Front-end readout ASIC for charged particle counting with the RADEM instrument on the ESA JUICE mission

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INTRODUCTION

The detector readout for the Radiation-hard Electron Monitor (RADEM) aboard the JUpiter ICy moons Explorer (JUICE) uses a custom-made application-specific integrated circuit (ASIC, model: IDE3466) for the charge signal readout from silicon radiation sensors. RADEM measures the total ionizing dose and dose rate for protons (5 MeV to 250 MeV), electrons (0.3 MeV to 40 MeV) and ions. RADEM has in total three chips of the same design: one chip for the proton and ion detector, one for the electron detector, and one for the directional detector. The ASIC has 36 charge-sensitive pre-amplifiers (CSA), 36 counters of 22-bits each, and one analogue output for multiplexing the pulse heights from all channels. The counters count pulses from charged particles in the silicon sensors depending on the charge magnitude and the coincidence trigger pattern from the 36 channels. We have designed the ASIC in 0.35-µm CMOS process and an ASIC wafer lot has been manufactured at AMS. This article presents the ASIC design specifications and design validation results. The preliminary results from tests with bare chips indicate that the design meets the technical requirements.

FEATURES

4 low-gain channels (LG), charge-sensitive inputs:
- + Spectroscopy up to +20.8 pC, ENC ≈ 33000 e + 3 e/pF
- + 1 threshold, 10-bit linear prg. from +260 fC to +22.8 pC, 260 fC lowest threshold above noise
- + 1 trigger logic OR digital output

32 high-gain channels (HG), charge-sensitive inputs:
- + Spectroscopy up to +2.2 pC, ENC ≈ 3320 e + 9 e/pF
- + 1 low threshold (HGLT), 10-bit linear prg. from 1.2 fC to +0.1 pC, 2.2 fC lowest threshold above noise
- + 1 high threshold (HGHT), 10-bit linear prg. from 15 fC to +1 pC, 15 fC lowest threshold above noise
- +1 trigger logic OR digital output

Energy-resolved counting:
- + 36 digital counters read out via serial peripheral interface (SPI)
- + 22-bit Gray code counters
- + 1 Mcps / HG-channel count rate for 600 fC input charge
- + 100 kcps / LG-channel count rate for 10 pC input charge
- + 68-to-1 programmable coincidence pattern logic per counter

Pulse-height (charge) spectroscopy:
- + Analogue mux. output from all channels

Power consumption:

150 mW (typical operation), 240 mW (worst-case register settings)

SEL/SEU radiation hardened (triple-modular redundant, parity check, enclosed layout structures)

APPLICATIONS

Instruments:	**Fields**:
Compact radiation monitor,	Space, High-Energy / Astro
Dosimeter,	/ Atmospheric Physics,
Particle spectrometer	Medicine, Nuclear Industry,
	Aerospace

Detector type: optimised for silicon diodes (p-side, Si).

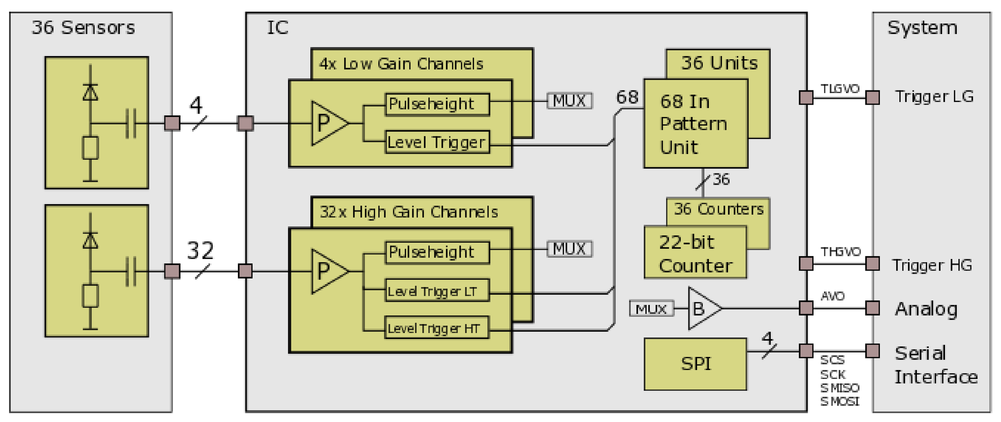

Fig. 1: Block diagram of ASIC (centre) in a typical application with detectors (left) and readout system (right).

