Hodoscope with Timepix Detectors for PilsenCube2 Cubesat

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INTRODUCTION

One of the interesting applications of Timepix detectors is spectroscopy of cosmic radiation. Some projects regarding this topic have already been successfully tested, however most of the spectroscope boards use either high performance external computer for the data analysis, or the entire frames are sent to the ground control station. This hodoscope was designed to provide on-board data analysis using radiation hardened components. Thanks to the on-board data processing the required data throughput between the pico-satellite and the ground control station is greatly reduced. It also allows more measurements between the data transmissions, because only the energy spectra have to be stored.

Hodoscope board description

- The board is mounted with two Timepix detectors, forming a telescope setup.
- Each detector has its own radiation hardened power supply, including the high voltage bias up to 250 V.
- Radiation hardened SoC Smartfusion2 is used for data processing and power supplies control. This SoC comprises a Cortex-M3 microprocessor, operating up to 160 MHz, 64 kB SRAM and 256 kB of embedded flash memory (eNVM).
- The communication interface is provided via two RS485 buses.
- 3x SPI FRAM non-volatile memories for data storage, providing 1,5 MB storage for data and calibration matrices.
- USB interface (for calibration, diagnostics and debug purposes).

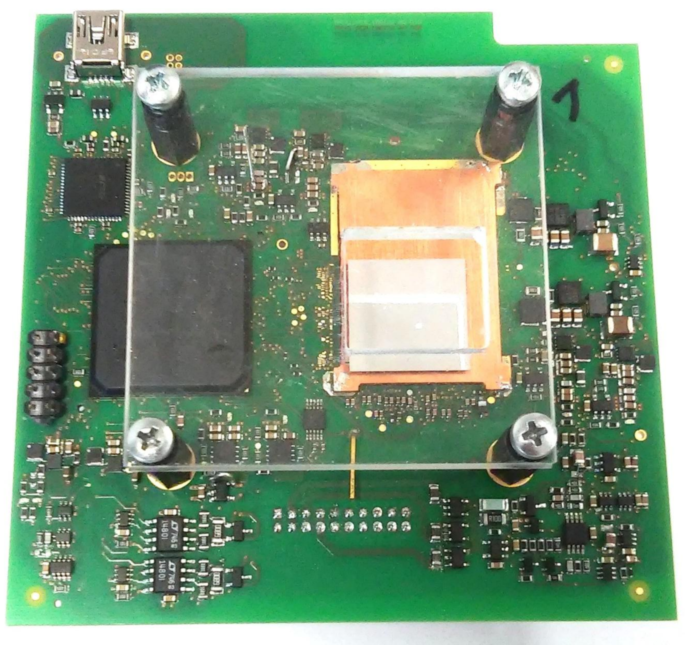

Fig. 1: Prototype of the hodoscope board

Board power consumption

- The power consumption of the board is being monitored using the on-board current measurement circuitry.
- Measurements were made for three different states of the board (see Tab. 1).
- The variations in power consumption during the measurement mode will be present as a result of different power consumption during the detector activity (exposition and readout) and the data processing, which duration depends on the number of captured clusters.
- The setting of the Timepix internal DACs also has a significant impact on the detector consumption.[1]

Tab. 1: Power consumption of the hodoscope board

Mode	Power [W]
Measurement mode	1,789
Detectors OFF	1,002
Sleep mode	0,546

Electron separator

- The Timepix detectors are mounted on a 2 mm thick copper plates
- This copper layer provides two main functions:
  - Heat dissipation from the Timepix ASIC.
  - Separation of the electrons and low energy protons from the high energy protons (the threshold is approximately 50MeV)

