THE PLATO PAYLOAD DATA PROCESSING SYSTEM

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Short Paper

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ABSTRACT

The objective of the PLATO mission is to detect and characterize exoplanetary systems. The PLATO payload is made up of 34 very high-precision photometric cameras, each camera having its own CCD focal plane constituted by four 20-million pixel CCDs. The huge amount of raw data produced for each exposure has led the PLATO Payload Consortium to propose a design of the onboard data processing system based on a hierarchical architecture in which the SpaceWire technology is extensively used and plays a key role.

1 INTRODUCTION

1.1 THE PLATO MISSION

PLATO (PLAnetary Transits and Oscillations of stars) is one of the three Cosmic Vision M-class missions which have been approved on February 2010 by the ESA's Science Programme Committee to enter the definition phase.

The objective of PLATO is the detection and characterization of exoplanetary systems of all kinds, including both the planets and their host stars, reaching down to small, terrestrial planets in the habitable zone [1]. The PLATO instrumental concept is based on an ultra-high precision, long (few years), uninterrupted photometric monitoring in the visible of very large samples of bright stars. The resulting high quality light curves will be used on the one hand to detect planetary transits, as well as to measure their characteristics, and on the other hand to provide a seismic analysis of the host stars of the detected planets.

During the assessment phase which has been completed at the end of 2009, studies of the whole mission have been carried out independently by two industrial contractors.

At the same time, an assessment study of the PLATO payload (telescopes, detectors, cameras, on-board data processing system) has been provided by a consortium of research institutes and universities: the PLATO Payload Consortium (PPLC). The design of the PLATO payload data processing system presented in this paper is the result of the PPLC studies and will serve as a baseline for the further studies of the definition phase.

1.2 INSTRUMENTAL CONCEPT

The instrumental concept proposed by the PPLC is based on a multi-camera approach, involving a set of 32 normal cameras monitoring stars fainter than mV=8, plus two fast cameras observing extremely bright stars with magnitudes lower than 8. The 32 normal cameras are arranged in four sub-groups of 8 cameras. All 8 cameras of each sub-group have exactly the same field of view, and the lines of sight of the four sub-groups are offset by half the size of the field of view. This particular configuration allows surveying a very large square field at each pointing, with various parts of the field monitored by 32, 16 or 8 normal cameras. This strategy optimizes both the number of targets observed at a given noise level and their brightness.

Each normal camera is equipped with its own CCD focal plane array (FPA) constituted by four 20-million pixel CCDs working in full frame mode. The fast cameras are equipped of four 10-million pixel CCDs working in frame transfer mode. With 32 normal cameras working at the cadence of 25 seconds and 2 fast cameras working at the cadence of 2.5 seconds, the amount of raw data produced by the PLATO payload at the output of its 136 CCD detectors is close to 189 Terabits per day. This volume must be compared to the 109 Gigabits which can be actually downloaded each day to the ground. It is clearly not possible to transmit the whole amount of raw data. The role of the on-board treatments will be to reduce by a factor of more than 1700 the flow rate by downlinking light curves, centroid curves and imagettes at the cadence required by the science.

This huge amount of data to process has led the PPLC to propose a design of the onboard data processing system based on a hierarchical architecture in which the SpaceWire technology is extensively used and plays a key role at each stage of the architecture.

2 OVERVIEW OF THE PLATO PAYLOAD DATA PROCESSING ARCHITECTURE

The PLATO payload data processing system is made up of 34 Data Processing Units (DPUs) responsible for reducing the data flow by computing light and centroid curves. The 34 DPUs are connected to two central Instrument Control Units (ICUs) through a SpaceWire network built around ten SpaceWire routers to which ten other routers are added for the redundancy management. The ICUs are working in cold redundancy and are connected to the spacecraft Service Module (SVM) through SpaceWire links.

There is one DPU per camera performing the basic photometric tasks and delivering a set of light curves, centroid curves and imagettes to the active ICU, which stacks and compresses the data, then transmits them to the spacecraft SVM for downlink. Data from all individual cameras are transmitted to the ground, where final instrumental corrections, such as jitter correction, are performed. The DPUs of the fast cameras will also deliver a periodic pointing error signal to the spacecraft AOCS (Attitude and Orbit Control System). Several photometry algorithms (aperture photometry, weighted mask photometry, Line Spread Function fitting) are planned to run on board, each star being processed by one of them, depending on its brightness and level of confusion.

