The Data Processing Unit of the Solar Wind Analyzer SWA onboard Solar Orbiter

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Abstract

The Data Processing Unit (DPU) is the "heart" of the plasma suite SWA and is the only interface with the S/C. The DPU is interfaced with EAS, PAS and HIS sensors via SpW dedicated links and is in charge of supporting EAS and PAS with power, functionality control, temporary storage, communication and computational capability and, in addition, supports HIS with communication to the S/C. Its architecture derives from a trade-off analysis aiming to define a system able to perform the needed computational tasks while keeping mass, volume and power within the limits imposed by the constraints. Additionally, the DPU has been designed to be "single fault" tolerant and the "cold-spare" concept has been adopted as redundancy philosophy. It implements data and command interfaces with the S/C via the redundant SpaceWire (SpW) data links and the redundant power input HV-HPC command interface. Two independent, executable SW images represent the overall SWA DPU SW: the Boot SW (BSW) and the Flight SW (FSW). While the BSW manages the basic hardware initialization, the FSW manages TC/TM, controls all the processes related to the state of the sensors, validates and executes TC, acquires, processes, compresses and formats science data prior to downlink for EAS(1&2) and PAS sensors, while HIS autonomously processes its scientific data. In particular, FSW is in charge of data compression, moments calculation and telemetry generation restrictions to keep each sensor within its respective telemetry allocation. Remarkable level of data compression for EAS, which generates the largest data volume, is reached via customized implementation of lossless CCSDS 121.0 based on a "Complex Reordering" mechanism, which avoids periodical jumps among acquisition directions in phase space. Moments of proton and electron velocity distribution functions are computed onboard. Different Look-Up Tables (LUT) for PAS and EAS allow to perform moments calculation modulating the counts in each volume of phase space by a combination of the factors contained in these tables. Finally, since SWA data production greatly changes from normal to burst mode, a book keeping algorithm (BKA) will monitor and control, continuously along the orbit, the amount of burst mode, scheduled or triggered, used against the pro-rata expectation.

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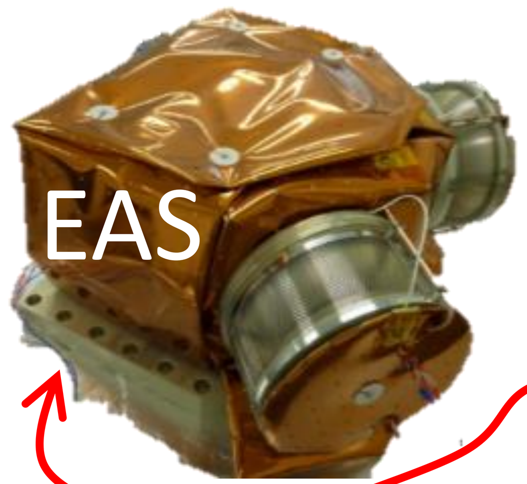
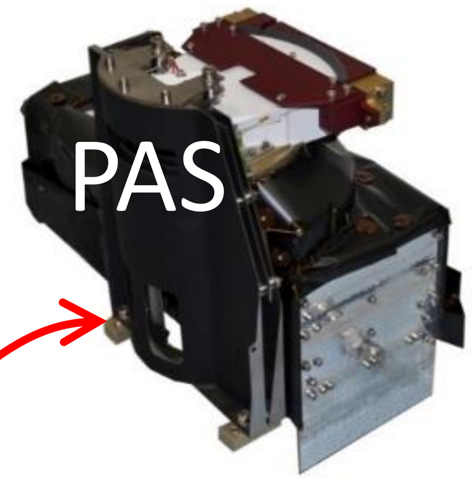
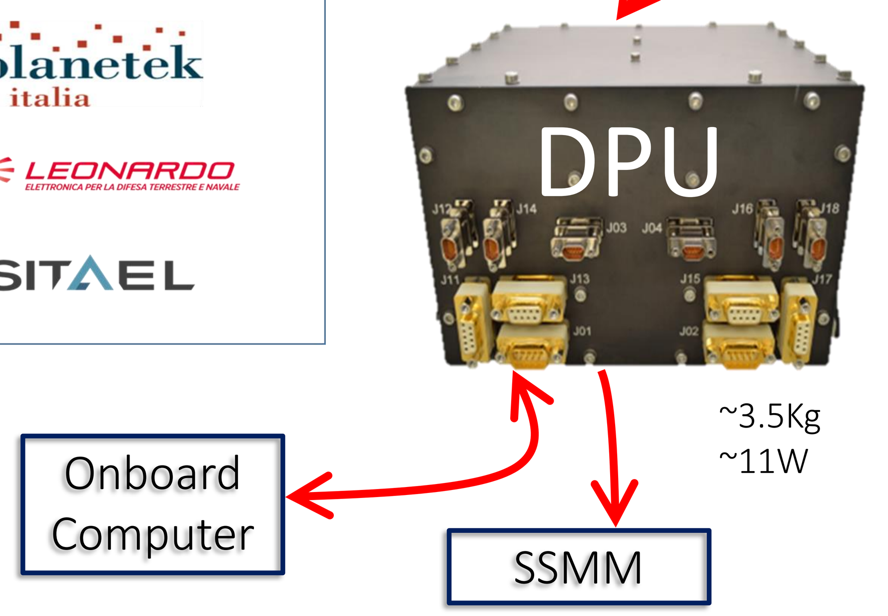


