Testing of the HCC and AMAC functionality and radiation tolerance for the HL-LHC ATLAS ITk Strip Detector

Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA, USA

Luis Felipe Gutierrez Zagazeta on behalf of the ATLAS ITk Strip Collaboration

ATLAS ITk Strip Detector ASICs

The ATLAS Binary Chip (ABC), Hybrid Control Chip (HCC) and Autonomous Monitoring and Control Chip (AMAC) are three custom ASICs designed for the readout, monitoring and control of the ITk Strip detector modules.

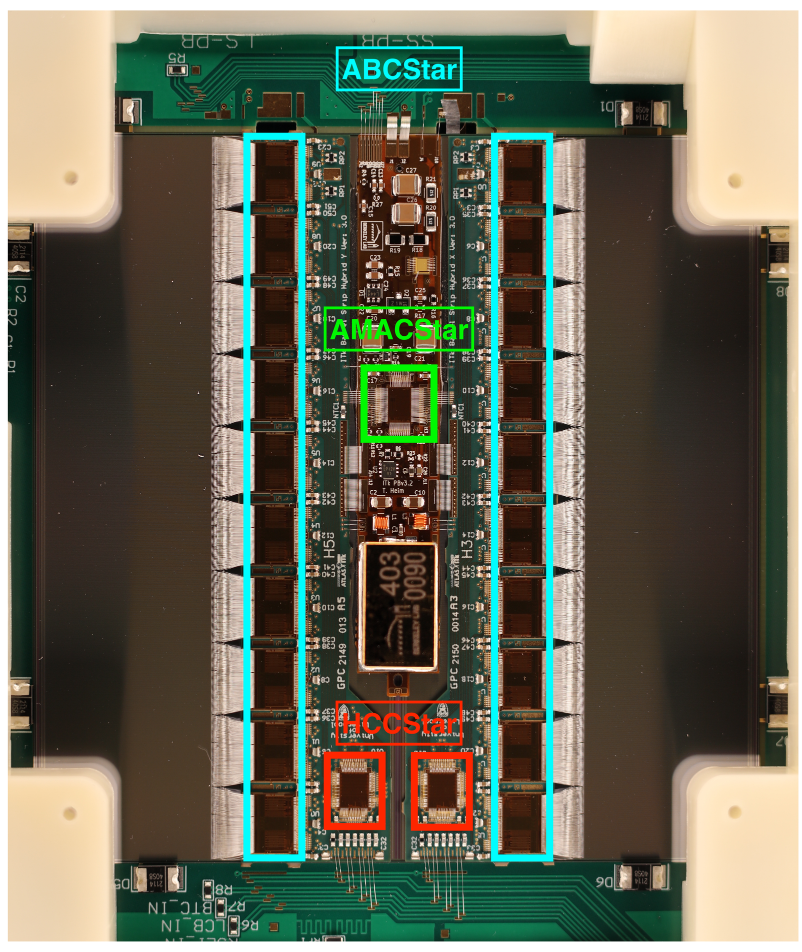

Fig. 1: ITk Strip detector short strip module assembled at Brookhaven National Laboratory

HCC and AMAC

HCC receives and forwards clock and control signals to up to 11 ABCs. The HCC collects and serializes the data from the ABCs, and transmits the outputs data to the End of Substructure (EoS) board at up to 640 Mbps.

AMAC monitors temperatures, voltages and currents via a 16 channel ADC and controls the module. The AMAC is capable of controlling neighboring modules via the OF mechanism. The AMAC interlock mechanism allows for autonomous turnoff of various module components.

