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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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I. THE STRUCTURE OF GAMMA-400 GAMMA-RAY TELESCOPE

Scientific project GAMMA-400 [1, 2] relates to the new generation of space observatories 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. For gamma-rays with the energy >100 GeV expected angular and energy resolution are ∼0.01° and ∼1-2% respectively and electron/protons rejection factor is ∼$5\cdot10^5$. The GAMMA-400 space observatory is planned for the launch at the end of this decade on the Navigator service platform [3] designed by Lavochkin Association on the elliptical orbit with following initial parameters: an apogee ~300000, a perigee ~500 km, a rotation period ~7 days, and inclination of 51.4º. The GAMMA-400 observatory is expected to operate more than 5 years, reaching an unprecedented sensitivity in the indirect search of dark matter signatures and in the study of the unresolved and unidentified so far gamma-ray sources. The planned scientific complex main technical parameters are: weight ~2500 kg, power consumption ~2000 W, total scientific and service downlink transmission up to 100 GByte/day.

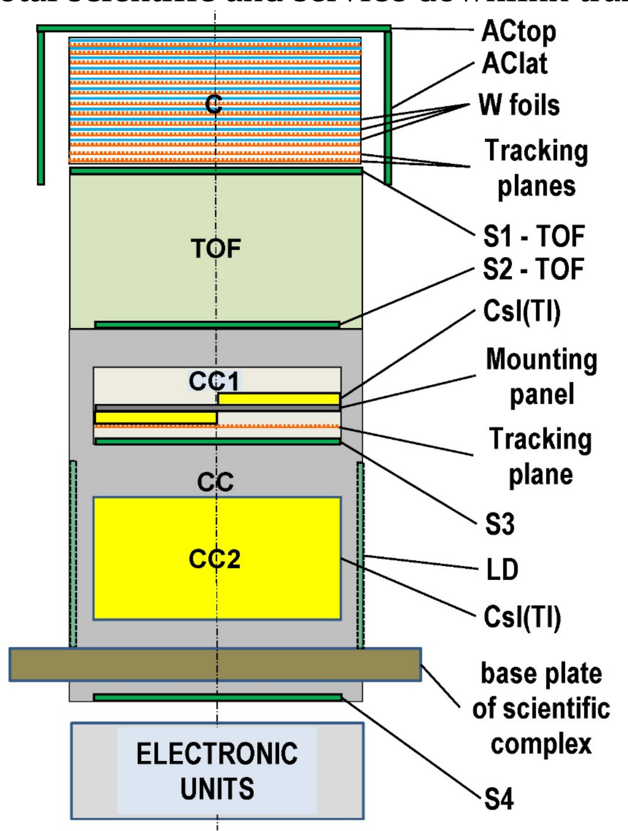

Fig. 1. The physical scheme of the GAMMA-400 gamma-ray telescope

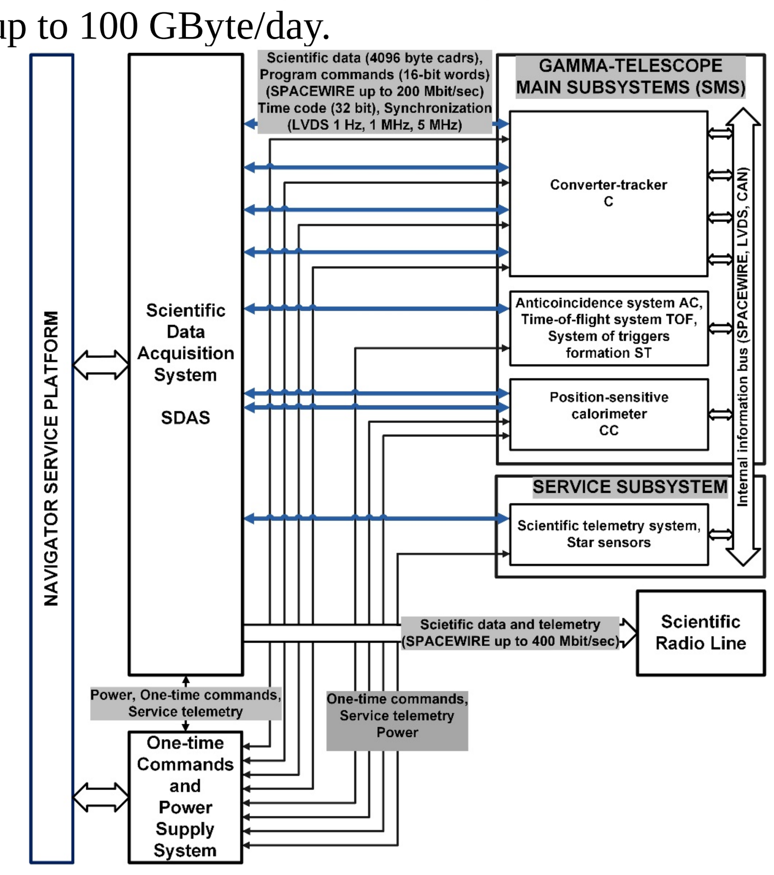

Fig. 2. The functional diagram of GAMMA-400 gamma-ray telescope

The under consideration variant of GAMMA-400 gamma-ray telescope includes following detecting modules (figure 1):

