The multilayer scintillation detector of high-energy charged particles for satellite experiments.

A Batischev, S Aleksandrin, S Koldashov, A Kuznetcov, V Loginov.
NRNU MEPhI, 115409 Kashirskoe sh, 31, Moscow, Russia
E-mail: alexey-batischev@mail.ru

Abstract. We present the detection system of high-energy charged particle telescope-spectrometer for space experiment, which is scheduled to take place on the outside the Russian segment of The International Space Station (ISS) and other spacecrafts and small satellites. One of the scientific objectives of experiment is to study electron beams propagation in the magnetosphere. Such a beam can form in acceleration electrons by high-altitude electrical discharge and are injected in the magnetosphere. The detection system for this experiment is developed on the basis of the multilayer scintillation detector (MSD). The MSD is made by polystyrene plates viewed photomultipliers. It can detect 3-30 MeV intense electron beams (up to $10^5 \text{cm}^{-2}\text{s}^{-1}$) of up several milliseconds, can measure time profiles with accuracy ~ 1 microsecond and energy spectra of particles evolution. MSD’s main parameters: geometric factor ~40 cm$^2$·sr, trigger system time resolution ~20 ns, energy resolution 5-10%, angular resolution ~ 10 grad.

1. Introduction
Presented MSD allows to simultaneously measure fluxes of electrons, protons, hydrogen and helium nuclei in one experiment on a spacecraft. Fluxes of these particles are the most intensive in outer space and measurement of them is necessary to solve actual fundamental scientific problems in the solar-magnetospheric physics and practical problems of monitoring precursory seismic effects in the magnetosphere for space weather forecast.

2. Instrumentation
MSD consist of a stack of scintillation detectors C1 – C10 with thickness of 5 and 10 mm made from polystyrene viewed photomultipliers. It is shown in Figure 1. This scintillator has high transparency (attenuation length L ~ 2 m), good conversion efficiency and short decay time (about 3 ns). Functionally the MSD consists of a hodoscopic trigger system (HTS; the C1-C3 detectors, which form the aperture of the telescope) and a scintillation calorimeter (SC, C3-C10 detectors). C1 and C2 detectors are located directly under each other closely and form the upper detector (UD). Each of them consists of identical strips. C1 strips are perpendicular to C2 strips, which provides the required angular sensitivity. SC is designed to identify particles and measure their energy. To prevent the registration of the aperture particles which passing through all detectors, and the particles moving in the opposite direction, the detector C10 operates in anticoincidence (AC) and a detector of the AC.
3. Analysis Modes

Signals from the HTS detectors are used to generate a trigger signal that release useful events in a steam of falling particles. To register high-energy charged particles (electrons and protons) are selected only those particles which passed through C1, C2, C3 detectors (a preliminary “hard” trigger signal). Also useful are the events registered in one of the following variants of combinations of triggered MSD detectors (a preliminary “soft” trigger signal) C1, C2, C4; C1, C2, C5; C1, C3, C4; C1, C3, C5; C1, C4, C5; C2, C3, C4; C2, C3, C5 and not registered by detector C10. In addition, for the registration of the background neutrons and gamma-quanta fluxes detector C1 is included in the mode AC. Gamma rays and neutrons are detected by secondary particles, formed as a result of their interaction with the detector material C1. Efficiency of detectors C1 and C10 are ~ 99.9%, and all the other MSD detectors are better than 99%

![Figure 1. Layout and photo of MSD: a) layout of MSD, b) ARINA spectrometer with MSD (inside view), c) VSPLESK on the installation bracket](image)

![Figure 2. Amplitude spectra obtained during the registration of 20 MeV electrons and 60 MeV proton detector C4](image)

![Figure 3. Dependence of the charged particle energy loss from their kinetic energy in polystyrene](image)

The MSD [1], developed for ARINA spectrometer [2] onboard Resurs-DK1 spacecraft and VSPLESK [3] on the outside the Russian segment of the ISS, provides a logical channel of measurement (LCI). LCI provides separate registration only of electrons and protons. Figure 1 shows photos of ARINA and VSPLESK.

