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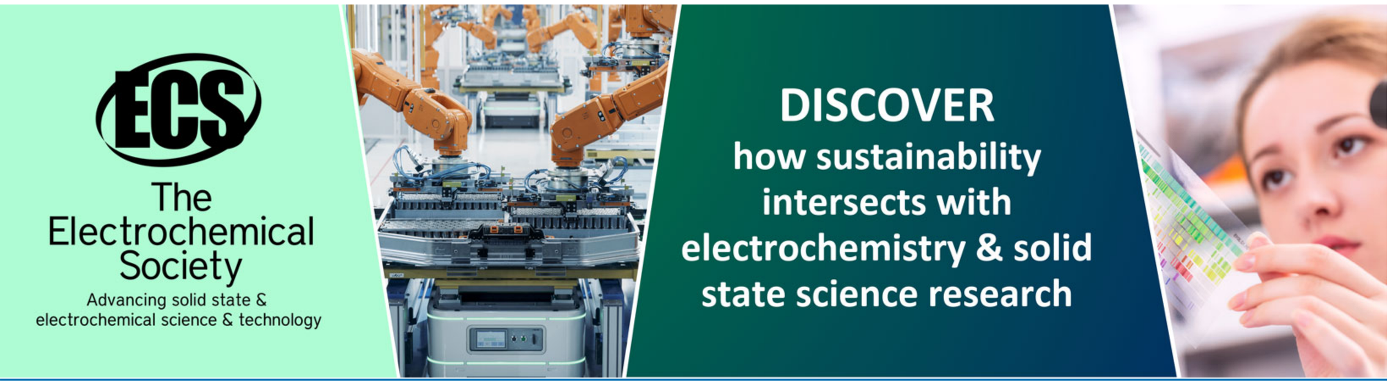

Design of the readout electronics for the fast trigger and time of flight of the GAMMA-400 gamma-ray telescope

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Abstract. The GAMMA-400 gamma-ray telescope is planned for the launch at the end of this decade on the Navigator service platform designed by Lavochkin Association on an elliptical orbit with following initial parameters: an apogee ~300000, a perigee ~500 km, a rotation period ~7 days and inclination of 51.4º. The apparatus is expected to operate more than 5 years, reaching an unprecedented sensitivity for the search of dark matter signatures and the study of the unresolved and so far unidentified gamma-ray sources. An electronics system, which consists of 14 front-end multichannel electronics modules and the main processing unit with a total power consumption of about 400 W (74W for main processing unit), has been developed for providing fast trigger and veto for the data taking to the experiment. The communication between front-end modules, main processing unit and scientific data acquisition system of the gamma-ray telescope is performed via high-speed SPACEWIRE network. To assure the long-term reliability in space environment, a series of critical issues such as the radiation hardness, thermal design, components and board level quality control, warm and cold redundancy are taken into consideration. The main design concepts for the system, measurements setups together with some test results are presented.

1. Introduction

Scientific project GAMMA-400 [1, 2] is intended to perform an indirect search for signatures of dark matter in the cosmic-ray fluxes, precision investigation of characteristics of diffuse gamma-ray emission and gamma-rays from the Sun during periods of solar activity, gamma-ray bursts, extended and point gamma-ray sources in the wide energy range from several MeV up to TeV region, electron/positron and cosmic-ray nuclei fluxes with energies up to ~10^{15} eV by means of the GAMMA-400 gamma-ray telescope represents the core of the scientific complex. The GAMMA-400 space observatory will be launched on the Navigator service platform [3] designed by Lavochkin Association for more than 5 years operation. The planned technical parameters of scientific complex are: weight ~2500 kg, power consumption ~2000 W, total downlink transmission up to

100 GByte/day. The under-consideration variant of GAMMA-400 gamma-ray telescope includes following detecting modules and subsystems (figure 1 and figure 2):

