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Data acquisition system for a km^3-scale Baikal neutrino telescope

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Abstract: A prototype cluster of the future Gigaton Volume Detector (Baikal-GVD) was installed in Lake Baikal in April 2011. The cluster consists of 24 optical modules located on three strings. We review the data acquisition system for the GVD cluster, describe the basic elements of GVD – new optical modules, FADC readout units, underwater communications and trigger systems, and present the prototype cluster design.

Keywords: neutrino telescopes, Baikal, data acquisition

1 Introduction

The Baikal Neutrino Telescope [1–5] is operated in Lake Baikal, Siberia, at a depth of 1.1 km. Lake Baikal is one of the most extraordinary lakes in the world. The light propagation in the Baikal water is characterized by an absorption length of about 20–25 m and a scattering length of 30–50 m. Good water properties and the possibility to use ice as a natural platform for detector deployment and maintenance make the Baikal site very attractive for the creation of a large scale neutrino telescope. Preparation towards a km3-scale Gigaton Volume Detector, GVD [6–9], in Lake Baikal is currently a central activity. A prototype cluster of GVD [8] was installed in Lake Baikal in April 2011. The cluster consists of 24 optical modules located on three strings. We present the data acquisition system (DAQ) for the GVD cluster and describe the basic elements of the detector electronics.

2 GVD data acquisition system

GVD will consist of strings of optical modules (OM). Each string will include a chain of OMs spaced uniformly at depths 900 – 1250 m. A conventional string structure is optimal for telescope deployment from the natural ice platform of Lake Baikal [9]. For inter-string communication and connection to shore, strings will be grouped in clusters. Each cluster will be controlled by the so-called cluster DAQ center placed near the water surface. The DAQ of the cluster has a flexible structure, which allows forming clusters with different number of strings and optical modules. Simulation of the GVD detector [7, 8] shows that 8-string clusters with radius of 60 m and distance between OMs of 15 m provide an optimum for cascade detection volume and muon detection area. Correspondingly, the present version of the DAQ is presented for an 8-string cluster with 24 optical modules on each string.

2.1 Optical module

The optical module is the basic element of the future GVD neutrino telescope. Each OM (figure 1) contains a photomultiplier tube (PMT), which detects the Cherenkov light produced by relativistic charged particles passing through the water. The information from the ensemble of OMs allows reconstruction of event topology and energy. After testing different options the photomultiplier Hamamatsu R7081HQE was selected as a light sensor for the OM. This PMT has a hemispherical photocathode with 10 inch diameter and quantum efficiency up to 35%. The functional scheme of the optical module electronics is presented in detail in [7].

Figure 1. GVD optical module.

Besides the PMT, an OM consists of a high voltage power supply unit (HV), a fast two-channel preamplifier, and a controller. The HV unit (Traco Power SHV 12-2.0 K 1000 P) provides the power for the phototube divider (18 MΩ resistance) in the range from 0 up to 2 kV. The tube gains have been adjusted to about 10^7. This gain is provided by divider voltages between 1250 and 1650 V, depending on the individual tube. An additional signal amplification by a factor of 10 is provided by the first channel of the preamplifier. For this gain value single photoelectron pulse amplitudes are 30 – 40 mV in average. This corresponds to a spectrometric channel linearity range up to about 100 photoelectrons. The second preamplifier output with factor 20 is intended for PMT noise monitoring. For time and amplitude calibration of the measuring channel, two LEDs in the optical module are foreseen. The dominant wavelength of the LED is 445 nm, the LED pulse has a width of ~5 ns (FWHM). The possibility of independent regulation of the LED light intensity and low cross talk between LED channels (<1%) allow to directly measure the linearity range of the spectrometric channel.

The OM controller is intended for HV regulation and monitoring, for PMT noise measurements, and for time and amplitude calibration. The OM controller is designed on the basis of the microcontroller SiLabs C8051F121. Slow control data to and from the OMs are transferred via an underwater RS-485 bus.

The OM electronics and the PMT are placed in a pressure-resistant glass sphere VETROVEX with 42 cm diameter. A high permittivity alloy cage surrounds the PMT, shielding it against the Earth's magnetic field.

2.2 The string section

The optical modules on a string are grouped into two sections, the lowest-level DAQ units. Each section includes 12 OMs and the central module CM (figure 2). PMT signals from all OMs are transmitted to the CM trough 90 meters of coaxial cables, where they are digitized by custom-made 4-channel ADC boards with 200 MHz sampling rate. Time bin value 5 ns provides optimum conditions for PMT pulse area and leading edge position measurements (PMT pulse is about 20 ns FWHM after 90 m coaxial cable). Corresponding time accuracy of the measurement channel is less than 2 ns [10].

