First Implementation of a Two-Stage DC-DC Conversion Powering Scheme for the CMS Phase-2 Outer Tracker

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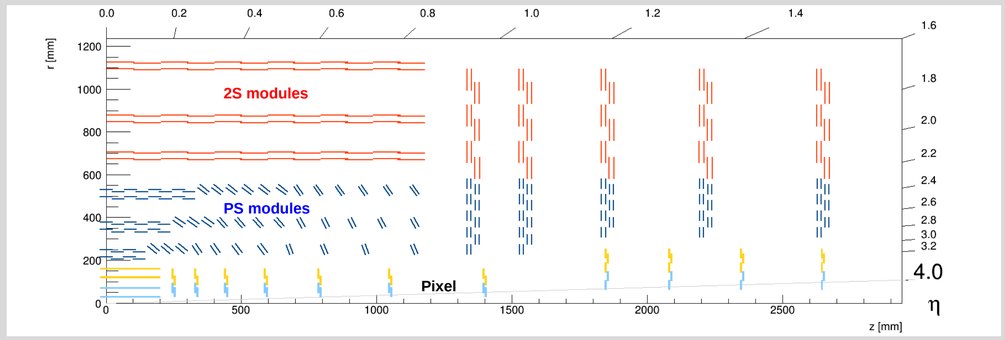
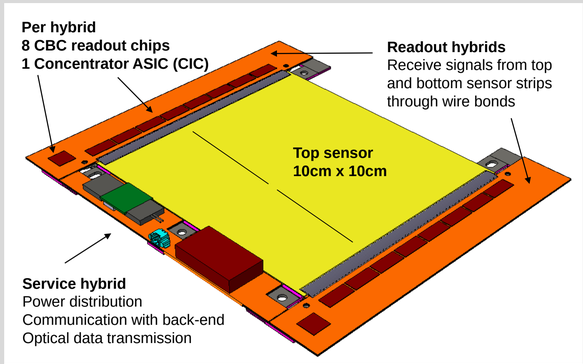
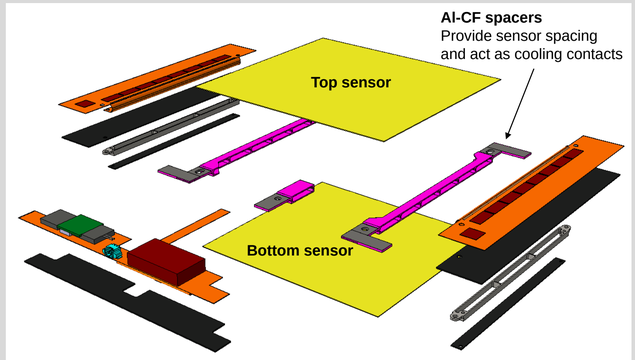
The CMS Phase-2 Tracker Upgrade

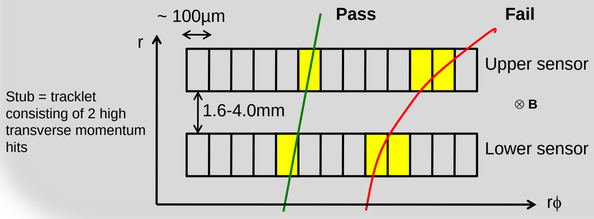


- CMS will install a completely new tracker for HL-LHC (2026)
  - Improved radiation hardness, less material, higher rate capability, provides data to the Level1 trigger
- Extended pixel acceptance up to pseudorapidity of 4 (pixel area: 4.7m^2)
- 5332 outer tracker modules with 1 strip sensor and 1 macro-pixel sensor (PS modules)
  - Macro-pixels with 100 µm pitch and 1.4mm length, strips with 90µm pitch and 5cm length
- 8224 outer tracker modules with 2 identical strip sensors (2S modules)
  - 90µm pitch, 5cm long strips

