Vol. 51 (2020) *Acta Physica Polonica B* No 3

DEVELOPMENT OF AN AUTOMATED SYSTEM FOR THE DETERMINATION OF THE SNOW WATER EQUIVALENT AND SOIL MOISTURE BY THE NEUTRON COMPONENT OF COSMIC RAYS*

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(Received January 12, 2020)

A method for determination of snow water equivalent and soil moisture is proposed. The method is based on measurements of the fluxes of cosmic-ray neutrons. Global fluxes of various components of cosmic rays are attenuated exponentially, depending on the thickness of the atmosphere and on the thickness of the absorber (water). Thus, the moisture content can be determined from two measurements: one without snow and the second with snow.

DOI:10.5506/APhysPolB.51.887

1. Introduction

For developing equipment for automatic measurement of the snow water equivalent by the neutron component of cosmic rays, it was proposed [1] to use two electrically connected and simultaneously operating detectors: one located under the snow on the soil surface, the second above the snow cover. Such a two-counter system makes it possible to almost completely eliminate the influence of variations in cosmic rays. However, even in this case, in principle, the amplitude of variations is described by a power function [2] as $AE^{-\gamma}$, where $\gamma = 1.0 \pm 0.2$. The energy spectrum of the Forbush decreases

* Presented at the XXXVI Mazurian Lakes Conference on Physics, Piaski, Poland, September 1–7, 2019.

is more rigid with $\gamma \approx 0.5 \pm 0.2$. From the above, it is possible to estimate the difference in the amplitude of variations above and below the absorber. Let us assume that the effective energy in the neutron energy spectrum for the used neutron detectors at mid-latitudes at mountain or sea level is $\approx$ 15 GeV, under the absorber $\approx$ 50 g/cm^2, the effective energy will be 15.5 GeV. Then the amplitude change will be less than 1% for 11-year variations. As for changes in barometric pressure, it is negligible for snow thicknesses of 50 g/cm^2 [2, 3].

Thus, a spatially separated two-counter detector is a feasible instrument for automated measurements of snow water equivalent by the neutron component of cosmic rays.

2. Selection of a system for measuring the snow water equivalent

Global fluxes of various components of cosmic rays are attenuated exponentially, depending on the thickness of the atmosphere and on the thickness of the absorber (water) in g/cm^2. Values of global fluxes at sea level (without absorber) and average effective attenuation factors for air and water in cm^2/g are given in Tables I and II [2].

TABLE I

Values of average effective attenuation coefficients for various components of cosmic rays in the air μ_a.

Component	Depth in the atmosphere [g/cm^2]	Energy [GeV]	μ_a [cm^2/g]
Neutrons	> 200	> 10^{-6}	0.0062
		> 10^{-3}	0.0080
Protons	> 200	> 10^{-3}	0.0080
Muons	> 600	> 10^{-3}	0.00020
Electrons	> 500	> 10^{-3}	0.0062
γ rays	> 500	> 0.03	0.010

Thus, moisture content P (or absorber thickness) in g/cm^2 can be determined, as in the case of the increment method, from two measurements: one without snow J_{0i} and the second with snow J_i from the relation [2]

$$P = \frac{\ln(J_{0i}/J_i)}{\mu_w}\,. \tag{1}$$

TABLE II

Global cosmic particle fluxes at sea level and average effective attenuation coefficients in water μ_{w}.

Component	Energy range [MeV]	Particle flux $[(\mathrm{cm}^2 \times \mathrm{s})^{-1}]$	μ_{w} $[\mathrm{cm}^2/\mathrm{g}]$
Neutrons	$0.1 \leq E \leq 30$	$> 1.6 \times 10^{-2}$	0.150
	> 30	$> 3.0 \times 10^{-3}$	0.00645
Muons	> 30	$> 1.66 \times 10^{-2}$	0.00076
Protons	> 30	$> 6.0 \times 10^{-4}$	0.0085
Electrons	≥ 2	$> 7.5 \times 10^{-3}$	0.00540
γ rays	≥ 2	$> 7.5 \times 10^{-3}$	0.00575

The nature of the attenuation of global neutron fluxes in water and polyethylene in a wide range of thicknesses is similar. The above is illustrated in Table III, where $J_n(P = 0) = 1$. From Table III, it can be concluded that it is possible to use solid hydrocarbon containing substances for the calibration of neutron snow gauges [2].

