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

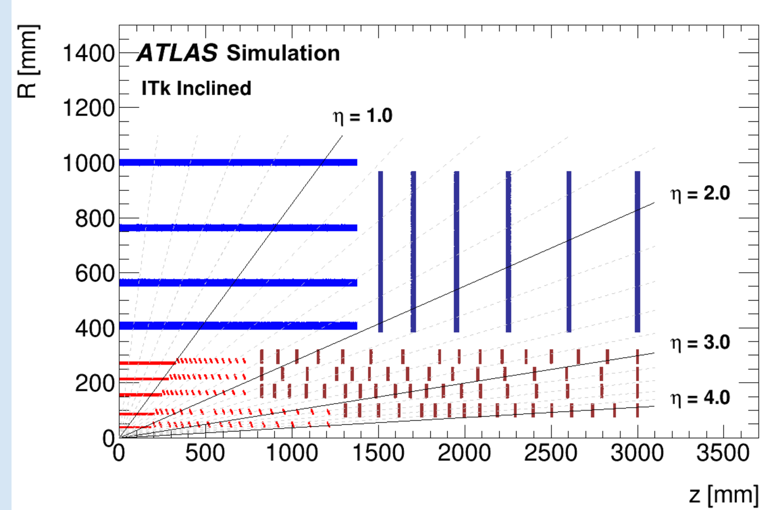
UNIVERSITY OF LIVERPOOL

Ashley Greenall*, on behalf of the ATLAS ITk Collaboration

*The University of Liverpool, United Kingdom

TWEPP 2017 - Topical Workshop on Electronics for Particle Physics, 11 - 15 September, UC Santa Cruz USA

The ATLAS Phase II Inner Tracker Upgrade



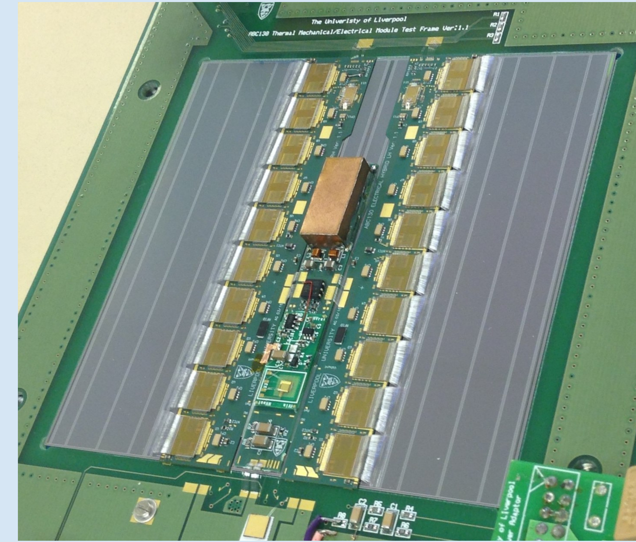
Schematic layout of the ITk for the HL-LHC phase of ATLAS

Blue - Strip Detector

Red - Pixels

- 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 and two layers of long-strip modules
  - Requiring ~11000 Barrel modules and ~7000 Endcap modules
    - The Barrel made up of ~3800 short-strip and ~7200 long-strip modules
- The proposed pixel system comprised of 5 Barrel layers and 4 Endcap ring layers