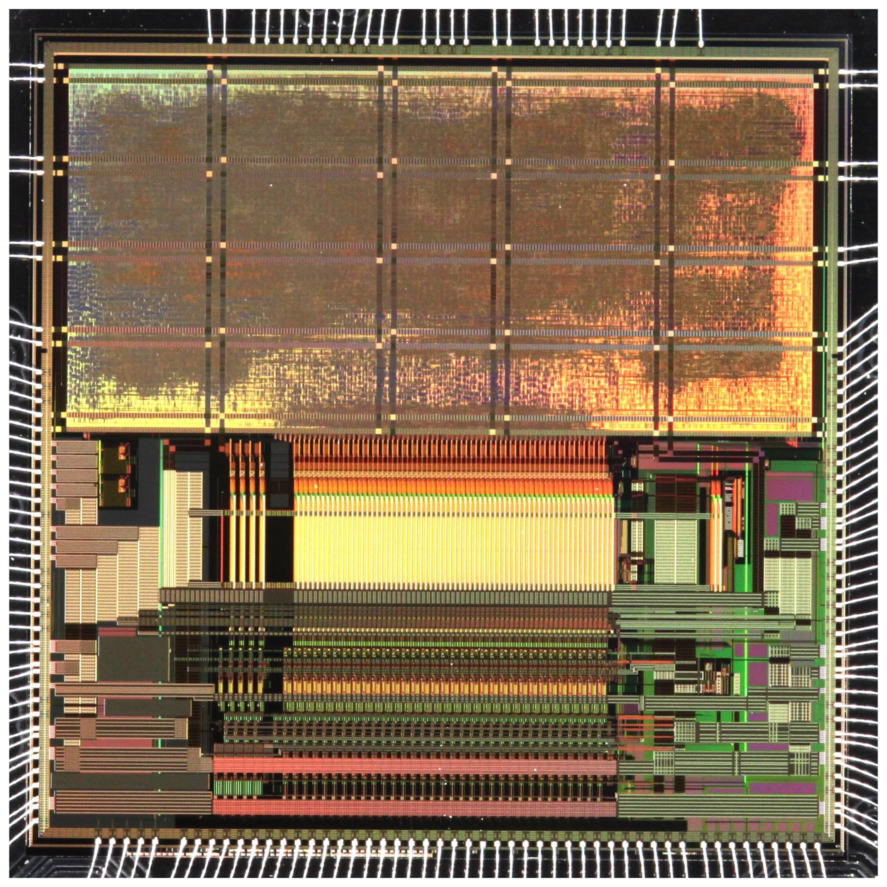

Fig. 2: Image of ASIC top-layer (not to scale, die size: 16 mm x 16 mm, thickness: 450 µm).

COUNTING PRINCIPLE

Each counter has access to a pattern unit with 68 trigger input signals L_i. It is configured using registers with veto-tokens V_i={0,1} for {anti-,coincidence} & masking bits M_i={0,1} setting inputs as {dis-,enabled}. The counter increments when the counting condition is fulfilled within a programmable coincidence time (50-700 ns).

Counting condition:

$$\prod_{i=1}^{68}\left[(V_i \oplus L_i) + \bar{M}_i\right] = \begin{cases} 1, & \text{counter increments.} \\ 0, & \text{counter remains constant.} \end{cases}$$

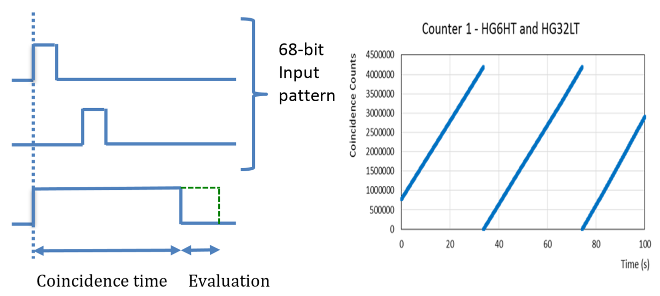

Fig. 3: Counting principle (left) and incrementing counters on device (right).

