Summator-multiplexor of the block of electronics of the NEVOD-EAS array cluster

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Abstract. The paper is devoted to the development of a new summator-multiplexor (SM) for the block of electronics of the cluster of detector stations (BECDS) of the NEVOD-EAS air-shower array. The new summator-multiplexor is designed to replace the currently used SMs based on CAEN N169 units. The developed basic circuit diagram and the operation principle of the new SM are described. The results of testing of a prototype of the new summator-multiplexor for the BECDS of the NEVOD-EAS array are discussed.

1. Introduction

At energies above 10^{15} eV, the intensity of the primary cosmic ray (PCR) flux decreases from 1 particle per year per m^2 at 3×10^{15} eV to 1 particle per century per km^2 for energies higher than 10^{19} eV. This makes it impossible to conduct direct measurements of the PCR particle energy and mass composition using detectors installed on spacecrafts and stratostats. Therefore, the only source of information on the PCR properties in this energy region are extensive air showers (EAS) [1] which are formed in the Earth's atmosphere as a result of the development of the nuclear-cascade process initiated by the interaction of the primary particle with the nuclei of the air atoms.

Regardless of the studied energy range, physical tasks, size and location (at sea level or at mountain altitudes), the organization of registering systems of air-shower installations is based on a single principle: deployment of a large number of detectors with a certain step in a certain configuration over a large area. In such installations, various types of detectors for registration of individual components of extensive air showers (electron-photon, muon, hadron, as well as Cherenkov, fluorescent and radio radiation) and their combinations can be used.

One of such installations is the Experimental Complex (EC) NEVOD. It is designed to conduct on the Earth's surface both basic research in particle physics and astrophysics, as well as applied research in monitoring and prediction of the state of near-Earth space using natural particle fluxes from the upper celestial hemisphere (zenith angles from 0° to 90°) in a wide energy range (1 - 10^{10} GeV). The Experimental complex NEVOD includes several detectors: the Cherenkov water detector (CWD) NEVOD [2] for measuring energy deposit of muon bundles, EAS cores and cascades from single muons, the CTS (Calibration Telescope System) facility [3] for the CWD detecting system calibration and measuring of the local density spectra of EAS electron-photon and muon components, the coordinate-tracking detector DECOR [4] for the study of muon bundles in inclined air-showers, the PRISMA-32 array [5] for detection of EAS neutron component. At present, new detectors [6-8] for registration of various EAS components are being developed and built at the experimental complex. The NEVOD-EAS array [9] is one of the new detectors of the complex. It is aimed at registration by the electron-photon component of EAS in the energy range from 10^{15} to 10^{17} eV.

2. NEVOD-EAS air-shower array

As the Experimental complex NEVOD is located at the MEPhI campus, the NEVOD-EAS detecting elements are deployed on the roofs of the University buildings and on the ground (the altitude difference reaches 20 m) that is the main difference of the array from the classical installations for EAS investigations in which detectors are usually located on a plane surface. The difference of altitudes of the NEVOD-EAS detectors determines the cluster organization of the array. At the same time, the clusters are completely independent from each other in the processing detector signals, selection of events according to triggering conditions, event timestamping and transmission of information to the central DAQ post of the array. Thus, the NEVOD-EAS array cluster represents an independent installation capable to determine in each event the number of particles registered by each detecting element and the EAS arrival direction. Cluster synchronization is performed by a specialized global time synchronization system [8] with an accuracy of 10 ns. At present, the array includes 9 clusters with typical dimensions of 15×15 m^2 deployed over an area of 10^4 m^2. The layout of clusters at the MEPhI campus around the Experimental complex NEVOD is shown in figure 1.

