The trigger system of the JEM-EUSO Telescope

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***Abstract*. JEM-EUSO is a space mission devoted to the investigation of Extreme Energy Cosmic Rays and Neutrinos (E $> 10^{20}$ eV) from the International Space Station (ISS) using the atmosphere as a giant detector, which is also the source of the largest fraction of noise (nightglow background). The trigger system should face different major challenging points: a) manage a large number of pixels (about 200 k); b) use a very fast, low power consuming, and radiation hard electronics; c) have a high signal-over-noise performance and flexibility in order to lower as much as possible the energy threshold of the detector, adjust the system to a variable nightglow background, and trigger on different categories of events; d) cope with the limited down-link transmission rate from the ISS to Earth, by operating a severe on-board and on-time data reduction. The general overview of the trigger system of JEM-EUSO is presented.**

***Keywords*: JEM-EUSO, detector, electronics**

I. Introduction

The observational concept of JEM-EUSO [1] is based on the observation of fluorescence and Čerenkov light emitted during the propagation of Extensive Air Showers (EAS), produced by the interaction of an Extreme Energy Cosmic Ray (EECR) or neutrino with the atmosphere. Typically, for a 10^{20}eV EAS, a few thousands photons are expected on the JEM-EUSO detector in few hundreds μs with an approximated rate of $\sim$1/day. In general, inclined showers will produce brighter signals as the EAS will develop in the less dense atmospheric layers. The signal will be partly influenced by the presence of cloud layers covering the last stages of the EAS development. Depending on the energy and direction of the primary particle, the expected signal will insist on few pixels for near vertical showers, while it will fire huge portions of the focal surface for near horizontal ones. At the same time, the atmosphere plays a manifold role: it is the medium where the EAS develops, it is the light emission and transmission medium where the light propagates and attenuates from its source location to the telescope site, and it is the source of the largest fraction of noise, the expected UV background. The major sources of background are: a) natural night sky diffuse and slowly varying sources whose light is being reflected through Earth albedo; b) man made sources like city lights; c) transient luminous phenomena in lower and upper atmosphere (below ISS height, $\sim$430km). Concerning a), different contributions have to be considered: Moon phases, diffuse night brigthness (zodiacal light, diffuse star light, planets), and airglow. The common effect of diffuse night brightness and airglow is expected to produce an average flux of Φ = 300 - 1000 photons/m^2/ns/sr for clear sky. These values have to be increased by 15% in case of cloudy sky. These estimations are in agreement with recent measurements of the nightglow background [2], [3]. If we accept that the Moon phase will contribute to the average nighglow background by no more than 20% compared to Φ in moonless nights, this means that the observational duty cycle will be $\sim$20%. The effect of man made sources like city lights will probably blind pixels in the Field of View (FoV) for a time corresponding to the persistency of its image within the relevant portion of the FoV. Since the ISS velocity is 7 km/s and the pixel size is $\sim$0.7 km, the expected persistency of a *steady human source* is on the order of 100 ms. Finally, Transient Luminous Events (TLE) such as Elves, Sprites, Blue Jets and Lightnings will be responsible of the most luminous signals in the night atmosphere with an average occurence of $\sim$700/day. Due to the different time scale and light involved in these phenomena compared to EAS, such events will be very easily recognized. Moreover, the continuous measurement of TLEs is one of the science objectives of the JEM-EUSO mission [4] which will require a special trigger system.

In conclusion, due to the variability of the atmospheric conditions and of the atmospheric phenomena, JEM-EUSO will need a dynamical trigger system capable of continuously adapting the triggering requirements. Moreover, an intelligent trigger system that exploits the peculiarities of the EAS signals on the random nightglow background will be able to operate a massive screening between real and fake events, contributing to lower the energy threshold of the detector.

II. Technical requirements

A detailed description of the data acquisition system and electronics of the JEM-EUSO project is being described in [5]. Here the main points for the following discussion on the trigger system are reported.

