Proposal for fiber-optic data acquisition system for Baikal-GVD

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The first stage of the construction of the Baikal-GVD deep underwater neutrino telescope is planned to be completed in 2024. For the second stage of the detector deployment, a data acquisition system based on fiber-optic technologies has been proposed, which will allow for increased data throughput and more flexible trigger conditions. A dedicated test facility has been built and deployed at the Baikal-GVD site to test the new technological solutions. We present the principles of operation and results of tests of the new data acquisition system.

**KEYWORDS:** Data acquisition concepts; Data Handling; Special cables

**ArXiv ePrint:** 2107.14183
1 Introduction

The large-scale neutrino telescope Baikal-GVD [1, 2] is under construction now. The beginning of the deployment of the telescope dates back to 2016, when the first cluster of the installation, which includes 288 photodetectors — optical modules (OM), began operation. By 2021, eight such clusters have been commissioned. In the next three years, it is planned to increase the number of clusters to 14, covering a total effective volume of about 0.7 km³ for the detection of astrophysical neutrinos. For the further expansion of the installation, the possibility of upgrading the data acquisition system to one based on fiber-optic communication is being considered. This will increase the efficiency of the telescope operations by reducing the registration thresholds and organizing a more flexible trigger system. This article discusses the general approaches to the modernization of the Baikal-GVD data acquisition system (DAQ) [3] with fiber-optic technologies and presents the first technical solutions, which are currently being tested in-situ as part of the experimental string of the neutrino telescope.

2 DAQ design

The design of the optical DAQ includes components associated with all basic elements of the detector, which are sections, strings, and clusters of optical modules (OM). Each section consists of 12 OMs [4, 5]. Three sections located on one carrier cable form a string. Eight strings with an underwater data acquisition center are combined into a cluster. The design aims at providing a fiber-optic communication solution for the data stream, as well as trigger and sync signals. Another important requirement is the use of detachable (dry-mateable) optical connectors for underwater optical cables and minimization of their number, which is due to the technical conditions for the deployment of the strings from the ice of the lake.

For the DAQ implementation, the CWDM technology (Coarse Wavelength Division Multiplexing) has been chosen, which is now widely used in fiber-optic systems. CWDM multiplexers are passive devices that allow transmission of up to 9 physical channels on one single-mode optical fiber using the frequency division method. This approach makes it possible to transmit all
information (the data stream, trigger, and synchronization pulses) over a single optical fiber and significantly simplifies the design of deep-water optical communications.

3 In-situ tests

To experimentally test the possibilities of using CWDM technology to build the Baikal-GVD DAQ, in 2020 an experimental section based on a fiber-optic technologies was installed as part of the telescope. The section included 12 optical modules (OM), two acoustic modems (AM) of the positioning system [6], and a section control module. To use all advantages of the high-speed optical transmission, the data acquisition unit of the section module (Master) was upgraded to Xilinx Zynq FPGA model XC7Z020-3CLG484E.

The experimental section was tested during 2020 in the mode of joint operation of fast and slow triggers. The standard for BAIKAL-GVD fast trigger requires two neighboring channels within the same section (of 12 OMs) to be hit within a 100 ns time window, with some minimal requirements for the hit amplitudes. It is intended for the detection of relativistic charged particles resulting from neutrino interactions. The transition to fiber-optic technologies promises to increase the rate of data transmission by two orders of magnitude, enabling substantially lower threshold and consequently higher efficiency of the trigger. The slow trigger is formed when the counting rate of any channel of the section exceeds during 1 ms the average rate by 4 standard deviations. It is focused on the selection of time-extended events, such as the passage of slow magnetic monopoles (the trajectory of the slow magnetic monopole crossing the water volume could look like a “chain” of flashes resulting from the reactions of catalysis of baryon decay [7]). During the year of the section operation no malfunctions were detected.

The success of the experimental section made it possible in April 2021 to start testing the experimental string, which can be considered as a full-scale prototype of a next generation Baikal-GVD string. The block diagram of the experimental string is shown in figure 1.

