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Prototype of hydroacoustic antenna for registration of EAS cores

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The key features of the prototype of acoustic antenna for registration of signals generated by EAS cores in water, and its joint operation with water Cherenkov detector NEVOD are described.

1. Introduction

Usually, surface arrays for investigations of extensive air showers (EAS) initiated by primary particles with energies $E_0 > 10^{18}$ eV represent a grid of detectors with typical sizes of square meters, located at distances of hundreds meters from each other. They detect only a small part of the total number of secondary particles flying at significant distances from the shower axis. Thus, most of high energy particles, including hadrons concentrated near the axis, are not registered, while such particles genetically are closer to the first interaction and contain important information about primary particles, processes of interactions and development of cascades in the atmosphere.

In this connection, acoustic method of registration of cascades [1] in large water volumes deserves a serious attention. Advantages of this method are determined by: 1) possibility of creation of array with a continuous sensitive area; 2) a weak absorption of acoustic signal in water that allows to cover the areas of tens and hundreds of square kilometers with a reasonable number of detectors; 3) linear dependence of amplitude of acoustic signal on the cascade energy (in the range of at least of 6 orders); 4) a good angular (~ 0.1°) resolution, as the direction of acoustic signal propagation is unambiguously related with cascade axis orientation. The basic disadvantage of hydroacoustic method is a small coefficient of transformation of particle energy to the sound that leads to a high energy threshold of registration. Hence, in order to practically realize the method it is necessary to use the adequate equipment, to develop techniques of noise suppression, and of location of rare events of short duration.

2. The hydroacoustic antenna

For creation of large-scale setup [2] for registration of EAS cores by a hydroacoustic method, the solution of many methodical and technical problems is necessary. With this purpose, a structural element (prototype) of the acoustic antenna HYDRA is mounted in the water volume of the NEVOD detector [3] with sizes $9\times9\times26$ m^3 (Fig.1). The antenna has a rectangular shape and is made of corrosion-proof steel pipes, at which 6 transducers are fixed. Each transducer consists of a hydrophone with built-in preamplifier, placed on a foam plastic screen of 0.5 m diameter. The screen ensures the frequency-independent directivity diagram of the hydrophone in a range of angles ± 60° and provides the suppression of ambient noise more than 10 times, and thus signal-to-noise ratio is improved 2-5 times in comparison with omni-directional hydrophone. Distances between hydrophone pairs are 2 m in horizon, and 2.5 m in vertical direction, the depth of the top edge of the antenna is 1 m underwater. Transducers are directed to the lattice of optical Cherenkov modules of the NEVOD detector. Analog signals from hydrophones after preliminary amplification are transmitted by waterproof cables of 30 m length to a multi-channel computer-based DAQ board (LA2M5PCI) with 12-bit ADC and 400 kHz digitization frequency. Testing of operation capability of the antenna is performed by means of a hydrophone as a sound projector.

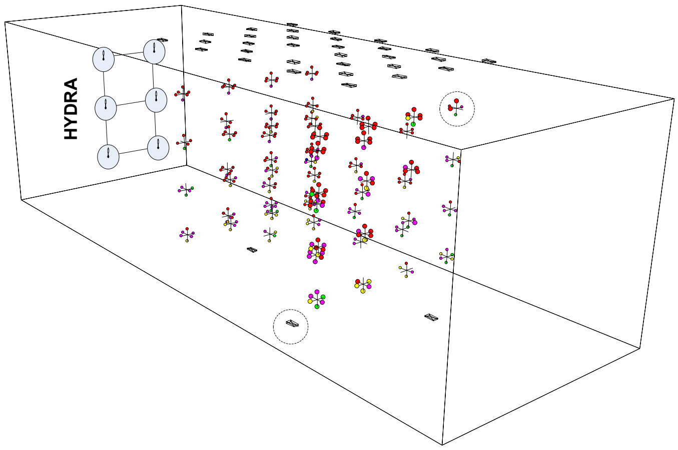

Figure 1. Acoustic antenna HYDRA in the water volume of the NEVOD detector with experimental event. Hit PMTs are shown by circles, scintillation counters of CTS by dark rectangles.

