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The Data Processor System of EUSO-Balloon: In Flight Performance

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The EUSO-Balloon experiment is a pathfinder mission for JEM-EUSO which has as its main objective an end-to-end test of all the key technologies and instrumentation of JEM-EUSO detectors. The instrument is a telescope of smaller dimension with respect to the one designed for the ISS. It is mounted in an unpressurized gondola of a stratospheric balloon. It was launched during the CNES flight campaign in August 2014 from the Timmins (Ontario) base. The flight lasted about five hours and the payload reached a float altitude of about 38 km. In this paper we will present the Data Processor (DP) of EUSO-Balloon. The DP is the component of the electronics system which performs the data handling and, through the interface with the telemetry system, allows the controlling and the monitoring of the instrument from the ground. We will describe the main components of the system and their performance during the flight.

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1. Introduction

The Extreme Universe Space Observatory on-board the International Space Station (ISS) Japanese Experiment Module (JEM-EUSO) [1] is a new type of observatory which observes transient luminous phenomena occurring in the Earth's atmosphere. The main objective of JEM-EUSO is to investigate the nature and origin of Ultra High Energy Cosmic Rays, UHECRs ($E > 5 \times 10^{19}$ eV), which constitute the most energetic component of the cosmic radiation. The instrument consists of Fresnel lenses, a Focal Surface covered by photomultipliers, front-end readout, trigger and system electronics. The instrument is planned to be attached to JEM/EF of ISS for a three years long mission. EUSO-Balloon [2] is a pathfinder mission for JEM-EUSO, in particular it is the technology demonstrator of the instrument. Its main goal is to demonstrate the operation of crucial components including the HV system, photo detectors and electronics, in a near-space environment. For many subsystems, this low pressure environment is more challenging than the vacuum of space. EUSO-Balloon consists of a Fresnel optics made from 2 PMMA square lenses (UV transmitting Polymethyl-Methacrylate), a focal plane detector made from a single PDM (Photo-Detector Module) and a Data Processor. This paper will focused on the description of the Data Processor and its performance during the flight.

2. The Data Processor

The Data Processor (DP) system includes most of the digital electronics of the instrument. It controls the front-end electronics, performs the 2$^{\text{nd}}$ level trigger filtering, tags events with arrival time and payload position, manages the data storage, measures live and dead time of the instrument, provides signals for time synchronization of the event, performs housekeeping monitor, controls the High Voltage (HV) power supply and handles the interfaces to the Tele-Commands and Telemetry system. The DP functionalities are obtained by connecting different specialized items, which form a complex system. The main sub-assembly items of DP are listed below:

- GPS receiver
- Clock (CLK) board
- Cluster Control Board (CCB)
- CPU
- Data storage
- Data Processor Power Supply (DP-LVPS)
- Housekeeping (HK) system.

A block diagram of the DP is shown in Figure 1.

The DP acquires and stores data from the PDM through a Field Programmable Gate Arrays (FPGA) based board, called the PDM-Board. This board handles the front end electronics, namely the Elementary Cell (EC) units, and the interfaces with the CCB. The PDM board receives two

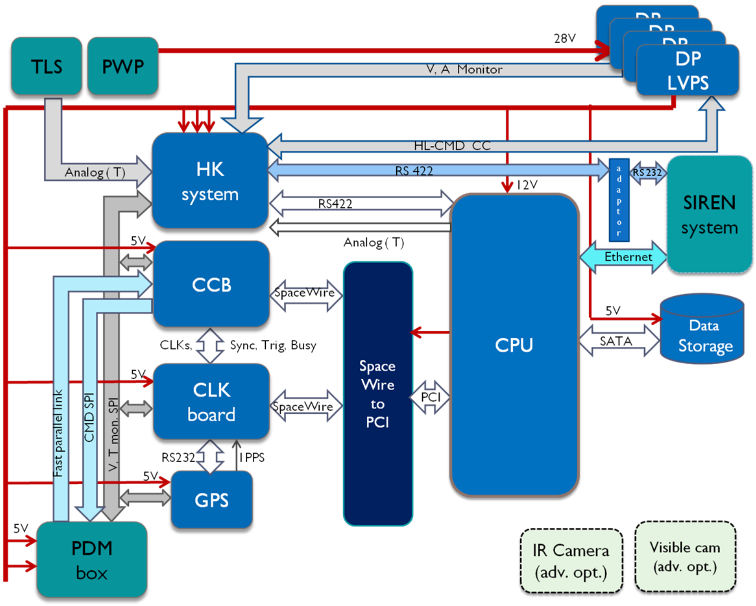

Figure 1: Block diagram of the Data Processor.

clock signals, generated by CLK-Board, from the CCB and distributes them to the front end electronics.