• a converter-tracker C consists of 13 layers of double (x, y) tracking coordinate detectors. The first 11 layers are interleaved with tungsten conversion foils meanwhile the last two layers have no tungsten. The total converter-tracker thickness is about 1 radiation length. The data from converter-tracker is used for high precision determination of the gamma-quanta conversion point coordinates and reconstruction of primary and secondary charged particles trajectory;

• an anticoincidence system AC: ACtop is top detector and AClat are four lateral detectors AClat1–AClat4 surrounding convertor-tracker for discrimination between incoming charged particles and gamma-quanta with an efficiency of ≥99.999%. All anticoincidence counters are made of two layers of 1 cm thickness, 10 cm width BC-408 polyvinyltoluene scintillator strips with different length;

• a hodoscope of four oriented perpendicularly layers of 1 cm thickness, 10 cm width, 100 cm for S1 and 80 cm for S2 length BC-408 plastic scintillation counters (time-of-flight system TOF) combined in two detector planes S1 and S2 located at the distance of 50 cm between convertor-tracker C and calorimeter CC. TOF system provides the fast trigger to gamma-ray telescope readout electronics through the system of triggers formation signals ST and measures the particle charge, crossing time and position, and separates upward from downward going particles within at most 10^{-2} level;

• an 80 cm x 80 cm, ~18 radiation length thick coordinate-sensitive calorimeter CC to measure the incoming particles energy with resolution of 1-2% for gamma-rays with $E_\gamma \geq 100$ GeV and separate $e^\pm$ and photons from hadrons at the ~$5\cdot10^{-5}$ level. The CC includes 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, and anticoincidence LD and leakage S4 plastic detectors.

Three fast plastic 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 absence of time analysis units in S3 and difference in counters number, length and orientation. Each side of every plastic scintillation counter in gamma-telescope sub-detectors is viewed by photo sensor block on the basis of matrix of silicon photomultipliers SensL MicroFC-60035-SMT mounted on printed circuit board.

The GAMMA-400 gamma-telescope can be subdivided into a following subsystems (figure 2):

• the main scientific measuring subsystems (SMS) of gamma-telescope – AC, C, TOF, CC, 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 secondary 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.

II. THE READOUT ELECTRONICS FOR FAST TRIGGER AND TOF

The readout electronics for fast triggers formation represents the electronic structure consists of 14 programmable front-end detector units; fast trigger logic modules for fast trigger signals formation from discriminator signals of detecting subsystems; master trigger logic modules for the final level triggers formation, events data reduction and processing; control module for primary and spare power supply selection and telemetry parameters transmitting to OCPSS; commutator and processor modules, that provide communication with scientific data acquisition system SDAS. In order to increase the reliability, the system is designed using a crossover scheme with two hot- and cold-reserved subsystems. Data exchange signals are double redundant and each redundant line assigns with its own allocated data transceiver. Simplified functional diagrams of interconnections within trigger formation cluster and triggers formation unit itself are presented in figure 3 and 4. The total power consumption and weight of triggers formation unit are ~75W and ~40 kg accordingly.

All front-end units of AC, TOF and S3 detectors, providing incoming information for triggers generation, are similar and consists of two parts for time and charge measurements. Each time analysis channel includes fast shaper-preamplifier and constant fraction discriminator CFD. The CFD outputs are fed to fast trigger modules that include time analysis circuits with 20 ps resolution, based on 4-channels ASICs ACAM TDC-GPX2 and FPGA based processing unit. Each charge measurement part is based on 16-channel IDEAS IDE3380 ASIC.

The GAMMA-400 trigger system is based on three levels of triggers: two fast, hardware levels LVL0 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 each TOF plane produces a signal above a threshold within predefined time gate, and provides, in about 100 ns, the reference time label for the time measurements. For this purpose, all "fast" outputs of each TOF counter side are combined in OR to form TOFL signals,

