RWTH AACHEN UNIVERSITY

Development and System Tests of DC-DC Converters for the CMS SLHC Tracker

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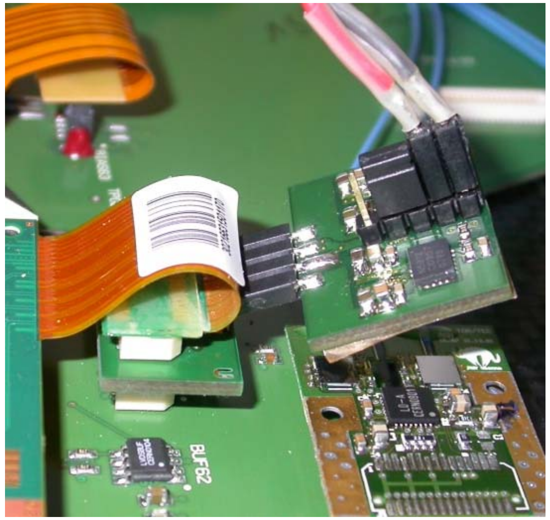
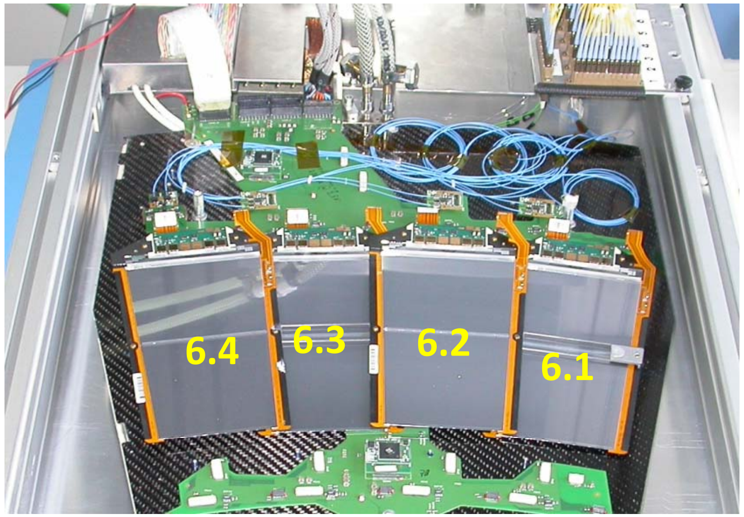
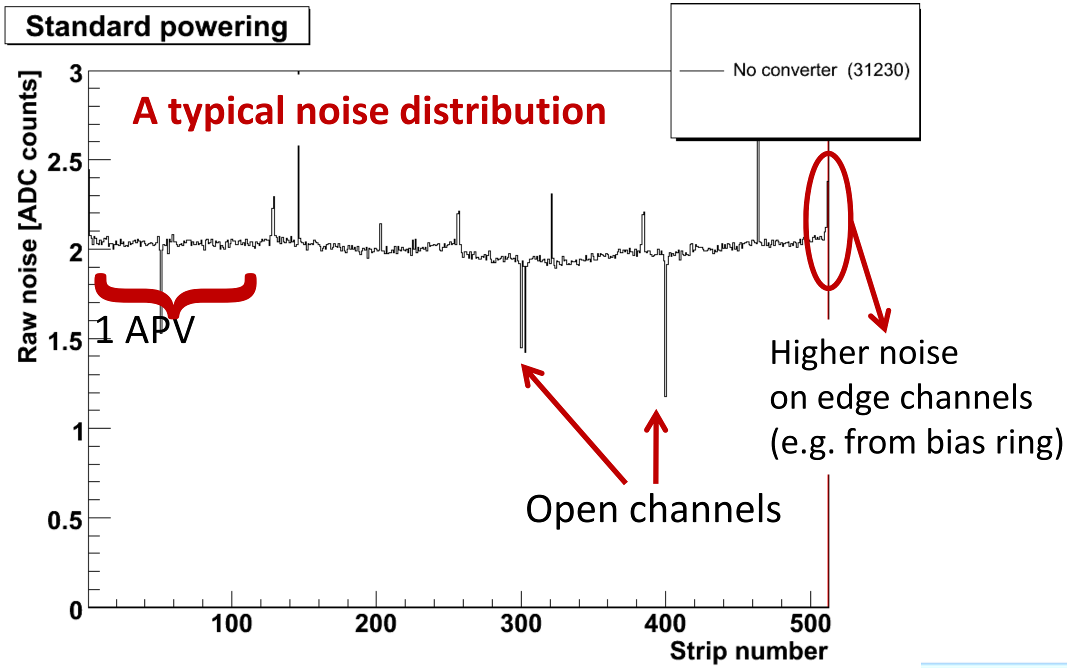
Outline

- Introduction
- Tests with Commercial Buck Converters
- Tests with CERN Buck Converter
- Optimization of Buck Converter
- EMI Test Stand
- Material Budget
- Summary and Outlook

System Test with a TEC petal

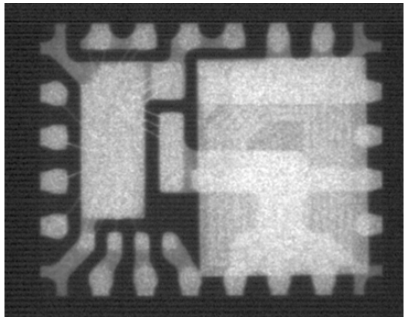


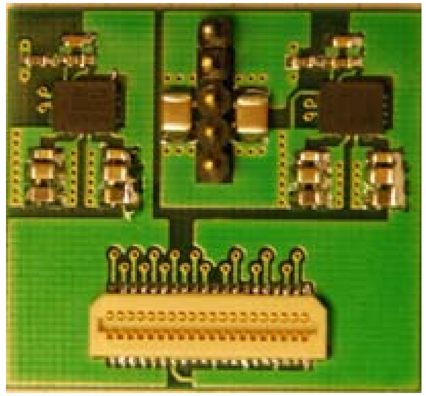




Commercial Inductor Based DC-DC Converters

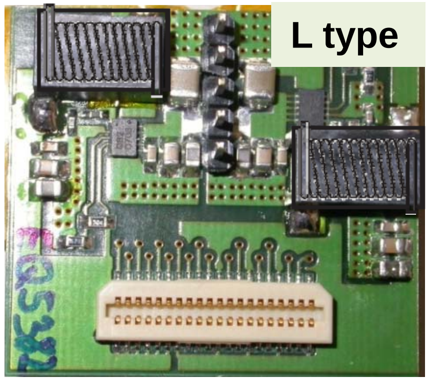
- Enpirion EN5312QI
  - switching frequency fs ≈ 4 MHz
  - Vin = 2.4V – 5.5V (rec.) / 7.0V (max.)
  - Iout = 1A
  - integrated planar inductor





- Enpirion EN5382D (similar to EN5312QI)

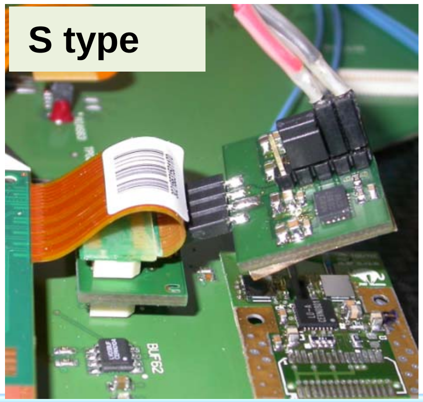
  operated with external inductor
  - air-core inductor Coilcraft 132-20SMJLB (538nH)
  - ferrite-core inductor Murata LQH32CN1R0M23 (1μH)