The DP system of EUSO-Balloon operates at high altitude in unpressurised environment and this represents a technological challenge for heat dissipation. To address this challenge, a passive cooling system that exchanges heat directly from the modules through the mechanics of the DP box to the gondola structure has been developed. The metal cooling plate of the DP box is connected mechanically to each subsystem and transfers the heat by conduction to the outside of the gondola. In addition, every subsystem is provided with a temperature monitoring system.

2.1 GPS receiver

The GPS receiver records, for each event, the position of the instrument and the UTC time with a precision of few microseconds.

The GPS receiver is interfaced to the DP through the CLK-Board, which associates the GPS relevant data to each acquired event. To properly interface with the CLK-Board, the GPS receiver was chosen with a 1PPS (Pulse Per Second) output and RS232 data/command communication port. The GPS receiver used for EUSO-Balloon is the Oncore M12+ manufactured by Motorola. The M12+ Oncore receiver provides position, velocity, time, and satellite tracking status information via a serial port. The receiver is capable of tracking twelve satellites simultaneously. To comply with ITAR restrictions, there is a limit in velocity (515 m/s above 18 km altitude, the working temperature range is -40°C + 85°C.

2.2 The Clock board

The CLK-Board [3] hosts the interface with the GPS receiver, it tags the events with their arrival time (UTC) and payload position. It generates the main clock (40 MHz) and the GTU clock

(400 kHz) which are distributed to all the other subsystem. It also measures the operating time and dead-time of the instrument and provides signals for time synchronization of the event. The CLK board can generate a trigger signal on a CPU command or in coincidence with the 1 Pulse Per Second (1PPS) signal provided by the GPS receiver or at a fixed frequency of 20 Hz. The last two trigger sources were added to synchronize the acquisition with the light emission time from calibrated light sources, laser or Xenon flasher, installed on the helicopter flying inside the instrument field of view [4]. Each trigger source correspond to a DP operative mode. During this first flight the trigger was provided exclusively by the CLK board. Most of the functions of the CLKB are implemented in a FPGA Xilinx Virtex-5 XC5VLX50T.

2.3 The Cluster Control Board

The CCB [5] has a direct connection to the PDM board through a 40 MHz parallel bus. It processes and classifies the received data to perform the 2^{nd} level trigger. In addition, CCB passes the clock signals from the CLK-Board to PDM board and the configuration data from CPU to PDM. The circuit is developed around a Xilinx Virtex-4 FX-60 with extended industrial temperature range.

2.4 CPU and Data Storage

The CPU, based on Atom N270 1.6 GHz processor, collects data from the CCB and CLK-Board through two (200 Mbits/sec) SpaceWire (SPW) links. It manages the Mass Memory for data storage and handles the interface with the telecommand/telemetry system. One acquired event represents roughly 330 kB of data. Since only a limited number of events can be transmitted to the ground through CNES' new NOSICA telemetry system, all data are stored on board using two 512 GB Solid-State Drives (SSD) operating in fault-tolerant RAID-1 configuration disks (Redundant Array of Independent Disks).

2.5 HK system

The House-Keeping system [6] collects telemetry from the sub-systems of the instrument in slow control mode. It is responsible for monitoring voltages and currents of the Low Voltage Power Supply. It uses a serial bus to convey telemetry and telecommands through the CPU interface and to other sub-systems. The HK is implemented around an off-the-shelf microcontroller board (Arduino Mega 2560), combined with 5 custom-made protocol interface boards to pre-process the various signals.

3. The flight

On August 24, 2014 at 20:53 Local Time (LT) (August 25, 0:53 Universal Time (UT)) EUSO-Balloon was launched successfully from Timmins Stratospheric Balloon Base (latitude 48.5° N). The payload was lifted using a 400000 m^3 Zodiac balloon filled with helium.

The instrument reached a float altitude of 38300 m at 23:43 LT.

While the balloon was ascending the High Voltage of the PMT was powered off because it was not yet dark, and the rest of the electronics was on. The monitoring and status (from the HK) was recorded during the ascension to verify that each element powered continued to operate properly.

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The HV was switched on at 22:50 LT, at an altitude of 32 km while the balloon was still on its ascent. The HV was increased progressively. The flight was terminated on August 25 at 4:20 LT. The instrument separated from the balloon, descended by parachute, and landed about 100 km to the west of Timmins.

3.1 Instrument control during flight

The instrument was controlled by two access points: a serial line toward HK microcontroller and an Ethernet port connected to the DP-CPU. During the flight, the serial line and the Ethernet port of the instrument were connected to the NAUSYCA CNES telemetry module (TM). The Ground Support Equipment (GSE) server sends or receives the Ethernet data to/from the instrument through its internal network via the two Siren modules. The GSE server or the Gateway computer was used as the centralized detector control.