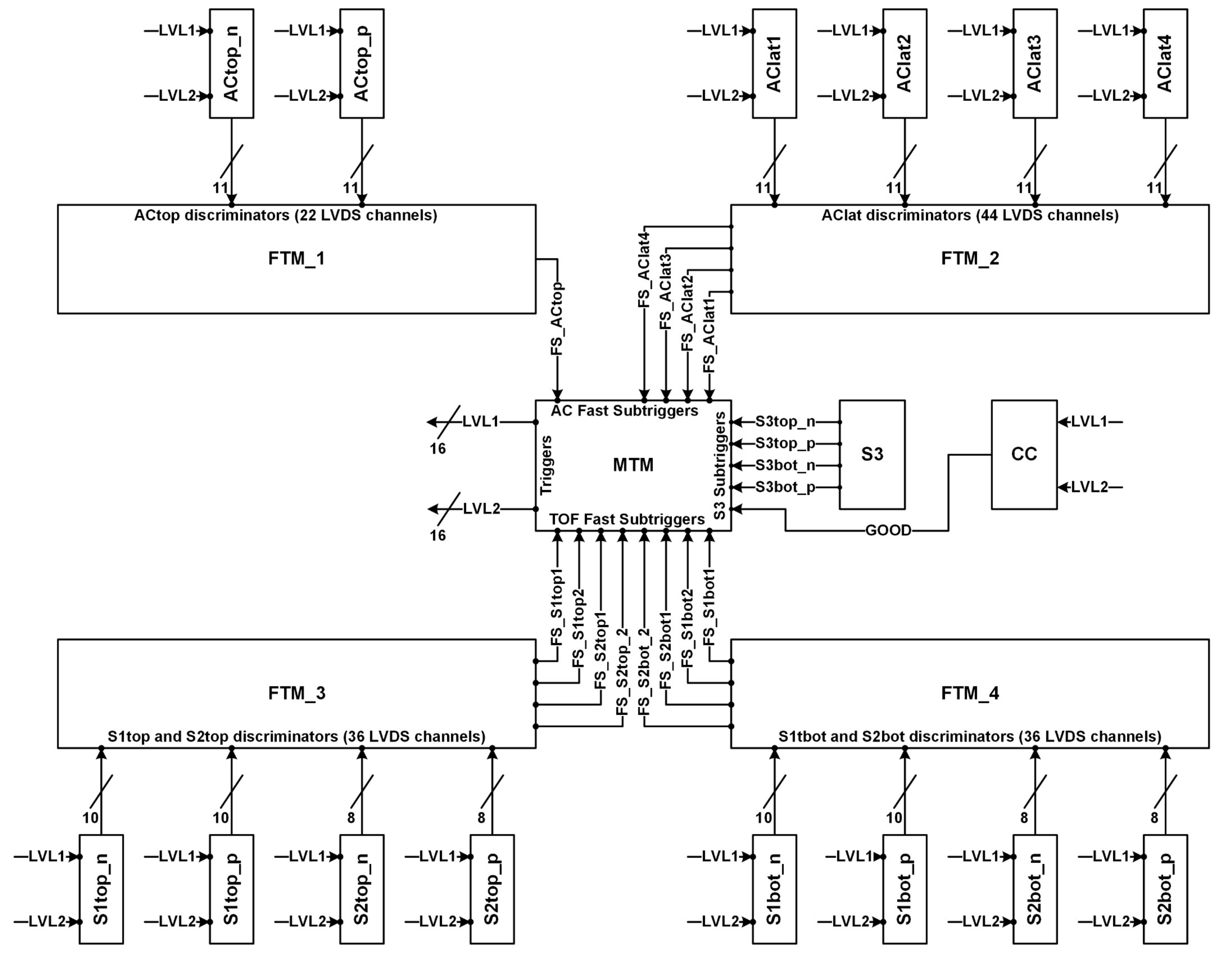

Fig. 3. Functional diagram of interconnections within trigger formation cluster. FTM and MTM are "fast" and "master" trigger modules. The _n and _p postfixes designate the opposite ends of scintillation strips

