---- Additional 100 μF capacitor

Powered externally
Study correlations between pairs of strips i, j (R = raw data):
\[ \text{Corr}_{ij} = \frac{\langle R_i R_j \rangle - \langle R_i \rangle \langle R_j \rangle}{\sigma_i \sigma_j} \]

⇒ No cross-talk between neighbouring modules observed
⇒ High correlations only within single modules (common mode)