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PERFORMANCE

A limited amount of key performance features are shown in the following figures:

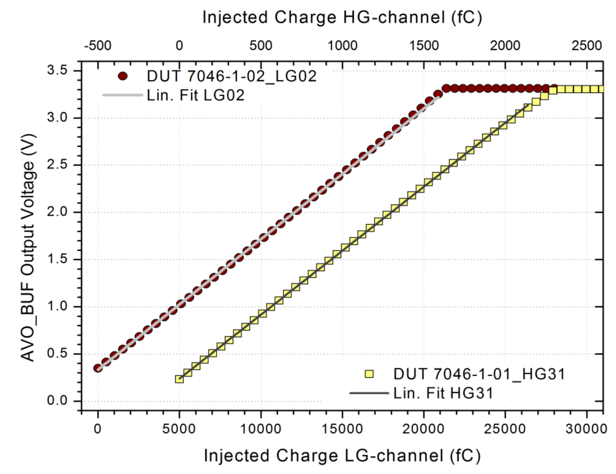

Fig. 4: Pulse-height spectroscopy.

Fig. 5: Slow shaper output.

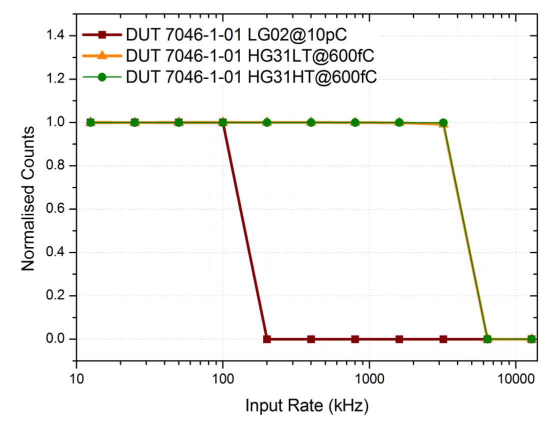

Fig. 6: Count rate capability.

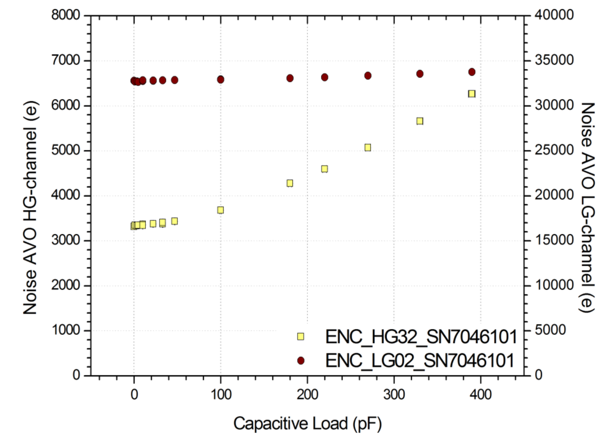

Fig. 7: ENC over load capacitance.

CONCLUSIONS

We have designed the ASIC for the front-end detector readout in the RADEM instrument. A wafer lot has been manufactured and we have tested the design with several chips in the lab. The preliminary results show that the ASIC is fully functional and performs as required for the RADEM instrument. We have implemented similar analogue designs for other space projects and the results are as expected from the previous experience. The digital design of the ASIC with the programmable coincidence pattern unit and Gray counter is entirely new. While the preliminary results of the digital design have not shown any unexpected effects, further tests are needed, i.e., irradiations with heavy ions are planned to test the triple modular redundancy, parity bits and transient filters, and further tests of the coincidence logic are planned with the ASIC assembled in the RADEM engineering model. In general, the combined integration of analogue and digital designs on the same ASIC design allows one to increase functionality and improve the instrument performance in terms of reduced power, smaller volume and lower mass. This is important for RADEM and for the development of future spaceborne systems.

Interested? Read our open-access paper:
Timo A. Stein et al., "Front-end readout ASIC for charged particle counting with the RADEM instrument on the ESA JUICE mission", SPIE Proceedings, 2016. Paper ID: 9905-119, DOI: 10.1117/12.2231901

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