The High Energy Particle Detector operational status during 3 years of flight on board the China Seismo-Electromagnetic Satellite

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ABSTRACT

The China Seismo-Electromagnetic Satellite is a multi-instrument space mission dedicated to the investigation of the topside ionosphere structure and dynamics (plasma parameters, electromagnetic fields and charge particles fluxes) and the possible correlation of its perturbations with the occurrence of high magnitude earthquakes. The main contribution of the Italian collaboration to the mission is the High Energy Particle Detector (HEPD), designed and built for the detection of electrons and protons in the energy range 3-100 MeV and 30-200 MeV, respectively. The satellite was launched on February 2, 2018 from the Jiuquan Satellite Launch Center (Inner Mongolia, China) and HEPD is fully operational since July 28, 2018.
To ensure correct operations and optimal performances during the expected life time of 5 years, the HEPD on-board software hosts the Control & Housekeeping system responsible for the detector management and monitoring.
The system handles instrument data acquisition and calibrations, HEPD configuration and monitoring and acts as the main interface of the detector with the satellite platform. The continuous monitoring of HEPD status allows to control the detector functionality, to check electronics stability, to identify anomalous behaviors and to perform recovery actions if necessary. Besides, the high configurability of the detector allows to modify HEPD configuration in order to preserve its detection efficiency that can deteriorate along with the detector age. In this paper we describe the HEPD Control & Housekeeping system and HEPD operational status during its 3 years of flight.

Image credit: NASA

THE HIGH ENERGY PARTICLE DETECTOR

The High Energy Particle Detector (HEPD) on-board CSES [1] is devoted to the observation of electrons and protons in the range 3-100 MeV and 30-200 MeV, respectively [2,3]. To this aim HEPD comprises several sub-detectors (Fig.1), electronic (ELS) and power supply subsystems (Fig.2).
To avoid permanent failures, each electronic board and power supply is duplicated in a MAIN and SPARE side.
The CPU board hosts the Control & Housekeeping (C&H) system responsible for the detector management and monitoring, as well as for its communications with the satellite platform via CAN-bus interface.

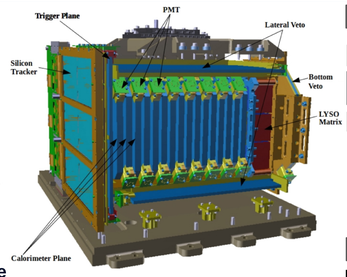

Fig. 1: High Energy Particle Detector (HEPD)

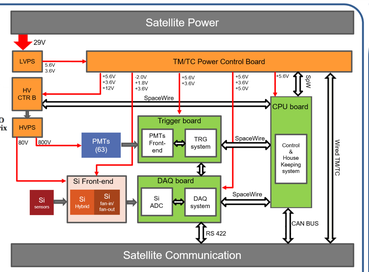

Fig. 2: HEPD electronics and power supply subsystems.

THE CONTROL & HOUSEKEEPING SYSTEM

The Control & Housekeeping (C&H) is responsible for:
- management of HEPD operations as well as for diagnostic routines, providing information about the detector status, by means of the internal Slow Control link (SpaceWire link) that allows communications between CPU and the other ELS boards;
- Management of the bi-directional CAN-bus interface allowing to receive both satellite broadcasts and TeleCommands (CAN-bus TCs) and to send back instrumental command replies and instrumental TeleMetry (CAN-bus TM) containing information about the detector status;
- management of temporal tag of runs and broadcast and storage of non volatile information.

For reliability, the C&H system is implemented in an application program stored in two non-volatile memory chips of CPU board: a writable FRAM and a read-only flash memory (EEPROM) [4].

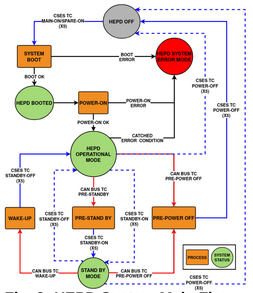

Fig. 3: HEPD System Main Flow

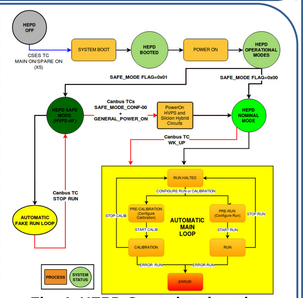

Fig. 4: HEPD Operational modes

At power-on the TM/TC Power Control board enables the voltage towards the CPU board; after CPU boot, the C&H system is responsible for the power-on and initialization of ELS. If all boards are booted correctly, HEPD is set in OPERATIONAL mode (SAFE or NOMINAL mode); if set in NOMINAL mode HVPSs are powered at their nominal values providing bias to PMTs and Silicon ladders. From OPERATIONAL mode, the HEPD can be powered off or set in STAND-BY mode (non acquisition zones) by means of dedicated wired and CAN-bus TCs, managed by the C&H itself (Fig.3). Once in OPERATIONAL mode, the system starts a main loop during which runs and calibrations are configured and executed automatically depending on the orbital zone configurations (Fig.4).
During operations, the C&H system periodically monitors the ELS via Slow Control link and sends TM data containing diagnostic information to the satellite via CAN-bus link, while other housekeeping and auxiliary information are sent to the DAQ in order to be included in the scientific data (Fig.5).

