SiPM-based camera for gamma-ray imaging air Cherenkov telescope

ID : 521

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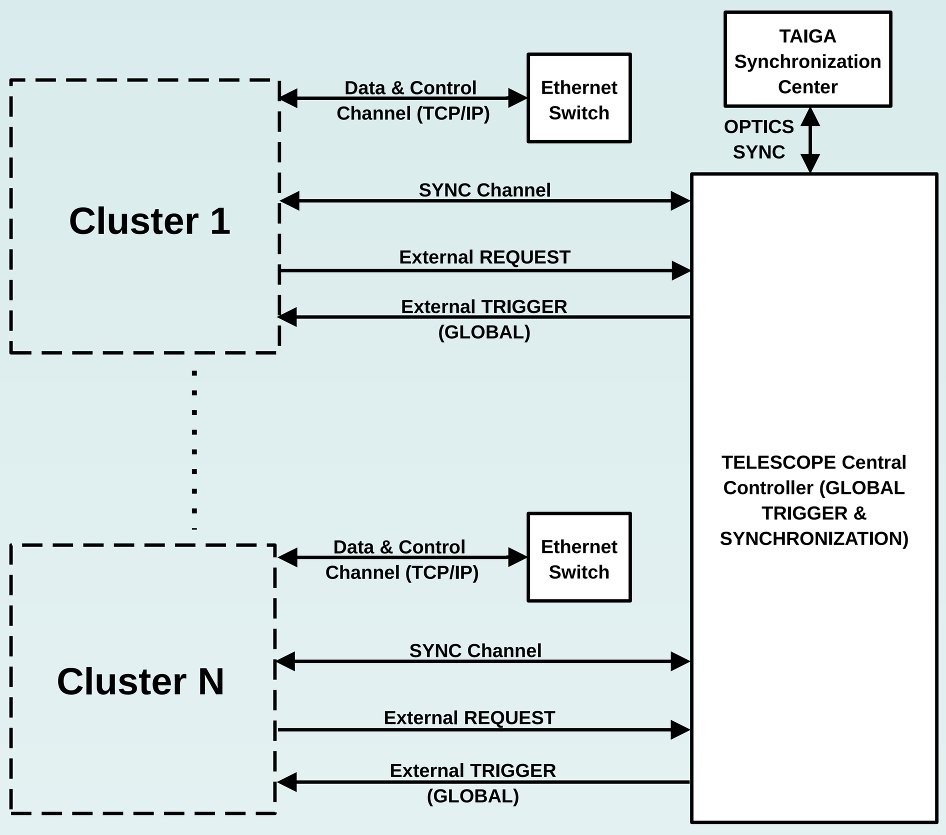
Abstract

The current status of the equipment development for the new wide-angle gamma-ray imaging air Cherenkov telescope for TAIGA hybrid installation [1] is presented. A front-end electronic and data acquisition system board based on the Zynq family Xilinx FPGA chips specially designed for this project have been produced and are being tested. A detailed description of the internal structure of the four main subsystems of the board: four 8-channel 100 MHz ADCs, boards control system, internal clock and synchronization system and the power supply. Additionally, the current status of a small scale prototype telescope SIT consisting of 49 SiPM is presented. The telescope includes a digital camera for observing the stars and weather condition. The SIT-HiSCORE synchronization systems and the telemetry information collection had been tested.

Introduction

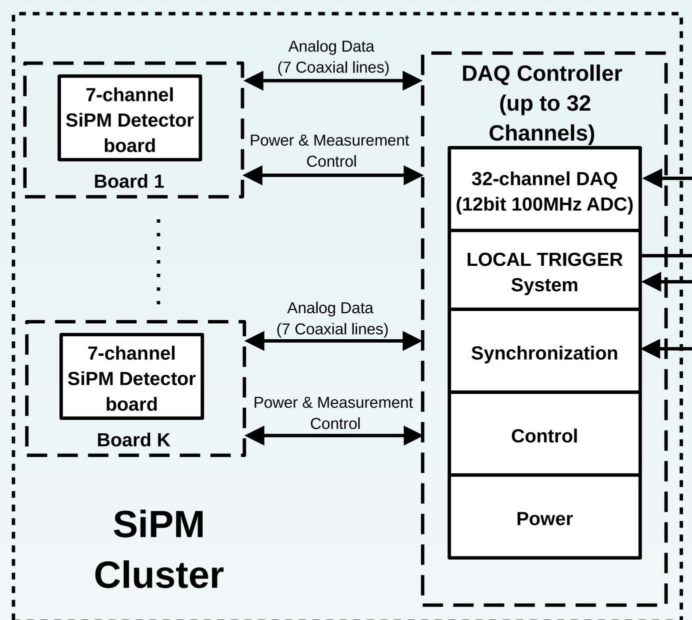
At present, the deployment of the first phase of the TAIGA gamma experiment is being completed in the Tunka Valley (Republic Buryatia). The main goal of the TAIGA experiment is to study gamma rays with energies above 30 TeV [1]. The experiment will consist of a regular network of wide-angle (0.6 ster) optical stations located on an area of 1km^2 (TAIGA-HiSCORE installation) and 3 IACTs with FoV 9.6°. Presently a new IACT is designed with a 15-20 maximum viewing angle and effective area of around 1 m^2. The energy threshold of such IACT will be approximately 10 TeV. The new detector utilizes around 1000 – 1200 SiPMs for its imaging camera.

