ATLAS ITk Short Strip Prototype Module with Integrated DCDC Powering and Control

Phase II Upgrade of the ATLAS Inner Tracker detector at the HL - LHC

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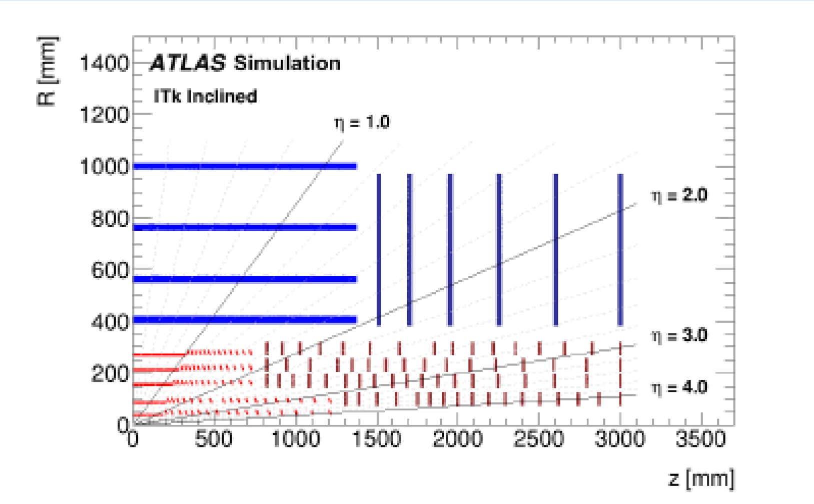
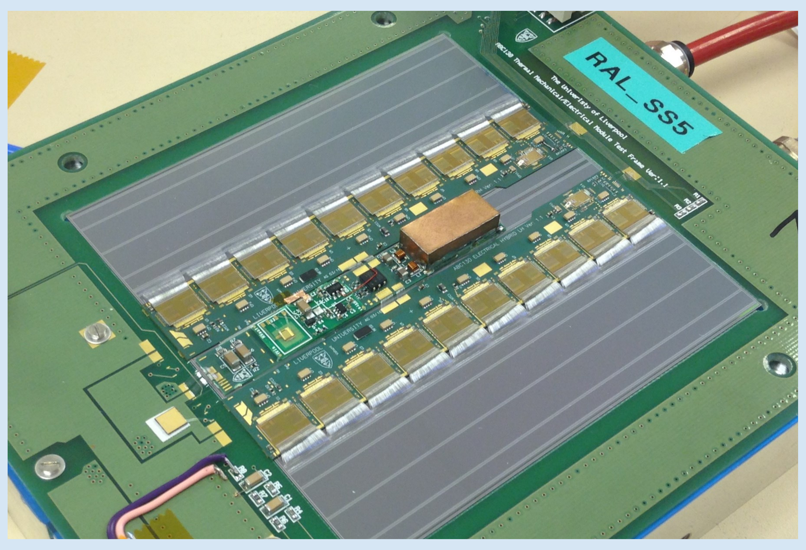
The ATLAS Phase II Inner Tracker



- Plan for new central tracker for operation at High Luminosity LHC (HL-LHC) in 2026
  - Targeting increased radiation hardness, reduced material and operation at 1MHz trigger rate
- The strip system is made up of 4 Barrel layers and 6 disks in the forward region
  - Barrel composed of two layers of short-strip (~3800 total) and two layers of long-strip modules
  - Requiring ~11000 Barrel modules and ~7000 Endcap modules
    - ~3800 short-strip and ~7200 long-strip modules
- The proposed pixel system being comprised of 5 Barrel layers and 4 Endcap ring layers

