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Development of front-end electronics of TAIGA-IACT

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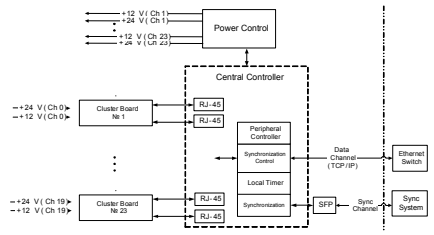
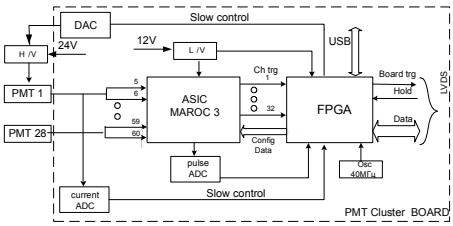
Currently, the Observatory TAIGA (Tunka Advanced Instrument for cosmic rays and Gamma Astronomy) is being deployed in the Tunka valley (Buryatia). A special feature of the complex is a hybrid method of gamma-ray shower detection by a wide-angle HiSCORE Cherenkov detector and a system of atmospheric Cherenkov telescopes TAIGA-IACT [1]. The basis of the registration system of each IACT is a matrix camera, which consists of 547 pixels based on the PMTs, with a field of view of 8x8 degrees and an angular pixel size of 0.36 degrees.

DAQ of IACT camera [2]



The date acquisition system (DAQ) of the atmospheric Cherenkov telescope camera is modular and consists of 23 identical Cluster board serving the PMT units and the Central unit of the system – the Central Controller.
Central Controller provides control of operation of Cluster boards, development of a common trigger, synchronization, data collection from Cluster boards and data storage in the intermediate buffer, data exchange with the Central computer.

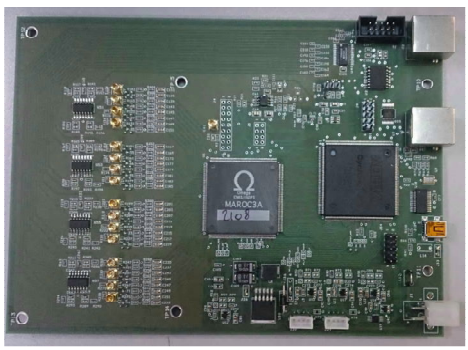
Schematic of PMT Cluster board



The entire camera array of pixels is divided into clusters of 28 pieces which are served by a single electronic board, the basic element of which is a 64-channel chip ASIC MAROC3. Trigger of the PMT signals formed by MAROC3 arrive to the FPGA , ensuring the formation of the first level trigger, the control of the analog-digital conversion, loading configuration in the MAROC3. Data exchange between the Central Controller of a DAQ system of the telescope and Cluster board and organization for a common trigger system using a specially developed interface. Data transmission is continuous, independent in two directions. Bit synchronization is carried out on the clock signal accompanying data, byte synchronization - through the use of 8 to 10 bit encoding. Coding also allows you to monitor the noise immunity of the communication line. Electrically the interface is made on the eight differential lines to the LVDS standard. Mechanically, the communication line consists of two cables with RJ45 connectors. Logically, the data interface allows you to record and read data from individual registers of the address space of the Cluster board, as well as continuous, automatic data transfer to the Central Board in the exposure mode.

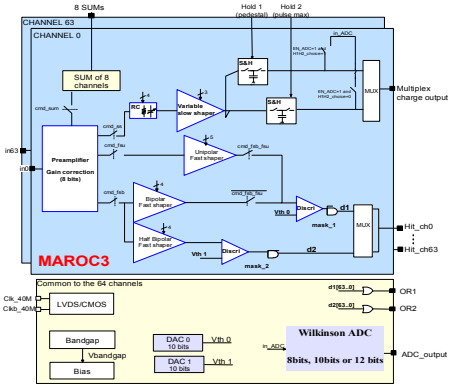
The performance analysis for the first season resulted in the development of upgraded PMT Cluster boards for the second IACT. The main differences from previous version:
1. Coaxial connectors of the signals from the PMT, the circuit fan-out signals, the elements responsible for the measurement of currents and PMT high voltage control power posted on-board.
2. Power and communication interfaces connectors are installed on one side of the board.
3. Instead of FPGA CYCLONE EP1C6Q240C6 installed FPGA CYCLONE III EP3C16Q240C8 [4].
4. Removed intermediate buffer trigger signals that reduce the time of signal "HOLD" reception.
5. Implemented automatic detection of USB interface connection.
6. Due to the decrease in amplitude of interference on the input signals during the measurement of the currents, Cluster board allows simultaneous registration of triggered events and measurement of the counting rate and PMT c

Top view of PMT Cluster board



ASIC MAROC3 - basis element of of front-end electronics [3]

MAROC3A is a 64-channel chip designed to readout negative fast input current pulses such as those provided by PMT. Each channel provides a 100% trigger rate for signal greater than 50fC and a charge measurement up to ~ 5 pC with a linearity of 2%. The gain of each channel can be tuned between 0 and 4 thanks to an 8 bit variable gain preamplifier . A slow shaper combined with two Sample and Hold capacitors allows storing the charge up to 5 pC as well as the baseline. In parallel, 64 trigger outputs are obtained thanks to two possible trigger paths: one made of a bipolar or unipolar fast (15 ns) shaper followed by one discriminator for the photon counting and one made with a bipolar fast shaper (with a lower gain) followed by a discriminator to deliver triggers for larger input charges. The discriminator thresholds are set by two internal 10-bit DACs. A digital charge output is provided by an integrated 8, 10 or 12 bit ADC Wilkinson. 828 Slow Control parameters allow versatility and various settings.