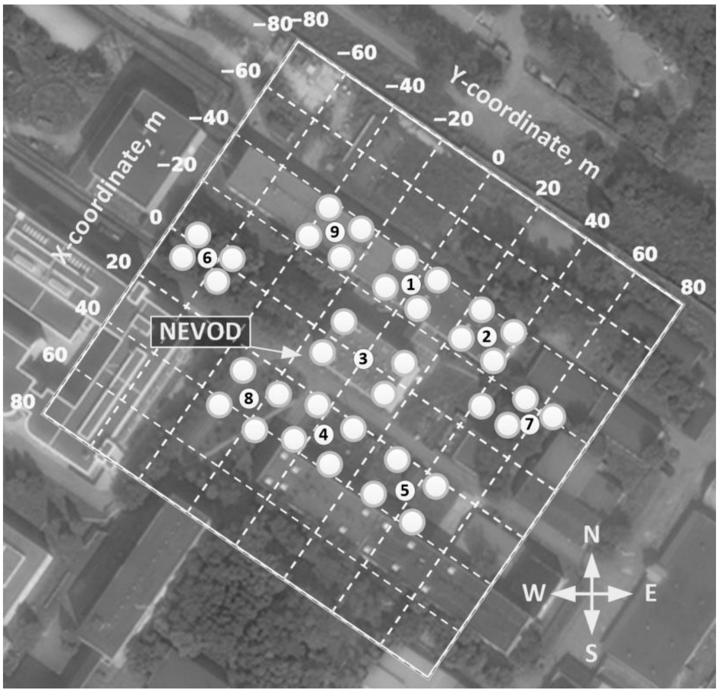

Figure 1. The layout of the NEVOD-EAS array clusters. Numbered circles correspond to the order numbers of the array clusters.

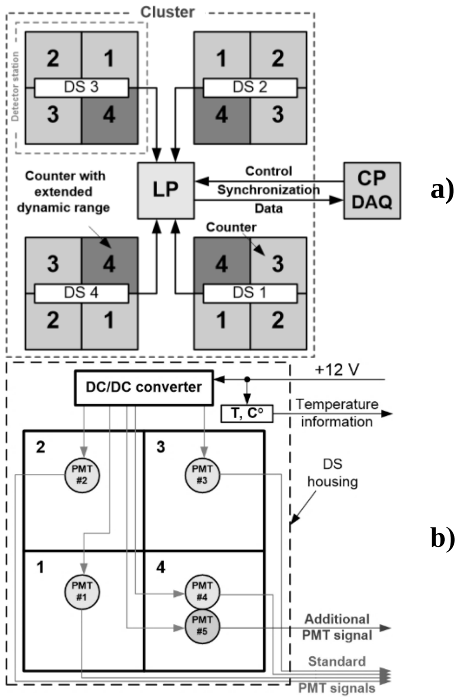

Figure 2. Structures of the cluster (a) and detector station (b) of the NEVOD-EAS array.

The structure of the NEVOD-EAS array cluster is presented in figure 2a. The cluster consists of 4 detector stations (DS) [10] combined by the local post (LP) of primary data processing [9]. Each DS includes 4 scintillation counters [11] of EAS electron-photon component particles.

The main elements of the counter are the plastic scintillator NE102A with dimensions of $800 \times 800 \times 40$ mm^3 and the photomultiplier tube (PMT) Philips XP3462 with a hemispherical photocathode placed inside the pyramidal stainless steel housing.

The detector station (figure 2b) consists of 4 scintillation counters located inside the protective housing and has an effective area of ~ 2.6 m^2. Three counters are equipped with one ("standard") PMT Philips XP3462. The fourth DS counter includes two PMTs Philips XP3462: "standard" and "additional" ones. Standard PMTs are used to measure particle density of registered air-showers and for time measurements. The dynamic range of counters with standard PMTs is from 0.5 to 150 registered particles. The additional PMT extends the dynamic range of the detector station up to ~

10.000 particles/m^2 and has a dynode system gain of about 90 times lower than the standard one. Each DS is equipped with one high-voltage power supply for the PMTs based on the DC/DC-converter TRACO PHV12-2.0K2500N (transforms constant voltage + 12 V into high voltage in the range from −600 to −2000 V). The PMT dividers are configured in such a way that all 5 photomultipliers of the detector station are powered by the same high-voltage nominal. A temperature sensor LM335z is installed in each DS for monitoring of temperature during the experimental runs.