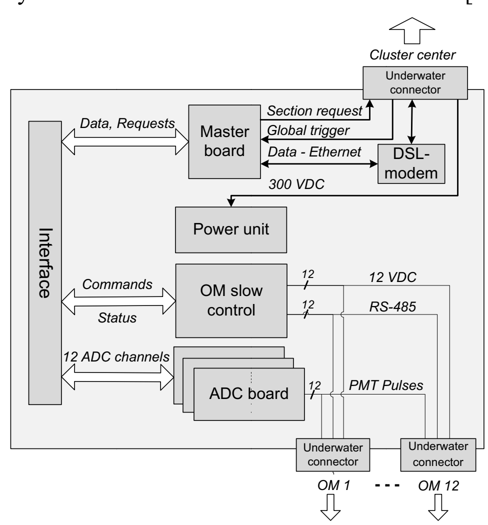

Figure 2. Block diagram of the string section center module (CM).

The CM consists of 3 ADC boards, an OM slow-control unit, and a Master board.

The OM slow-control board provides data communication between OM controllers and Master board via an underwater RS-485 bus. Also, this unit is intended for the OM power control (to switch power on/off for each optical module independently). The Master board provides trigger logic, data readout from FADC boards and connection via local Ethernet to the cluster DAQ center.

Each channel of an **ADC board** (figure 3) includes a fast digitizer on the basis of AD9430 microcircuits 12 bit resolution. The digitized signals from each ADC are transferred to a FPGA (Xilinx Spartan 3) which handles the data. A memory buffer of 12 KB allows to accumulate waveform data from the ADC for 30 μs. Two options of memory organization are possible: single or double-buffered memory. A double-buffered memory is minimizing the readout dead-time: while one buffer is ready for readout, the second one is connected to the ADC output.

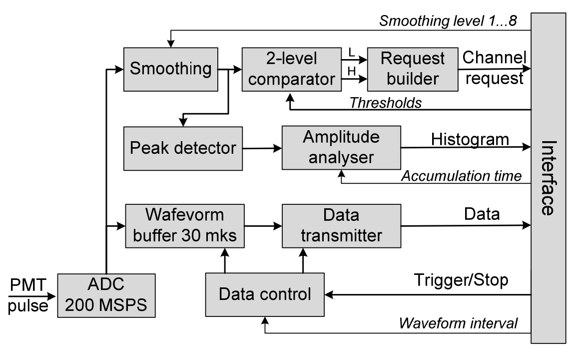

Figure 3. Block diagram of the ADC board (1 channel) of the string section center module.

The trigger signal from the Master unit stops the buffer accumulation, and the waveform information is transferred to the Master trough the interface board. The beginning and the length of the waveform interval can be configured. Each ADC data channel is also connected to a peak detector and amplitude analyzer, which accumulates monitor histograms in a programmable time interval. This information is intended for the monitoring of the channel trigger rate. An ADC trigger request channel includes a smoothing unit (smoothing level from 1 to 8) for electronics noise reduction, a two-level adjustable digital comparator (low threshold L and high threshold H), and a request builder, which build the request to the trigger logic. The requests L or H are transferred to the Master unit.

The block diagram of the **Master board** is presented in Fig. 4. The Master board provides trigger logic, data readout from ADC boards, connection via local Ethernet to the cluster DAQ center, and control of the section operation. The request analyzer forms the section trigger request (local trigger) on the basis of requests L and H from 12 ADC channels. This unit contains a programmable coincidence matrix (12H×12L), which provides a simple way to generate the section trigger request. The basic trigger modes are (A) coincidences of >N L-requests within a selectable time window ("L>N trigger") or (B) coincidences of L and H requests from any neighbouring OMs within a section ("L&H trigger").

The section trigger request is transferred to the cluster DAQ centre, where a global trigger for all sections is formed. The global trigger produces the stop signal for all ADC channels and initiates waveform information readout. The time delay of the global trigger is about 15 μs (2×1.2 km of the string cable and electronics delay). Waveform information is accumulated in the event buffer (512 KB). Each event contains waveform data for all ADCs of the section, the global trigger number, and the local time based on a 100 MHz clock. The event trigger number provides the possibility of event synchronization for the different sections. Data from the event buffer are transmitted via an Ethernet connection to the cluster DAQ center.