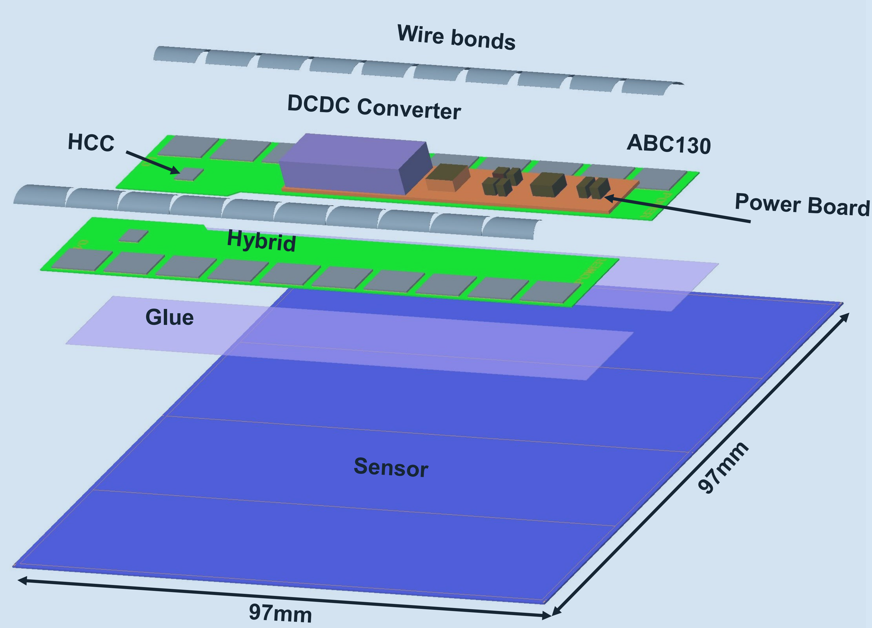
Short-Strip Barrel Prototype Module



Module with first generation Power board without AMAC controller

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

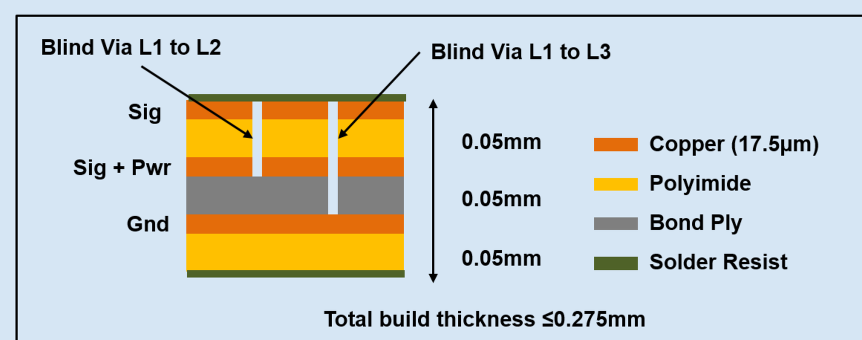
Short-Strip Barrel Module Overview



- Circuits attached to sensor using electronics grade epoxy
  - Sensor providing both mechanical support and thermal management
- Modules then glued directly to carbon-fibre stave support structure
  - Heat transferred to embedded cooling within the support structure

