PROCEEDINGS OF SCIENCE

Imaging Camera and Hardware of Tunka-IACT

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The array of wide-angle Cherenkov detectors, HiSCORE, which is presently under construction in the Siberian Tunka valley, is going to be complemented by a network of Imaging Atmospheric Cherenkov Telescopes (Tunka-IACT). Together they will form the TAIGA Gamma Ray Observatory. The hybrid operation of HiSCORE and Tunka-IACT considerably lowers the energy threshold of HiSCORE. In this article, we describe the IACT design and the camera measuring system which is based on the read-out chip (ASIC) MAROC3. We present and discuss first test results of the detection channels.

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1. Introduction

TAIGA (Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy) is a new hybrid detector system for the ground-based gamma-ray astronomy at energies from a few TeV to several PeV, and for cosmic-ray studies from 100 TeV to several 100s of PeV. TAIGA will be located in the Tunka valley (Siberia, Russia), where since 2009 the Tunka-133 Cherenkov EAS detector is in operation [1, 2]. The concept of the TAIGA Observatory foresees the creation of a complex of detectors able to provide the hybrid detection of EAS and to effectively separate gamma-induced EAS from hadron-induced ones.

The key advantage of the TAIGA gamma-ray observatory is the hybrid detection of EAS Cherenkov radiation by the wide-angle array Tunka-HiSCORE [3] and the narrow-angle imaging detectors Tunka-IACT [4]. The basis of the Observatoty is the new ground-based, large-area (up to 100 km^2), wide-angle ($\Omega \sim 0.6$–0.85 sr) air-shower detector HiSCORE (Hundred*i Square-km Cosmic ORigin Explorer) which is aimed to study cosmic rays and gamma-rays from a few 10s of TeV to 1 EeV using the non-imaging air-Cherenkov detection technique.

At present, the first prototype of the imagine telescope is being deployed in the Tunka valley. Mirrors of the telescope will have an area of about 10 m^2, and a focal lengths of 4.75 m. The camera will consist of 547 photomultipliers with the total field of view (FOV) 9.72° and the FOV of one pixel 0.36°. Preliminary results of simulations show that common operation of the HiSCORE array and a net of IACTs can be a very effective, inexpensive and quick way to expand gamma-ray astronomy in the unexplored ultrahigh energy region, as well as to increase the sensitivity of HiSCORE at lower energies and to improve the reliability of separating gamma-initiated EAS against the background of charged cosmic rays [3]. The timing detectors allow increasing the distance between the telescopes since they deliver part of the information which otherwise could be only obtained from IACT stereo operation. In this article we present results of the development of the measuring system of the camera based on a 64-channel ASIC MAROC3 which was designed for the readout of multianode PMTs [5].

2. Tunka-IACT setup

Each telescope will be composed of a mosaic, 34-segment mirror in Davis-Cotton design, with a diameter of individual mirrors 60 cm. The full diameter of the mirror is 4.3 m, its focal length 4.75 m (see Fig.1, left). At present, the camera with its 547 hexagonal-shaped pixels on 14 hexagonal rings around a central pixel (Fig. 1, right) is being assembled.

As a photodetector we use the XP1911 PMT with a window of 15 mm diameter. Each PMT is equipped with a Winston cone with an entrance size of 30 mm and an exit spot of 15 mm diameter. The sensitive area of the camera has a diameter of about 81 cm. The entire array of pixels is divided into clusters of 28 PMTs in each. Each cluster includes an electronic board MAROC, the basic element of which is a 64-channel chip ASIC MAROC3 (see Fig. 2, left).

In the Figure 2 (right), the layout of the block of a cluster of 28 photomultiplier is shown. The block is the basic camera unit. Structurally, the electronics of the cluster is divided into several boards: four divider boards of the 7 PMT groups (7HEX), four PMT power supply plates and cross-board with the DAC for the high-voltage source control and the ADC for the measurement of the PMT current and signal processing. The power supply board provides the monitoring of the PMT voltage up to -1600 V, and currents up to 1 mA. The output voltage setting accuracy is about 0.2%. Maximum power consumption is 4.5 W. All signals are connected with the adapter plate by means of coaxial cables. Signal processing is carried out by a PMT DAQ board based on the ASIC MAROC3.