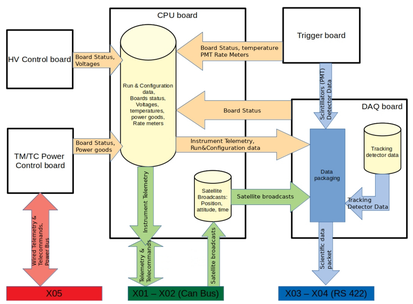

Fig. 5: HEPD scientific and housekeeping data handling and transmission

[1] X. Shen, et al., The state-of-art of the China Seismo-Electromagnetic Satellite mission, Sci.China Technol. Sci., vol. 61, no. 5 (2018) pp.634-642.
[2] G. Ambrosi, et al., The HEPD particle detector of the CSES satellite mission for investigating seismo-associated perturbations of the Van Allen belts, Sci. China Technol. Sci., vol. 61, no.5 (2018) pp.643-652.
[3] P. Picozza, et al., Scientific Goals and In-orbit Performance of the High-energy Particle Detector on Board the CSES, ApJS vol. 243 (2019) pp. 16.
[4] A. Sotgiu, et al., Control and Data Acquisition Software of the High-Energy Particle Detector on board the CSES Space Mission, Softw: Pract Exper. vol.51, issue 6 (2021) pp.1459–1480.

In-flight Operations and Status

In-flight Operations

The HEPD was launched on-board CSES on February 2, 2018 from the Jiuquan Satellite Launch Center (Inner Mongolia, China). After CSES launch and HEPD first power-on and "Health-Check", the apparatus underwent the Commissioning phase (February-July 2018), devoted to the study of HEPD performances with different settings and to the definition of the optimal in-flight detector configuration. Fixed the configuration, on July 28, 2018 HEPD has been set for regular data-taking mode. Up to day, post-commissioning operations have been mainly performed in order to power-off HEPD for satellite maneuvers or temperature issues (standard procedure), to reconfigure the detector and to recover HEPD from anomalous behaviors, identified by means of TM data. For almost all anomalies, HEPD functionality was recovered automatically exiting standby zone or by the application of power-off procedure; in two cases, involving the corruption of FRAM configuration, specific procedures have been necessary.

In-flight Status

From the end of the commissioning operations up to April 14, 2021, CSES has performed more than 15000 orbits, corresponding to more than 21000 hours of flight, for a total of about 14000 hours of acquisition, considering the limited duty time due to the high-latitude standby zones.
During this period, the HEPD has been able to acquire scientific data for about 89.45% of its lifetime; for the remaining 10.55% of time, the HEPD has not been able to acquire scientific data for regular reboots (agreed with satellite managers) or anomalies (malfunctions) and related recovery actions (Fig.6).

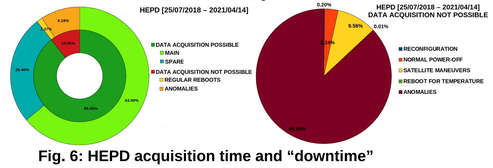

Fig. 6: HEPD acquisition time and "downtime"

Housekeeping data

The Telemetry data are mostly used to check the stability of the electronics, in order to identify anomalous behaviors and to investigate the possible source of malfunctions.
Anomalies mainly detected in HEPD functionality:
- Partial/Total power-off of HEPD electronics (or failed reboot of one ELS) due to LVPS issue related to a common problem/cause interesting the output section of the main LVPS (5.6 V) or to fast transient of current/voltage in the LVPS not detectable in telemetry;
- Anomalies related to Radiation issue: in two cases a SEU (Single Event Upset) could be the responsible of the corruption of the HEPD configuration written on the CPU FRAM.

Temperature (Fig.7): an abnormal increase of the temperature can indicate or can be the cause of a malfunction of the apparatus; because of such increases, the HEPD has been reboot few times in order to keep the instrument in its working range of temperatures; temperature spikes interest mainly the MAIN side and are often correlated with operational malfunctions.
HVPS voltages (Fig.8): the monitored values have been averaged over 5 days; despite the discontinuity due to the switch from the MAIN to the SPARE side of the electronics, the HVPSs show a very stable behavior with an overall variation below 0.75% for HVPSs biasing PMTs and below 1.5% for those biasing the Silicon sensors
Other parameters (PMT pedestals and rate meters and HEPD response to MIP) are periodically monitored using Scientific data.

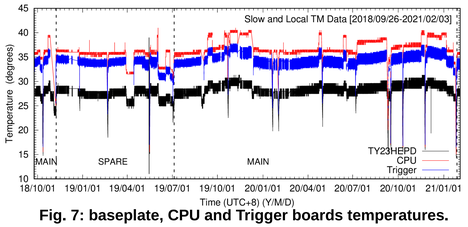

Fig. 7: baseplate, CPU and Trigger boards temperatures.

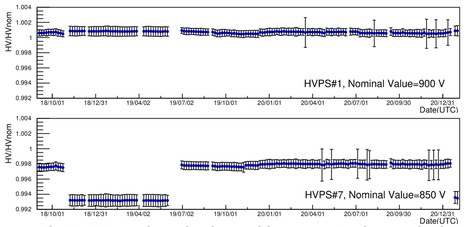

Fig. 8: HV monitored values with respect to the nominal one for HVPS #1,#7 biasing PMTs

CONCLUSION

The HEPD was launched on-board CSES on February 2, 2018 and, since July 28, 2018 it is fully operational for regular data taking. Since first flight phases, the C&H system demonstrated to handle correctly detector activities and operations, allowing several changes of configuration and to perform recovery actions in case of anomalous behaviors. Malfunctions and relative origins were identified by means of TM data, provided by the continuous monitoring of the apparatus carried out by the system; nevertheless more diagnostics would be needed to investigate deeply the causes at electronic level. For the improved version of HEPD detector on-board CSES-02 satellite (HEPD-02), currently under development, the C&H system will be upgraded with more diagnostics and operational functions.