ASIC for calorimetric measurements in the astrophysical experiment NUCLEON

E Atkin[1]**, A Voronin**[1,2]**, D Karmanov**[2]**, I Kudryashov**[2]**, I Kovalev**[2] **and V Shumikhin**[1]

[1] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia

[2] Skobeltsyn Institute of Nuclear Physics Lomonosov Moscow State University, 119991, Leninskie gory 1/2, Moscow, Russia

E-mail: voronin@silab.sinp.msu.ru

Abstract. A satellite with the NUCLEON apparatus was launched in Dec. 2014. The space NUCLEON project of ROSCOSMOS is designed to investigate cosmic ray nuclei energy spectra from 100 GeV to 1000 TeV as well as cosmic ray electron spectra from 20 GeV to 3 TeV. The method of energy determination by means of a silicon instrument for measuring the particle charge of cosmic rays and the calorimetric system were developed. The main parameters, that determine the quality of calorimetric systems are linearity of transfer characteristic and the dynamic range of input signals, which should reach 30 000 MIPs (minimum ionizing particles). The ASIC, satisfying these requirements, consisting of 32 channels with a unique dynamic range from 1 to 40000 MIPs, signal to noise ratio not less than 2.5 at a shaper peaking time of 2 μs and a low power consumption of 1.5 mW/channel has been designed. The first results of the ASIC functionality in space are presented.

1. Introduction

The space NUCLEON project of ROSCOSMOS is designed to investigate cosmic ray nuclei energy spectra from 100 GeV to 1000 TeV as well as cosmic ray electron spectra from 20 GeV to 3 TeV. Such investigations are very important for modern astrophysical research. Specific features of the experiment are a limited volume for the placement of electronics equipment and rigid power consumption requirements. This all results in the necessity to design an ASIC for reading the signals from silicon detectors used. The 32-channel ASIC with a unique wide dynamic range from 1 to 40000 mips and a low power consumption of 1.5 mW/channel was designed. The article describes the chip structure and its main parameters.

2. NUCLEON Apparatus

To reach this goal the NUCLEON [1, 2] apparatus consists of several subsystems: the silicon charge measurement system; the carbon target; the scintillator trigger system; the silicon energy measurement system; the silicon minicalorimeter; an auxiliary electronics unit.

The NUCLEON ASIC is used in the 6 planes silicon – tungsten minicalorimeter. Each plane includes a tungsten absorber and four ladders under it. The detector strips in neighbouring planes are oriented in such a way that they are orthogonal to each other. Each detector consists of 64 strips, 1 mm wide and 25 cm long. The detector wafer is 300 μm thick. One ladder contains eight 32-channels

ASICs and four silicon microstrip detectors. Thus the readout of the minicalorimeter is performed from 1536 channels.

3. The ASIC

The ASIC [2, 3] has 32 analog channels and 2 additional testing ones, placed at the die edges in order to reduce edge effects and improve the repeatability of parameters for the working channels. Figure 1 shows the ASIC structure.

The analog channel of ASIC consists of the following blocks: charge sensitive amplifier, shaper and a track and hold (T&H). The outputs of the channels are read out through analog switches, controlled by output logic, based on a shift register. Further the outputs are connected to a voltage-to-current converter. The converter transforms the single ended voltage into a differential current (outp and outn outputs).
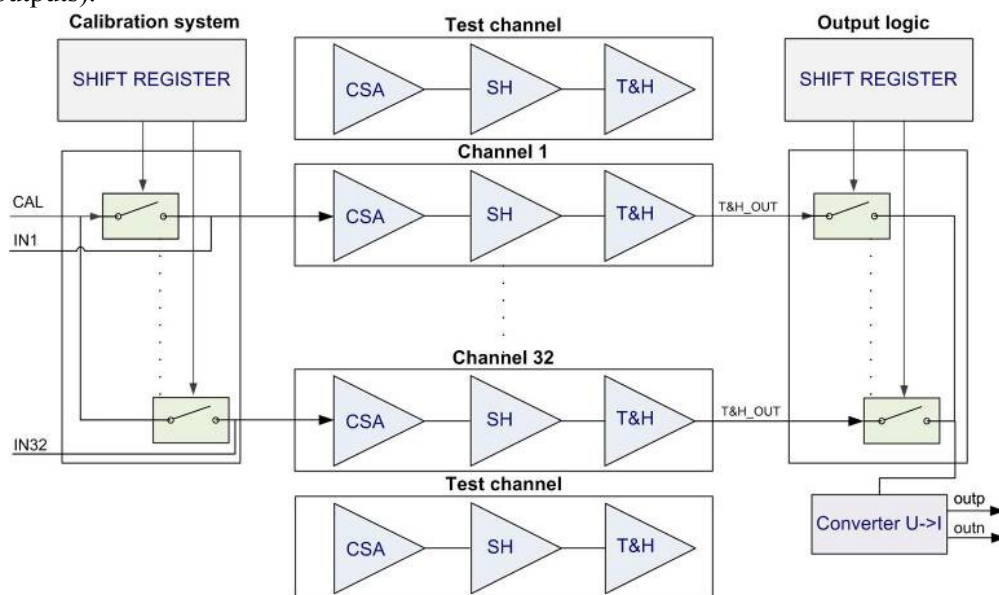

Figure 1. ASIC structure.

