Ultra-violet light-emitting diode calibration system for timing large area scintillation detectors

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Abstract. Timing large area plastic scintillation detectors are developing for the space gamma-ray telescopes now. The in-flight calibration of these detectors the use of ultra-violet light-emitting diode, irradiating the 1 m long detector module at the center of its lateral side is suggested. The results of the measurements show the possibility of this calibration system implementation as for amplitude as for timing properties monitoring.

1. Gamma-ray telescope GAMMA-400
The international Collaboration GAMMA-400 develops the gamma-ray telescope for the energy range from 20 MeV up to 3000 GeV on board of the space satellite. This device will investigate the point gamma-ray sources and the peculiarities in the energy spectrum of diffuse gamma radiation that can be produced by the annihilation of so-called “dark matter” particles [1, 2].

The gamma-ray telescope [1] layout is shown in the figure 1. It has the sensitive area of about 1 m² and consists of fast plastic scintillation anticoincidence detector AC to forbid with high efficiency the charged particle detection, multilayer (tungsten + silicon strip detectors) converter C for the conversion of gammas to the electron-positron pair and for their trajectories visualization. The time-of-flight system TOF (S1 and S2 fast plastic scintillation counters with 50 cm flight base) generates trigger for up-to-down moving charged particles after gamma-quantum conversion in converter C. Two sections of heavy CsI(Tl) calorimeter (CC1 and CC2) are interleaved by fast scintillation detector S3 indicating the degree of shower development. The system of the shower leakage detector S4 and the neutron detector ND for electron-proton discrimination is located below the calorimeter.

All of gamma-ray telescope components will be mounted on the base plate and installed at the space platform named NAVIGATOR.

We are considering here the prototype version of the gamma-telescope described in [3].

2. Plastic scintillation detectors
All of the plastic scintillation detectors (AC, S1, S2, S3 and S4) must have high detection efficiency for charged particles and in addition AC, S1 and S2 must have high timing properties for time-of-flight measurements to distinguish the particles movement direction (from up or down). All these detectors have the similar construction and each represents the set of BICRON BC-408 (Polyvinyltoluene) scintillator rectangular modules (bars with dimensions 1000x100x10 mm³). BC-408 light output corresponds 64% of anthracene one, rise time and decay time of scintillation pulse equals 0,9 ns and 2,1 ns correspondingly, wavelength of maximal intensity emission is 425 nm, light “e” times attenuation length equals 210 cm. This scintillator may be used in vacuum.
Scintillation in each module is seen from both ends by 6 photosensors, connected in parallel, representing silicon photomultipliers (SiPM) MicroFB 60000 Series SMT Package delivered by SensL with fast output using SMT Transformer RF1X9503. The electrical circuit of SiPM connection and the layout of SiPM wiring board are shown in the figures 2 and 3.

3. The monitoring
During the long (several years) space experiments the in-flight monitoring of detector response is quite necessary. For instance, the PAMELA magnetic spectrometer shows for almost 10 years of space experiment 27\% of light emitting diode (LED) pulses amplitude decrease for plastic scintillation counter as is shown in the figure 4.
Figure 4. Plastic scintillator detector LED calibration amplitudes during the spaceflight of PAMELA magnetic spectrometer (2006 - 2015).

For the GAMMA-400 space experiment provided for at list 5 years of operation we propose to use also the LED calibration. The LED diode will be located in the center of 1000x10 mm$^2$ side of scintillation module. We have chosen the ultraviolet BL-L189VC LED manufactured on the base of InGaN with dimensions 3.3x2.4x3.0 mm$^3$ and light wave length of 405 nm. Typical and maximal forward voltages are 3.8 V and 4.5 V respectively.

Ultra violet radiation is transforming in the scintillator to the visible light. The light distribution when direct current to LED was applied is shown in the figure 5.

Then the standard pulse generator for the LED power supply was used.

Figure 5. The layout of transformed light distribution of UV LED.

4. Testing of the LED monitoring
In the figure 6 the ground-level cosmic ray muons amplitude spectra of the detector module sum signal from the opposite ends SiPM’s triggered by the coincidence of the pulses from the small (3x3 cm$^2$) additional detectors signals (upper figure) and the UV LED spectrum with pulse amplitude 4.1 V (down figure) are shown.

We see that we can reproduce the muon amplitude distribution spectra with the irradiation by the LED pulses with better amplitude resolution.

Also the measurements of the time intervals distributions between the moments of cosmic muons detection at the detector opposite ends triggered by the coincidence of additional detectors signals and the same distributions under irradiation by LED pulses with self-triggers (figure 7). Three peaks shows the time calibration carried out by the delay line with the step of 10 ns. Time resolution (sigma) consists 0.62 ns for the LED calibration and 1.23 ns for muons one.
Figure 6. The ground-level cosmic ray muons amplitude spectrum of detector (upper figure) and the UV LED spectrum (down figure).

Figure 7. The time interval distributions between the moments of the LED pulses detection at the detector opposite ends. The time calibration was carried out by the delay line with the step of 10 ns. Time resolution (sigma) =0.62 ns.
5. Conclusion
The application of light emitting ultraviolet diode for the calibration and in-flight monitoring of the fast plastic scintillation detector amplitude and timing characteristics in the conditions of long-duration space experiment allows to get the amplitude and time resolutions better than using calibration from charged particles. The parallel implementation of these two methods allows determine the source of instability.

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