- scientific measuring subsystems (SMS): a converter-tracker C consisting of 13 layers of double (x, y) tracking coordinate detectors; an anticoincidence system AC consisting of multi-strip BC-408 top detector ACtop and four lateral detectors AClat1–AClat4 surrounding convertor-tracker C; an 80 cm x 80 cm, ~18 radiation length thick coordinate-sensitive calorimeter CC comprising preshower CC1 (consists of CsI(Tl) planes with total thickness of ~ $2X_0$, double (x, y) tracking coordinate detector and fast plastic scintillation detector S3), the total-absorption calorimeter CC2, based on the set of CsI(Tl) crystals, anticoincidence LD and leakage S4 plastic detectors; a time-of-flight system TOF represented by a hodoscope of four oriented perpendicularly multi-strip layers (S1top, S1bot, S2top and S2bot) of BC-408 plastic scintillation counters combined in two detector planes S1 and S2 located at the distance of 50 cm between C and CC; system of triggers formation ST;
- service subsystem, including two-star sensors for determining the GAMMA-400 axes with accuracy of approximately 5" and scientific complex telemetry system for cyclic registration up to 65535 housekeeping parameters of scientific complex;
- scientific data acquisition system SDAS [4] for acquisition and pre-processing data from SMS and service subsystem, storage it in non-volatile mass memory (1 TByte), scientific data and telemetry transfer into high-speed scientific radio line (up to 400 Mbit/sec) for their transmission to the ground segment of the project and control information reception from spacecraft onboard control system via multiplexed channel MIL-STD-1553B, its decoding and transfer into SMS;
- one-time commands and power supply system OCPSS, providing power supply for scientific complex, one-time pulse radio commands sharing and their transmitting to SMS and transit of the most important telemetry parameters directly to the satellite onboard telemetry system.

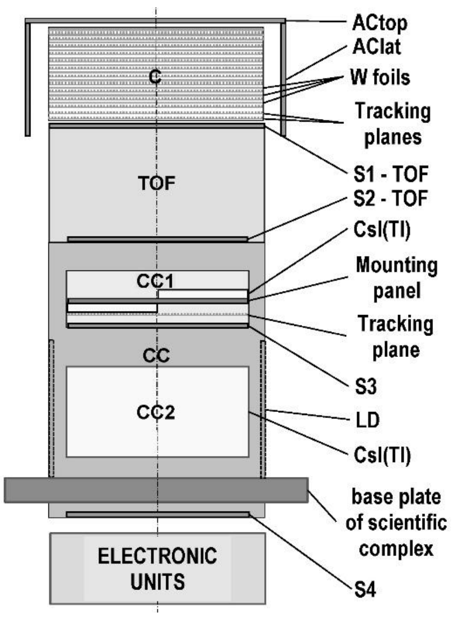

Figure 1. The physical scheme of the GAMMA-400 gamma-ray telescope.

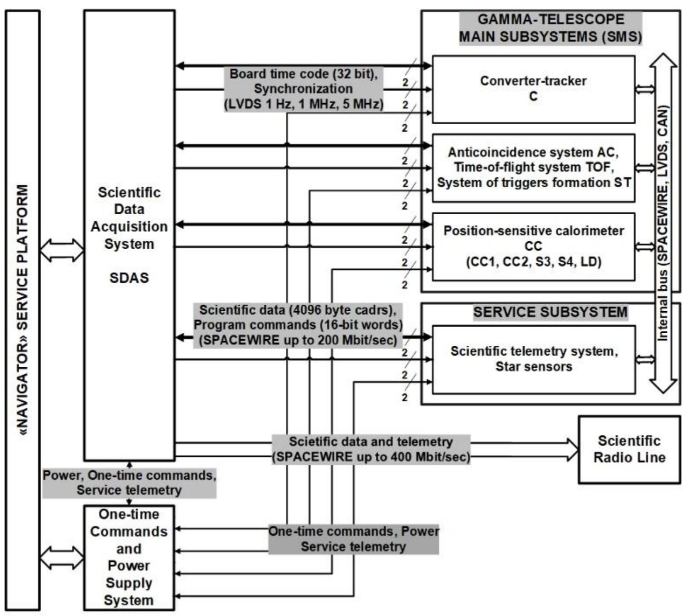

Figure 2. The functional diagram of the GAMMA-400 gamma-ray telescope.