For FMEA (Failure Mode and Effects Analysis) concerns and in order to optimize the resources (mass, volume, harness), the DPUs of the 32 normal cameras are distributed in 8 groups of 4 DPUs. Each group of 4 DPUs is gathered in a box called a Main Electronic Unit (MEU). A set of 2 MEUs corresponds to a set of 8 cameras sharing the same field of view. A MEU gathers in the same box four DPU boards, 1 power supply (DC/DC converter) and 2 SpaceWire routers to merge the data from the DPUs toward the ICU (one main and one redundant).

All the command / data exchanges between the payload units and with the spacecraft SVM are ensured thanks SpaceWire links except the AOCS link between Fast DPU and the spacecraft SVM. The figure 1 shows the architecture of the PLATO data processing system and its SpaceWire network.

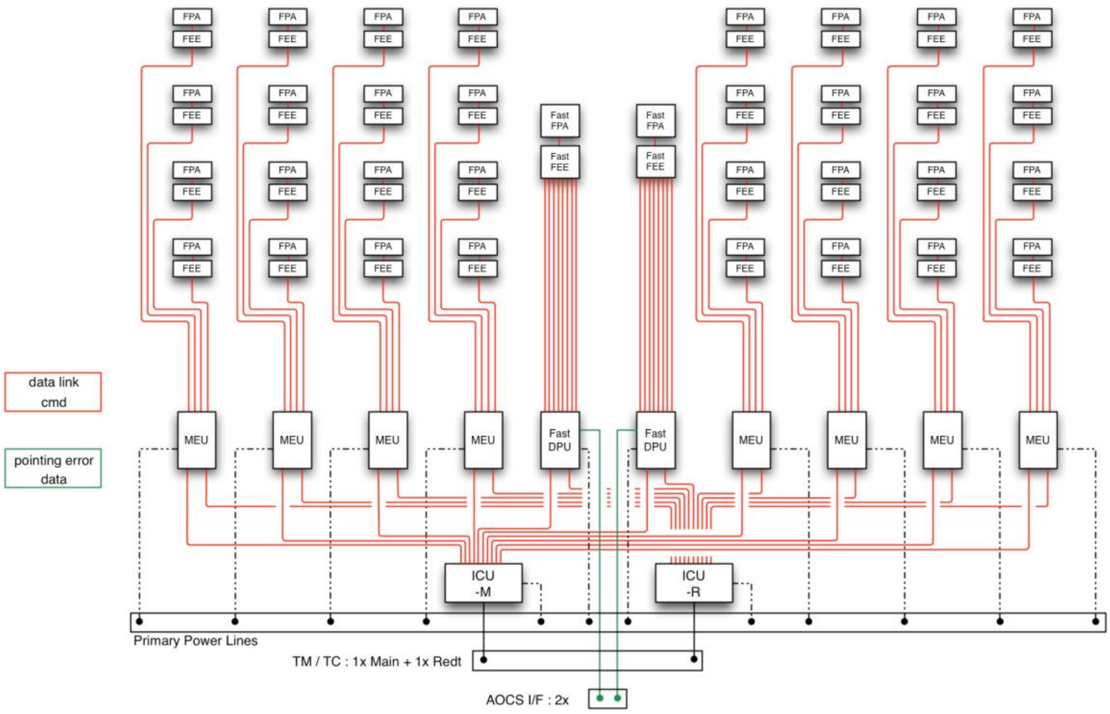

Figure1 – PLATO On-board Data Processing Architecture

3 THE DATA PROCESSING UNITS (DPUS)

Each normal camera has its own front-end electronics (FEE) driving the four CCDs and transmitting the pixel data to its DPU through a SpaceWire link. At the FEE level, no pre-processing such as windowing is done. The full images corresponding to each CCD are transmitted entirely. The raw data acquired from the ADC are just serialized and sent to each normal DPU through one point-to-point SpaceWire channel. The communication between the FEE and the DPU uses a point-to-point SpaceWire channel without any router in order to guarantee the real-time constraints on this interface. Over a period of 25 seconds corresponding to the CCD readout period, each normal DPU receives 4 CDD full-frame images (one 330-Mb image / 6.25 seconds). Each CCD full-frame image is entirely stored in SDRAM memory before processing. The RMAP protocol [3] is used to transfer at a very high rate close to 160 Mbps the full frame images directly to the DPU memory without any cost for the DPU software. The CPU occupation rate needed to acquire and to store the full-frame images shall be negligible: this is a strong requirement. The CPU resources shall be reserved for the photometric treatments of the 120.000 stars distributed on the four CCDs. The DPU hardware module in charge of the image reception relies on the DMA (Direct Memory Access) technology and provides a hardware implementation of the RMAP protocol. Using DMA and RMAP technologies, it could be possible to have an image transfer fully transparent for the CPU: the RMAP protocol is particularly well suited for this kind of application. The core of the normal DPUs will be a LEON-FT processor chip ideally integrating SpaceWire interfaces with RMAP and DMA support.

Unlike the normal DPUs, the fast DPUs receive the pixel data from the FEE of their respective camera through 8 specific LVDS high speed serial links (one link per CCD output): using 8 SpaceWire links was considered too costly in term of resources and merging the 8 outputs to one channel leads to a flow rates greater than 600 Mbps which is not compatible with the SpaceWire performances.

4 THE INSTRUMENT CONTROL UNITS (ICUS)

Both ICUs work in cold redundancy. They play the role of the payload conductor: they schedule the DPU tasks by the way of commands, manage the mode changes and regulate the data flow. They are connected to the eight MEUs and to the two Fast DPUs through SpaceWire links. The ICUs use the SpaceWire network to propagate a synchronization signal to all the DPUs thanks to the SpaceWire time-code functionality [2]. They are also responsible for formatting and transmitting to the spacecraft SVM the scientific telemetry packets and the housekeeping telemetry packets. Each ICU is connected to the SVM with two SpaceWire links (one main and one redundant) for telecommand reception and telemetry transmission.