To minimize distortions of detected signals, it is necessary to use a wide-band transducer with a large dynamic range, linear phase characteristics and flat frequency sensitivity. A frequency bandwidth (2-70 kHz) is determined by the form of pulses from cascade shower in water and the ratio of spectral density of signal to noise. With participation of VNIIFTRI specialists, piezoelectric hydrophones that satisfy to the listed requirements have been developed and manufactured. Before installation of hydrophones in the antenna, their certificate ratings were checked and supplemented. Calibration was carried out in the water tank of 3.6 m diameter and 1.2 m height by means of pulsing technique with combination of a standard reciprocity method (at frequencies ≥ 10 kHz) and the impedance method (at lower frequencies) [4] with the use of 8103, 8104 type hydrophones and the acoustic equipment of "Bruel & Kjaer" firm. As a result, voltage sensitivity of the hydrophones over 1-80 kHz frequency range is about 0.8 mV/Pa, resonance frequency is near 50 kHz. Deviation from the flatness of receiving characteristics for all frequencies is less than 4 dB. Directivity characteristics flatness at 30 kHz frequency is less than 1 dB in the horizontal plane, and is about 6 dB in the vertical plane. Accuracy of calibration of hydrophones is 10%.

For a sure registration, the transducer should possess not only high sensitivity, but also low inherent electric noise which is determined both by noise of a hydrophone and a preamplifier. Therefore preamplifiers have been made on the basis of precision operational amplifiers OPA37 with a low level of noise (4.5 nV/√Hz at 1 kHz), matched with hydrophones. The gain of preamplifiers is close to 180. Measurements of noise spectral density of (hydrophone + preamplifier) system were conducted in the soundproof environment with a shielding from any external electromagnetic interference. Output signal was passed through external third-octave filter 1617 connected to the frequency analyzer 2120. Inherent noise level of the transducers of HYDRA antenna is close to Wenz's lowest ambient [5] and does not exceed 10 μPa/√Hz over bandwidth.

3. Fast trigger

Taking into account a low velocity of sound wave propagation in water (~ 1500 m/s), realization of trigger system using only signals from different hydrophones is difficult in practice. The problem of the trigger for the HYDRA antenna has been solved by means of fast trigger signals of quasispherical modules of the water Cherenkov detector NEVOD (59 QSM, consisting of 6 PMT each) and of scintillation counters of calibration telescope system (CTS, 64 counters, located on the cover and on the bottom of the water pool).

The EAS cores passing through the NEVOD detector should be characterized by the significant number of hit counters of CTS and QSM (many particles) and by high values of total PMT amplitudes (large energy deposition). For choosing the optimum configuration of the trigger which would allow to select effectively such events, the analysis of various combinations of triggers of the NEVOD detector has been performed. The numbers of hit QSM, PMT within QSM, top and bottom counters and correlations between them were examined. A two-level scheme, including the hardware trigger of the first level and the program trigger of the second level has been chosen. Fast hardware trigger allows to reject high rate background events, leaving not distorted the distribution of high energy events for their subsequent analysis with a program selection.

The hardware trigger is a combination of coincidences of signals ≥ 2 top counters and ≥ 40 QSM, its frequency is about 0.25 Hz. By this condition, the central computer of the NEVOD detector sends a signal to COM-port of the computer of the HYDRA antenna. Such signal is used to start ADC of the HYDRA setup for measurements. As the acoustic pulse from EAS core will pass to hydrophones the distance ~ 10 m, this time is sufficient for the NEVOD computer to analyze the event. Formation and transfer of a package of the information on the number of hit QSM, PMT, counters, etc. to HYDRA computer is carried out via Ethernet within 4-5 ms from the beginning of the event. If characteristics of the event satisfy to the program trigger, computer of HYDRA saves the event of 30 ms duration to the hard disc. Scheme of trigger organization and of data acquisition is shown in Fig. 2. The program trigger is a logical OR combination of following conditions: 1) ≥ 10 hit top counters; 2) ≥ 3 hit bottom counters; 3) the ratio of the number of hit PMT to the number of hit QSM is more than 4.2. These conditions ensure selecting of the events in the NEVOD detector with total amplitude PMT $\geq 3\times10^4$ (in ADC units) with efficiency more than 80% and mean counting rate of 0.04 Hz. Then, basing on a flux of primary protons, it is possible to estimate the energy threshold for selected EAS as 5×10^{13} eV. Operation live time for HYDRA is counted by the NEVOD computer.