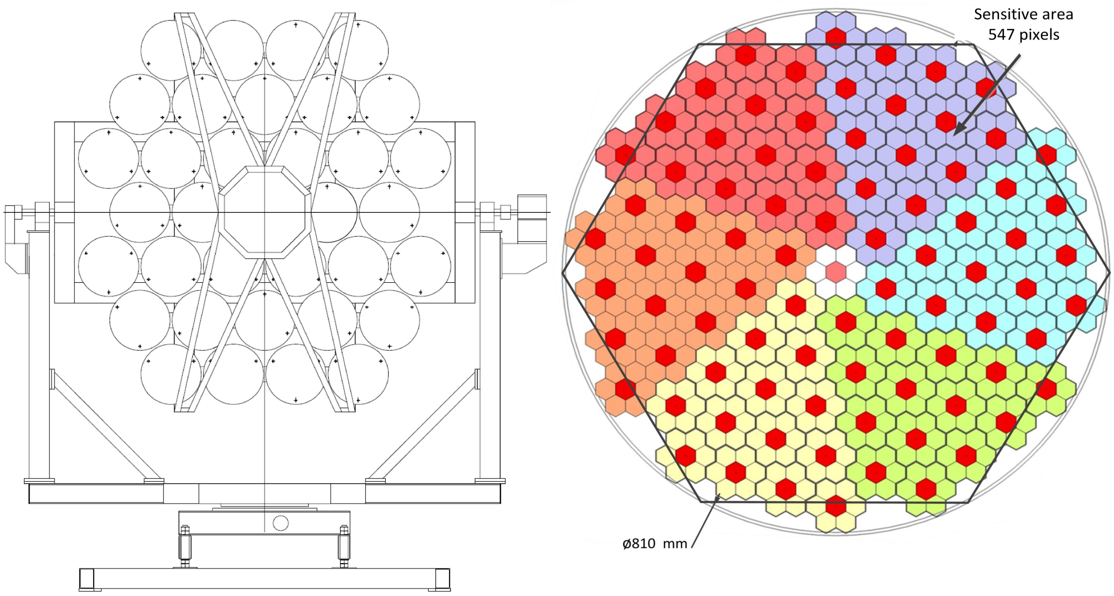

Figure 1: Mechanical design of the first TAIGA imaging telescope (left). The matrix of pixels of the Tunka-IACT camera (right).

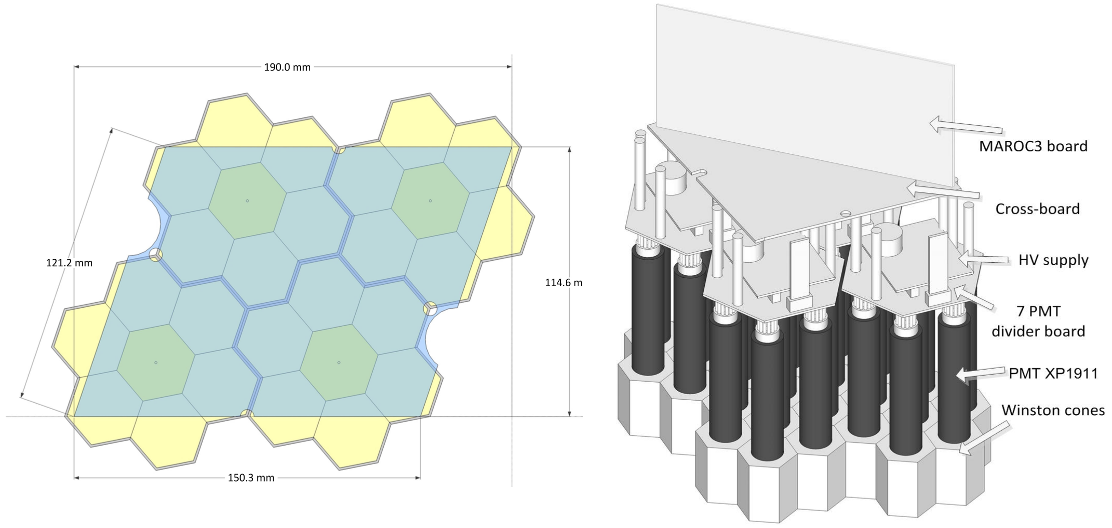

Figure 2: One cluster of 28 pixels arranged in four hexagonal cells 7HEX, served by a single MAROC3 board (left). The shaded area corresponds to the cross-board plate. Right: the basic PMT block of Tunka-IACT camera.

3. Hardware of the Tunka-IACT camera

The measurement system of the camera of the IACT is designed modularly and includes the camera detection system, the DAQ, the systems of triggering and the monitoring of noise currents and the PMT high-voltage supply. The general scheme of the camera electronics is shown in Fig. 3.