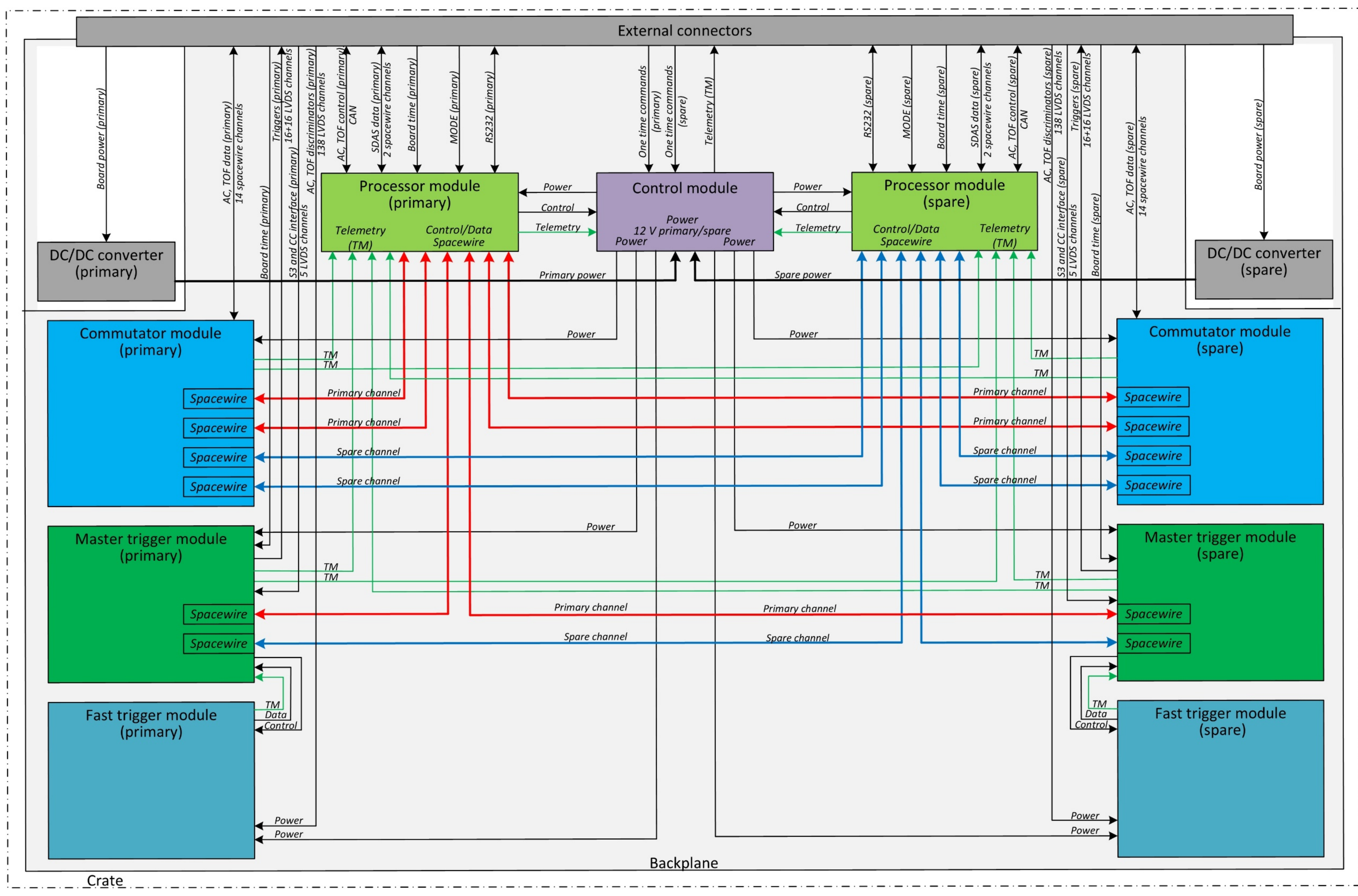

Fig. 4. Functional diagram of triggers formation unit

according to the threshold that has been passed. Indeed in the TOF readout electronics both a low ~40% MIP threshold is implemented for signals from each counter side. Then the signal originated from one plane side is matched in OR or AND with one coming from the other side (depending on a programmable setting). The coincidence of TOF planes with a trigger mask enables TOFL signals. The TOFL signal is send to TOF, AC and S3 sub-detectors as LVL0 trigger;

• 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. Then the AC hit counters pattern is considered, taking into account backsplash events suppression by time analysis method [5]. The S3 preshower response is also included in trigger for hadron and electromagnetic showers separation, and the S3 signal is enabled if the conditions on a defined combination of the S3 hit counters pattern with enough energy deposition are fulfilled. The leakage detector S4 signal indicates that some part of incident particle energy is not absorbed in CC2 total absorption calorimeter and this event has a bad energy measurement precision. In this case the subsequent analysis of the shower spatial profile in calorimeter is needed for the energy reconstruction. The LVL1 trigger initiates the process of data acquisition from gamma-telescope subsystems and storing it into intermediate buffer memory. The set of counters in trigger modules count how many various discriminators, subtriggers and triggers signals are presented in a predefined time interval;

• the level 2 trigger LVL2 suppress spurious fast triggers, finds preliminary tracks on the convertor-tracker and analyzes energy deposition in position-sensitive calorimeter by using stored on level 1 stage data, and makes 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, based on 100 MHz 1907VM056 32-bit rad-hard RISC-microprocessor with integrated 8-channel SPACEWARE switch, 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. Control module represents interface with one-time commands and power supply system OCPSS of gamma-telescope, providing secondary power supply for trigger signals formation system, one-time pulse radio commands receiving and transmission of the certain telemetry parameters to the satellite onboard telemetry system.

III. 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 double redundant and selected electronics components are space qualified and rad-hard or rad-tolerant.

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