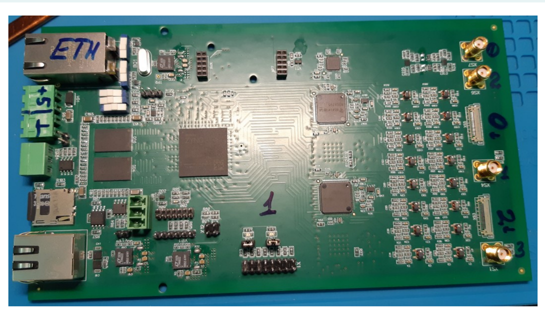
DAQ System of the SiPM-based telescope



SIPM-based DAQ is a modular system in which each block consists of a DAQ controller board and up to four 7-channel SiPM detector boards SIPM (up to 28 channels total). This approach allows construction of a sensitive area with any number of pixels required. Each DAQ controller board has a separate data and control channel (600 Mbit/s Ethernet) and a separate optical channel used for detector both internal and external synchronization and timing purposes. Thus, telescope's DAQ in general and each individual DAQ controller board are integrated into the TAIGA installation general synchronization system.

Each 7-channel SiPM detector board that comprise telescope sensitive camera ID connected to its designated DAQ controller board. Analogue signals from the 7-channel SiPM detector boards are digitized and processed using FPGA-based logic in real time. Each DAQ controller board in turn is connected to the Central Controller board that generates Global Trigger (External Trigger) signal for the whole telescope and serves as an interface between the telescope and TAIGA installation synchronization system.