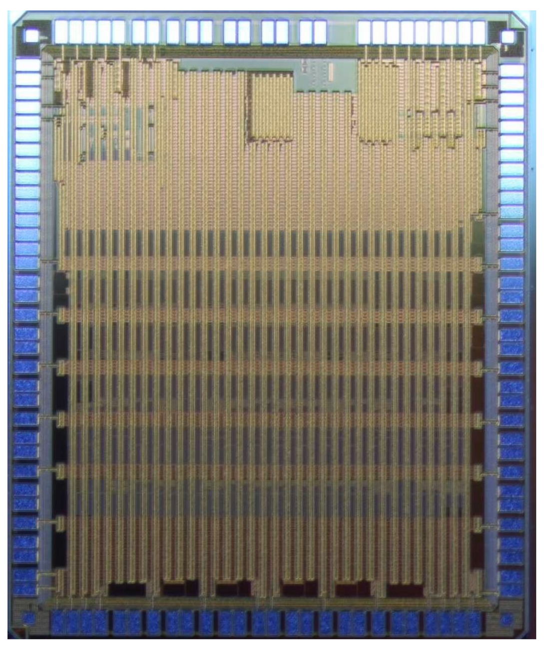

Fig. 2: Photo of a single HCCStar v1

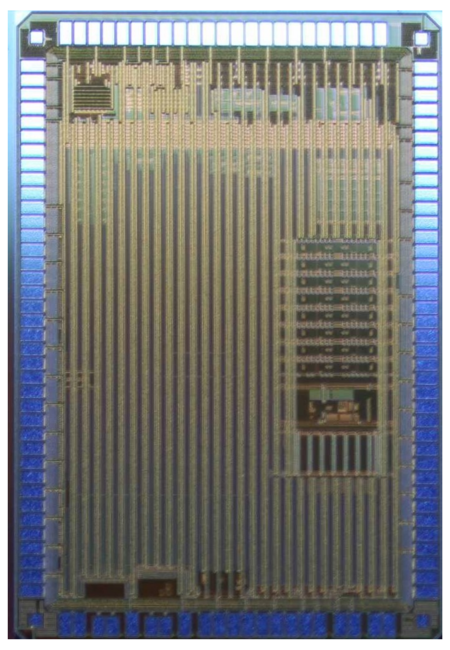

Fig. 3: Photo of a single AMACStar

Different versions of HCC and AMAC have been tested under:

1. Cold temperatures,
2. Low regulated voltages, and
3. Gamma and x-ray radiation.

HCC functionality has been tested for different Bunch Crossing clock (BCO) frequencies.

References

1. ATLAS Collaboration, *Technical Design Report for the ATLAS Inner Tracker Strip Detector*, Tech Rep. CERN-LHCC-2017-005, 2017.
2. F. Faccio and G. Cervelli, *Radiation-induced edge effects in deep submicron CMOS transistors*, Nucl. Sci. IEEE Trans., 52(6): 2413-2420, 2005.
3. ATLAS Collaboration, *Simulated, functional, probing, and irradiation testing of the HCC and AMAC ASICs for the ITk Strip Detector*, ITK-2022-002, 2022

Functionality Testing

Increase in current of active components due to radiation could cause the ASICs to operate at a lower than desired regulated voltage.

HCCStarV1 and AMACStar successfully operated at regulated voltages as low as 1.06 V and 1.0 V, respectively.