Such a structure has been used for the possibility of summing the output signals of multiple ASICs into a single differential current bus.

The calibration system, built in the ASIC, allows supplying the input test pulses subsequently to each working channel via a shift register.

The charge sensitive amplifier (CSA) has a folded cascode structure with a p-MOS input transistor. To achieve a wide dynamic range the CSA has a switchable gain. The division of the full dynamic range (from noise to saturation) into two subranges should be considered as a fundamental special feature of the designed CSA circuit. The inflection point of the transfer characteristic is at the input charge value of about 3 pC and can be adjusted. On the one hand, this allows one to ensure a higher slope of the transfer characteristic in the small amplitude region and thus reach a satisfactory SNR. On the other hand, this allows one to ensure a lower slope in the high amplitude region and thus expand the dynamic range beyond 100 pC. The subranges in the designed scheme are automatically switched.

To attain this aim, an additional circuit is introduced into the CSA structure (see figure 2). At small amplitudes the additional circuit is switched off and exerts no effect on the CSA feedback. In this case, the CSA gain is set by the relatively small feedback capacitor 6.6 pF. It may be calculated by the formula $K_Q = U_{OUT}/Q_{IN} = 1/C1 = 0.15$ V/pC. That provides an optimum signal to noise ratio for a 1 mip signal.
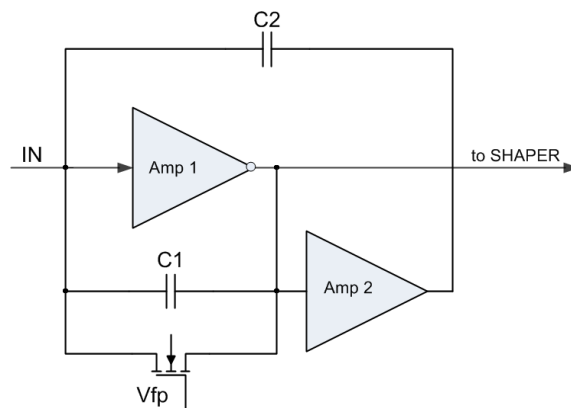
Figure 2. CSA structure.

At higher amplitudes (starting approximately from 3 pC), an additional capacitor C2 is added to the feedback network through an auxiliary amplifier, operating in the class B mode. The gain of this auxiliary amplifier and capacitance of C2 determine the feedback circuit for the CSA at large amplitudes. The equivalent feedback capacitance of the CSA is about 67 pF in this case. To discharge
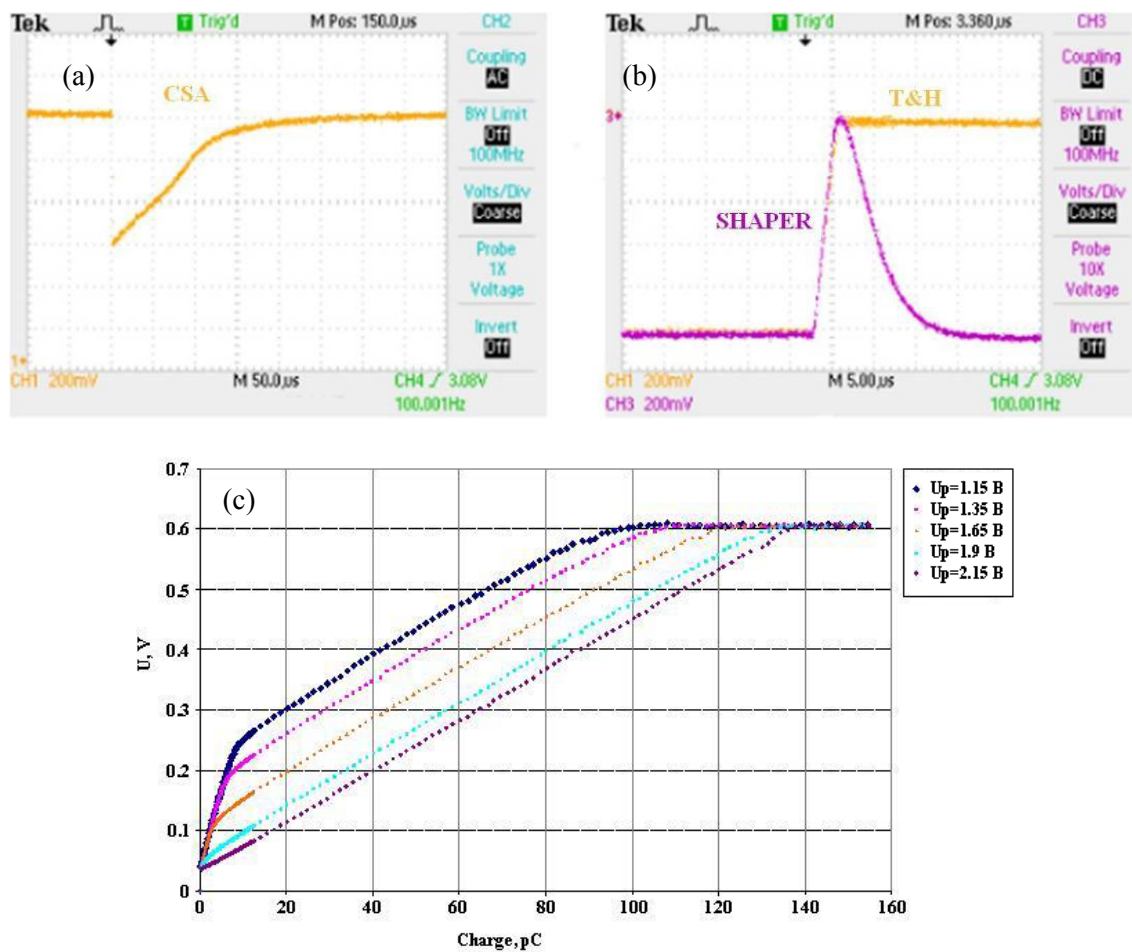