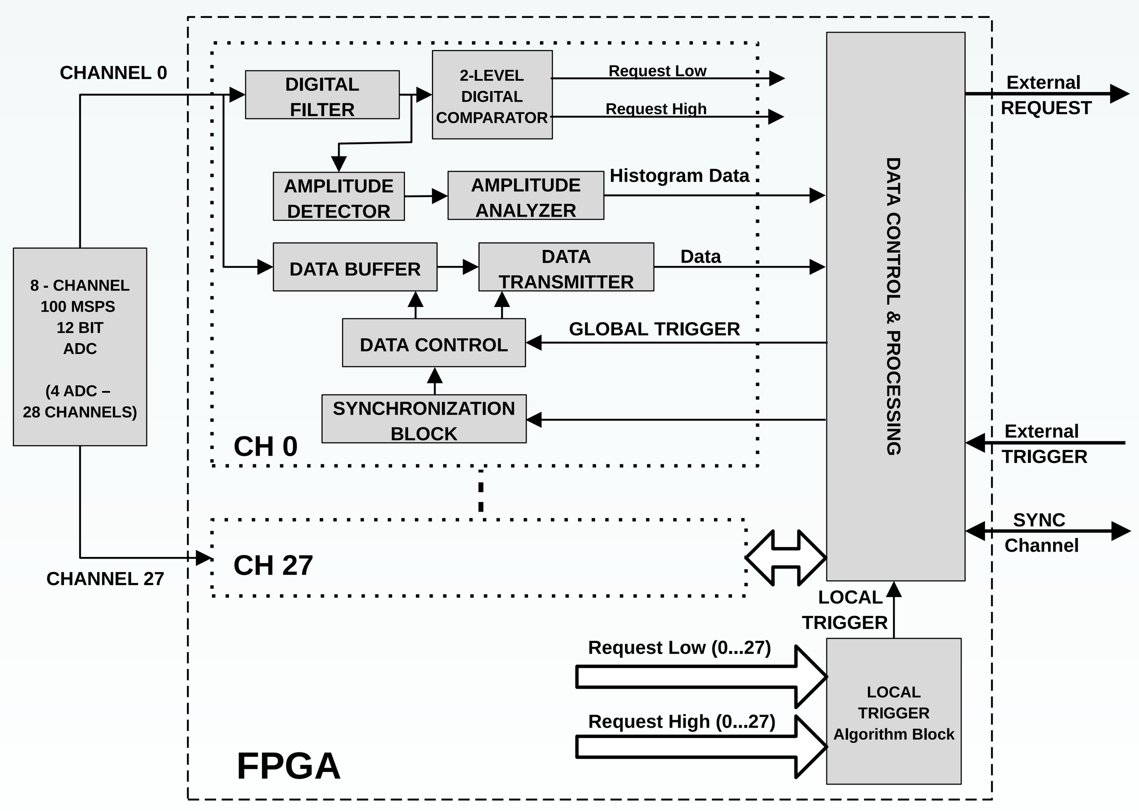




DAQ controller board

The DAQ controller board utilizes Zynq-family Xilinx FPGA chips and 32-channel 12-bit 100 MHz ADCs.

In order to generate the Global Trigger (External Trigger) for the telescope the DAQ controller board has an "External Request" output (used if Local Trigger conditions are met) and "External Trigger" input (for requests from the Central Controller Board if the global telescope's trigger conditions are met). The DAQ controller board also houses power supply units for detectors and other ancillary units for temperature, average SiPM currents measurements etc.



Global trigger is based on the local triggers and may use addition information: number of local triggers, position of pixels and etc. Global trigger if generated by the Central Controller Board using incoming "External Request" signals (produced by Local Trigger Algorithm Block) from each DAQ controller board. Local trigger (and Global trigger) can be produced using different algorithms that can be altered, changed or updated on the fly. The "topological condition" is planned as a base one (is formed only if a predefined number of neighboring pixels are hit). The "topological conditions" effectively suppresses (10 times or more) the background from random coincidences.

SiPM segment for detector's retina

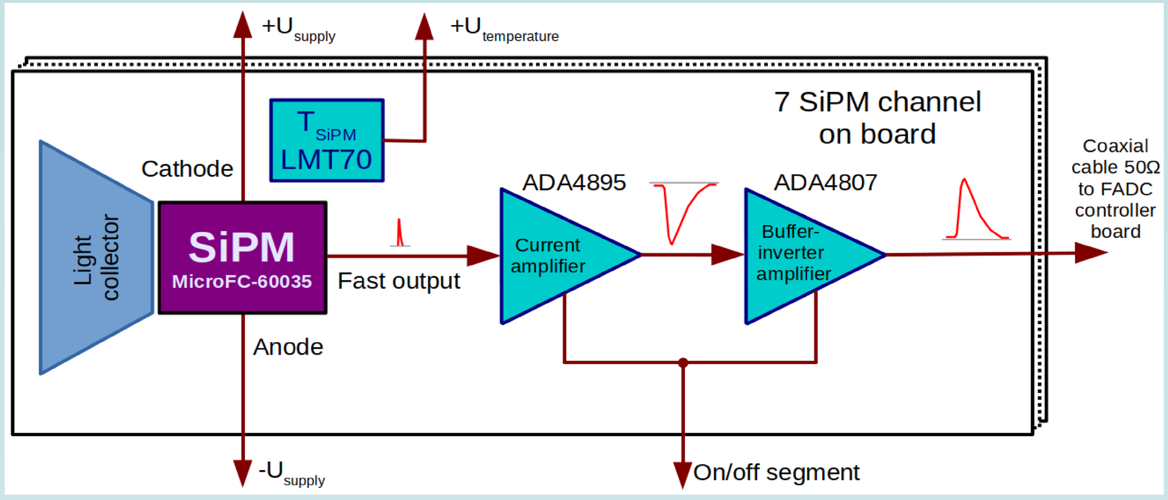
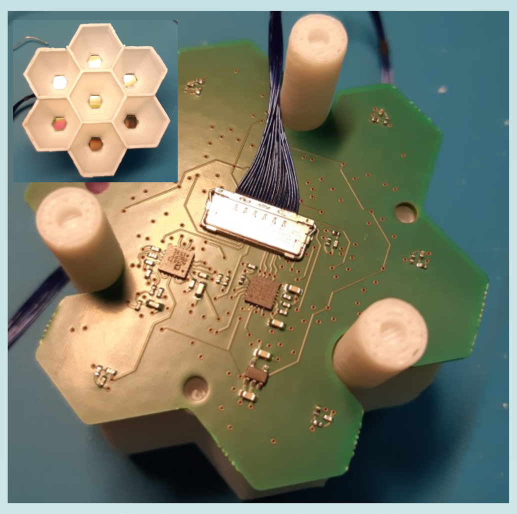


Diagram of SiPM segment. The negative SiPM supply voltage is common to all 7 channels, and the positive voltage can be set separately for each channel. An LMT70 temperature sensor has an accuracy of ±0.23 °C is installed next to each SiPM. A cascade of two amplifiers generates an output pulse for FADC with FWHM of 20-25 ns and amplitude of up to 3.5 mV / photoelectron.