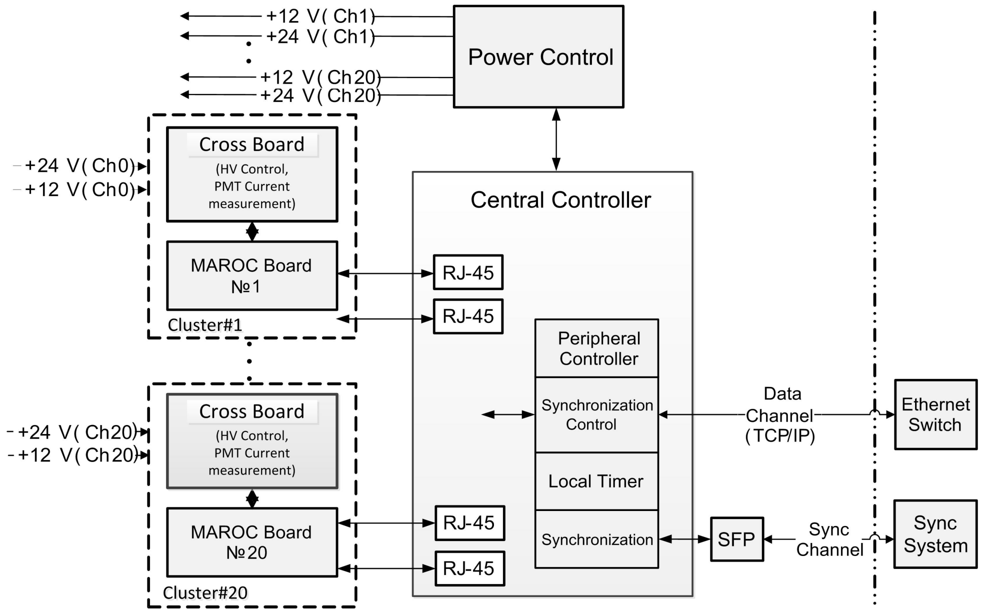

Figure 3: The scheme of the Tunka-IACT camera electronic.

The detection system consists of 20 identical clusters serving 28 PMTs, its central unit is the Central Controller. The Central Controller controls the PMT board operation (setting the high voltage and monitoring the PMT current), the common trigger formation, the PMT cluster data collection, synchronization, storage of data in the intermediate buffer, and the traffic of data between data collection centers and the Controller via Ethernet. The lines of communication between the boards and the PMT controller are configured in standard LVDS and provide the timing of trigger signals not worse than 5 ns. The data transfer rate is at least 20 Mbit/s. The length of the transmission lines is determined by the dimensions of the camera housing and does not exceed 2 m. Each cluster of 28 PMT also has an additional standard port for the control and data transmission (USB) for the autonomous (without a central controller) operation with a computer.

4. ASIC MAROC3

The basis of the entire camera readout electronics is the 64-channel ASIC MAROC3, which receives signals from the 28 PMTs. Each channel includes a preamplifier with adjustable amplification (6 bit), a charge-sensitive amplifier and a comparator with an adjustable threshold. The ASIC chip comprises a 12-bit Wilkinson ADC. It has a multiplexed analogue output to an external ADC with a shaped signal proportional to the input charge, and 64 output trigger signals. The shaped signals are sent to the FPGA (FPGA EP1C6Q240C6), ensuring the formation of the first level trigger (*n*-majority coincidences from 28 PMTs). The FPGA controls the settings of the 64-channel amplifier-shaper-comparator and the ADC operation. The system of the MAROC3 control includes generating a local trigger, analog-to-digital converting, the loading of the MAROC3 configuration, and the interface with the upper level system. Two channels of MAROC3 process the signals from one photomultiplier to provide the necessary dynamic range. Pulses are divided by a passive splitter (see Fig. 4). Before splitting, signals from each photomultiplier are sent to the current monitoring circuit.

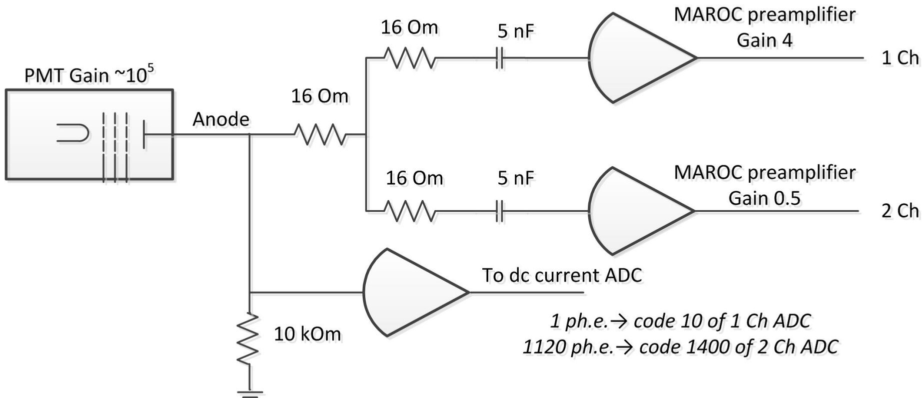

Figure 4: Splitter of PMT output pulses.