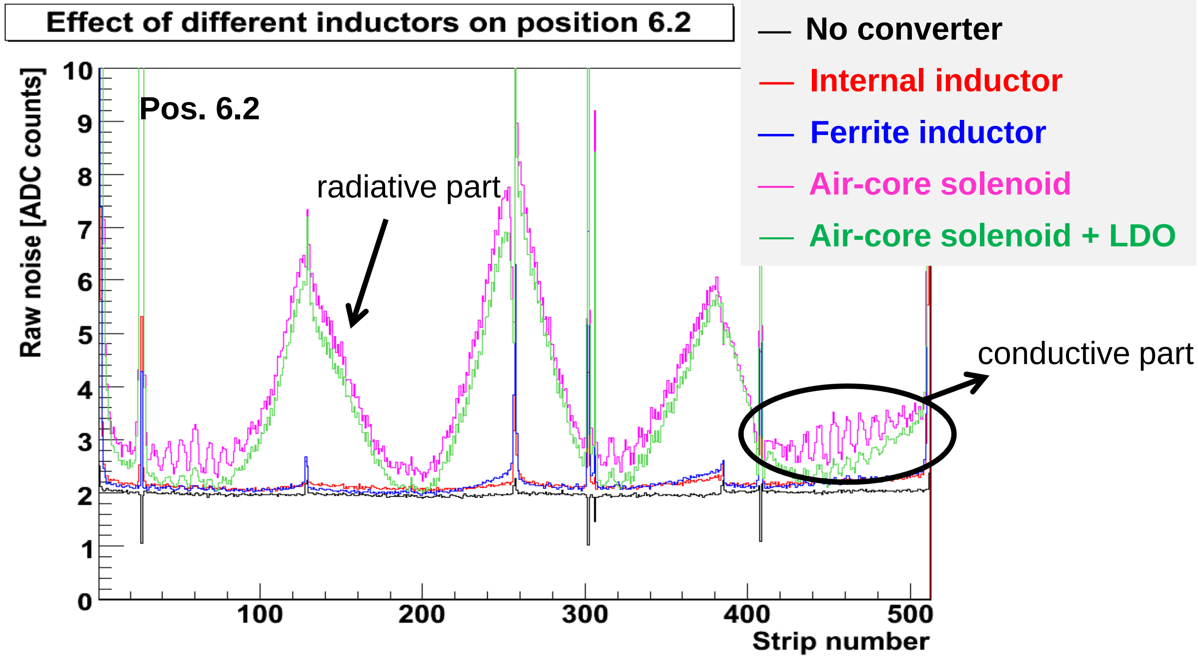
- 4-layer PCB with 2 converters provides 1.25V and 2.5V
  - Input power (Vin = 5.5V) provided externally or via TEC motherboard
  - Various designs:

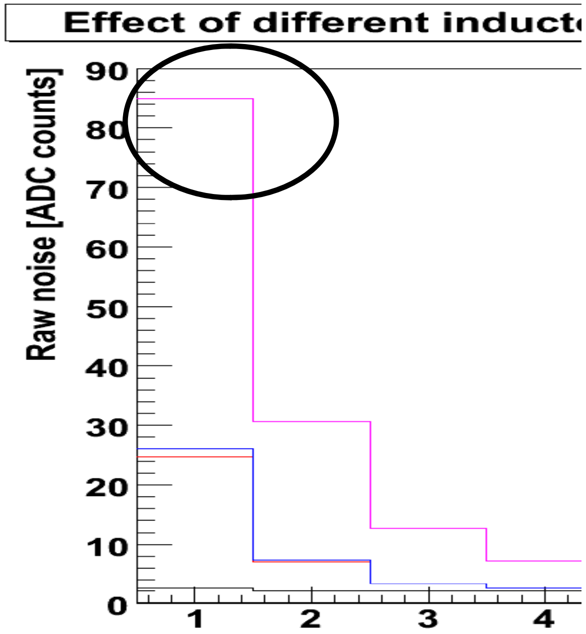
    type L: larger board with integrated connector,

    type S: smaller board with separate connector
  - with and w/o LDO regulator (50 mV voltage drop)



System Test with Commercial DC-DC Converters





- internal or external ferrite core inductor: 10% noise increase
- air-core inductor: huge noise increase, the noise of the edge strips increases by a factor > 10
- APV contains on-chip common mode noise subtraction
- output of irregular channels is affected by this common mode subtraction:
  - un-bonded (low noise) channels become noisy
  - higher common mode on edge channels is not fully subtracted
- **un-bonded channels and edge channels indicate true common mode noise**

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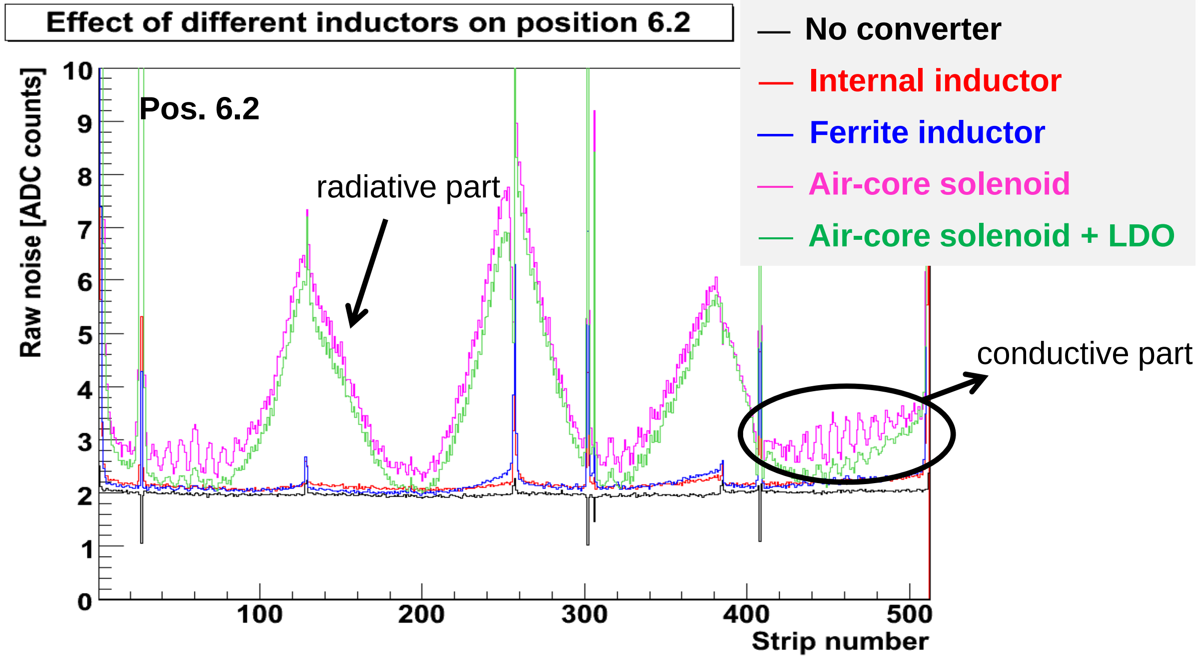
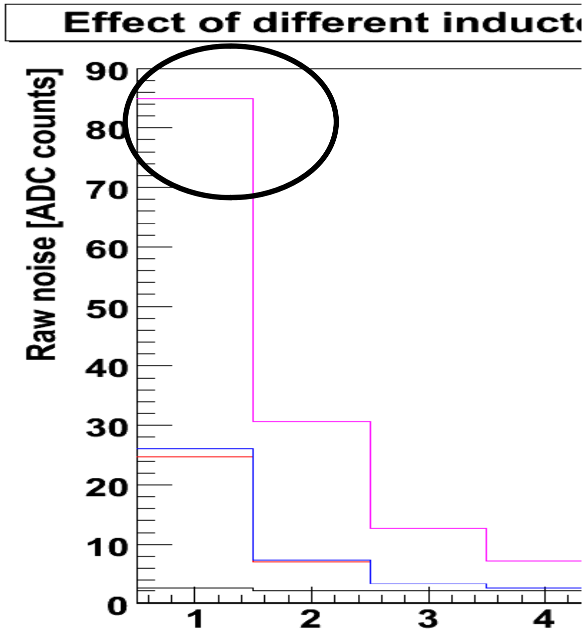