Figure 3. The ASIC output of: a) CSA; b) shaper and T&H. c) Channel transfer function.

the CSA feedback capacitance there was used a long channel (L = 100 μm, W = 1 μm) p-MOS transistor. The shaper has a CR–RC active filter structure. The peaking time of the shaper output is about 2.2 μs. The main purpose of the shaper consists in shortening the pulse duration and improving the signal-to-noise ratio (SNR) in a channel. Maximum swing at the shaper output is 2 V. The track and hold circuit fixes the peak amplitude at the shaper output. To store the T&H signals a capacitor of 1 pF is used. The circuit of a single stage operational amplifier with a 100% feedback is used as a buffer.

The ASIC was designed in the 0.35 μm CMOS technology process of AMIS (OnSemi) [4, 5]. At layout design there were used 5 metal and 2 polysilicon layers. Examples of test are presented on figure 3.

4. First space results

The goals of NUCLEON experiment also methodics, simulations, equipment are detailed described in [1]. In December 2014 the satellite with NUCLEON apparatus was launched on orbit. First experimental minicalorimeter result (for six planes: m0–m5) for the cosmic ray particle energy deposit on the orbit of 475 km is shown in figure 4. It demonstrates the latitudinal energy distribution of a hadron shower. The experimental result confirmed the simulations [1] for the minicalorimeter and are in full correspondence with previous cosmic experiments (ATIC, Pamela, AMS).
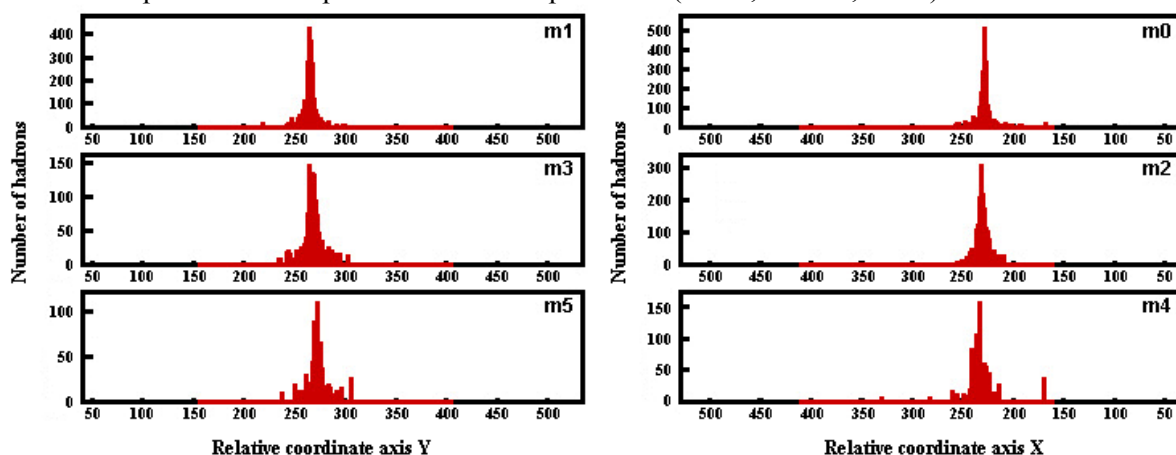
Figure 4. Cosmic ray particle Energy deposit profile of the NUCLEON minicalorimeter (6 silicon plates), obtaining by ASICs. (Y axis – m1, m3, m5; X axis – m0, m2, m4).

5. Conclusion

The 32-channel read-out ASIC for calorimetric measurements in the astrophysical experiment NUCLEON has been developed. It has a unique dynamic range of 120 pC, SNR=2.5 for the minimum ionizing particles (1 MIP) and a low power consumption of 1.5 mW per channel. The experimental results of the laboratory test are presented.

The ASIC was embedded in the hardware of the NUCLEON experiment on board of a satellite, launched to orbit in December 2014. First space results have been given.

References

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