The detection system of the IACT camera provides read-out and processing of the PMT signals in the following modes:

1) exposition; 2) measurement settings; 3) monitoring of the PMT noise.

In the exposition regime, the detection system of the camera provides amplification and discrimination of the PMT signals with a predetermined threshold, the selection of events corresponding to the light spot from an EAS (multiple PMT channels trigger within a specified time gate), and stores them in the internal buffer for processing in real time conditions. The minimum threshold is 50 fC. At this trigger, the numbers of all triggered PMT channels in the interval t_{max} (20 ns), the amplitudes of the signals and the event waiting time are recorded. The estimated "dead" time (time of signal digitizing and feeding the events to the buffer) is not more than 200 μs which is about 1% of full-time detection at the expected rate of ~ 50 s^{-1}. The power consumption of the system is less than 20 mW/channel.

In the noise monitoring mode the system counts PMT pulses which exceed a given threshold within a certain time window (adjustable from 10 to 500 ms). At the same time the MAROC board can count the total noise from 28 parallel channels, which is a logical OR of 28 PMT channels. It is also possible to count the noise for each PMT channel in multiplexing mode.

The block scheme of the MAROC board of a camera is shown in Fig. 5, and a photo in Fig. 6.

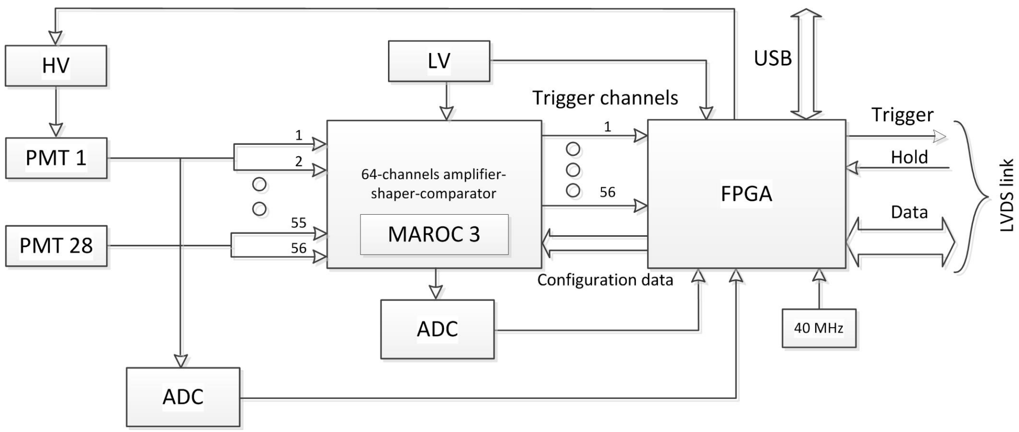

Figure 5: The block diagram of the MAROC board.

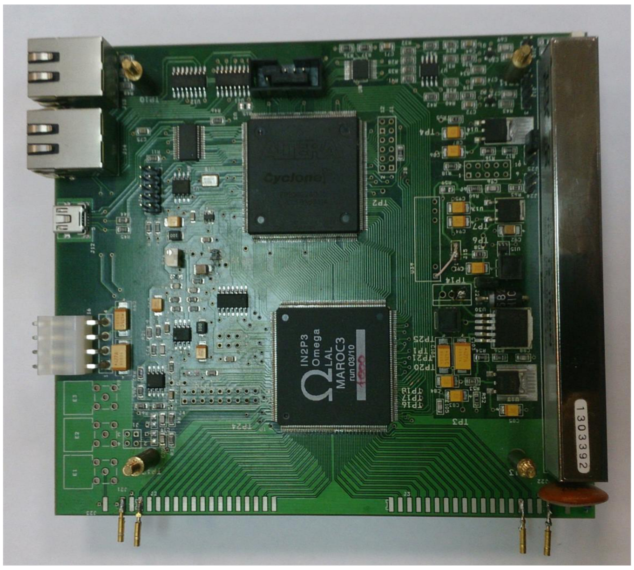

Figure 6: The MAROC board .