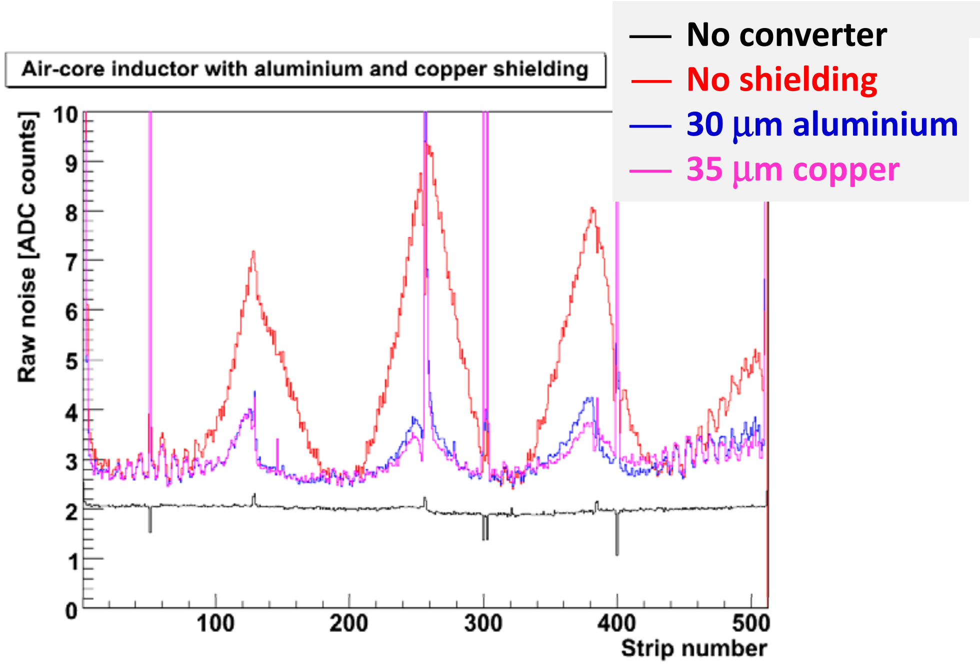


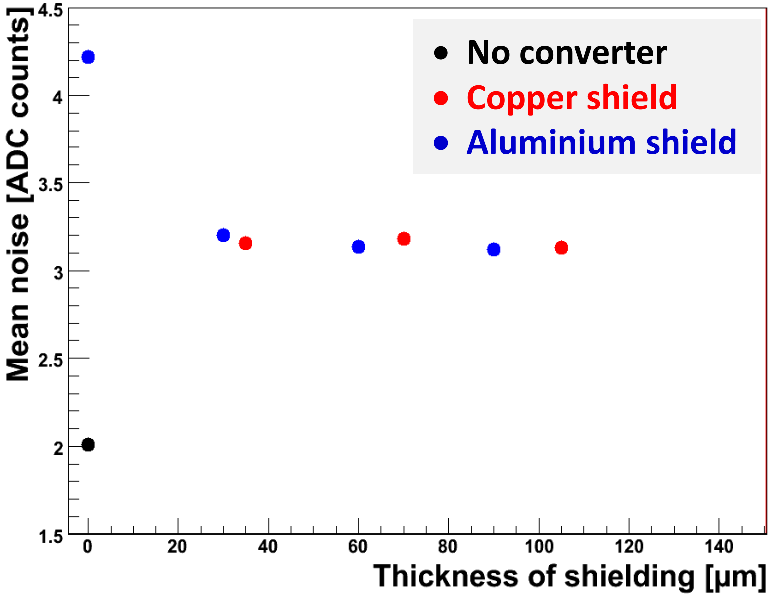
- interference with module has two contribution: radiative and conductive
- "radiative part" , wing-shaped noise, can be reproduced by exposing the module to radiation from air core coil converter (not connected to a module) located above hybrid
- "conductive part", comb-shaped noise, can be reproduced by noise injection into the cables
- LDO decreases the conductive part, but not the wings

Shielding

- radiative interference can be eliminated to a large extend by shielding the converter with 30 µm aluminum
  - no further improvement for > 30µm
  - thinner shield could be sufficient
- no significant difference in shielding efficiency between Cu and Al observed
- contribution of 3x3x3cm^3 box of 30µm alum. for one TEC: 1.5kg

  (= 2 per mille of a TEC)

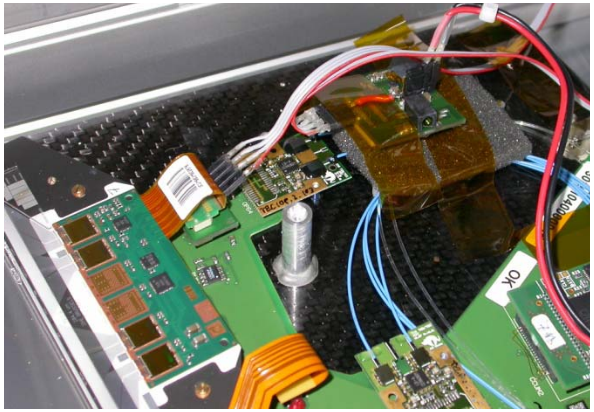


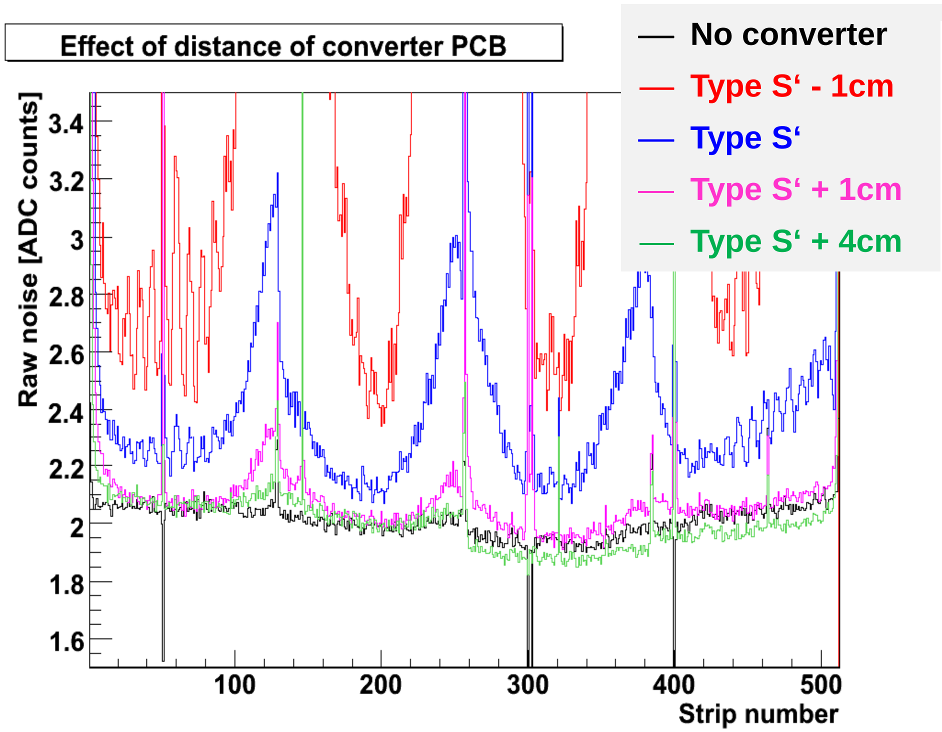


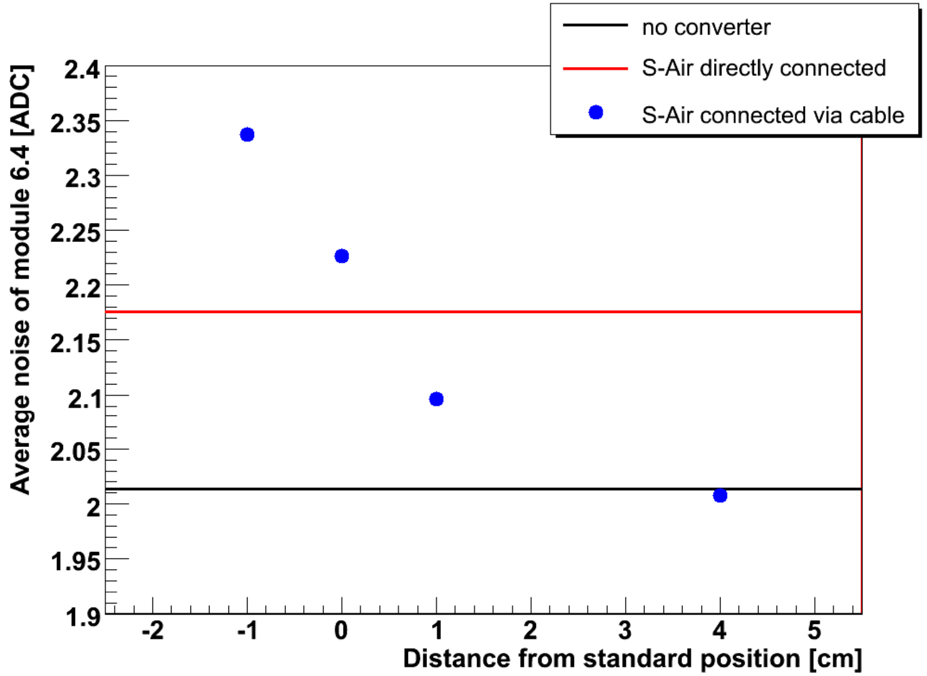
Converter Placement

- The distance between converter and FE-hybrid has been varied using a cable between converter and hybrid connector
- Sensitivity to distance is very high
- majority of noise removed over the first two cm
- Conductive noise is decreased as well due to filtering in the connector/cable