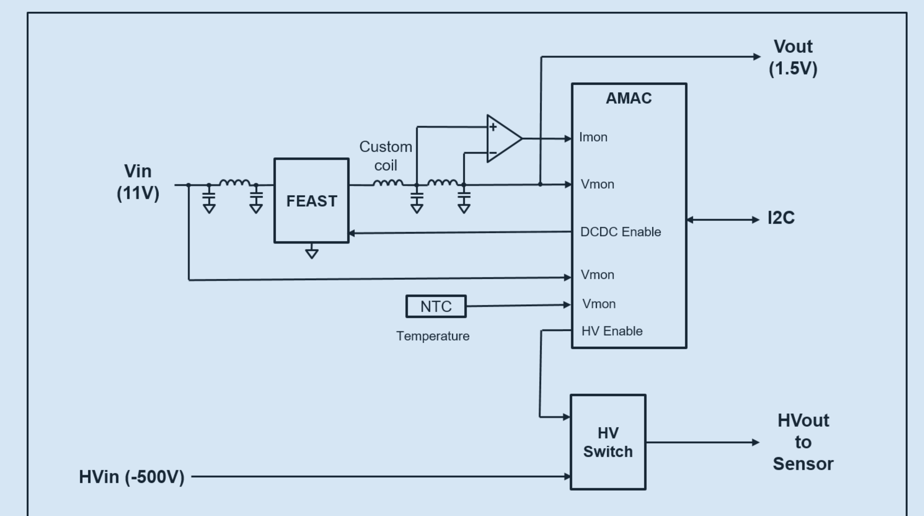
Hybrid

- Polyimide 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



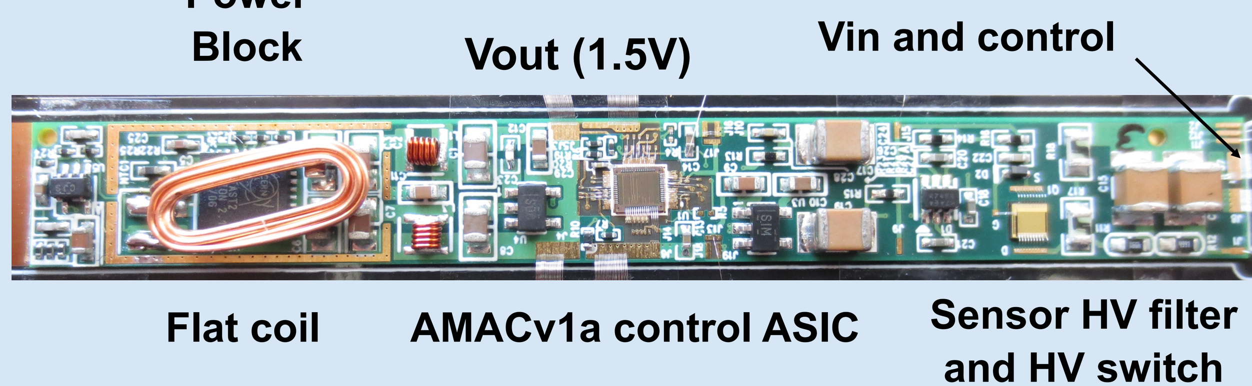
Hybrid Flex Circuit Stack up

Power board

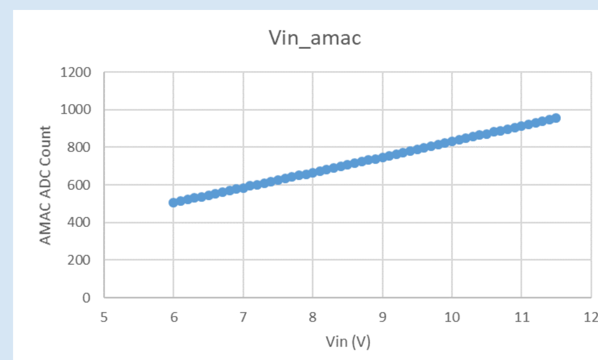


- DCDC buck converter powers module
  - Regulating common 11V feed down to 1.5V
- AMACv1a providing monitoring and control
  - Measuring Voltage, Current and temperature
  - Enable/disable of converter and sensor HV bias
- Sensor bias switched via a GaNFET

Prototype Power board[3]



ADC count vs Vin

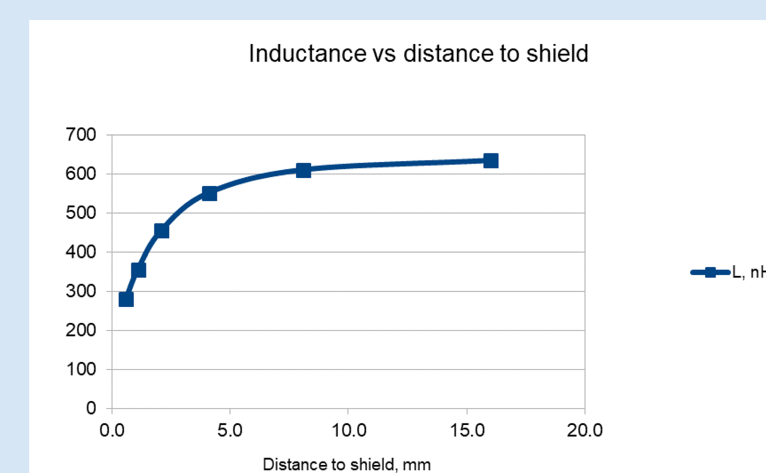


DCDC Efficiency

- 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 (0.038Ω)
- 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
    - Sensor current return is via the controller ASIC
- 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 B-field emission
  - Has negative affect of lowering the inductance of the coil (see below)
    - Inductance without shield ~650nH, with shield ~450nH



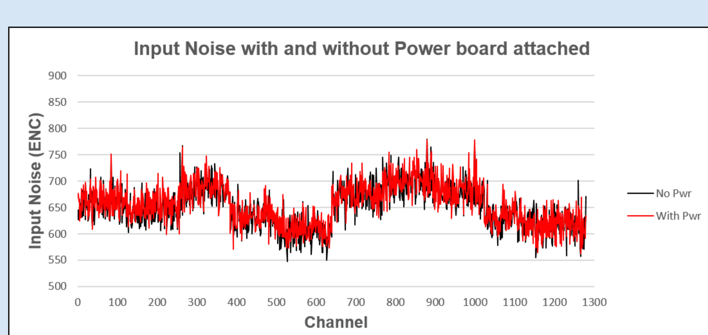
Prototype Shield Box with coil, box dimensions: 18 x 8 x 4.5mm

Module Noise Test Results[4]

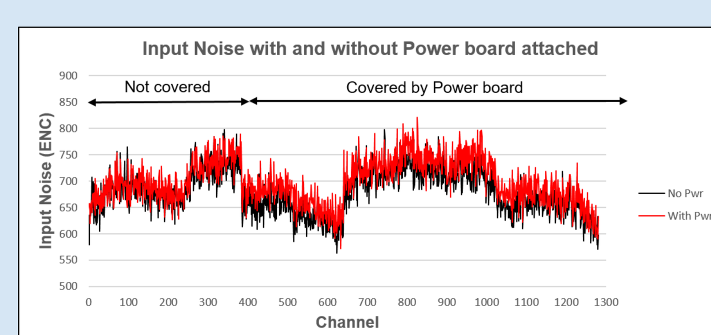
- If shielding works, expect increase in input noise only by sensor strips covered by the Power board
  - Due to proximity of shield layer within circuit increasing load capacitance to front-end ASICs
  - Expect ~10e to ~20e increase, determined by glue layer thickness - thinner layer increases capacitance
- Whilst those strips not covered by the Power board should show no change

- Tests reveal uncovered strips show negligible increase in noise, see Plot 1.
- Whereas sensor strips covered by the Power board show <20e ENC increase (in Red), see Plot 2
  - With channels 1 to 384 showing negligible change due to not being covered by the Power board

Power board with EMI shielding shown to have negligible effect on module noise



Plot 1. Strips not covered by Power board



Plot 2. Strips covered by Power board

Summary

- An integrated module assembly with DCDC power conversion attached to the top surface of a silicon strip sensor has been successfully demonstrated.

- The 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. **D.Lynn**: 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
4. **P.Phillips**: TWEPP 2017: ATLAS ITk Short-Strip Stave Prototypes with 130nm Chipset