In JEM-EUSO baseline, the Focal Surface (FS) of the telescope is conceived as a mosaic of ~5000 multi-anode photomultipliers (MAPMT) with 36 pixels each (R8900-M36), for a total number of $\sim 2\times10^5$ channels, arranged in 1250 Elementary Cells (EC) (4 MAPMT/EC). The ECs, which are the basic units of the front-end electronics are organized in groups of 9 items (3×3) in Photo Detector Modules (PDM), the basic units of the data acquisition system [6]. The Gate Trigger Unit (GTU) is currently set at 2.5 μs in order to match with the time span required by a light signal to horizontally cross the FoV of a pixel (~0.7 km). This means that the total amount of data that the electronics has to deal with is on the order of 2×10^5 pixel/FS $\times$ 4×10^5 GTU/s $\times$ 8 bit/pixel $\approx$ 640 Gbps. However, the telemetry budget of the JEM Exposed Facility (JEM/EF) is of ~300 kbps. This means that a huge data reduction (10^6) has to be performed on-time by the on-board electronics. Moreover, the limitations imposed by the power budget (~1 kW for the entire telescope) and space requirements (radiation hard electronics) contribute to make such task even more challenging.

III. The trigger system and its topology

A general description of the trigger system in connection with the data acquisition system has been already described in [5]. In this paper, we focus on the most important points. A structural scheme of the different levels of trigger is shown in fig.1.

The trigger system has to be selective in order to tag the EAS-produced signal while rejecting the background in an efficient way. It consists of trigger modules that are independently operated for each PDM. The trigger system is operated in the following 4 modes: a) EECR mode; b) slow mode; c) detector calibration mode; d) analog mode.

The EECR mode shall be the standard one where the trigger looks for signals which rise above the 3^{rd} trigger (the last trigger level) for a duration between about 30 μs and about 300 μs (the exact value shall be in-flight programmable). The EECR are observed by means of this mode. Event which does not match the above duration window will be ignored.

The Slow mode shall be normally not active, it will be activated by telecommand when required by the observers or as a programmed feature in the System Trigger. When the Slow mode is activated, the signals with 3^{rd} level trigger activity lasting more than a pre-set time (e.g. 300 μs) will be anyway recorded, even though, with a slower sampling frequency (GTU). Most of atmospheric phenomena (e.g. meteoroids) are observed with this mode.

The Fast mode shall be also normally not active, being activated by telecommand when required by the observers. When the Fast mode is activated, the sampling frequency is increased by a factor 8 with respect to the EECR mode, and signals with 3^{rd} level trigger activity lasting less than a pre-set time (e.g. 30 μs) will be anyway acquired. This feature will be used during on board calibration.

The Analog Trigger should allow the instrument to trigger on: (i) transient phenomena, i.e. extremely short ($<<$ 1 GTU) but intense flashes (Čerenkov mark or Čerenkov from τ neutrinos), and (ii) events with propagation speed $<<$ c (meteors) and lightning.

To reject the background, JEM-EUSO electronics operate with several trigger levels. The trigger scheme relies on the partitioning of the Focal Surface in subsections, named PDM (Photo Detector Module) which are large enough to contain a substantial part of the imaged trace under investigation (this depends on the zenith angle and energy of the shower). The general JEM-EUSO trigger philosophy asks for a System Trigger organized into four trigger-levels. The System Trigger works on the statistical properties of the incoming photon flux in order to detect the interesting events hindered in the background, basing on their position and time correlation. Its input signals are the anodic signals.

The four Main Trigger levels are detailed here below:

0^{ed} level or anode-level analog trigger. Two circuits are implemented on the Front-End ASIC: a digital one and an analogue one. The digital part is based on the Single Photon Counting technique whereas the analogue is based on the Charge to Time conversion. The digital part consists basically of an analog discriminator and a former to recognize the arrival of a single photo-electron event at each anode. Special fucntions as the equalization of the pixels' gain, the adjustment of the pixels' threshold, and the enabling and disabling are also built in the ASIC. The analogue part makes use of a Charge to Time technique to convert the analogue pulses (Charge) arriving to the anodes to Time [7]. The resulting time divided by the average time-unit corresponding to a single photo-electron gives the total number of photo-electrons per pulse. The digital and analogue parts will work in a complementary mode, so that a dynamical range from 1 photo-electron to several hundred photo-electrons can be achieved. At this trigger-level the electronic noise effect at PMT level is greatly reduced due to the fact that the strong anodic pulses are easily discriminated above the preamplifier electronic noise. This trigger is implemented on the Front-End ASIC that hosts also the analog trigger supplied by the Charge to Time circuit.