Type S‘ 4cm further away

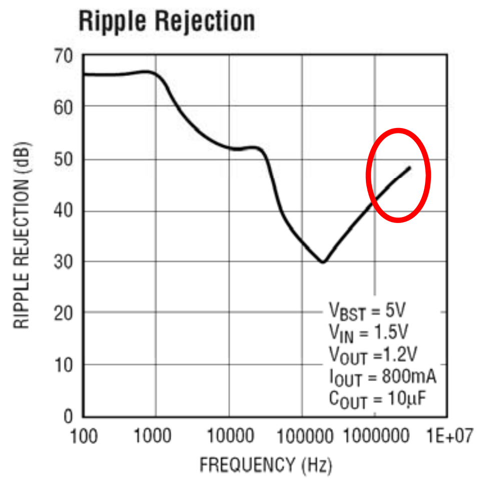


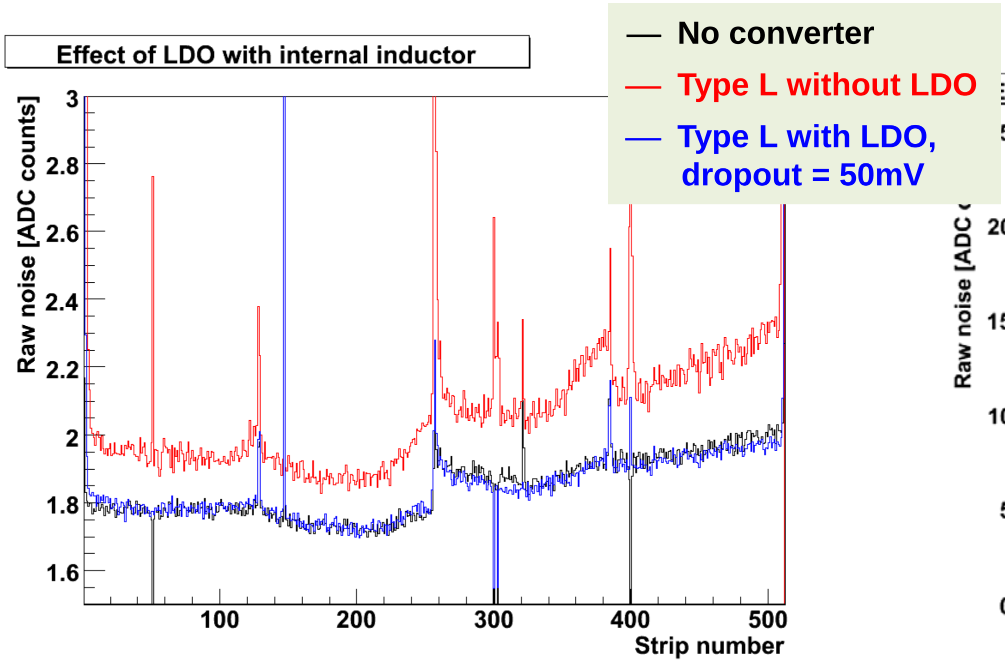


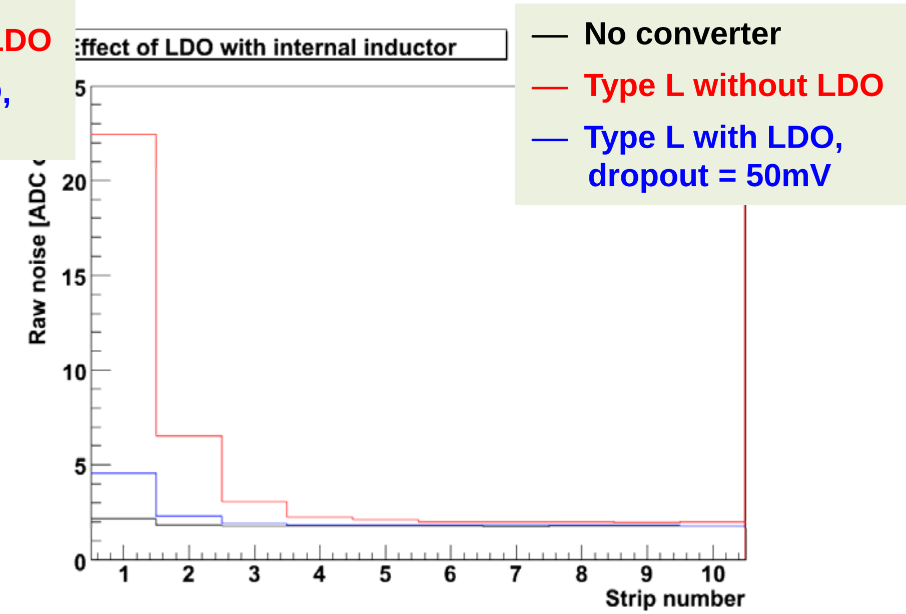


Low Drop-Out Regulator

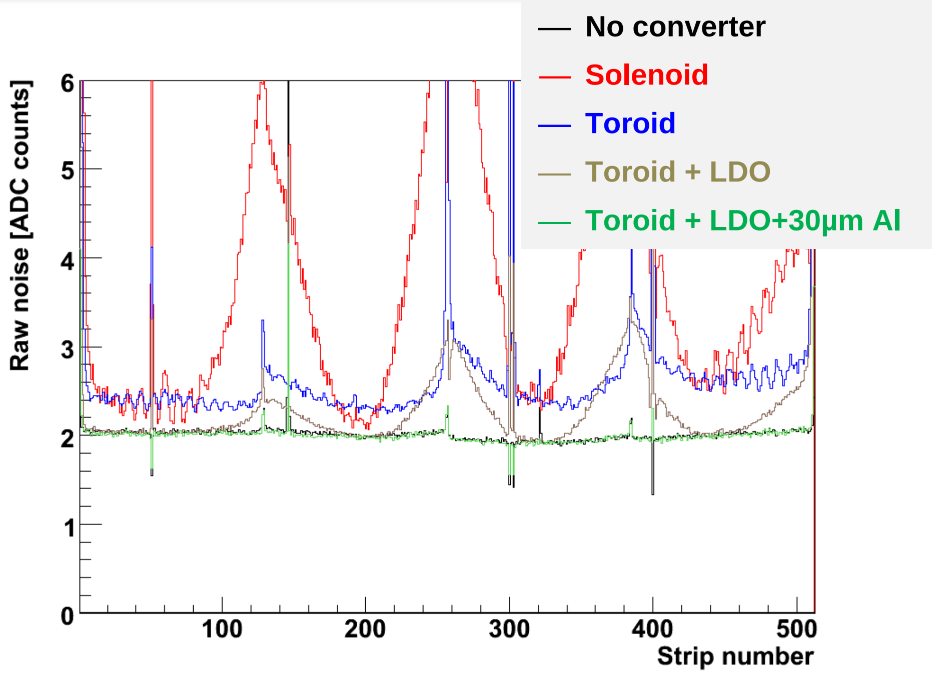
- **Low DropOut Regulator (LDO)** connected to output of EN5312QI DC-DC converter with internal coil
- VLDO regulator LTC3026, 50 mV voltage dropout only
- Ripple rejection ~ 45 dB at 4 MHz
- LDO reduces noise of the module significantly
- The noise on edge strips is “only” a factor ~ 2 above normal level