3.2 Data acquisition during the flight

Calibration runs (S-curves) were acquired during ascension to check the noise level and its evolution with altitude/pressure/temperature. Monitoring and status from the HK were continuously recorded and checked. Data were recorded continuously using the external trigger sent by the CPU with a fixed periodicity. Regular calibration runs (S-curves) were taken.

The data taking sequence was:

- first operation: acquisition of 200 events and an S-curve and transmission to ground via TM.
- a sequence of automated procedure:
  - 5 long runs of 2000 events each
  - 1 short run of 200 events that was transmitted to ground
  - an S-curve

The system was configured to operate even if the data link to the ground was lost.

Two acquisition modes were defined:

- CPU-Trigger mode: baseline data acquisition mode, trigger generated by CPU, trigger rate about 19 Hz
- Synchronized acquisition mode: modified mode to allow the helicopter based laser/flasher system to be synchronized with the trigger: trigger generated by CLK-Board at a fixed rate of 20 Hz.

Acquisition mode were changeable from ground. In both modes the trigger signal was in OR with the 1PPS signal from GPS.

We changed the configuration of the ASIC from ground during the flight:

- 3 hours: same fixed threshold and gain for all of the pixels;
- 1 hour with a threshold table: optimized threshold for each ASIC;
- 1 hour with a gain table: optimized gain at the level of each ASIC for each channel.

4. Data Processor performance

During the 5h 20' of operation about 256000 events of 128 GTU each were acquired. This translates into 83 GB of data that was recorde on the disks. 8 GB of these data was transferred to ground during the flight. In total, about 8000 data-packets (i.e. nearly a million GTU) were transmitted to the ground together with telemetry data (voltages, currents and temperatures) through the 1.3 Mbit/second link.

As shown in Figure 2, the data taking was continuous with only one significant interruption due to a problem on the HV setting of the PMT.

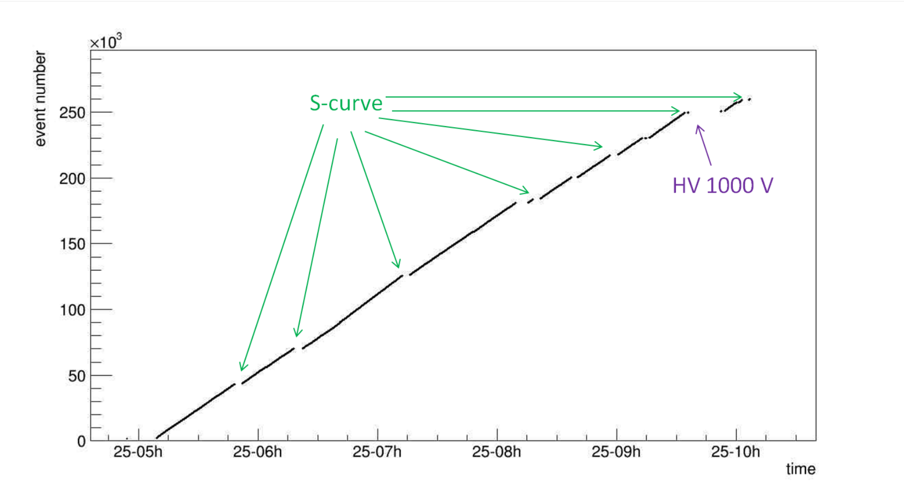

Figure 2: Number of acquired events as a function of time, (UTC), S-curve arrows indicate calibration runs.

4.1 Live and dead time measurement

In Figure 3 and 4 the live and dead time distributions are shown. From these plot, it results

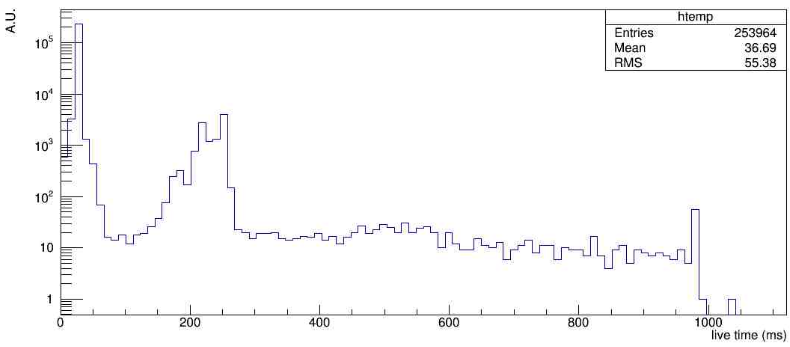

Figure 3: Live time distribution.