The "2S" Silicon Strip Modules

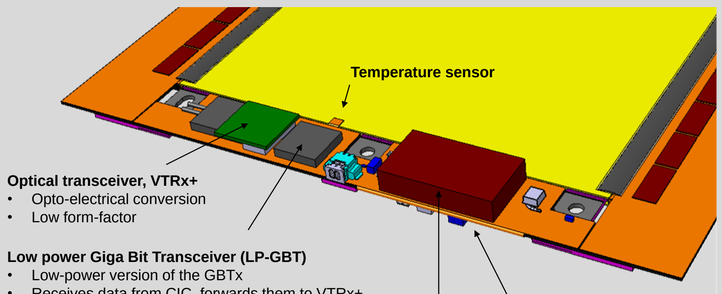






- Module provides "stub" data to the L1 trigger at 40MHz
  - Tracks are bent in the 3.8T magnetic field of CMS
  - Tracks with high transverse momentum are bent less
  - Hit patterns in two closely spaced sensors of a module are compared on-module, in the CMS Binary Chip (CBC)
  - If compatible with transverse momentum above a threshold, stub is sent to L1 trigger. Tracks are formed from stubs at the back-end.
- Upon reception of a trigger signal, the full event information is sent out at ~100kHz

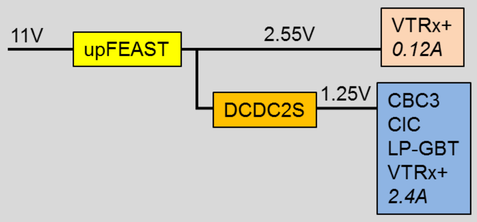
The Service Hybrid of the 2S Module



All active components are common CERN developments

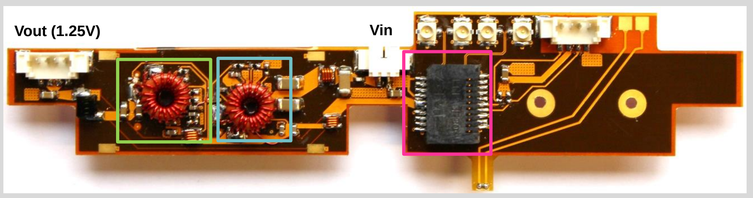
Two-Step DC-DC Powering Scheme

- Total outer tracker front-end power: 72kW
- Power per 2S (PS) module: 4.7W (6.3W)
- Power supplies will be located 80m away → high ohmic losses
- Step-down DC-DC buck converters on each module
  - Supply power to detector at higher voltage → less current
  - Lower power losses
  - Thinner cables in the detector → less material
- The 2S module requires 1.25V and 2.55V
- Solution adapted: two DC-DC converters in series*

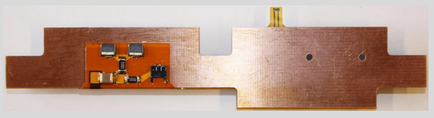


* The PS module will use three DC-DC converters

Service Hybrid Prototypes



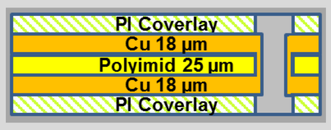
FEAST2 (CERN): 10V → 2.5V
2.0 MHz switching frequency
Air-core solenoid, 200nH (CERN)



Commercial DC-DC converter LTC3412A: 2.5V → 1.2V
2.45 MHz switching frequency
Air-core solenoid, 200nH (CERN)

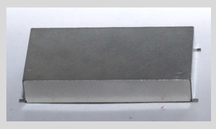
DC-DC converters located under a common shield
Filtering at the input, output and between the converters (pi-filters)