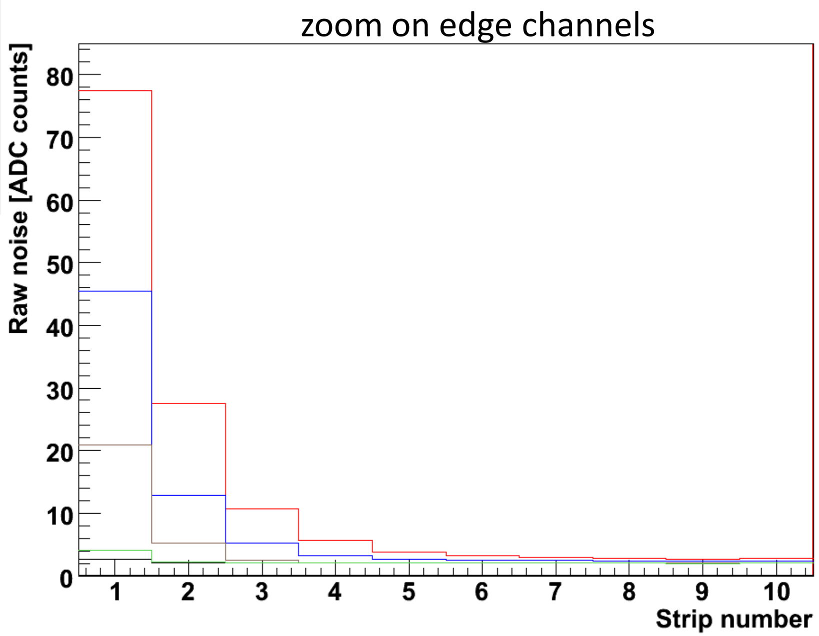






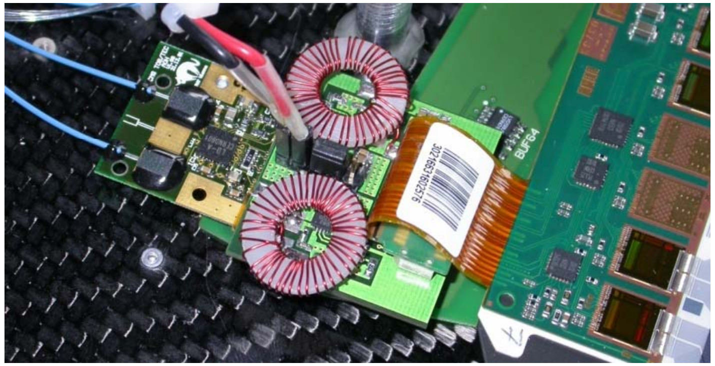
Toroid inductors



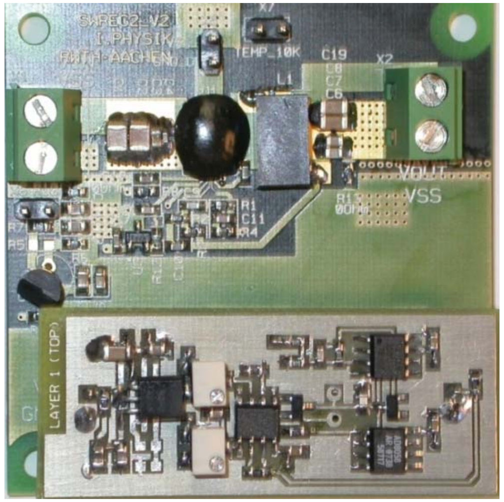


- Toroid inductors radiate less power
- Toroid reduces the noise by factor ~ 3
- Toroid: radiative and conductive noise
- Toroid with LDO: radiative noise only
- Toroid with LDO and 30µm aluminum shield

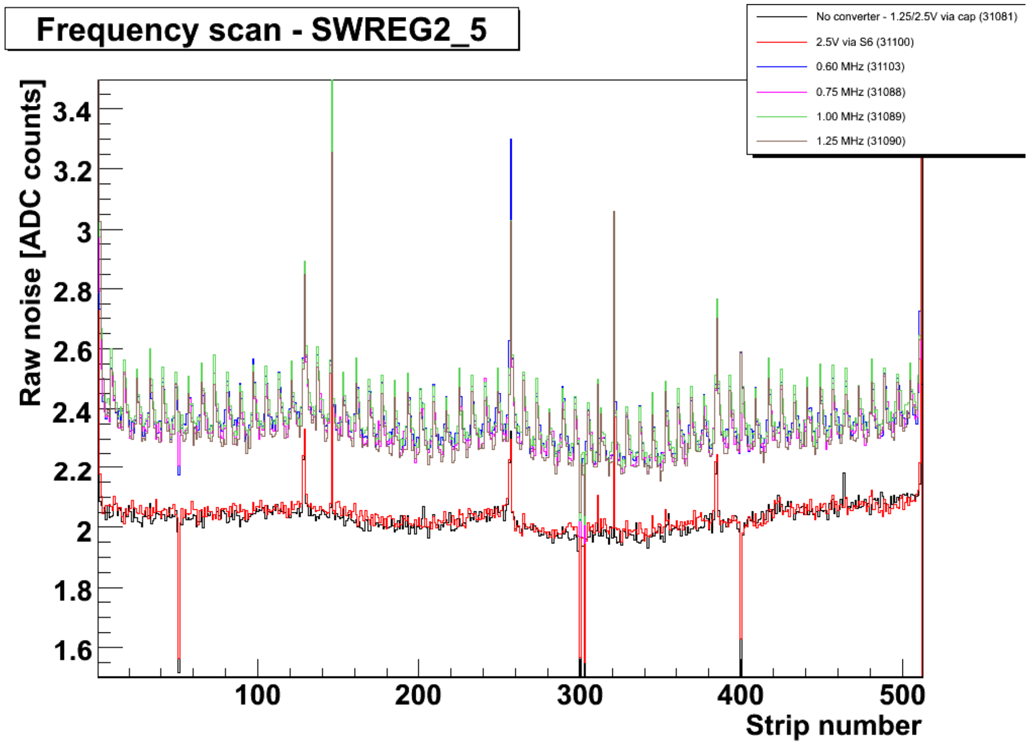
  hardly any noise increase is observed



System Tests with CERN Buck Converter SWREG2



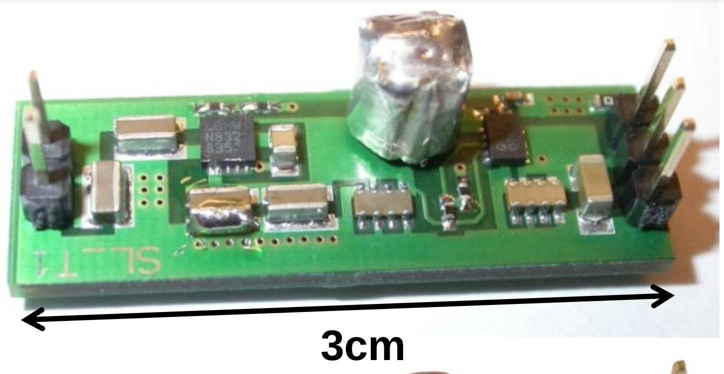
- Buck controller chip “SWREG2“ dev. by CERN electronics group (F. Faccio et al.) in AMIS I3T80 technology
- PCB with air-core coil, located far away from module
  - ⇒ noise is conductive
- SWREG2 provided 2.5V to APVs, 1.25V taken from ICB
- Data recorded for V_{in} = 5.5V
- test with several switching freq. between 0.6MHz and 1.25 MHz