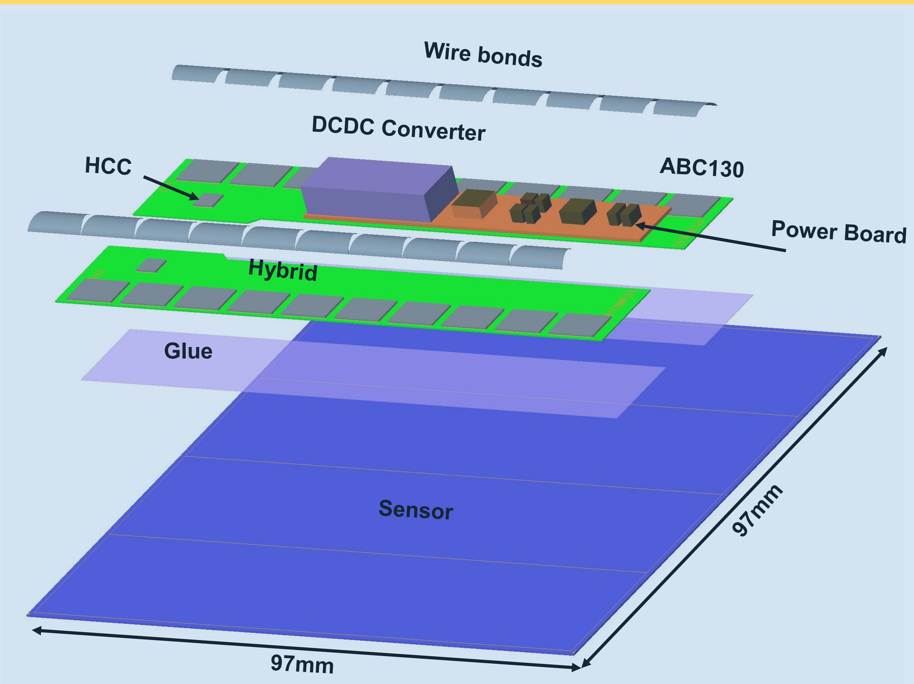
Short-Strip Prototype Module



Module with first generation Power board without AMAC controller

- Made up of two hybrids plus single DCDC Power board
- Hybrids come with ten ABC130 front-ends and single HCC controller ASIC
- Power board has a DCDC buck converter, HV GaNFET switch and control ASIC
  - Module power provided by buck converter (CERN, FEAST2)[1]
  - HV GaNFET[2] allows failing sensor to be disconnected from single multi-drop HV bias line
  - AMACv1a control ASIC provides monitoring and control of module via I2C link

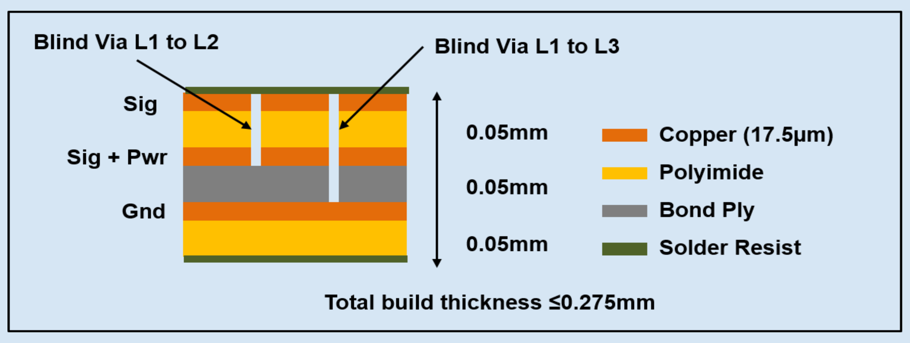
Short-Strip Barrel Module Overview



- ~3800 modules and Power boards required
- Circuits attached to sensor using electronics grade epoxy
  - Sensor providing both mechanical support and thermal management
  - Heat transferred to embedded cooling within stave support structure

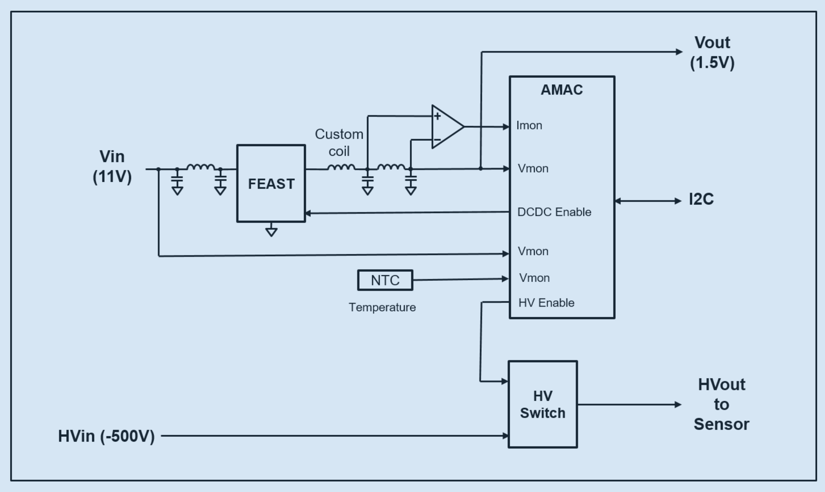
Hybrid

- Kapton flex, optimised for yield and low material
  - >15000 circuits required
- 3 Cu layers with 50µm dielectrics (<275µm thickness)
  - Bottom layer acting as a 'pseudo' shield
  - Impedance control of all fast signalling
  - Utilising blind vias throughout
- Single power/ground domain on hybrid serving ASICs
  - Internal analogue/digital power domains within ASICs