3. Block of electronics of the cluster of detector stations (BECDS)

Analog signals from the detector station PMTs are fed to the cluster local post (LP) of primary data processing. The local post of primary data processing of the cluster performs the following functions:

- digitizing of analog signals from 20 photomultipliers of four detector stations of the cluster;
- selection of events according to specified intra-cluster triggering conditions (registration thresholds, the minimal multiplicity of DS hits within the coincidence time gate);
- timestamping of selected events with an accuracy of 10 ns;
- transferring of time and amplitude information on registered events to the central DAQ post;
- providing of power to the cluster PMTs, maintaining of the temperature regime acceptable for the operation of LP electronics and measuring of the temperature inside DS and LP.

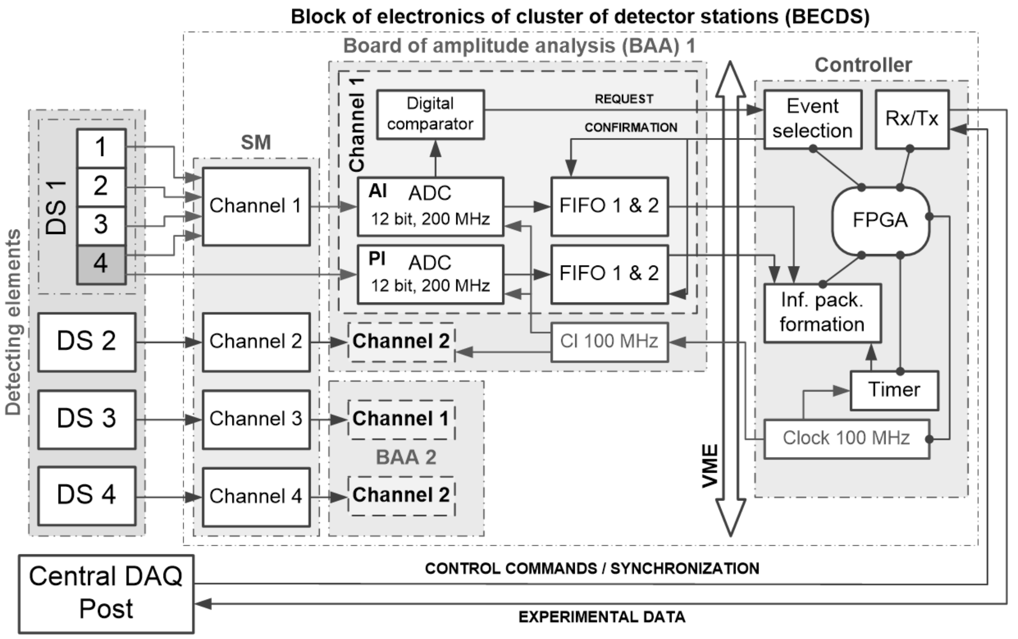

Figure 3. The scheme of the block of electronics of the cluster of detector stations (BECDS) of the NEVOD-EAS array.

The main LP element is the block of electronics of the cluster of detector stations (BECDS). It digitizes signals from the PMTs of the cluster detector stations, selects events according to the intra-cluster triggering conditions, timestamps the event and transfers information to the central DAQ post of the array. The functional scheme of BECDS is shown in figure 3. The BECDS includes:

- summator-multiplexor (SM) summing analog signals from 4 standard PMTs of scintillation counters of each cluster detector station;
- I/O-module PET-7019 for SM control and temperature measurements;
- two 2-channal boards of amplitude analysis (BAA) (VME, Euromechanics 19", height of 6U) based on FPGA Xilinx Spartan-6 for digitizing of PMT signals with 12-bit flash-ADCs with a sampling frequency of 0.2 GHz;
- BAA controller (VME, Euromechanics 19", height of 6U) based on FPGA Xilinx Spartan-6 for control of BAA, event selection and data transmission;
- BECDS crate and cross-board for connecting BAA to the BECDS controller.