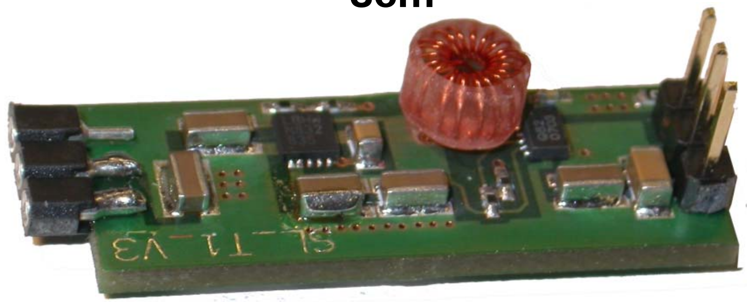


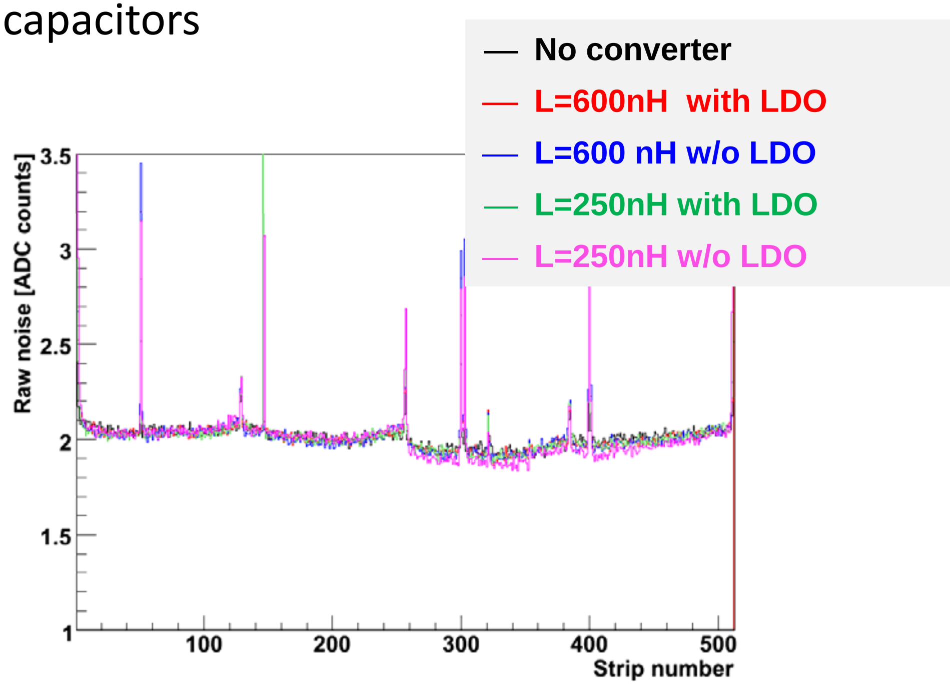
- the noise level is increased by 20%
- noise ripple with a period of 8 strips
- sawtooth structure understood to be artefact of strip order during multiplexing;
- converter affects backend stages of APV
- **noise performance not satisfactory**

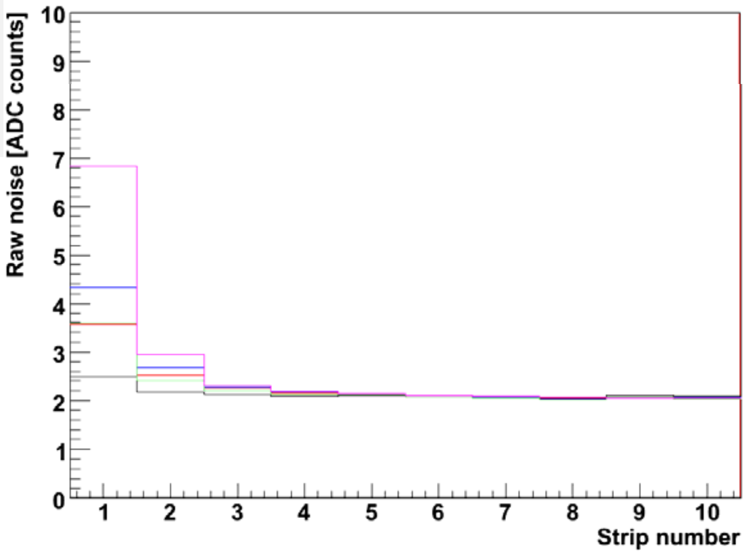
optimization of converter design

- focus on design of low mass, low noise shielded converters
- study to improve noise behaviour
  - different toroids L= 600nH and L=250 nH
  - standard ceramic capacitors
  - reverse geometry low ESL capacitors
  - 8 terminals low ESL capacitors
  - with and w/o LDO
- First measurements with reverse geometry capacitors



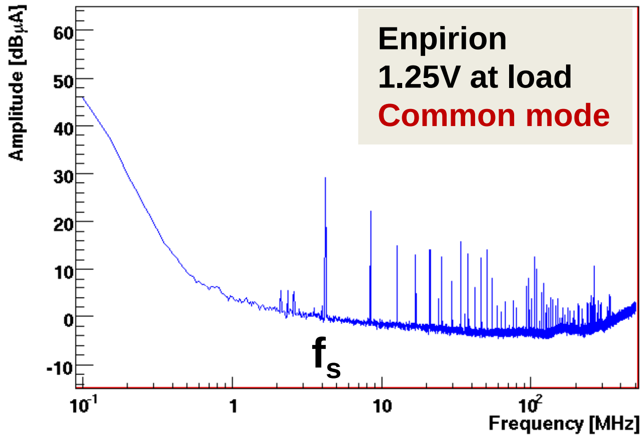


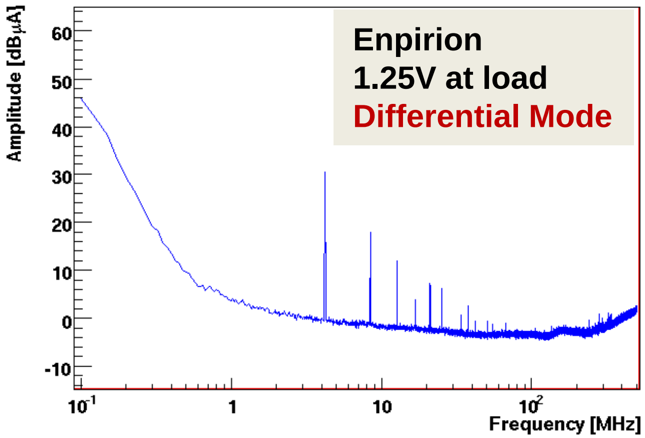


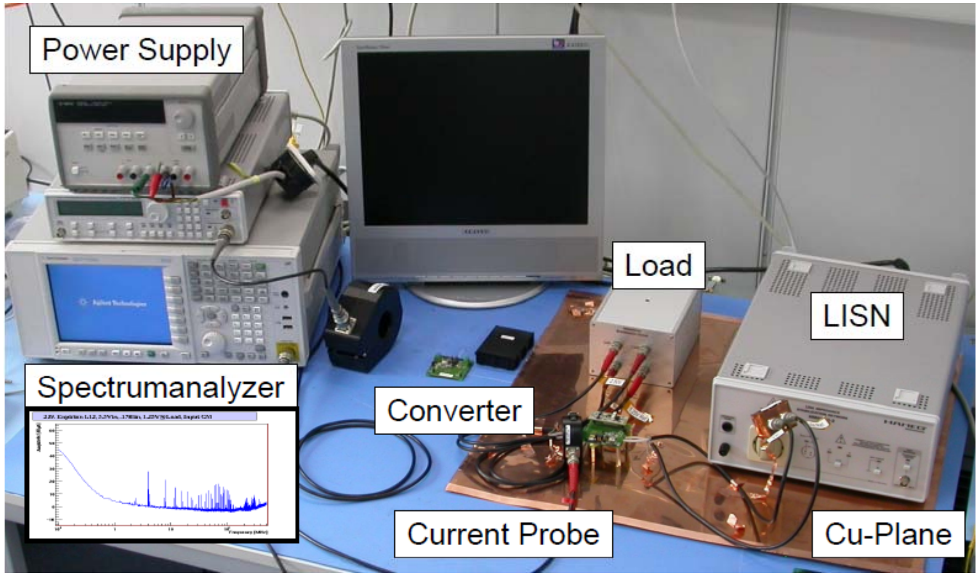


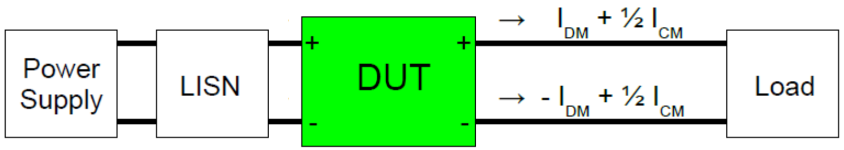
EMI Test Stand

Standardized EMC set-up to measure **Differential & Common Mode** noise spectra (similar to set-up at CERN)

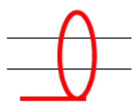






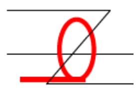


CM-Setup:



$I_{DM} + ½ I_{CM} - I_{DM} + ½ I_{CM} = \mathbf{I_{CM}}$

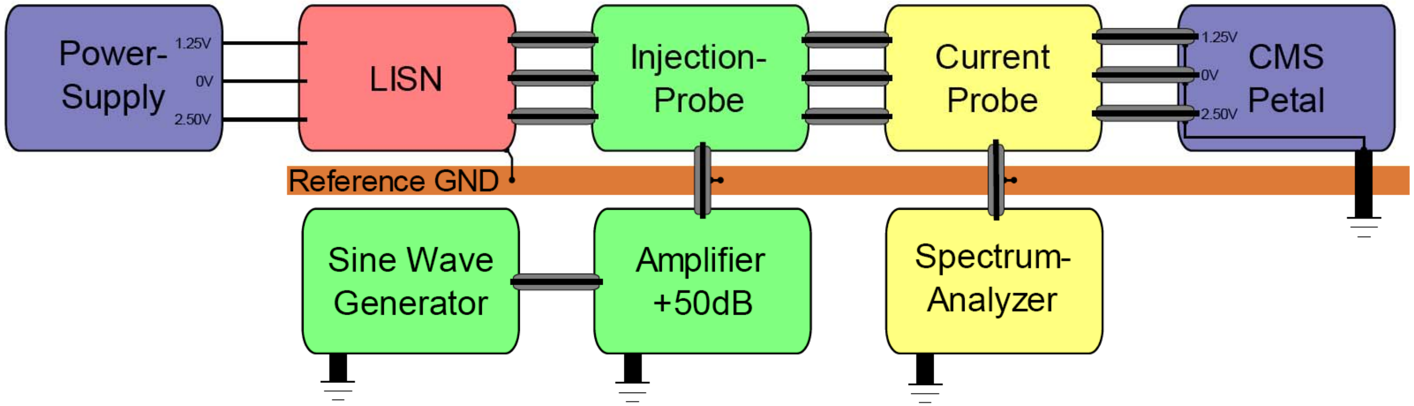
DM-Setup:

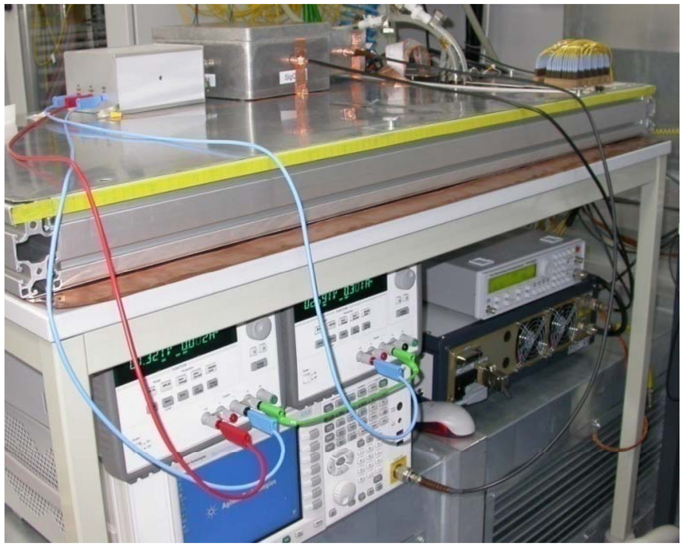


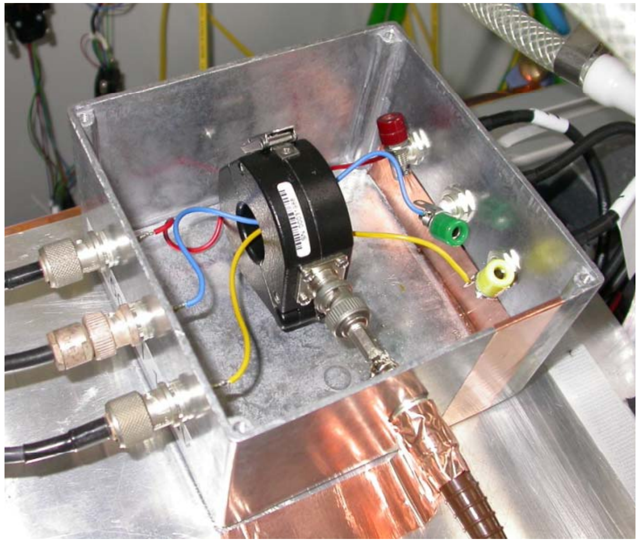
$I_{DM} + ½ I_{CM} - (- I_{DM} + ½ I_{CM}) = \mathbf{2 \cdot I_{DM}}$

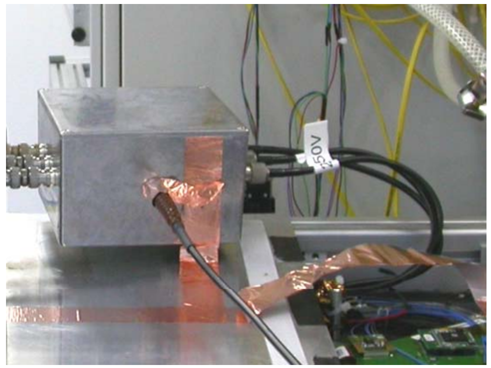
Noise Susceptibility Studies

- Goal: identify particularly critical bandwidth(s) for converter switching frequency
- Bulk current injection test-stand has been set up





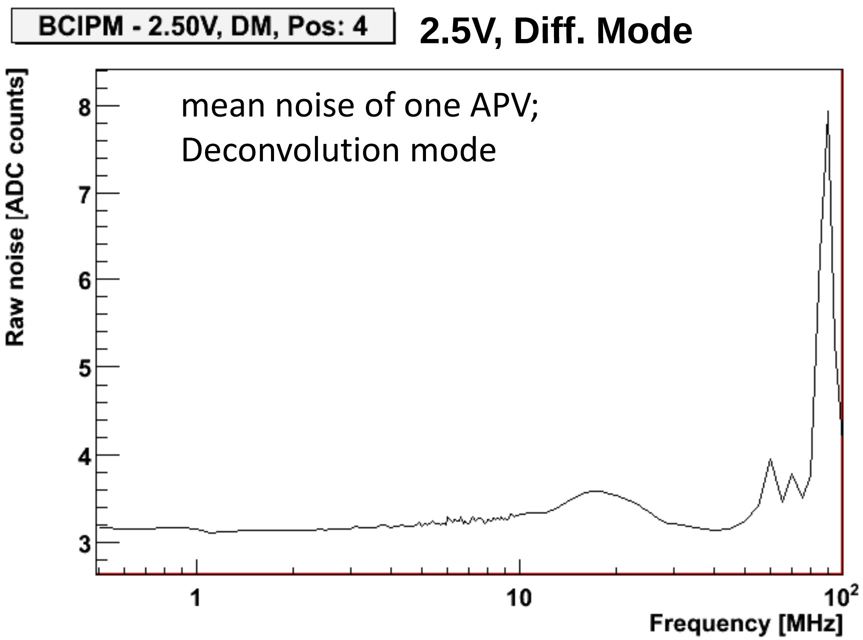


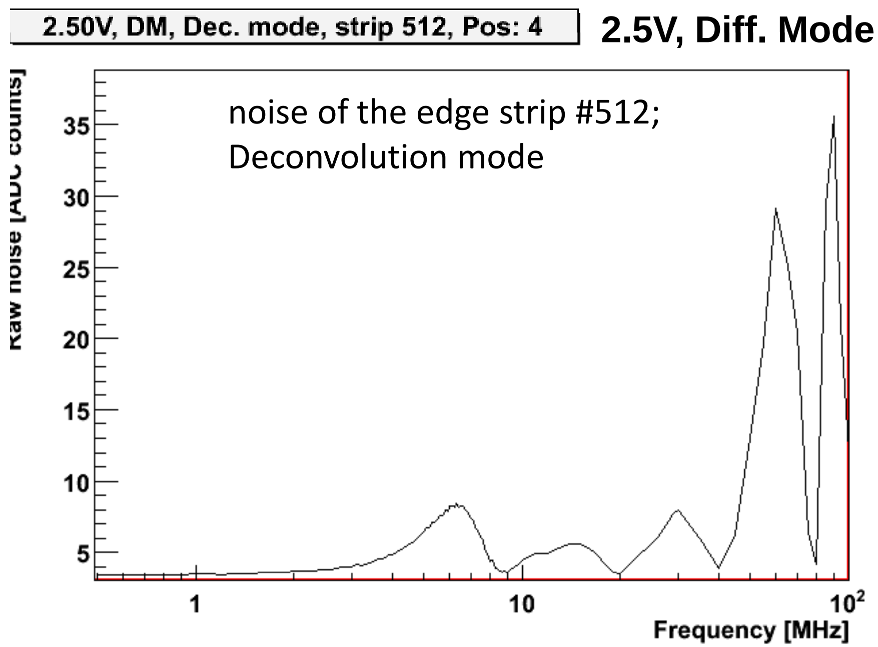


Noise Susceptibility Studies

- Injection of I=70dBμA (3mA) into 2.5V, 1.25V power lines in differential/common mode
- Frequency swept in the range from 0.5MHz to 100MHz
- Results not quite as expected;
  - Peak at around 6-8MHz seen for edge strips, but not in mean APV noise
- current interpretation: APV25 on-chip common mode subtraction