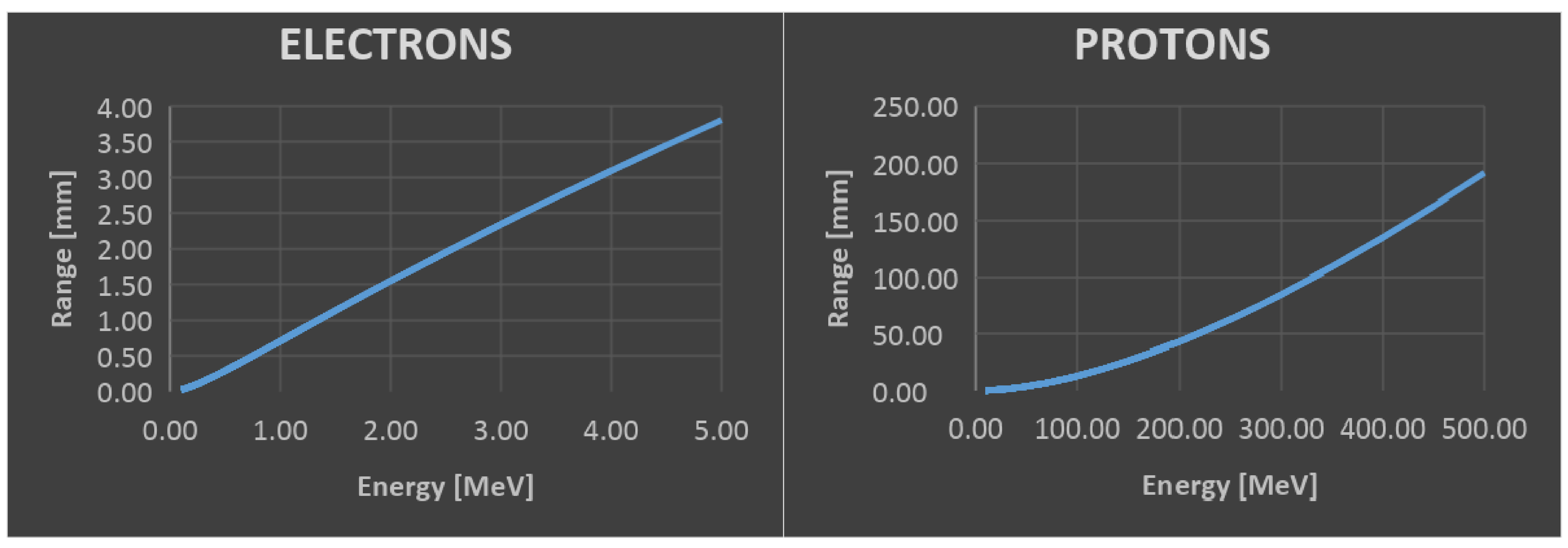

Fig. 2: Electron and proton range in copper.

- The thickness of the separator has been chosen according to the range of the 5 MeV electrons in copper (see fig. 2).

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Auto-exposure

- Due to variation of the space radiation at different positions within the low earth orbit, it is convenient to dynamically control the Timepix exposition time to prevent the clusters overlapping.
- The Timepix detector does not support this feature by default, thus software solution had to be developed.
- The MSS (microcontroller subsystem) monitors the number of hit pixels, and according to this information the exposition time is shortened or prolonged to provide optimal frame occupancy.

On-board analysis

- The integrated MSS (Microcontroller Subsystem) is responsible for complete processing and analysis of the received data.
- After the serial data conversion and de-randomization, the matrix analysis is performed in order to find the individual clusters and compute the total energy of each cluster.
- Due to the limited memory of the integrated microcontroller the clustering has to be computed independently for each row of the matrix.
- The cluster is then classified into one of the following categories:
  - Dot (gamma, x-ray, electron)
  - Small blob (proton)
  - Heavy blob (alpha, proton, ion)
  - Straight track (MIP, electron)
  - Heavy track (proton, ion)
  - Curly track (electron)
- The classification is based on the cluster parameters, such as size, inner to border pixels ratio, linearity, energy peak position within the cluster, and the roundness of the cluster.
- Sorting of the clusters as stated above is convenient for two main reasons. Firstly, the coincidence analysis time requirements are greatly reduced, because only a certain type of cluster is searched each time. Secondly, the cluster type provides good way to separate the resulting spectra and thus provide e.g. better energy resolution when the binning is applied.
- The coincidence is evaluated based on both particle tracks properties, e.g. cluster type, energy centroid, angle of impact or relative rotation. The exact method of the coincidence evaluation depends on the type of the analyzed cluster. If the coinciding cluster is found, the deployed energy per unit length (dE/dx) within the detector silicon layer is usually stored.
- The division into different spectra can be easily modified, depending on the requirements of the target application. In this particular case five different spectra are stored. The gamma spectrum (up to 200 keV), the electron spectrum, proton spectrum, heavy track spectrum and the blob spectrum.