Photographs of the BECDS are shown in figure 4. The operation principle of the BECDS of a cluster local post is described in detail in [9].

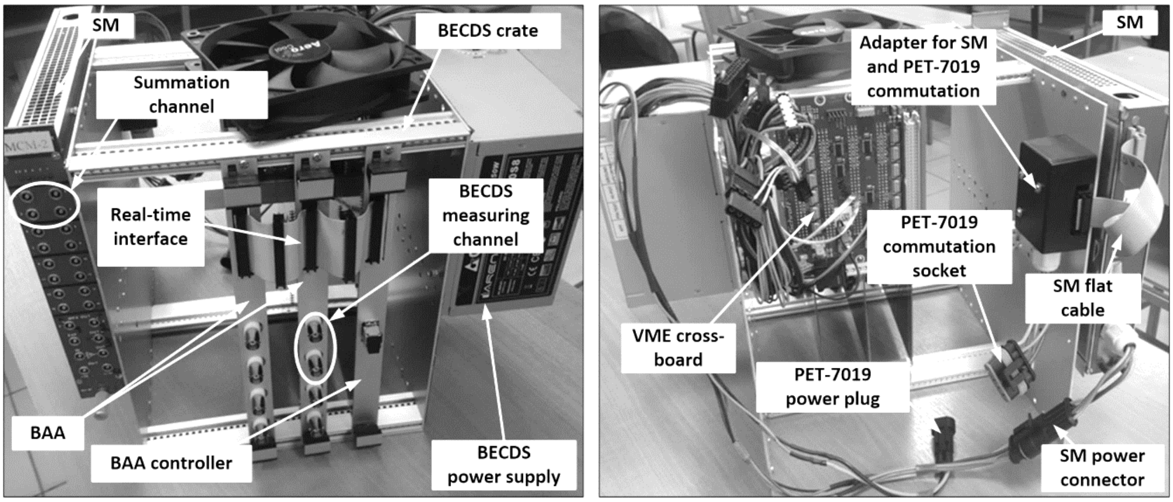

Figure 4. Photograph of the BECDS of the NEVOD-EAS array cluster local post: front view (left) and back view (right).

4. Summator-multiplexor of BECDS

The summator-multiplexor performs summation of analog signals from four standard PMTs of each DS scintillation counters and has 4 summation channels with 4 inputs. One summation channel serves 1 detector station of the NEVOD-EAS array cluster. The outputs of the DS standard PMTs are connected to the corresponding inputs of the SM summation channel. The summed signal from 4 PMTs formed at the output of the summation channel is fed to the corresponding measuring channel of the BAA of the cluster BECDS. The SM also allows us to turn on only certain input(s) of each summation channel for measuring amplitude and charge spectra of responses of selected counter(s) of each DS to the passage of near-vertical muons.

To control the SM multiplexor, the industrial I/O-module PET-7019 is used. It has 4 discrete outputs for setting a mask of turned on inputs of summation channels and 8 separate analog inputs for receiving information from the LP and DS temperature sensors. Communication with PET-7019, transmission of control commands and receiving of temperature information are carried out via Ethernet using the Modbus TCP protocol.

At present, in the NEVOD-EAS array BECDS the summator-multiplexors based on modified CAEN N169 units are used. These units were previously used as part of the registering electronics of the KASCADE-Grande detector stations [12]. These SMs are morally and physically outdated that is manifested in the deterioration of contacts and electronic components, their frequent breakdown and, as a result, in the instability of characteristics of cluster measuring channels and in the decrease of the obtained experimental data reliability. In addition, a significant drawback of such summator-multiplexor is the impossibility of independent control of the individual summation channel inputs.