1^{st} level trigger is issued whenever the number of single-photoelectrons recorded by an anodic chain within a

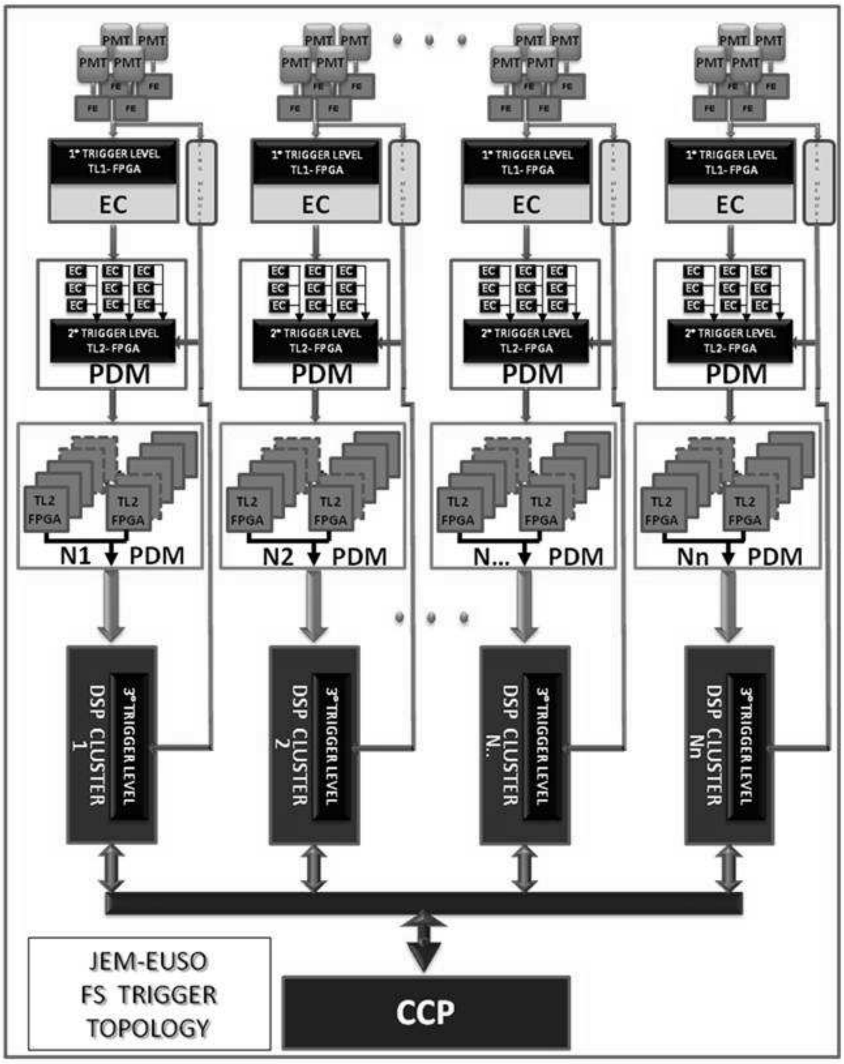

Fig. 1. Structural scheme of the different levels of trigger.

GTU exceeds two pre-set digital threshold values. The gate time is named GTU (from Gate Time Unit); its duration is about 2.5 μs. The 1^{st} level trigger is based on the over-threshold persistency of summed 3 x 3 grouped pixels. At this trigger-level the random background at PDM level (randomly arriving photons) is greatly reduced by setting the digital threshold values above the observed background fluctuation.
The 2^{nd} level trigger is issued whenever the signal integrated in a 2x2 pixel box for 9 consecutive GTU centered around the seed triggered by the 1^{st} trigger level and searched in 16 different directions (θ,ϕ) is greater than the integrated background in the same pixel boxes (linear track trigger algorithm) . This trigger algorithm has been already extensively reported in [8]. At this level the statistical noise at PDM level is further reduced.
The 3^{rd} trigger level is the last level of trigger and the one where the final decision is made to start the readout procedure. The 3^{rd} level trigger applies again the linear track trigger algorithm of level 2 in a more refined set of directions around (θ,ϕ). The signal is integrated up to a maximum of 128 GTU. Further selection criteria as shower profile and Čerenkov mark will be implemented. The decision will be made in agreement to one of some possible trigger modes that will be implemented in order to optimize the triggering action for the different phenomena to be observed. At this level the remaining statistical noise will be reduced to the point that only the interesting patterns will initiate the

readout sequence. The 3^{rd} level trigger will be fully on-flight programmable in order to allow for any adjustment in the trigger modes.
All the trigger levels will be programmable on flight. In fact, it will be necessary to adjust the threshold of each level to cope with the varying background. The redundance of the different trigger levels will allow to operate the 1^{st} trigger level also as a $1^{st} - 2^{nd}$ one, if needed, by sufficiently change the threshold. Even though the trigger efficiency might decrease, this simple trigger meachanism will represent a backup solution in the ECs where the 2^{nd} trigger level might be temporary shut off.