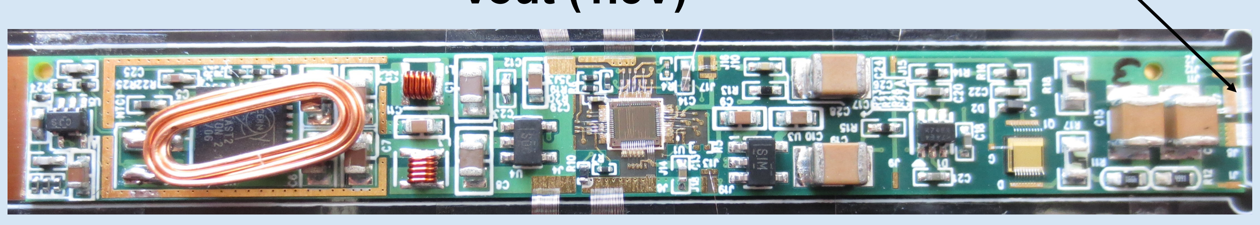
Hybrid Flex Circuit Stack up

Power board

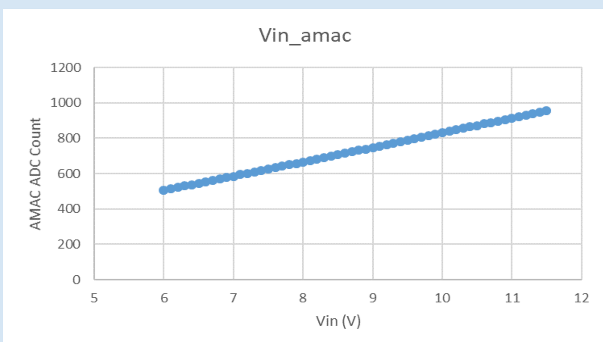


- DCDC buck converter powers module
  - Regulating common 11V feed down to 1.5V
- AMAC providing monitoring and control
  - Measuring V, I and temperature
  - Enable/disable of converter and sensor HV bias
- Sensor bias switched via a GaNFET

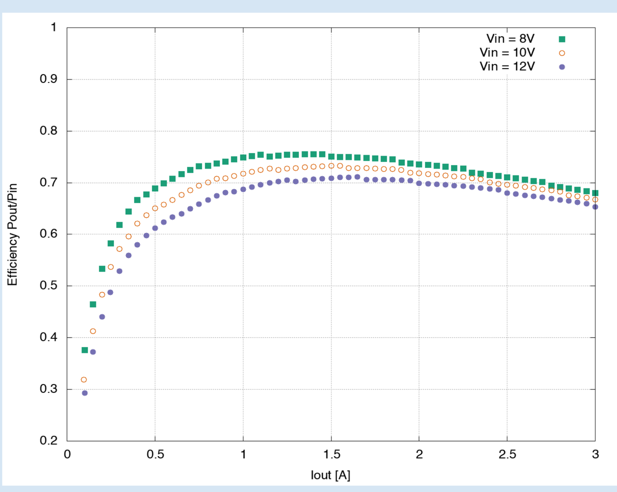
Prototype Power board[3]