4.1. Basic circuit diagram of the new BECDS summator-multiplexor

The basic circuit diagram (BCD) of a new summator-multiplexor is developed based on the operational amplifier (OA) connected according to the summation circuit (figure 5). In such scheme (see formula (1)), the output voltage is directly proportional to the algebraic sum of the input voltages supplied to the non-inverting input of the OA and inversely proportional to the nominal values of the input resistors. In addition, this summation circuit allows us to control the OA conversion coefficient by changing the nominal values of the resistors installed in the feedback circuit.

$$U_{OUT} = U_{IN} \times K = U_{IN} \times \left(R_{AF} / R_0 + 1\right) \tag{1}$$

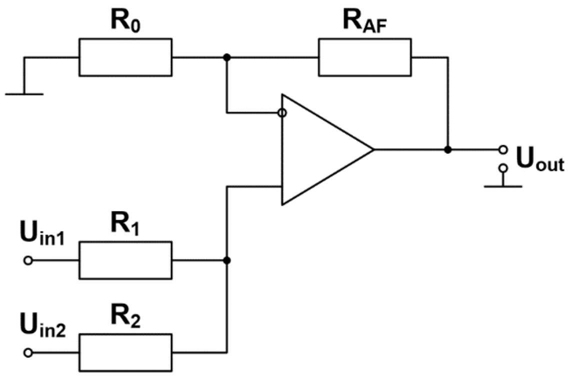

Figure 5. Circuit diagram of the non-inverting summator.

The basic circuit diagram of one summation channel is presented in figure 6. The electronic components of the circuit allow to work with analog signals with frequency of up to 300 MHz and amplitudes in the range from -3 to +3 V. They have dual-supply operation of -5 and +5 V. The operating temperature range for the circuit components is from -40° C to +85°C. The circuit has two options for the summation channel control:

- using the industrial I/O-module PET-7019, individual inputs of the summation channels are turned on/off in parallel on all channels;
- using Arduino Uno R3 board with Ethernet Shield extension (or Arduino Leonardo ETH), individual inputs of the summation channels are turned on/off on all channels independently.

The basic circuit diagrams of the control unit are implemented using shift registers 75HC595 and bi-directional transceivers 74HS245. The BCD of power and control of the developed summator-multiplexor are shown in figure 7.