2. The readout electronics for fast trigger and time of flight of the gamma-ray telescope

Three fast detectors of the gamma-ray telescope: AC, TOF and S3 are included in fast trigger logic in the main telescope aperture. The construction and electronics of these detectors are similar with the exception of difference in counters number, size and orientation. Both sides of plastic scintillation counters are viewed by photo sensor blocks based on matrix of silicon photomultipliers MicroFC-60035-SMT mounted on printed circuit board with the exception of AClat and LD with only one active side. The front-end units comprise two multichannel sections for time and charge measurements controlled by 100 MHz Milandr 1986VE8T 32-bit rad-hard RISC-microcontroller with ARM Cortex-M4F core. Each time analysis channel includes fast shaper-preamplifier and constant fraction discriminator CFD. The CFD outputs are fed into “fast” trigger submodules that include multichannel TDC with 20 ps resolution, based on 4-channel ASICs ACAM TDC-GPX2. Each charge measurement section is based on 16-channel ASIC IDEAS IDE3380. The readout electronics for triggers formation represents the structure combines 14 programmable front-end detector units and main processing unit that consists of: four “fast” trigger submodules (FTM_1-FTM_4) based on FPGA 5578TC034 (rad-hard functional analogue of Altera EPF10K100E) for fast trigger signals formation from discriminators signals of front-end units; “master” trigger module (MTM) for the final level triggers formation, events data reduction and processing; control module representing the interface with one-time commands and power supply system OCPSS, providing primary and spare