In the current design, two SpaceWire routers are foreseen in each ICU. An alternative solution, which consists to put the SpaceWire router function outside the ICU box, with the aim of reducing the number of links directly connected to the ICU and also to improve the redundancy scheme, will be studied in the definition phase of the mission.

In the global architecture, the ICUs are also in charge of a second level of data reduction. All the flux and centroids sent by the normal DPUs and the fast DPUs at the cadence respectively of 25 seconds and 2.5 seconds are cross-checked, stacked and temporally averaged in order to produce the final telemetry at the cadence required by the science (50 seconds and 600 seconds). Lastly, before being transmitted to the SVM, the data are compressed using a lossless compression algorithm.

In order to reduce the complexity of the DPUs, the in-flight maintenance of the DPU application software is delegated to the ICUs. The DPUs don’t have locally an EEPROM and don’t manage the maintenance of the application software. The ICUs are responsible for storing in their EEPROM the DPU application software and managing its maintenance (changing the content of the EEPROM, adding a new version of the application software in EEPROM). After a switch-on or a DPU reset, during the boot process, the DPU boot loader (stored in the DPU PROM) loads the Application Software code and data over the SpaceWire link from the ICU.

5 CONCLUSION

The design of the PLATO payload data processing system is well advanced. However, several issues must still be consolidated until the end of the definition phase and the final selection of the Cosmic Vision M-class missions by ESA which is expected for June 2011. Firstly, the technical budgets of each subsystem (DPUs, ICUs) concerning the CPU resources, the power consumption, the surface and the mass will be refined. The design of the different units will be then detailed. Finally, the critical functions and interfaces which have been identified like the high-throughput interface between the FEEs and the DPUs of the normal cameras will be prototyped.

The future studies will be pursued always keeping in mind the two main principles that have governed the preliminary studies. The first principle is to have standard interfaces between the different units of the payload in order to minimize the specific developments at the instrument level and at the test equipment level, to simplify the tests and finally to reduce the global cost. As we have shown in this paper, SpaceWire technology is the ideal response to this requirement. The second principle is to get the most compact design and the less power expensive solution possible at the subsystem level. There are 34 DPUs: 1 watt saved is 34 watts saved. The goal is then to minimize as much as possible the complexity of the DPUs: if a function can be delegated to the ICU, then it shall be delegated to the ICU.

The PLATO definition phase will be also an opportunity to address the complex question of the data processing system AIT (Assembly, Integration and Tests) and to propose a global approach for conducting these activities.

6 REFERENCES

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