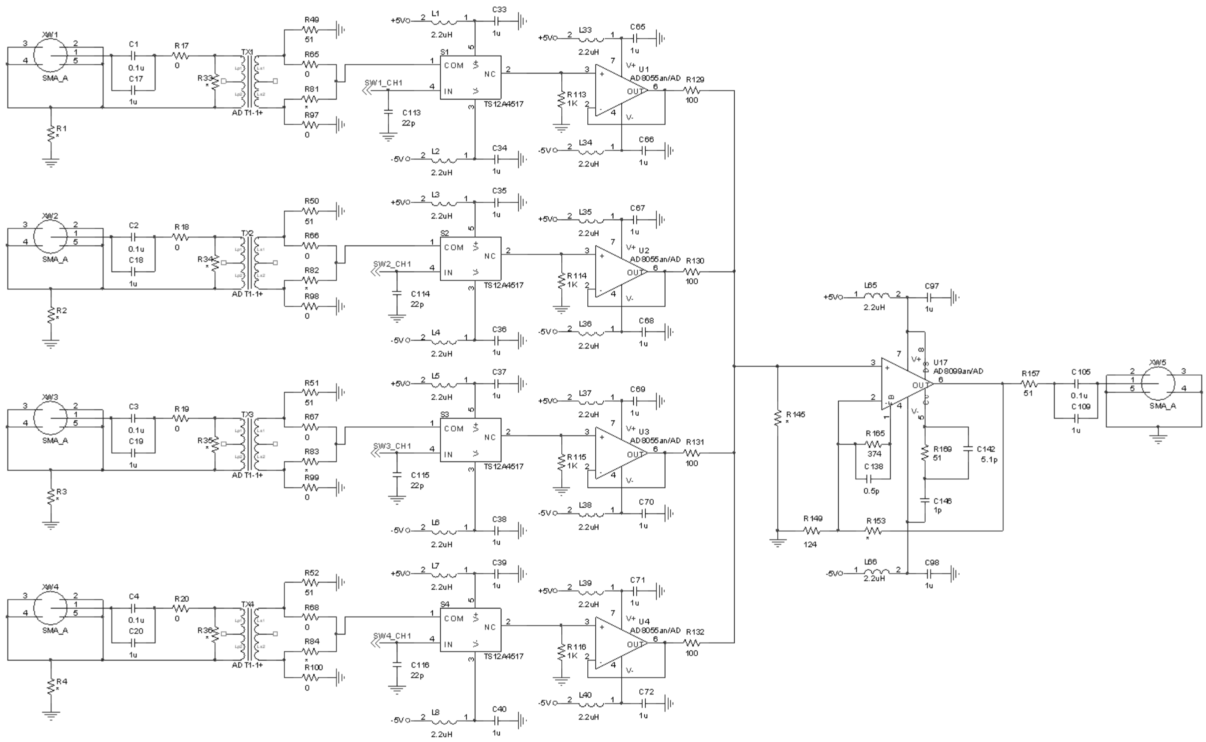

Figure 6. The basic circuit diagram of one channel of the new BECDS summator-multiplexor.