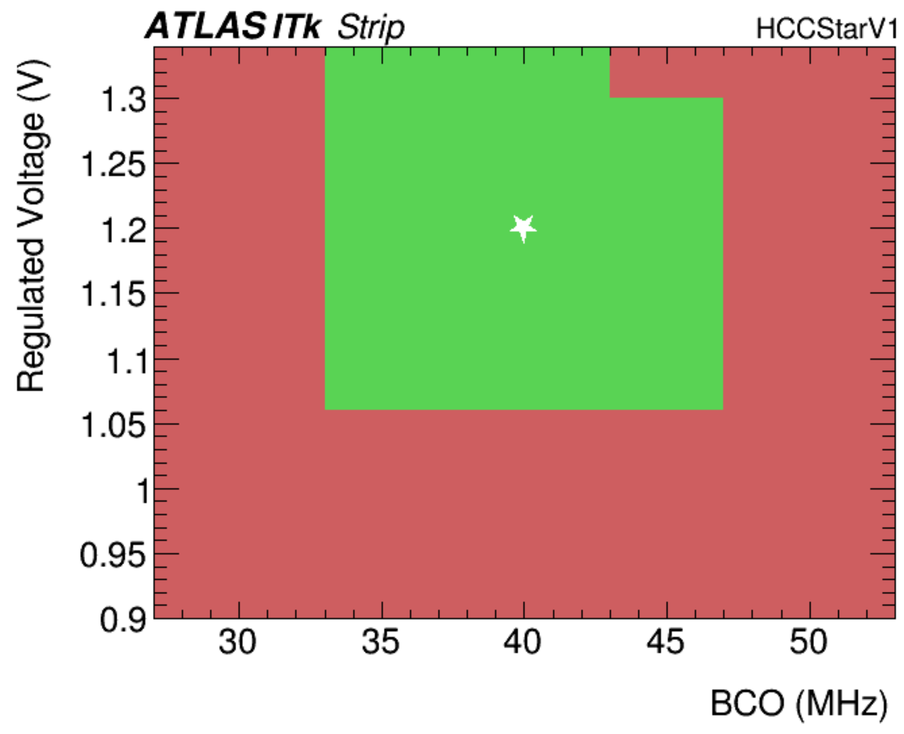

Fig. 6: HCCStarV1 shmoo scan performed at -45 °C showing operational range as a function of regulated voltage and frequency of the BCO. Operating phase space shown in green, while failing or untested (presumed failing) phase-space shown in red. White star denotes the nominal operating parameters of 1.2 V and 40 MHz. [ITK-2022-002]

Radiation decreases the signal to noise resolution of sensors. Effect damped by running the detector at colder temperatures.

AMACStar was tested at startup temperatures ranging from 25 °C to -70 °C. HCCStarV1 was tested at startup temperatures ranging from 25 °C to -45 °C. Both AMACStar and HCCStar functionality successfully operated at all temperatures.