![Figure 1. Block diagram of the experimental string.](image)

The experimental string consists of three sections, a string control module, and an optical cluster center. The construction of the sections is similar to the previously deployed experimental section. The control modules of the sections are each connected to the string control module by
two separate cables: an optical one with a single fiber and an electric one for the power supply. The signals received from the OMs are processed in the Master unit, which is equipped with a 12-channel ADC with a sampling rate of 200 MHz. The Master uses two optical channels trigger and synchronisation (sync), and one electrical channel (data), which is converted to optical using an Ethernet switch. A clock frequency of 100 MHz is transmitted via the sync channel from the shore station to all Masters to synchronize their clocks. This allows for joining data from several sections even when the local section trigger does not initiate a common trigger for the entire string (slow trigger mode) and improves the accuracy of the inter-section synchronization from 2 ns [8] to less than 1 ns. For the basic Baikal-GVD DAQ the sync channel is not implemented, and the multi-trigger mode of operation is not supported.

The OMs and AMs of the section are controlled via a 16-channel power switch and a COM server. The input voltage of 300 VDC is supplied to the section control module via two independent lines, separately for control electronics and OMs. The data channels of the three sections are combined into one using the Ethernet switch of the string module. Data, sync, and trigger from all sections are transmitted from the string module to the cluster DAQ center via a CWDM multiplexer using 7 physical channels by a single optical fiber.

The experimental string started operation on 8 April 2021 in the mode of operation of two joint triggers, similar to the experimental section of 2020. The fast trigger initiates the reading of information from all sections of the string, while the slow trigger operates only for the section that formed it. Currently, the main task of investigations with the experimental string is to evaluate the efficiency and reliability of the operation of the fiber-optic DAQ: both electronic components and underwater cable network.

There are two types of fiber-optic (FO) cable lines used for the experiment. Most of the connections are made by commercial cable assemblies manufactured by DWTEK Co., Ltd, Taiwan. The Bulkhead Connector Receptacles (BCR) MSS-OP-BCR were used in combination with the Cable Connector Plugs MSS-OP-CCP, installed on a radially sealed underwater FO cable manufactured by the same company (DWTEK MO1-I01590/OPY402 900 μm). The experimental string comprises 5 such cable lines with different lengths from 3 to 750 m. To install the BCR in the openings of the glass sphere of the underwater modules, special stainless adapters were used to securely fix the connector and reduce the local pressure on the glass surface.

The main condition for reliable optical communication is low attenuation and long-term stability of fiber-optic lines. To monitor this parameter, the power measurement function of transmitters and receivers built into the SFP modules was used. Figure 2 shows the time dependence of power attenuation of the optical channels (trigger and sync) for one section of the string during three months of operation. The main source of power loss is CWDM multiplexers (7–8 dB). The threshold power of the NS-SFP 1.25 G CWDM optical transceivers used in the experimental string is −23 dBm (power of 1 mW corresponds to 0 dBm). The measured power of the transmitters is no less than 2 dBm and is quite stable. Thus, the received power exceeds the threshold value of the receivers by more than 10 dB and provides reliable communication. At the same time, there are fluctuations in the power attenuation, and the study of the causes of the loss increasing is in progress now.
4 Conclusion

To improve the efficiency of the Baikal-GVD neutrino telescope and expand the possibility of reconfiguring its measurement system, studies are being conducted on the possibilities of modernizing the data acquisition system using fiber-optic communication. The first successful experience with such a system was obtained in 2020 when the experimental section with the upgraded DAQ was put into operation. In 2021, the research was continued and the experimental string, which includes three sections (36 OMs), was installed in Lake Baikal. In general, it is already possible to draw a preliminary conclusion about the positive effect of introducing a fiber-optic communication system based on the CWDM technology in the Baikal-GVD DAQ. In 2022, it is planned to take further steps in this direction with additional experimental strings, which are planned to be installed. This work was supported by the Ministry of Science and Higher Education of the Russian Federation within the financing program of large scientific projects of the “Science” National Project (Grant No. 075-15-2020-778).

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