TABLE III

Dependence of $J_n(P)$ for water and polyethylene with $J_n(P = 0) = 1$.

P $[\mathrm{g/cm}^2]$	Water	Polyethylene	P $[\mathrm{g/cm}^2]$	Water	Polyethylene
0	1.0	1.0	6.0	0.828	0.803
0.5	0.979	0.974	8.0	0.796	0.772
1.0	0.960	0.950	10.0	0.771	0.748
1.5	0.742	0.928	12.0	0.751	0.730
2.0	0.925	0.908	14.0	0.735	0.715
2.5	0.910	0.890	16.0	0.721	0.703
3.0	0.895	0.874	18.0	0.709	0.692
4.0	0.870	0.846	20.0	0.699	0.681

From Tables I and II it follows that in the low-energy region, neutrons have the highest attenuation coefficient with a relatively large flux. The attenuation coefficients and fluxes of gamma rays and electrons in water are close to those for high-energy neutrons, and the attenuation coefficient of the latter is about an order of magnitude higher than that of muons.

Taking into account the conclusions above, simulations using a Monte-Carlo-based Geant4 simulation toolkit [4] will be performed.

3. Development of equipment for automated measurement of snow water equivalent by the neutron component of cosmic rays

For developing equipment for automated measurement of the snow water equivalent by the neutron component of cosmic rays, the determining criteria for optimization are power consumption, weight and dimensions.

The optimal levels of supply voltages, as well as the design of the equipment for automated measurement of snow water equivalent by neutron component of cosmic rays [5–7] were determined from the conducted experimental studies. The main elements of the neutron detector design are as follows:

— A block of hydrogen-containing moderator;

— A thermal neutron proportional counter tube;

— An amplifier and a microcontroller for analyzing the signal from the detector;

— A high-voltage power supply and signal transmitter.

The amplifier design has been debugged. The amplifier contains novel circuit solutions in order to reduce power consumption, see Fig. 1. Its frequency response was optimized in order to obtain the maximum signal-to-noise ratio.

A high-voltage power supply board was developed for neutron counters and its schematic circuit is presented in Fig. 2. In order to reduce the overall power consumption of the electronics, the high voltage was reduced. This led to a decrease in the signal from the neutron counter, which required an increase in the amplification of the electronics. With high gain, the thermal noise of the electronics becomes significant — the signal-to-noise ratio decreases. In order to improve it, it is necessary to reduce the bandwidth of the amplifier. This can be tuned because the spectral density of the noise is approximately constant and the spectral density of the signal increases in the low-frequency region, and because in this realization the signal can be described by an integral of a delta pulse. Since the estimated neutron counting rate was lower than 1 per second, the frequency band was chosen in the region of 100 Hz.

The main connection points and signal transmission from the equipment have been mounted and installed on seats. In particular, high-voltage power boards and data acquisition boards for equipment have been installed. A USB 2.0 connector is used for fast signal transmission (Fig. 3).

The next stage of this work is to perform experiments in field and compare the obtained results with the Geant4 simulations.