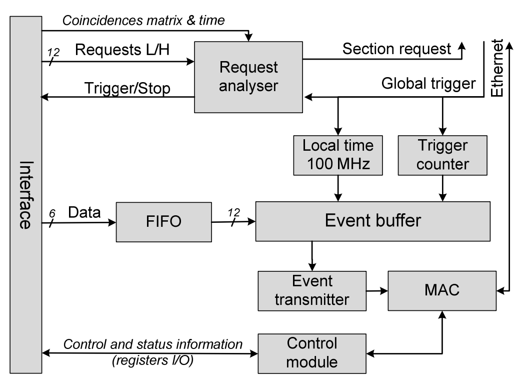

Figure 4. Block diagram of the Master board of the string section center module.

The control module provides access to the I/O registers of the Master and ADC boards and the control for the data transmission via RS-485 bus.

3 A prototype of a GVD cluster

The operation of GVD prototype strings in 2009 and 2010 allows a first assessment of the DAQ performance. On the basis of the experience of prototype string operation, in April 2011 a prototype GVD cluster with 3 strings was installed in Lake Baikal. Each string consists of one section with 8 optical modules. Distances between the OMs are 10 m along the string; distances between the strings are 40 m. The OMs house photomultipliers of different types: 16 PMT R7081HQE, 3 PMT XP1807, and 5 PMT R8055.

Analog pulses from PMTs of the string section are transferred to the central modules (CM). The configuration of the central module was presented in Fig. 2. For the connection between the CM and the cluster center an armored 1.2 km carrier cable was deployed (custom designed for this setup). This cable includes 2 coaxial lines for request and global trigger signals, a screened twisted pair for the DSL-modem data channel, and 3 power lines.

The cluster DAQ center is placed near the surface (~30 m depth as for GVD layout). It provides the string triggering, power supply, and communication to shore. A block diagram of the cluster center electronics is presented in Fig 5. The organizations of central and section trigger systems are the same. The section request lines are connected to three inputs of the central ADC board. The request pulse waveforms are accumulated in the ADC buffers. The Master board works out the global trigger for all strings. Data from the strings are transferred through DSL-modem Ethernet channel to the cluster centre. The DSL-modem bandwidth was set to the level 4 Mb/s (about half of maximum data rate supported for 1.2 km cable line). This value restricts the maximum event rate per string section to about 25 Hz. Each event has a fixed length of 16 KB and contains waveform data for all ADC channels for a 5 μs time window centered around the trigger time.

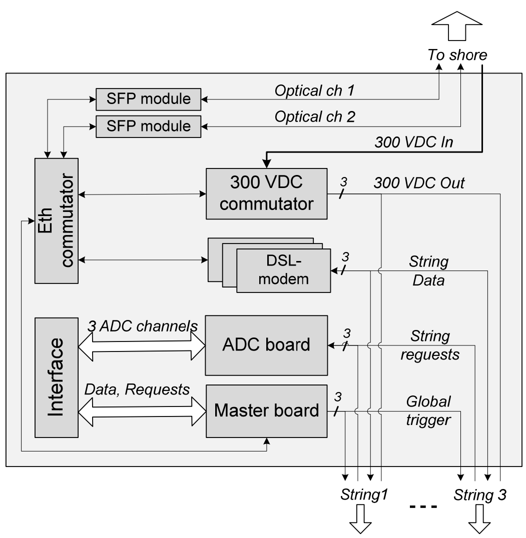

Figure 5. Block diagram of the cluster DAQ center unit of the 2011 prototype GVD cluster.

The prototype cluster DAQ center is connected to shore by two optical 1Gbit Ethernet lines. An electro-optical cable of 6 km length with 3 pairs of optical fibers and 3 copper lines was deployed in 2011.

The prototype cluster is successfully operating now. The cluster DAQ system is tested with the Baikal underwater calibration laser [11], with LED flashers, and atmospheric muons. Two trigger modes are used for muon detection: 4-fold coincidences of optical modules on a string (trigger 4/1, event rate 4 Hz), and inter-string 2-fold coincidences of 2 strings (trigger 2/2, event rate 0.5 Hz). All tests of the prototype cluster show good performance of the basic cluster elements.

4 Conclusion

Preparation towards a km^3-scale Gigaton Volume Detector in Lake Baikal is currently a central activity. A simple and reliable data acquisition system was designed for the GVD neutrino telescope. Basic building blocks of this system are optical modules on the basis PMT R7081HQE, sections with 12 OMs, and clusters with 8 strings (16 sections). Data communication is based on Ethernet technologies (DSL-modems and optical Ethernet).

For detailed investigations and in-situ tests of the new basic elements of the DAQ, a prototype cluster with 24 large-area hemispherical PMTs and with FADC readout technology was designed and installed in spring 2011 in Lake Baikal. The prototype cluster is presently successfully operating. First in-situ tests of the prototype cluster with the underwater laser, the LED flasher and atmospheric muons show good performance of all string elements.

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