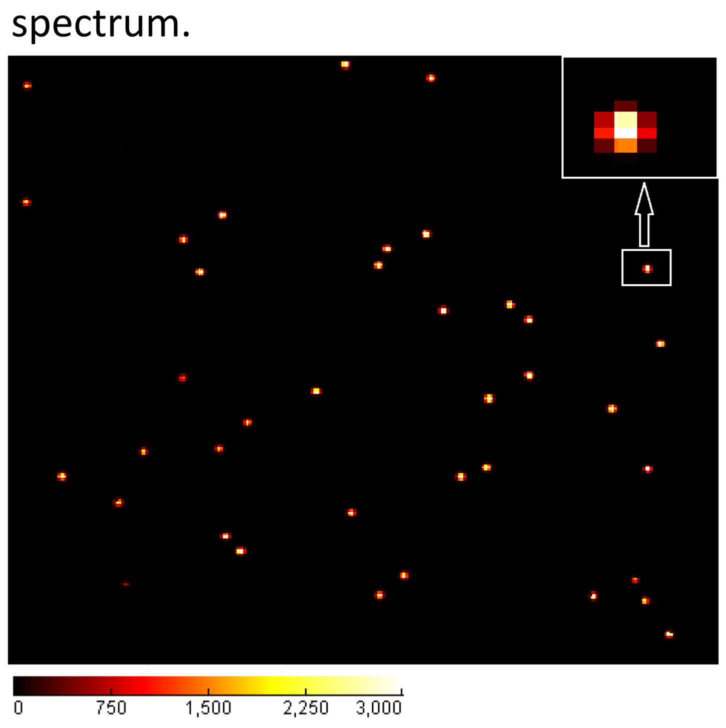

Fig. 3: Captured frame with alpha particles from Am-241.

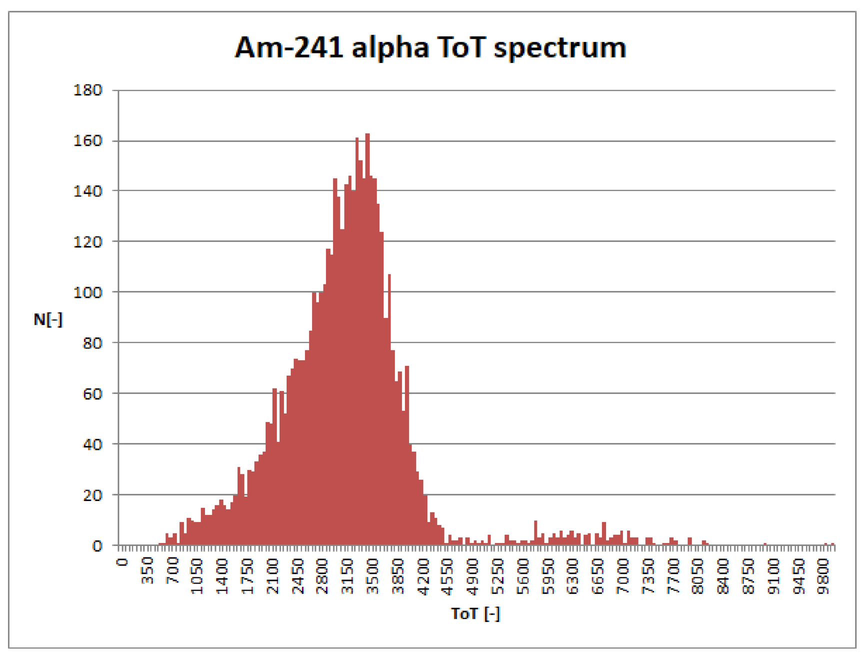

Fig. 4: Measured TOT spectrum of Am-241 alpha radiation source.

CONCLUSION

The presented device is suitable solution for radiation field monitoring in small satellite missions. It implements both low-level data processing (FPGA part of the device) and high-level processing (MCU part), which allows direct production of measured data spectra. This board can be easily integrated as a payload for picosatellites and can be controlled using RS485 bus via control/status commands. The designed firmware offers wide range of tools for data evaluation that makes it possible to modify the system for specific mission.

References:

[1] BURIAN, P., et al., *Study of Power Consumption of Timepix3 Detector*, JINST, 2019, 14 C01001.

[2] KRAUS, V., et al., *FITPix — fast interface for Timepix pixel detectors*, JINST, 2019, 6 C01079.