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The analog readout channel for the Si(Li) tracker of the GAPS experiment

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This paper describes the first experimental results from the characterization of the analog front-end designed for the readout of a Si(Li) detector based tracker. The instrument is conceived for the identification of low-energy cosmic-ray antiprotons and antideuterons in the GAPS (General Antiparticle Spectrometer) experiment to search for dark matter, whose launch is currently scheduled for late 2021. The analog front-end, featuring a dynamic signal compression to comply with the wide input range, has been designed in a 180 nm CMOS technology and was produced in two prototype ASICs. The development will be completed by early summer 2020.

Summary

GAPS (General Antiparticle Spectrometer) is an experiment that is being built by an international collaboration that aims to detect indirect signatures of dark matter through the identification of cosmic particles of antimatter. The experiment involves the use of a stratospheric balloon with a detection system composed of Si(Li), Silicon-Lithium, sensors divided into strips.

Each segment requires a readout channel suitable to resolve both X-rays (with a resolution of 4 keV FWHM at a strip capacitance of about 40 pF and a leakage current less than 10 nA) in the range of 20 to 100 keV and charged particles with energy up to 100 MeV. To comply with these requirements, the analog conditioning scheme is based on a low-noise charge-sensitive amplifier (CSA) performing a dynamic signal compression. This solution takes advantage of the non-linear features of a MOS capacitor in the feedback loop of the charge-sensitive preamplifier.

In the CSA, a continuous reset is provided by a Krummenacher feedback network.

This architecture was specifically chosen for its capability to compensate for the detector leakage current.

The amplifier is followed by a unipolar second order semi-Gaussian shaper. The shaping actually takes place in two steps. First the signal from the preamplifier undergoes an integration, then the shaping is completed by an active filter which provides one more integration and a differentiation. The signal peaking time at the shaper output is selectable among eight values, from 250 ns up to 2 us. After the filtering stage, the analog conditioning scheme is split into three different paths. On one side, a comparator is used to discriminate the amplified pulse: a threshold circuit converts the single-ended signal at the shaper output to a differential one and a differential DC threshold voltage is superimposed to the signal to drive the comparator. Another branch includes a single-ended to differential Sample\&Hold which provides a signal proportional to the peak of the shaped signal to the subsequent differential SAR ADC for the event data acquisition. On the third branch, the signal at the shaper output undergoes a further differentiation. The identification of the zero-crossing of the resulting bipolar signal provides a trigger, synchronous with the shaper peaking time, for the single-ended to differential Sample\&Hold.

The first two prototypes of this analog processing channel were designed in a 180 nm CMOS technology. The ASICs, named SLIDER4 and SLIDER8 (Si-Li DEtector Readout) were submitted and fabricated in 2018. The former includes only 4 standalone analog readout channels, whereas the latter is comprised of 8 readout channels, an 8:1 analog multiplexer, an 11-bits SAR ADC and a digital backend section which is responsible for ASIC slow control and serial interface communication. Experimental results will be used for the design of the final 32-channel ASIC. The device has to be ready in time for the launch of the balloon, that is currently scheduled for the second half of 2021 from the McMurdo station in Antarctica.

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