Preliminary version (without microcontroller) of the SiPM segment board with the light collector prototype.

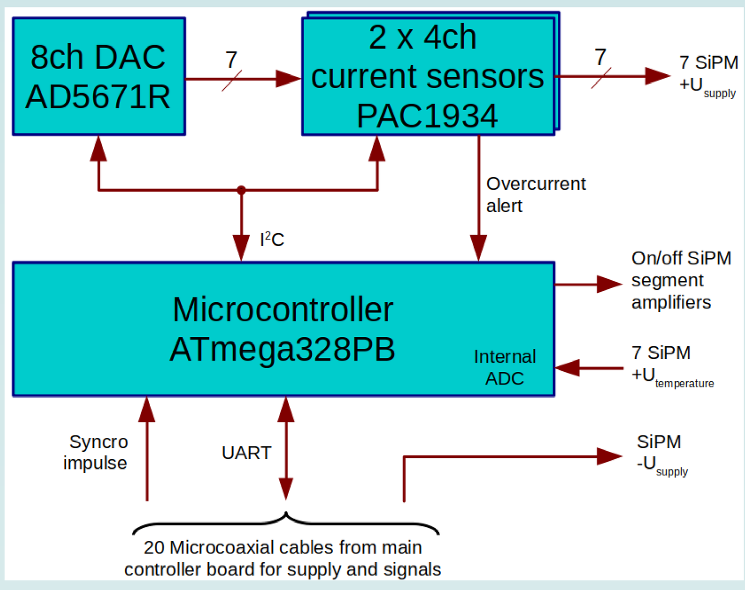
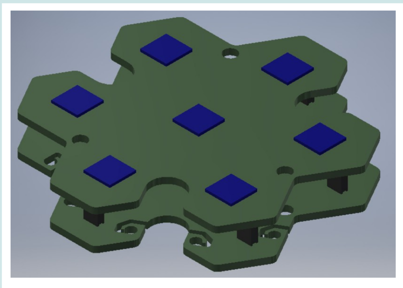
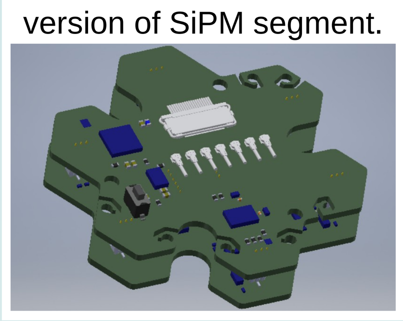


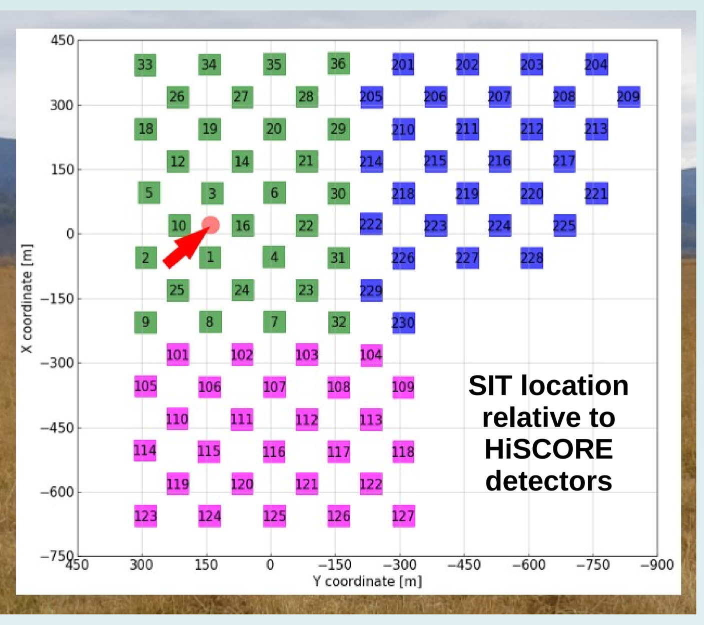
Diagram of the SiPM segment control board. The microcontroller registers the values of the SiPM currents and temperature individually for each channel, as well as to perform an emergency shutdown of the SiPM power supply in case of excessive illumination. The common negative breakdown voltage ($-U_{supply}$) for all SiPMs is generated on the main controller board, and the overvoltages ($+U_{supply}$) are generated using the DAC. Two chips measure direct current through the SiPMs with an accuracy of 0.1 µA.