Check list of all board characteristics.

Check list of all main Board characteristics.
1. Voltage at the test points
2. The presence of connection interfaces, correctness of loading / reading the configuration data
3. The correct operation in the measurement mode rate account
4. Correct operation in the mode of measuring the currents of the PMT: several control points for each channel
5. Correct operation in the mode of measuring the pedestals: characteristics of the spectra symmetry, continuity, Sigma, spread between channels, crosstalk between channels, external and internal ADC
6. The correct operation in the measurement mode of the signal amplitudes: the characteristics of the spectra of the symmetry, continuity, Sigma, dispersion between channels, crosstalk between channels, the transfer coefficients, the linearity, the read mode of the registers and automatic transmission, external and internal ADC.
7. The correctness of the set values of the DAC (HV): multiple cue points for each channel
8. Characteristics trigger system : the trigger efficiency for different thresholds and multiplicities, the width of the gate is a match, the HOLD time of development, interaction with Central Controller, stability under intense random flow of input signals.

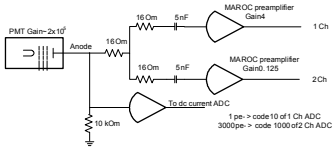
Conclusion

- **The camera of the telescope has a wide, two-level mode of trigger event and registration.**
- **The system configuration remote update mode is implemented.**
- **The mode of simultaneous registration of triggered events and measurement of the counting rate and PMT currents is implemented.**
- **Currently, the camera is being assembled and adjusted with upgraded PMT Cluster boards for the second telescope.**

References

1. L.A. Kuzmichev for the TAIGA Collaboration. TAIGA Gamma Observatory: Status and Prospects. Physics of Atomic Nuclei, July 2018, Volume 81, Issue 4, pp 497–507.
2. I.I.Yashin for the TAIGA Collaboration. Imaging camera and hardware of Tunka-IACT. Proceedings of Science, 2015r. Vol. 30-July-2015.
3. MAROC 3A –Datasheet. www.weeroc.com/products/maroc-3.
4. Cyclone III Device Handbook CIII5V1-4, www.intel.com/content/dam/www/programmable/us/en/pdfs/literature/hb/cyc3/cyclone3_handbook.pdf

Matching on the single PMT anode output with MAROC



To expand the dynamic range, two channels of ASIC MAROC3 process signals from the same PMT. Signals from each PMT are transferred to the scheme of current monitoring.
The range of linearity of measurements when using two MAROC 3 channels for each PMT is 1000 - from 50 fC to 50 pC.

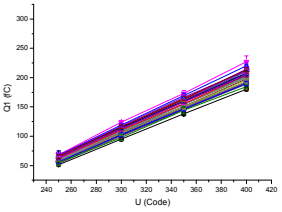
Time specification.

- The integration time 35 ns
- Gate of coincidence 12 ns
- MAROC triggers delay 25 ns
- External ADC conversion time 51.2 us
- Maximum internal ADC conversion time 120 us
- Trigger data transfer time 1.4 us
- Event data transfer time 51.2 us
- PMT current measure time 60 us
- MAROC board load time ~ 0.22 ms
- H/V setup time 4.8 us

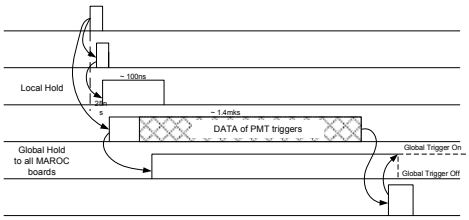
Trigger conditions

Triggers in a coincidence window 12нс signals exceeding a predetermined threshold from a predetermined amount of PMT

The dependence of the input charge at 50 % of the trigger efficiency of 32 channels on the DAC threshold code

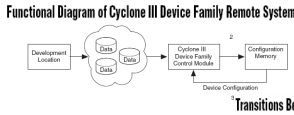


The two-level mode algorithm to determine the global trigger allows you to register the amplitude of each triggered PMT.



- The local HOLD is generated on any trigger of PMT at the time of the signal maximum of the slow shaper. The duration of the signal is about 100 ns.
- The local trigger is generated on coincidence of local PMT triggers and transmits to the Central Board information about the PMT triggers.
- The global HOLD formed a Central Board on any local trigger and passed on all MAROC Boards.
- The global trigger is generated on coincidence of all PMT triggers. If a global trigger is formed, MAROC Boards, which was a local HOLD, starts the ADC. If a global trigger is not formed, the global HOLD reset.

The system configuration remote update mode



The capacity of the configuration ROM is increased by 16 times, which allows you to store up to 16 different configurations.

Each application configuration can be remote overwritten by duty personne.l