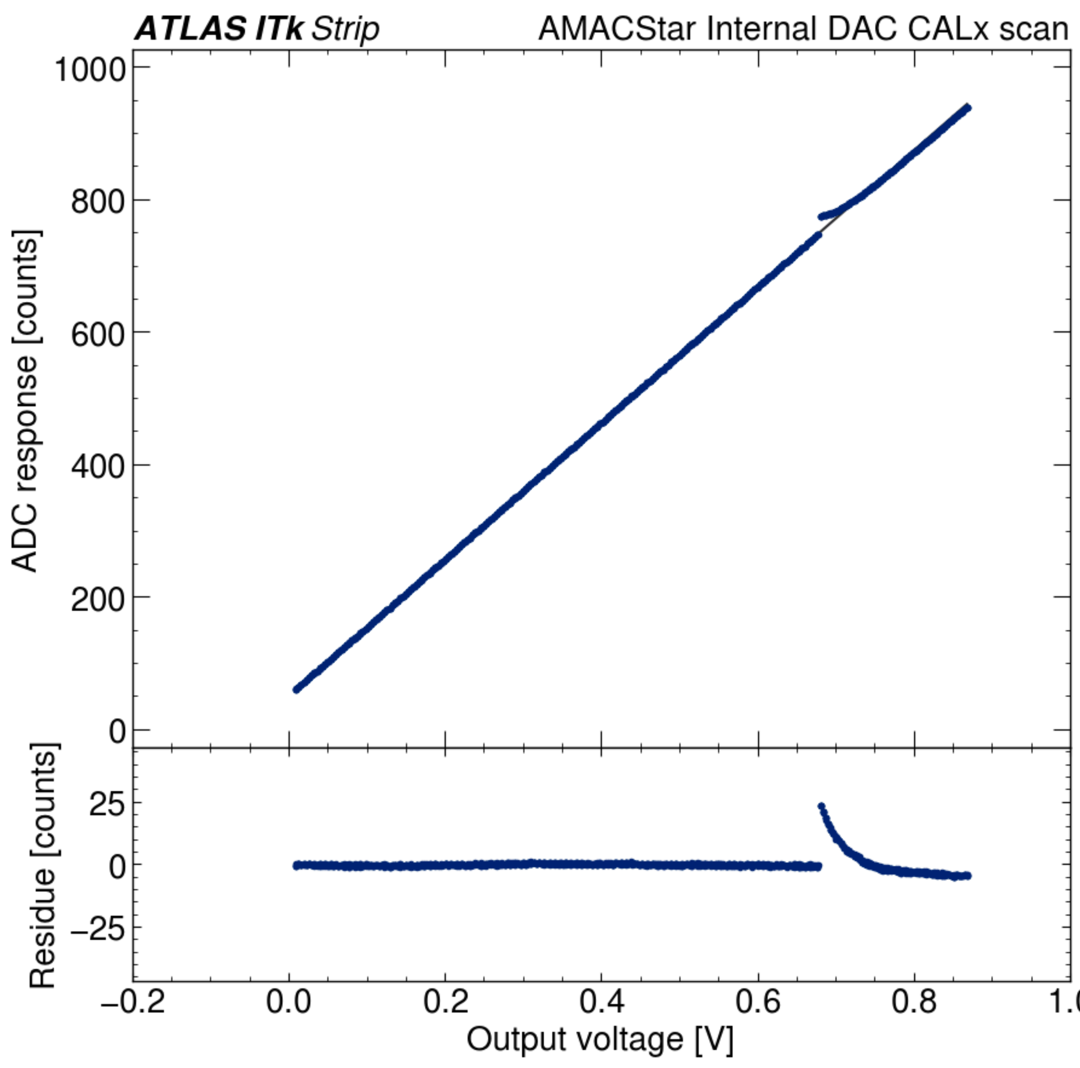

Fig. 7: AMACStar CALx analog monitor response as a function of independent ADC output voltage at -70 °C. AMACStar is expected to operate significantly warmer. [ITK-2022-002]

Nonlinearity observed near 700 counts due to cold temperature effects present at the comparator swap in both HCCStarV1 and AMACStar. No significant effect on detector operations expected.

Conclusion

1. HCCStarV1 and AMACStar started and operated successfully at low temperatures and regulated voltages.
2. HCC and AMAC operated as expected during the various irradiation campaigns.
3. Pre-irradiation will avoid issues near TID peak.

Radiation Tolerance

Slow irradiation of the HCCStarV0 and AMACv2a was performed at BNL with a dose rate of 1.1 krad/hr at a constant temperature of -10 °C.