LCI is realized by the application of the MSD double threshold pulse former from photomultiplier (PMT). The lower permanent threshold suppresses noise from PMT, the upper adjustable threshold identifies pulses whose amplitude corresponds to the useful events with “proton” energy release. The
lower threshold is chosen on 0.1 mip (minimum ionization particle) level, which corresponds to the $A_\text{lt}$ amplitude, the upper threshold is chosen on 2.5 mip level, which correspond to the $A_\text{ut}$ amplitude (Figure 2). We adjust the upper level to identity electrons and protons with probability of imitation better then 1% [1], [4]. LCI allows to perform quick identification of the type of detected particles (relativistic-nonrelativistic) The separation of particles by their energy release in the MSD detectors (Figure 3 shows the range of energies registered particles by MSD: electrons ($E_e$) from 3 to 30 MeV, protons ($E_p$) from 30 to 100 MeV, the energy of the particles (with an accuracy of 10-15%) is determined by their range (number of detectors passed until complete absorption in the SC).

To increase the accuracy of measuring the energy of the particles and provide separate registration of the isotopes of hydrogen and helium nuclei in a modified version of the MSD (MSD-M), in addition to the LCI added amplitude measurement channel. C1 and C2 detectors are used as transit (thin) $\Delta E$ detectors, in passing through them, the particle loses energy $\Delta E = d \times \frac{dE}{dx}$, where $\frac{dE}{dx}$ - specific energy losses in the transit detector, $d$ - thickness. SC detectors are used as a total absorption detector, they, together with a amplitude analysis of pulses, provides separation of particles based on the measurement and analysis of energy-release in the scintillation detectors (modified $dE/dx$-E method). This method was first applied to the space experiment NINA in Resurs-01 №4 spacecraft [4]. The particle energy is determined by the total energy-release in C1, C2 detectors and SC. SC also allows determining in addition particle energy by the number of passed detectors to the particle’s stopping point.

For positron registration selected only those events, which correspond to the topology, which described by the following formula: $C_1 \times C_2 \times C_3 \times C_n \times (\text{the absence of } C_{n+1}) \times C_{n+2}$, where $n=3, ..., 7$.

Detection efficiency of electrons, positrons, isotopes of hydrogen and helium nuclei are shown in Figures 4. MSD-M registers most effective the isotopes of hydrogen and helium in the energy ranges: for $^2\text{H}$ - from 18 to 48 MeV/nucleon, for $^3\text{H}$ - from 23 to 62 MeV/nucleon for $^3\text{He}$ - from 32 to 92 MeV/nucleon for $^4\text{He}$ - from 41 to 106 MeV/nucleon. For positrons the most effective range is 3.5 to 13 MeV.

Background neutron flux (in the energy range from 40 to 110 MeV) and gamma-rays (in the energy range from 4 to 20 MeV) are registered MSD-M with the efficiency ~2%. Relative energy resolution of the MSD-M for gamma-quanta is a value of about 6-12%, for the protons and helium nuclei of 1.5-3.4%, and for electrons 6-8%. Figure 5 shows the dependence of the mass resolution of MSD-M from the energy for isotopes of hydrogen and helium. The geometric factor of MSD-M is 40 cm$^2$sr (for «hard» trigger) and up to 60 cm$^2$sr (for «soft» trigger).
To confirm the possibility of registering with the MSD-M bursts of particles having a duration of 1 ms and above, we tested of the photomultiplier R5611A-01 in the regime of single pulses of light at high loads. The illumination of the PMT was carried out in pulse batches of light from the led. Frequency of impulses in a batch is changed from 100 KHz to 30 MHz. The results are presented in Figure 6 and allow to make a conclusion, that the MSD-M, made on the basis of the photomultiplier R5611A-01 together with electronic high-speed analog tract can work in high-intensity beams of particles and to register events with frequency up to $2.5 \times 10^7$ particles per second.

Figure 6. a) Amplitude-frequency dependence of PMT Hamamatsu R5611A-01 (RB9968); b) dependence of the critical frequency of the output signal in the batch on batch length for three samples PMT with the amplitude of illumination 200 mV

References
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