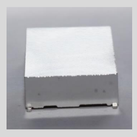
Connector for VTRx+

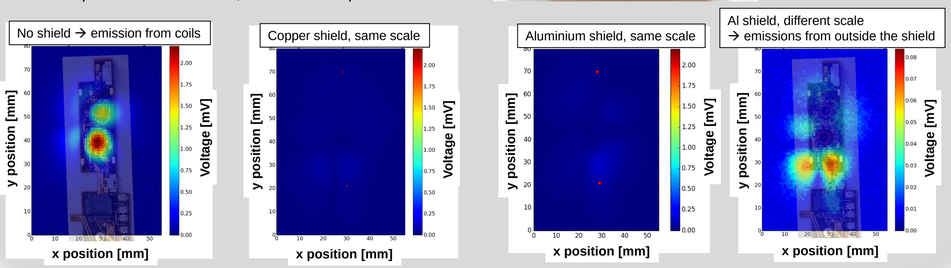


Electromagnetic Shielding

- Shield required to protect the silicon sensor and front-end electronics from electromagnetic radiation
- Prototypes produced in two technologies:
  - **Aluminium shield**
    - 150µm thick etched Al foil
    - 5µm tin plating
    - Spot welded corners
  - **Copper shield**
    - Plastic body from rapid prototyping
    - Galvanic deposition of 60µm of Cu outside
- Reduction of peak emission by factor 30 (Al) and 16 (Cu)
- Al shield preferred: less material, finer structures possible

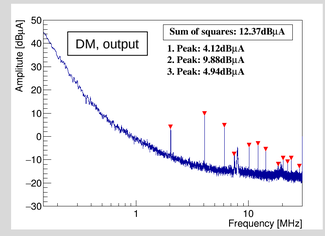


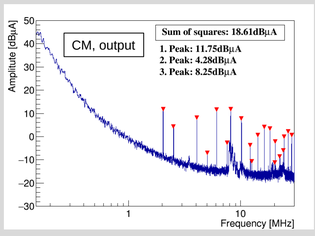


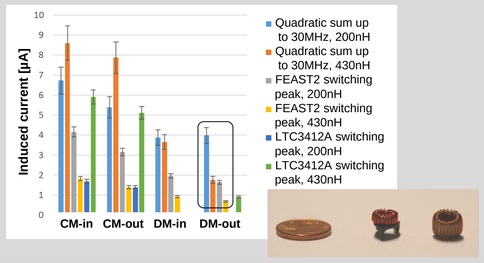


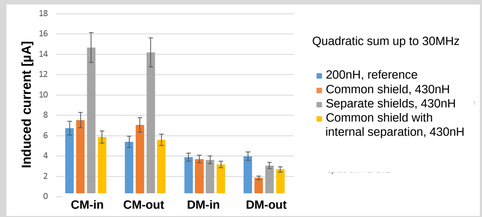
Common Mode and Differential Mode Noise Spectra

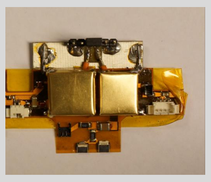
- DC-DC converters are switching large currents at MHz frequency → noise propagating through cables, both Common Mode (CM) and Differential Mode (DM), at input and output
- Measured behind both DC-DC converters (1.2V)
- In DM, only peaks of FEAST2 are visible
- DM noise of FEAST2 reduced by using coil with higher inductance (430nH)
- Both DC-DC converters are located under a common shield → potentially mutual coupling between the DC-DC converters
- No improvement using separate shields → coupling is not a problem