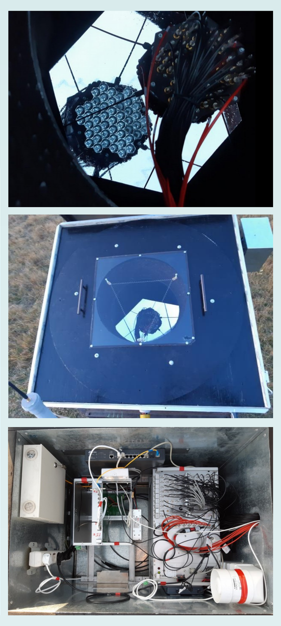


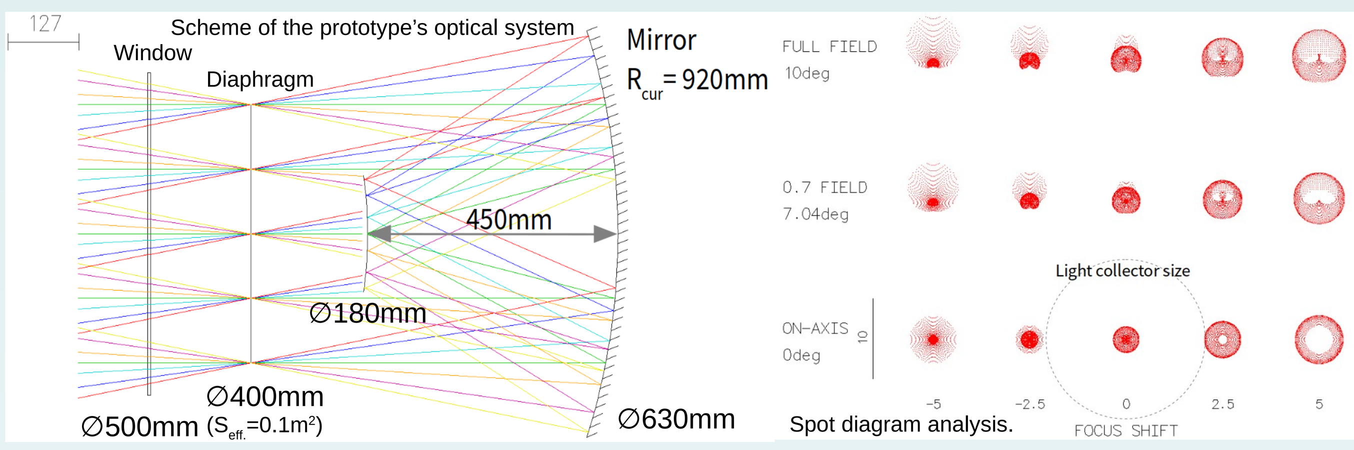
3D-model of a new version of SiPM segment.



Prototype of Small Image Telescope (SIT)

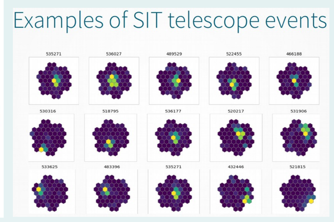






2020-2021 Statistics:
6 moonless periods
81 measuring nights
Total working time 461.7 h
Total triggers 2,992,498
Recorded events 2,605,674
Average counting rate 1.9 Hz

Examples of SIT telescope events



Conclusion

The development of the DAQ and the detector module of the new IACT is almost complete. During this the telescope prototype with a camera of 28 silicon photomultipliers and data acquisition system described in this report will be test in the laboratory and in the next year we plan to deploy telescope on the TAIGA Astrophysical complex.

Acknowledgements

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References

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DOI: 10.1016/j.nima.2016.06.041.
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[3] D. Chernov, et al. Development of a novel wide-angle gamma-ray imaging air cherenkov telescope with sipm-based camera for the taiga hybrid installation, Journal of Instrumentation. 15 (2020) C09062. DOI: 10.1088/1748-0221/15/09/c09062
[4] D. Podgrudkov et al. First Results from Operating a Prototype Wide-Angle Telescope for the TAIGA Installation. Bulletin of the Russian Academy of Sciences: Physics. 85 (2021) 408–411. DOI: 10.3103/s1062873821040286