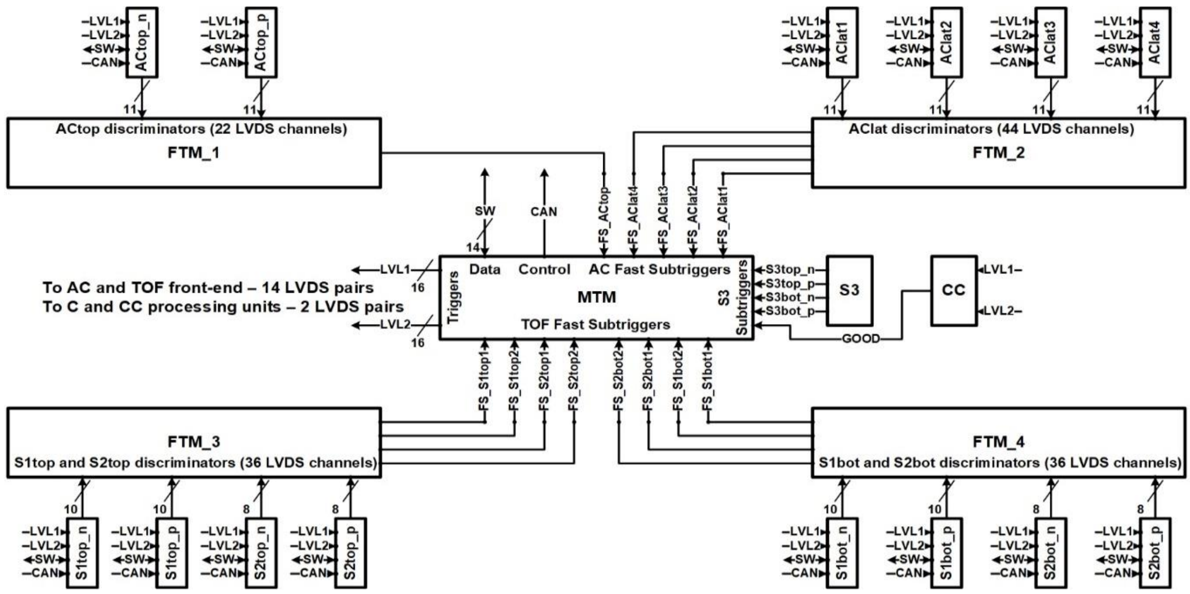

Figure 3. The functional diagram of interconnections in the frame of triggers formation cluster. The _n and _p postfixes designate the opposite ends of scintillation strips. FS_x – “fast” subtriggers in accordance with predefined scintillation strips patterns in AC and TOF. S3x – the signals from discriminators of S3 layers. The LVDS signal GOOD from CC main processing unit that confirms the fulfillment of predefined trigger conditions in CC1, CC2, LD, S3 and S4. SW – the high-speed SPACEWIRE network, CAN – Controller Area Network internal bus for control of front-end units.

power supply selection for trigger signals formation system, one-time pulse radio commands receiving and transmission of the most significant telemetry parameters directly to the satellite onboard telemetry system; commutation and processor modules based on 100 MHz 1907VM056 32-bit rad-hard RISC-microprocessors with integrated 8-channel SPACEWARE switch, providing communication with scientific data acquisition system SDAS. In order to increase the reliability, the system is designed using a double hot- and cold-reserved crossover scheme. Data exchange signals are double redundant, and each redundant line assigns with its own allocated data transceiver. Simplified functional diagram of interconnections inside of the triggers formation system is presented in figure 3. The total power consumption and weight of main processing unit are ~74W and ~40 kg respectively.

The GAMMA-400 triggers formation system is based on three levels scheme: two fast, hardware levels LVL0 (internal for MTM) and LVL1, and slower software level LVL2. The level 0 trigger LVL0 is generated by TOF system when a charged particle passing through the gamma-telescope acceptance, when at least one counter side in three of four TOF layers produces a signal above a threshold within predefined time gate, and provides, in ~100 ns, the reference time label for the time measurements. For this purpose, all discriminator outputs of each TOF counter side are combined in OR logic with two predefined trigger masks. In the TOF readout electronics ~40% MIP programmed thresholds are implemented for signals from each counter side. Then the signals originated from one TOF layer side is matched in OR or AND with ones coming from the other side (depending on a programmable setting) forming the set of FS_x subtrigger signals. These signals are sent to the MTM and combined into LVL0 trigger, initiating start of LVL1 generation. The level 1 trigger LVL1 formation begins with the TOF particle hit counters pattern analysis and crossing time one for acceptance checking and upward/downward particles selection. At the same time AC hit pattern is analyzed too for VETO signal generation. The S3 preshower response is also included in trigger for hadron and electromagnetic showers separation, and the S3 signal is enabled and suppress VETO signal if the conditions on a defined combination of the S3 hit counters pattern with enough energy deposition are fulfilled. The LVL1 initiates the process of data acquisition from gamma-ray telescope subsystems, storing it into intermediate buffer memory and starts level 2 trigger LVL2 generation. At the LVL2 formation stage spurious fast triggers are suppressed and energy deposition and hit counters pattern in position-sensitive calorimeter CC are analyzed by using data stored on level 1 stage (CC answers to LVL1 trigger by sending the LVDS logical signal GOOD to MTM in the positive case), making a final decision about transmitting or not registered information to the ground segment of scientific complex. Then the collected event information is compressed, structured, combined with the service data by means of “master” trigger formation module MTM and sent to scientific data acquisition system SDAS for temporary storing in non-volatile mass memory or for direct transferring into high-speed scientific radio line. The set of counters in trigger modules count how many various discriminators, subtriggers and triggers signals are presented in a predefined time interval.

3. Conclusion

The readout electronics for fast trigger and time of flight system of the GAMMA-400 gamma-ray telescope constitutes the multiprocessor structure which collects data from the gamma-ray telescope detector subsystems and produces summary information used in forming the trigger decision for each event. The use of the flexible distributed system provides possibility for adaptive and operational management of the parameters of gamma-telescope registration modes, allows for the optimization of a search for a specific physics channel according to the survey strategy. In order to increase the reliability, the system is crossover and double redundant and selected electronics components are space qualified and rad-hard or rad-tolerant.

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