ADC count vs Vin



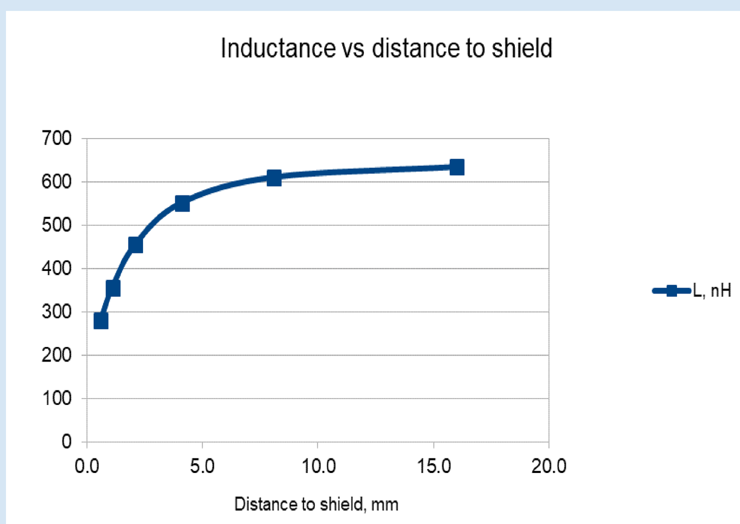
DCDC Efficiency

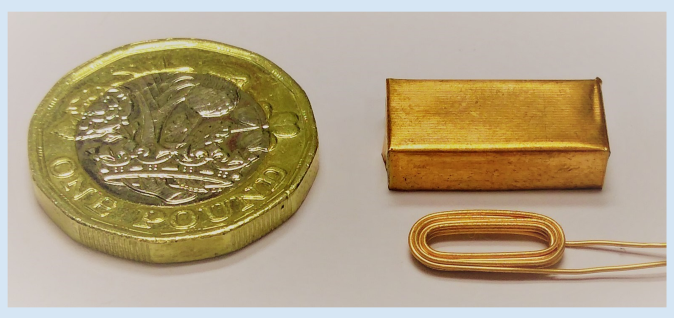


- Comes with FEAST2 converter utilising 'flat' air-core solenoid coil
  - Coil choice driven by geometrical and electrical constraints
  - Coil <2mm high with >400nH inductance and low DCR (0.038mΩ)
- Achieves >70% efficiency at 20°C with nominal 2A load
  - Target is ~75% at expected operating temperature of -30°C
- AMACv1a controller ASIC shown to work
  - I2C link tested with successful configuration and readback of data
  - 8-channel 10-bit ADC and I/O (LV/HV enables) tested
    - Monitoring of voltage/current, sensor current and temperature
- GaNFET sensor bias switch tested successfully up to -500V

DCDC Converter Shielding

- EMI emissions from buck converter necessitates use of a shielding box
  - Complicated by close proximity to silicon sensor and use of solenoid coil
- Mixed material shield box (<5mm high), 75µm Al wall with <10µm Cu plating
  - Cu plating required for solder attachment and increased HF conductivity
- E-field shielding provided by 'Faraday cage' enclosure of shield box
- B-field shielding achieved by 'Eddy current cancellation'
  - Eddy currents set up on shield surface produce B-field in opposition to incident aggressive field - attenuating emission
  - Has negative affect of lowering the inductance of the coil (see below)
    - Inductance without shield ~650nH, with shield ~450nH



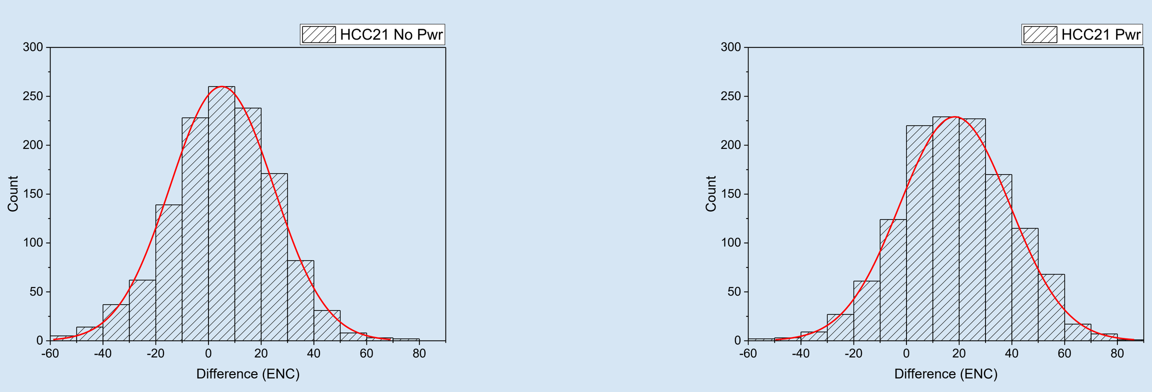


Prototype Shield Box with coil, box dimensions: 18 x 8 x 4.5mm

Module Noise Test Results

- Module tested with and without a Power board attached - then checking for differences in noise
  - Power board covers 2 inners columns of strips on sensor only, outer 2 columns not covered
- Strips not covered by the Power board show ~5e ENC change in noise (<1% affect)
- Whereas sensor strips covered by the Power board show ~20e ENC increase
  - Front-end ASICs having increased capacitive loading due to proximity of Power board shield layer
- No other affect seen due to the presence of the Power board

EMI shielding and Power board shown to work very well



Difference noise plots (with/out Power board) showing sensor strips not covered (left) and covered by the Power board (right)

Summary

- An integrated module assembly with DCDC power conversion attached to the top surface of a silicon strip sensor has been successfully demonstrated.
- Attachment of hybrids and Power board with DCDC power conversion to the silicon strip sensor has been adopted as baseline for the ITk Strip Detector.

  As defined in the Technical Design Report, April 2017
  https://cds.cern.ch/record/2257755/files/ATLAS-TDR-025.pdf

References

1. http://project-dcdc.web.cern.ch/project-dcdc/public/Documents/FEAST2.1%20datasheet.pdf
2. TWEPP 2017: Radiation Hard GaNFET High Voltage Multiplexing (HV-Mux) for the ATLAS Upgrade Silicon Strip Tracker
3. https://indico.cern.ch/event/602928/contributions/2432341/attachments/1403746/2144186/pbv3_specs.pdf