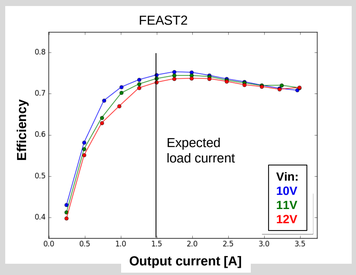


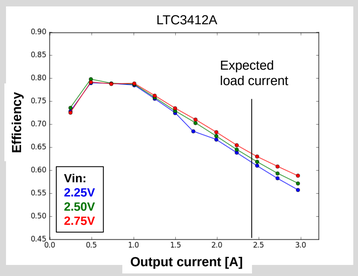


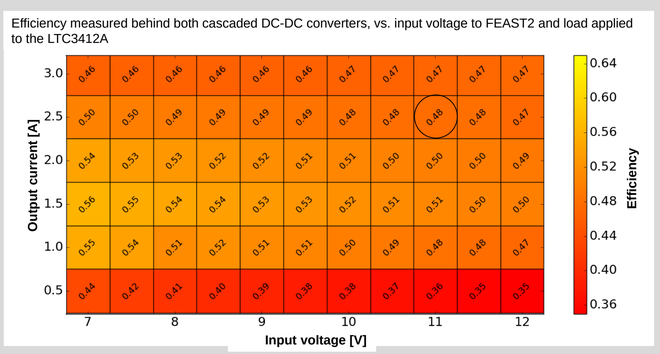


Power Efficiency

- In a 2-step scheme, the efficiencies of the DC-DC converters multiply → potentially low efficiency
- Targets: efficiency for upFEAST 75%, efficiency for DCDC2S 85%, total 67%
- FEAST2 efficiency close to target; LTC3412A not optimized for large currents
- Total efficiency presently ~48% → to be revisited once final DC-DC converters available



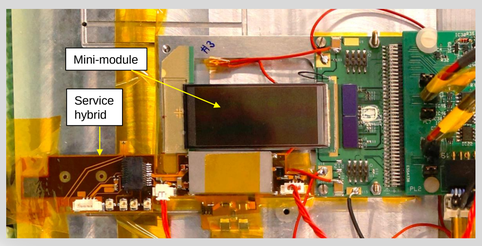


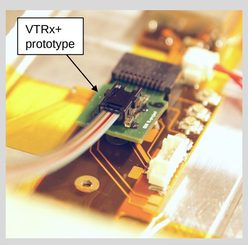


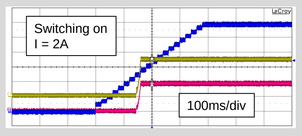
System Tests with a 2S Mini-Module

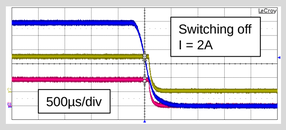
- Service hybrid used to power a 2S module prototype
  - 2 CBC2 readout chips, 2 strip sensors with 1 row of 5cm long strips
  - 80m long cable and prototype power supply with line drop recovery
- Noise extracted from width of S-curves
- Noise measured for various positions of the service hybrid
- VTRx+ prototype also powered from service hybrid and GLIB used to push random data through VTRx+ at 5GB/s → no bit errors observed in loop-back mode

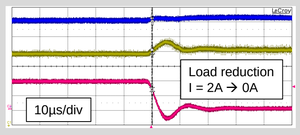
→ Module performance is not affected by the usage of shielded DC-DC converters
→ Good dynamic behaviour



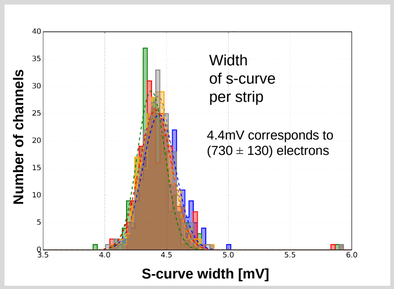








Vin at SH (2V/div)
Vout (1.2V) at SH
(top: 500mV/div; bottom: 100mV/div)
Iout of SH (1A/div)

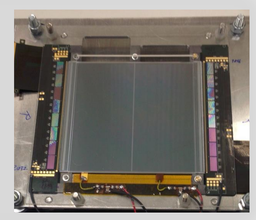


Conventional powering, reference
Service hybrid, far away
Service hybrid, far away; VTRx+
Service hybrid, very close
Service hybrid, very close; VTRx+

Mean & RMS from Gauss fit
(4.44 ± 0.13) mV
(4.38 ± 0.11) mV
(4.41 ± 0.13) mV
(4.42 ± 0.12) mV
(4.43 ± 0.12) mV

Summary and Outlook

- First implementation of a point-of-load two-step DC-DC conversion powering scheme in High Energy Physics – no show stoppers found
- Next steps include: system tests with a full-size module; integration of upFEAST and DCDC2S, once available



References

[1] CMS Collaboration, Technical Proposal for the Phase-II Upgrade of the Compact Muon Solenoid, CERN-LHCC-2012-016 (2012).
[2] http://project-dcdc.web.cern.ch/project-dcdc/

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