  is again hiding the real system response





Material Budget of Buck Converter

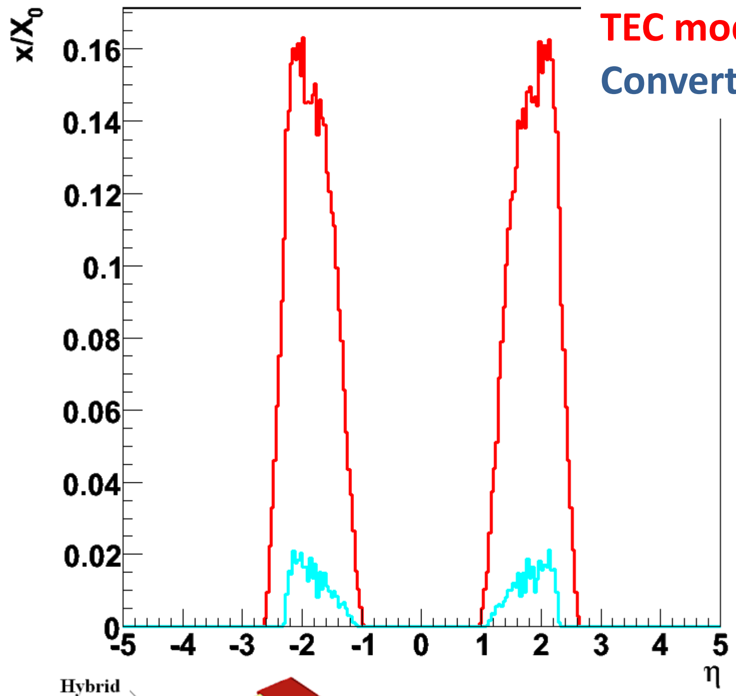
- Analysis performed for the whole strip tracker
- one converter per module assumed
- Official CMS software used for simulations (CMSSW_1_8_4)

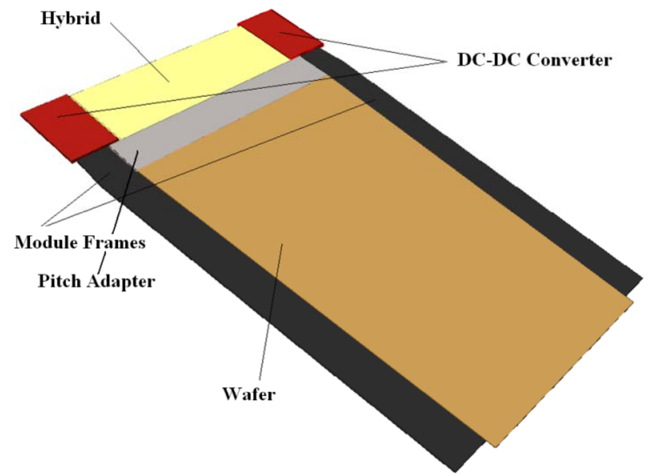
<u>Buck Converter Design:</u> (inspired by converter used in Aachen system tests)

- **Chip:** 3mm x 2mm x 1mm
- **Board**: Kapton
  30mm x 33mm, in total 200µm thick
- **4 copper layers:** each 20µm thick
  fill factor: 2 x 100%, 2 x 50%
- **Coil**: toroid
  42 windings, copper wire
  +plastic core
- Capacitors/resistors

Converter does not exist, this design was a starting point for the simulation

Modules and Converter





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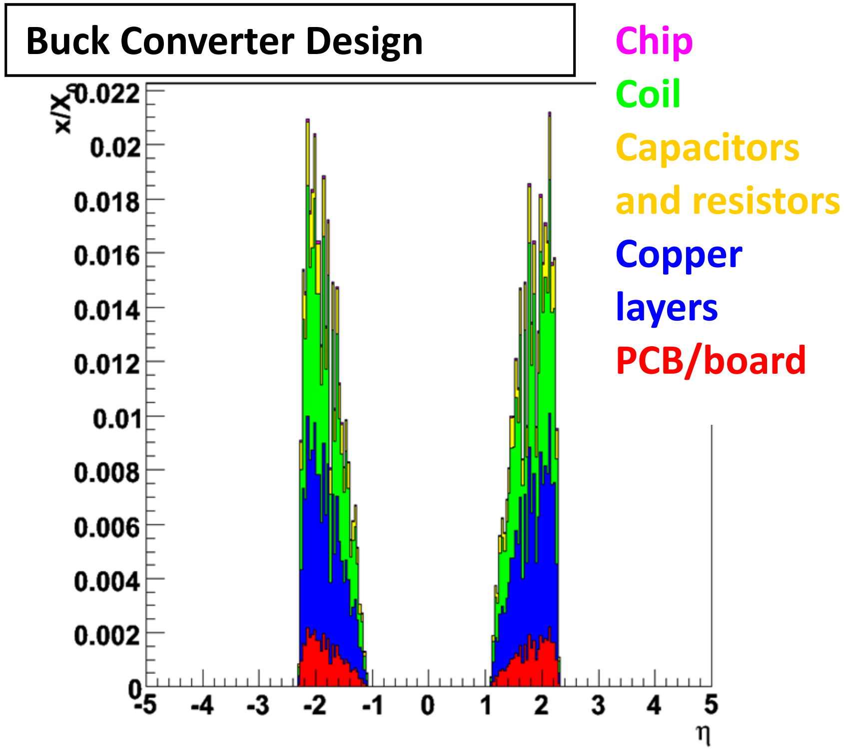

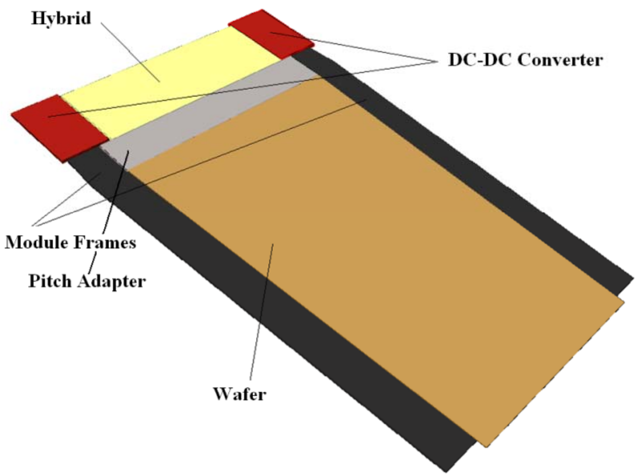

- for the whole strip tracker material budged reduction of ~8% has been estimated when powering via DC-DC converters

Summary

- system test measurements with DC-DC converters have been performed
- many symptoms in current test system are due to actual APV25 (and hybrid) layout
  - might be different for the SLHC FE ASIC
  - some understanding achieved
- switching noise of buck converters can be controlled even with air core inductors
- magnet test with 7T, converters with air-core inductors and charge pump worked fine
- The 'Task Force' recommended DC-DC conversion as a baseline powering system for an upgraded CMS Tracking system, with Serial Powering maintained as a back-up solution
- Contribution of converters to material budget is small but not negligible
- for the whole strip tracker material budged reduction of ~8% has been estimated when powering via DC-DC converters

Outlook

- gain better understanding of correspondence between converter noise spectra and noise induced into the modules
- optimize buck converter design ; focus on low mass, low noise, shielding
- evaluate radiation hard converter ASIC (CERN)
- further tests of charge pumps
- follow closely the developments on serial powering
- continue material budget simulation: combine novel powering schemas and new cooling system (CO_2)