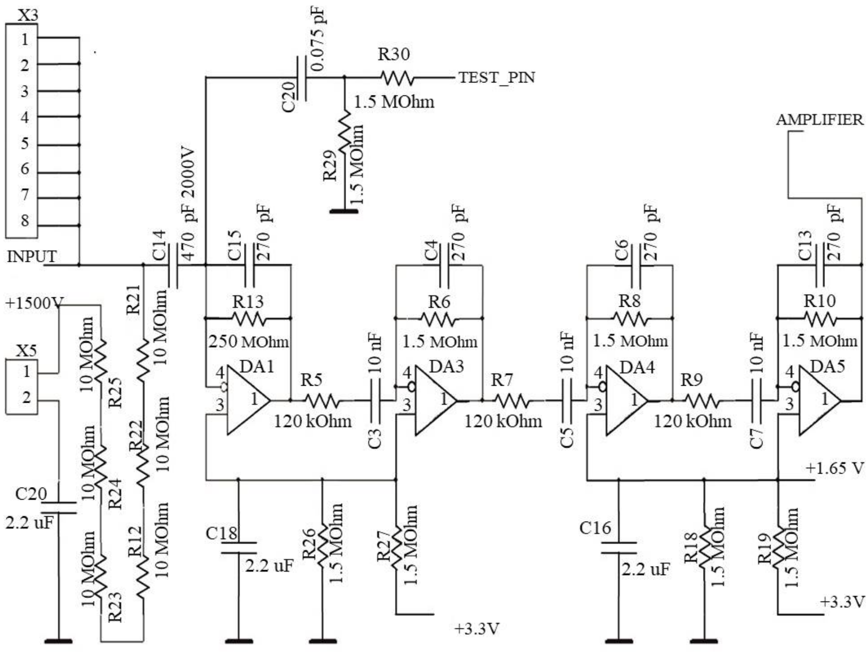

Fig. 1. Schematic circuit of the amplifier used.

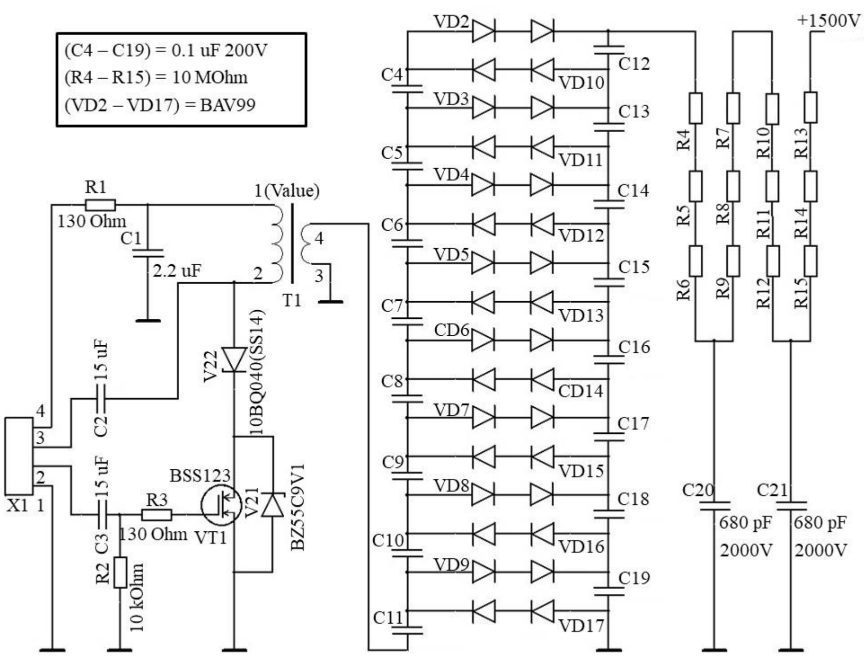

Fig. 2. Schematic circuit of the high-voltage power supply.

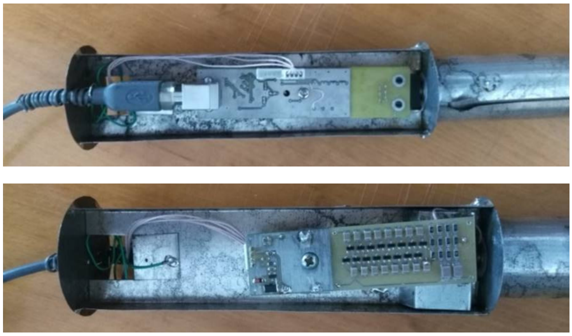

Fig. 3. The main connection points and the transmission of signals from the equipment under development for an automated measurement of the snow water equivalent by the neutron component of cosmic rays.

This work has been supported by the Program No. BR05236494 "Fundamental and applied studies in related fields of physics of terrestrial, near-earth and atmospheric processes and their practical application".

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