that the mean values of live and dead time are:

$$< \text{Live time} >= 37.86\,ms$$

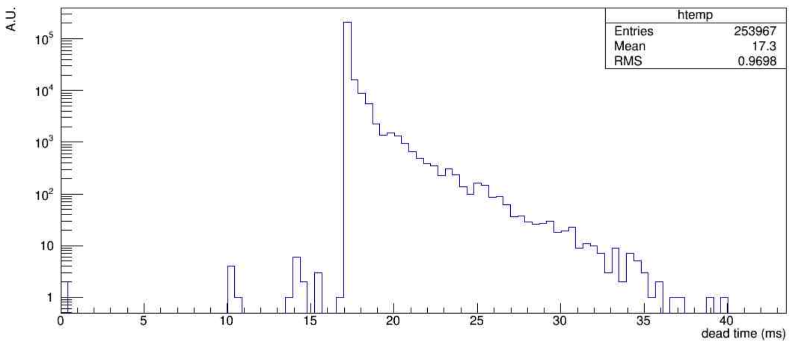

Figure 4: Dead time distribution.

$$< \text{Dead time} >= 17.25\,ms$$

The live time is compatible with the time needed by CPU to send a new trigger signal, while the mean dead time is comparable with the data transfer time via SPW link (330 Kbyte) at 200 Mbits/second. Using these value it is possible to estimate the mean trigger rate:

$$< \text{Trigger rate} >= 18\,Hz$$

Taking into account the time at float (about 5h 15' $\sim$ 18900 s), the total number of events ($\sim$ 256000) and the event duration (128 GTU = 320 μs), it is possible to calculate the total acquisition time:

$$T_{acquisition} = N_{events} \cdot \text{event duration} \simeq 80s$$

which corresponds to the 0.4% of the time at float.

If we consider the sum of live and dead time:

$$T^{tot}_{dead+live} = N_{events} \cdot [< \text{Dead time} > + < \text{Live time} >] = 14080s$$

and the time needed to take s-curves:

$$T_{s-curves} = 7 \cdot 3' \sim 1200\,s;$$

the total data taking time is:

$$\text{Total data taking time} = T_{acquisition} + T^{tot}_{dead+live} + T_{s-curves} = 15300\,s$$

which means:

$$\frac{\text{Total data taking time}}{\text{Time at float}} = 81\%$$

The remaining 19% of the time included the configuration procedure at the start of every run, problems related to communication with PDM and a HV problem near the end of the flight.

In the plot of Figure 5, the sum of dead and live time is reported as function of the UTC time. The clear vertical band structure is due to the data transfer. After a short run the CPU has to transfer the data on ground, so the data acquisition becomes slower. As expected when the Synchronized acquisition mode was used the sum of dead time and live time is exactly 50 ms, which corresponds to a trigger frequency of 20 Hz.

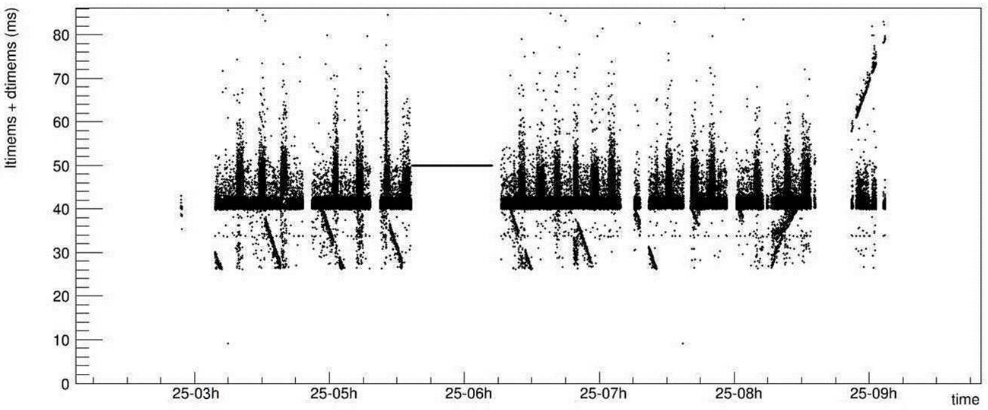

Figure 5: Dead time + live time as a function of time (UTC).

5. Conclusions

The EUSO-Ballon flight in 2014 has demonstrated the maturity of the key technologies and methods that will be used for JEM EUSO. The Data Processor system provided successfully the full control of the instrument and smooth data taking for the full length of the flight. All the subsystems of the DP worked as intended contributing to the success of the mission.

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