IV. Read-Out Specifications

A free running method is adopted to store temporarily the information in ring memories and recover the relevant data at the time that a qualified trigger signal occurs. The ring memory (one for each PDM) is a Dual Port buffer memory. The digitalized counts per GTU per pixel coming by the Front-End ASIC counter registers are recorded in the memory at each GTU. The memory buffer shall be properly deep in order to keep the maximum expected time-length for a track. Unless a read-out is started by 3^{rd} level trigger the older data are dropped from the memory buffer in order to make room for the new ones. The reading of the buffer memory is allowed for the 2^{nd} and 3^{rd} level trigger. While the memory can be read when requested by the 2^{nd} and 3^{rd} level trigger to perform the linear track trigger algorithm, the writing of the memory will continue cycling until a trigger signal is issued by the 3^{rd} level. When a read-out is started by the 3^{rd} level trigger the track data will be already stored into the memory buffer so they are simply to be read out. Only in this case and for test purposes the memory writing is stopped. The 3^{rd} level trigger with the associated electronics will be in charge to transfer the raw data of the relevant PDMs to the Cluster Control Processor (CCP) any time a trigger meets the imposed defined condition. Memory writing will be initiated by the CCP for a further operation at the completion of the read-out procedure.
Fig.1 shows the Focal Surface triggers topology. Looking to the figure starting from the top, the following components appear : a) 4 MAPMTs with the related Front-End electronics (ASIC) and the 1^{st} trigger level FPGA (TL1) that constitute the EC electronics. b) The outputs of 9 ECs (1 PDM) are connected to the 2^{nd} trigger level FPGA (TL2). The 2^{nd} trigger level FPGA can access the ring memory for data reading operation. c) 12 PDMs (2^{nd} trigger level FPGA output) are connected to the DSP Cluster, performing the 3^{rd} trigger level (TL3) (see fig.2). The 3^{rd} trigger level FPGA can access the ring memory for data reading operation. d) The DSP cluster communicates with CCP that in turn can access it as well as the others components. e) A ring dual port memory, one for PDM, is used for data storage.

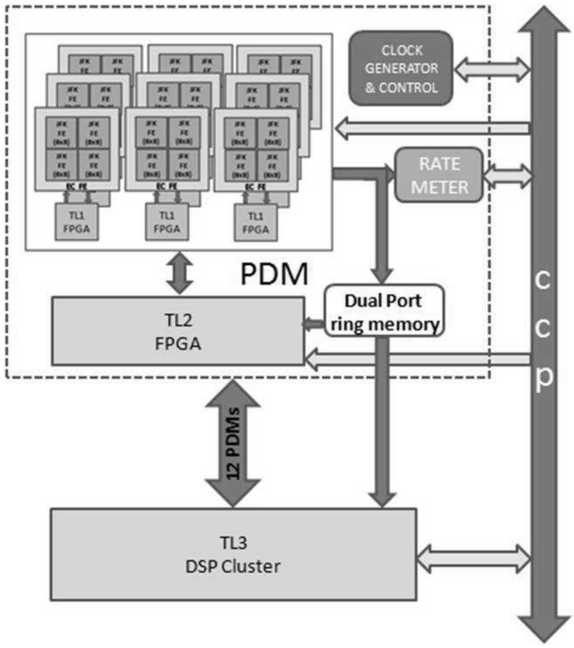

Fig. 2. Block diagram of the FS PDM electronics. In this case 12 PDMs are connected to one of the Digital Signal Processor (DSP) cluster.

V. Conclusions

The general architecture of the JEM-EUSO trigger scheme has been presented. The implementation of this scheme inside FPGA circuits is right now in progress. A further adjustment and fine tuning of the trigger algorithms to match the hardware constraints is then expected.

VI. Acknowledgments

This work has been partially supported by the Italian Ministry of Foreign Affairs, General Direction for the Cultural Promotion and Cooperation.

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