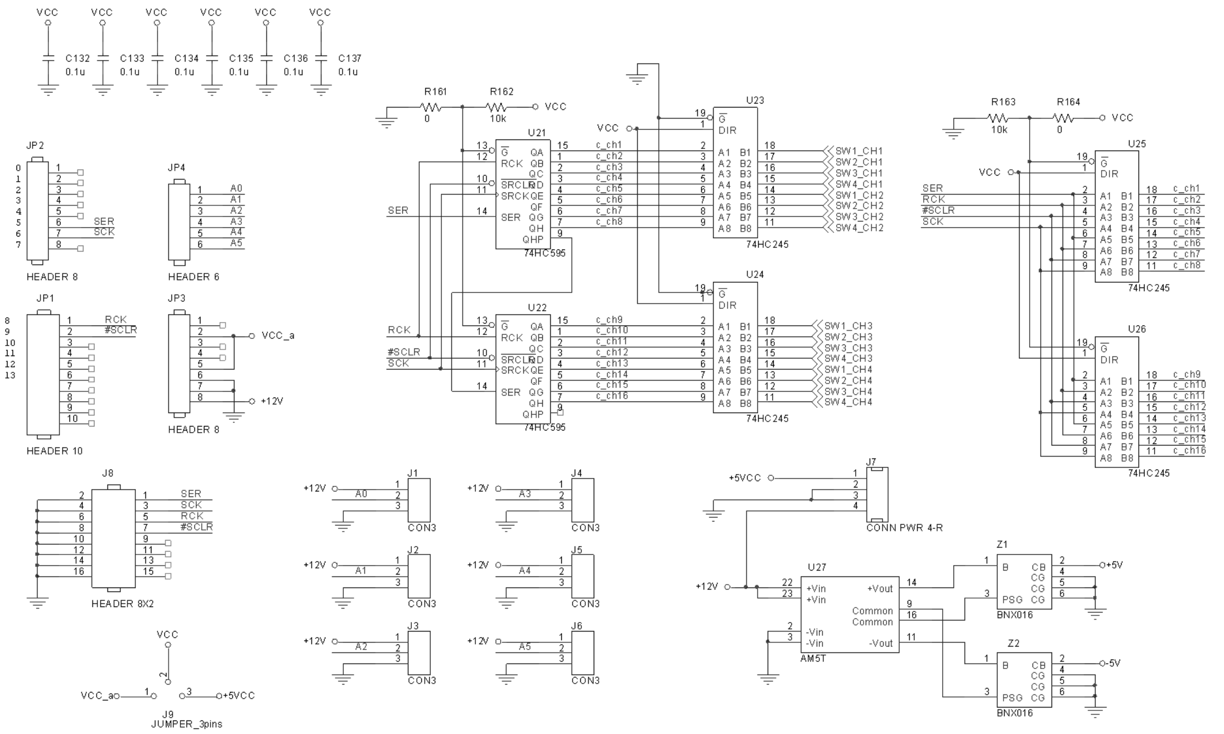

Figure 7. The BCD of power supply and channel control of the new BECDS summator-multiplexor.

4.2. Prototype of the new BECDS summator-multiplexor

After the development of the BCD, a two-layer printed circuit board of the BECDS summator-multiplexor was designed and manufactured. The printed circuit board has a size of 6U (168×233 mm^2) according to the 19" Euromechanics standard. The photograph of the printed circuit board of the summator -multiplexor of the BECDS of the NEVOD-EAS array is presented in figure 8.

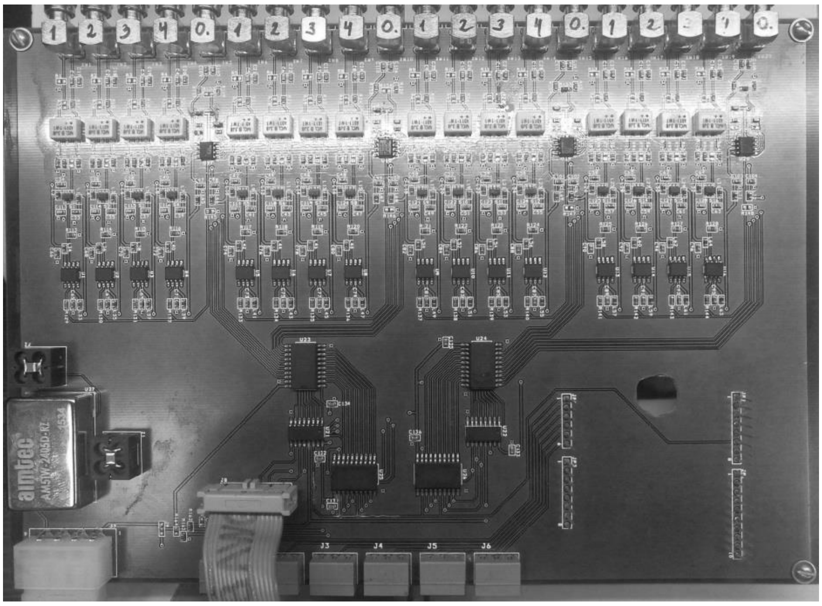

Figure 8. Prototype of the printed circuit board of the new summator-multiplexor for the NEVOD-EAS array BECDS.

At the top of the board, the high-frequency SMA connectors (SMA HYR-1141) are installed. In the corners of the board, the fasteners for its mounting to the crate guides are made. At the board bottom there are connectors for the power supply (THP-4MR), temperature sensors and control board (ECH381R-03P). Most electronic components of the board have SMD design. This allows us to reduce the weight and dimensions of the board, as well as to improve its electrical characteristics: due to the lack of pins and small length of tracks, the parasite capacitances and inductances, as well as the delay in the ultra-high frequency signals are reduced.

4.3. Testing of the summator-multiplexor prototype

After the manufacturing of the summator-multiplexor prototype, its testing was carried out. Testing the SM prototype was performed using a Tektronix (MSO 3014) digital oscilloscope. It has been shown that the amplitude of the internal noise of the circuit in the passbands of 250 and 500 MHz does not exceed 5 mV. The power consumed by the summator-multiplexor for the +12 V power supply circuit was 1.86 W at a current of 155 mA. For the +5 V power supply circuit, the power consumption was 15 mW at a current of 3 mA.