5. The MAROC board test

Fig. 7 shows how the efficiency of generating a first-level trigger on the PMT board depends on the delay between the input signals, for the coincidence gates of 10 ns and 20 ns, respectively. The measurements were performed with a two-channel generator Tektronix AFG3252 with 1 ns delay increments. The efficiency of the trigger was defined as the ratio of the frequency of the PMT, measured by the MAROC plate, to the frequency of the generator signals. The result confirms the stability of the circuit triggering operation for gates larger than 20 ns, which satisfies the requirements of useful event selection.

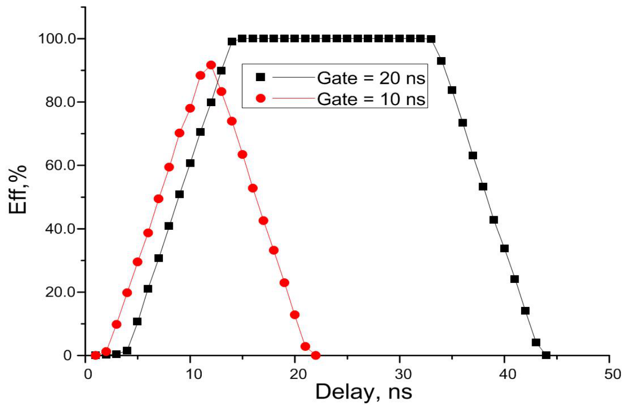

Figure 7: Dependence of the first level trigger formation efficiency on the delay.

Calibration characteristics of a spectrometric channel for different transmission coefficients of the preamplifier are shown in Figure 8 (left). The PMT gain was set to 10^5 by means of HV supply ajustment. The measurements were made with a Tektronix AFG3102 generator in automatic mode under the control of a computer with a step of charge of the input signals 50 fC. The range of linearity of one channel of the spectrometric tract of the ASIC MAROC3 board is not less than 100.

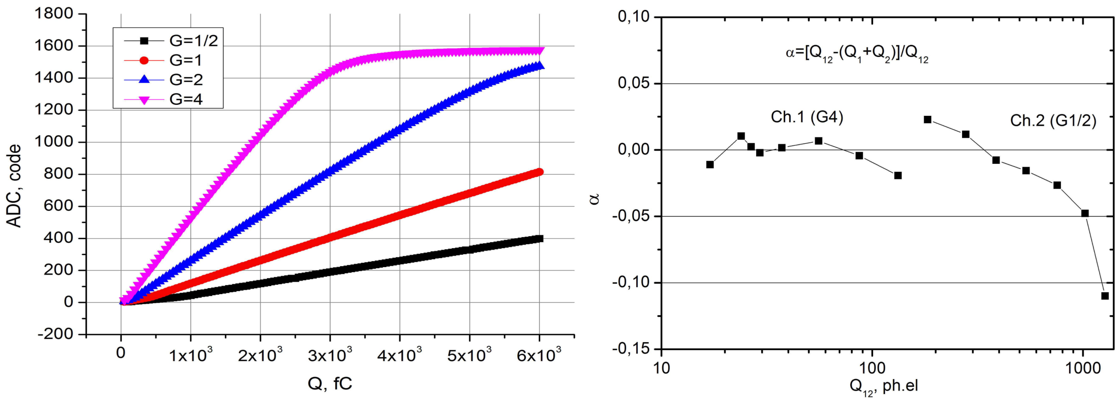

Figure 8. Calibration characteristics of a spectrometric tract of the ASIC MAROC3 (left). The linearity of the spectrometric tract (right).

Figure 8 (right) shows the dependence of the linearity coefficient α on the response of PMTs, recorded by the MAROC board at simultaneous detection of light flashes from two independent LEDs. For one PMT we used two MAROC channels with different transmission preamplifier coefficients: G=4 for the Channel#1 and G=1/2 for the Channel#2, respectively. As seen from Fig. 8 (right), the linearity range ($|\alpha| \leq 0.05$) for one PMT is about 1000 ph.el.

6. Conclusion

We have developed a registration system of the IACT camera of the TAIGA Gamma Ray Observatory. It is based on 547 photomultipliers XP1911, united in clusters of 28 PMTs. The PMT signals are processed by an electronic board on the basis of the 64-channel ASIC MAROC3. The signals from each PMT are processed by two independent channels of the ASIC, corresponding to different gains of the preamplifiers. This ensures that the linear range of the PMT signals is at least 1000 ph. el. At present, the construction of a prototype camera for the first IACT is underway.

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