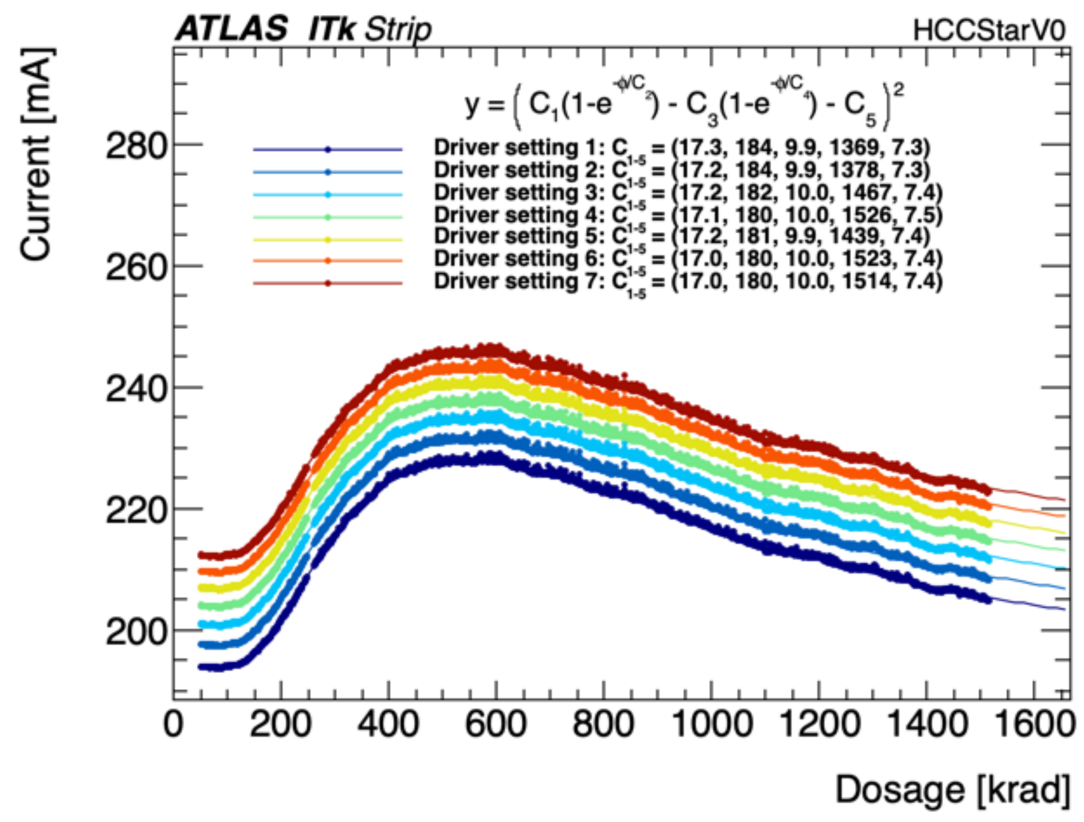

Fig. 8: Current increase under slow gamma irradiation for HCCStarV0 for seven different driver currents. Each current distribution is fit with the functional form displayed on the plot. [ITK-2022-002]

HCCStarV0 current increased by about 15% (40 mA) for all operating conditions considered. AMACv2a current increased by about 17% (41 mA to 48 mA).

Fast irradiation of the AMACStar and HCCStarV1 was performed at LBNL with a dose rate of 0.8 Mrad/hr at a constant temperature of 20 °C.