To determine the conversion coefficients of the operational amplifier of the BECDS SM prototype, a specialized experimental facility (figure 9) was used. Its main elements are:

- the BECDS crate for mounting and power supplement of the SM prototype;
- 2-channel signal generator Tektronix AFG 3052C;
- digital oscilloscope Tektronix MSO 3014 for digitizing signals from the SM outputs;
- I/O-module PET-7019 to control the inputs of the SM summation channels via the Ethernet;
- personal computer (PC) with dedicated software for the control of oscilloscope and PET-7019 module, as well as for reading out it signal waveforms and their processing.

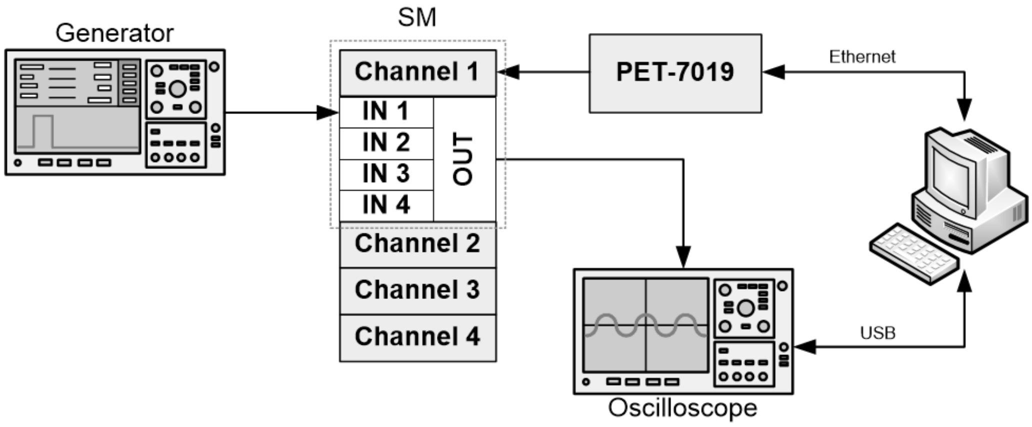

Figure 9. Experimental facility for testing of the new summator-multiplexor prototype for the NEVOD-EAS array BECDS.

With the PC software and PET-7019 module, the mask of active inputs of the SM summation channels was specified. Signals resembling in shape the pulses from the NEVOD-EAS DS photomultipliers (frequency of 1 MHz, leading edge duration of 40 ns, trailing edge duration of 56 ns, signal duration of 60 ns, amplitude of 200 mV, negative polarity) were generated. The signals from the SM channel outputs were registered with the oscilloscope which, after signal digitizing, transmitted the data buffers containing a pulse waveform to the PC. With the PC, the amplitudes and charges of registered signals were calculated.

For all inputs of the SM summation channels, the spectra of signal amplitudes with statistical reliability of 500 events were obtained. For the obtained amplitude spectra the mean values and standard deviations were determined. According to this information, the conversion coefficients of inputs of the summation channels were calculated as the ratio of the signal amplitude at the output of the SM board to the signal amplitude at the channel inputs. The conversion coefficients obtained for all inputs of the SM summation channels are in the range from 0.43 to 0.45.

5. Conclusion

A prototype of a new summator-multiplexor of the NEVOD-EAS array block of electronics of the cluster of detector stations has been developed. It is designed to replace the obsolete SMs based on CAEN N169 units. The results of the SM prototype testing showed that the developed unit can be used as part of the array cluster BECDS. The conversion coefficients of summation channel inputs of the new (≈ 0.45) and currently used (≈ 0.25) SM versions differ by almost 2 times. It will significantly increase the accuracy of adjustment of the registration thresholds of the NEVOD-EAS cluster measuring channels and, correspondingly, enhance the efficiency of event registration. This, together with the improvement of stability of spectrometric channels, will increase the reliability of the obtained experimental data.

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