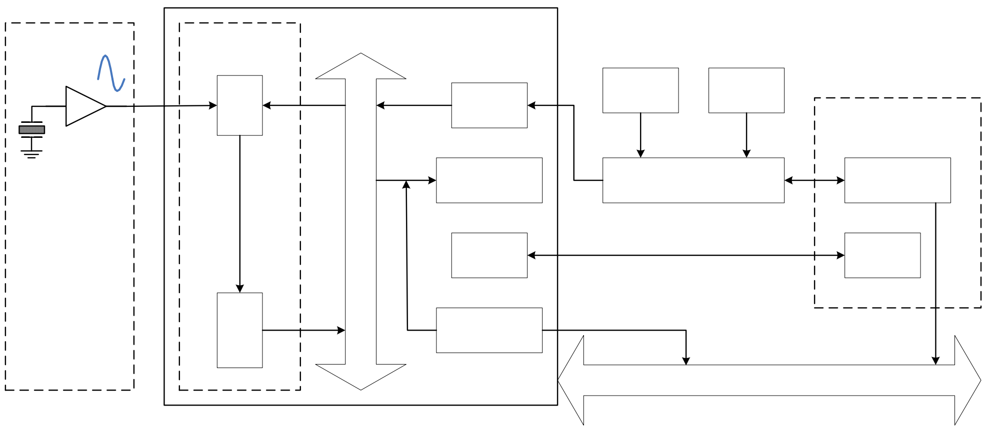

Figure 2. Block-scheme of triggering and data acquisition of HYDRA antenna.

4. Measurements in the NEVOD detector

During a joint operation of the HYDRA acoustic antenna with the NEVOD detector in 2005 about 3.6×10^5 events for 100 day of live time have been registered. Since several technological systems of maintenance are operated in the NEVOD complex, and it is located within Moscow city boundaries, one should expect the presence of external noise of various origin. Since realization of methods of location of useful events in many respects depends on the background conditions, the time-and-frequency analysis of noise in the NEVOD pool has been performed. As a whole, an integral level of noise is rather high; in the day-time it fluctuates within 0.35-0.75 Pa over the frequency range 1-80 kHz, and decreases by approximately 1.5 times at night. But it appears that the considerable contribution to it is given by some certain frequencies. For example, a fraction of noise of the NEVOD systems (pumps of water purification, fans of the power supply units, etc.) is about 3% at frequencies 4-5 kHz and is more than 15% at 60 kHz. About 25% of noises are concentrated at frequencies of 39.5 and 56.2 kHz, and they have strongly pronounced character only during day time. In Fig. 3, the time dependence of RMS hydrophone signal for one day of operation is given, which has a valley corresponding to time period between 1 and 6 AM. Such behavior of noise is obviously connected with the city activity, most probably – with operation of underground trains.

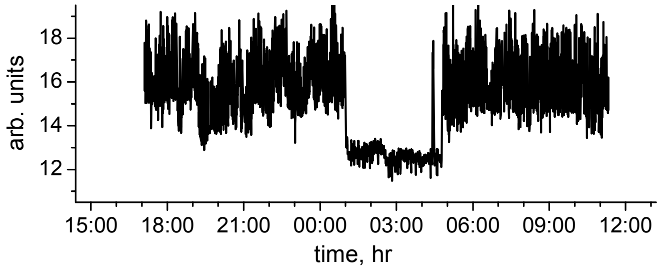

Figure 3. Dependence of noise RMS value in the NEVOD pool on the local time.

5. Conclusions

The HYDRA acoustic antenna has been constructed and deployed in the water volume of the NEVOD detector. The most suitable trigger for the antenna from the point of view of selection of EAS cores is implemented, and a test series of measurements is conducted. The fast trigger from NEVOD systems, registration of EAS in a near field, temperature of water ~ 20°C, application of specially developed methods of improvement of signal-to-noise ratio will allow to significantly decrease the threshold of acoustic method. The accumulation and analysis of experimental data will show whether these factors are sufficient for detection of useful signals in the NEVOD volume. In any case, joint operation of the HYDRA setup with the NEVOD detector helps a further development of hydroacoustic method of registration, and can provide a basis for elaboration of large array for registration of EAS cores initiated by UHE cosmic rays.

6. Acknowledgements

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