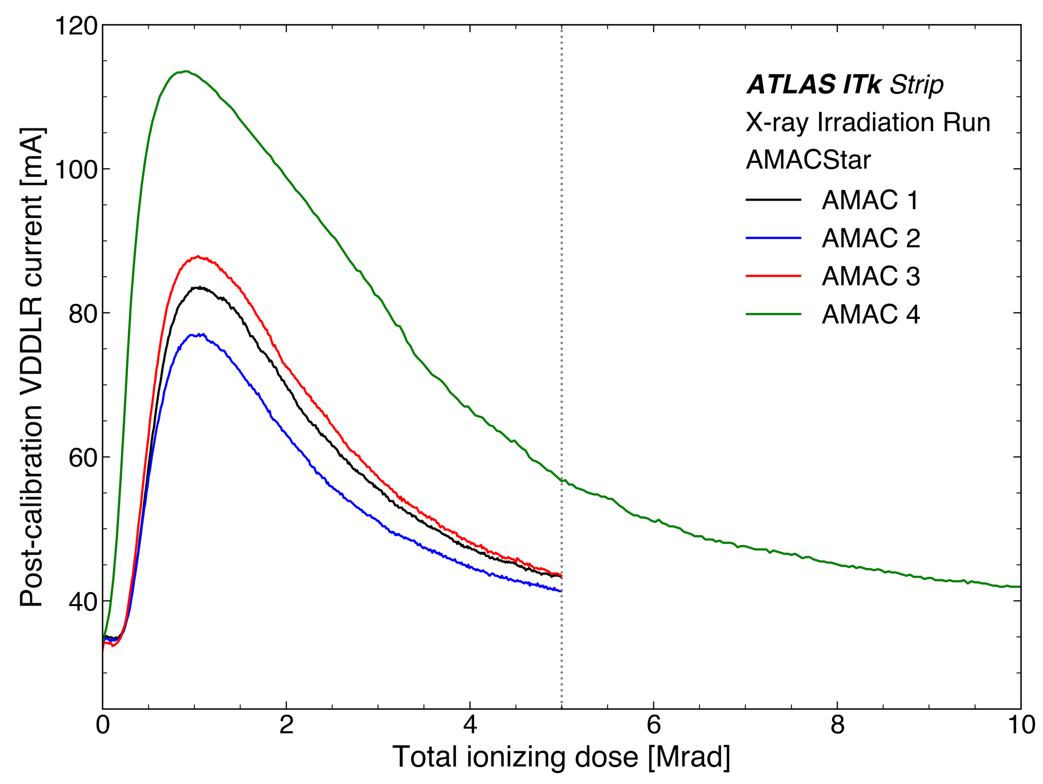

Fig. 9: Current increase of the AMACStar's internal low-dropout regulator input voltage line as a function of total ionizing dose (TID) during the fast irradiation campaign. AMACs 1 through 3 were irradiated up to 5 Mrad and AMAC 4 was irradiated up to a 75 Mrad. [ITK-2022-002]

Functionality slightly affected near current peak but regular behavior recovered past current peak.

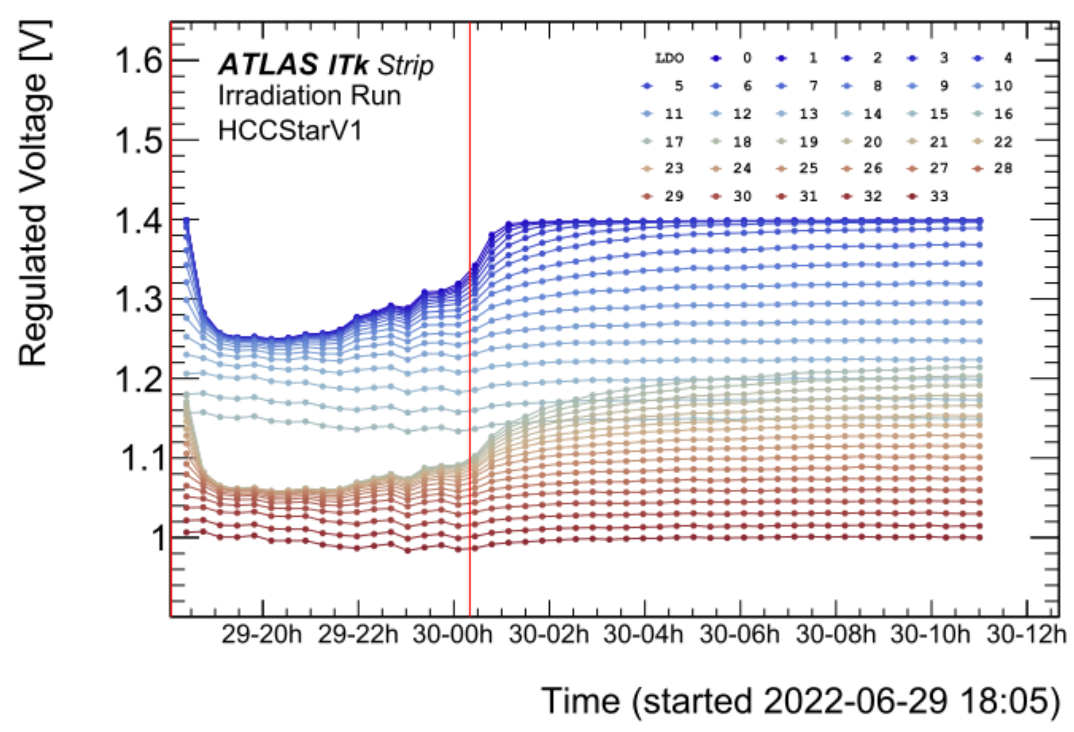

Fig. 10: Fast irradiation effects on the HCCStarV1's regulated voltage for all 34 internal low-dropout voltage settings, which are split into two ranges. [ITK-2022-002]

The current increase will have no effect on detector operations since the ASICs will be pre-irradiated up to about 8 Mrad, where regular behavior is recovered.

 luis.felipe.gutierrez.zagazeta@cern.ch