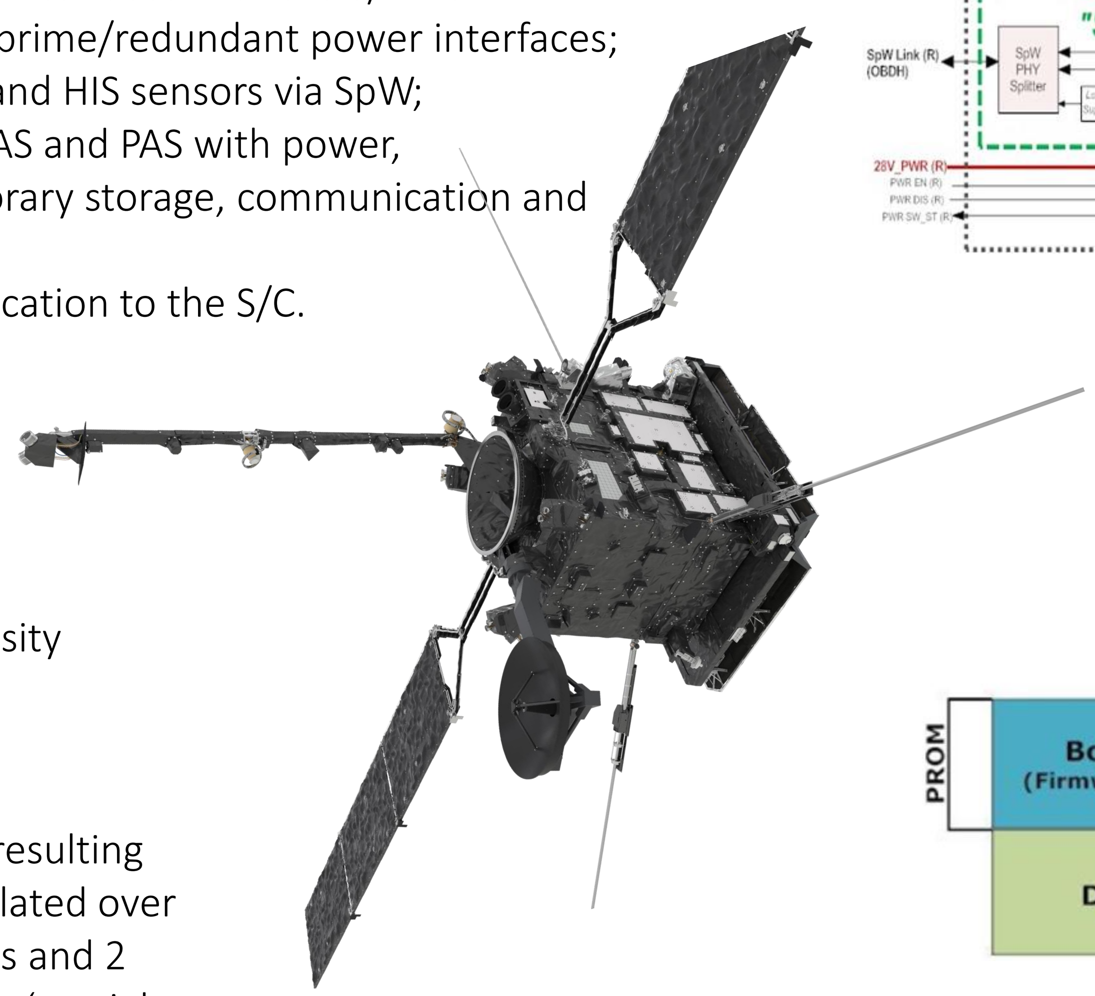


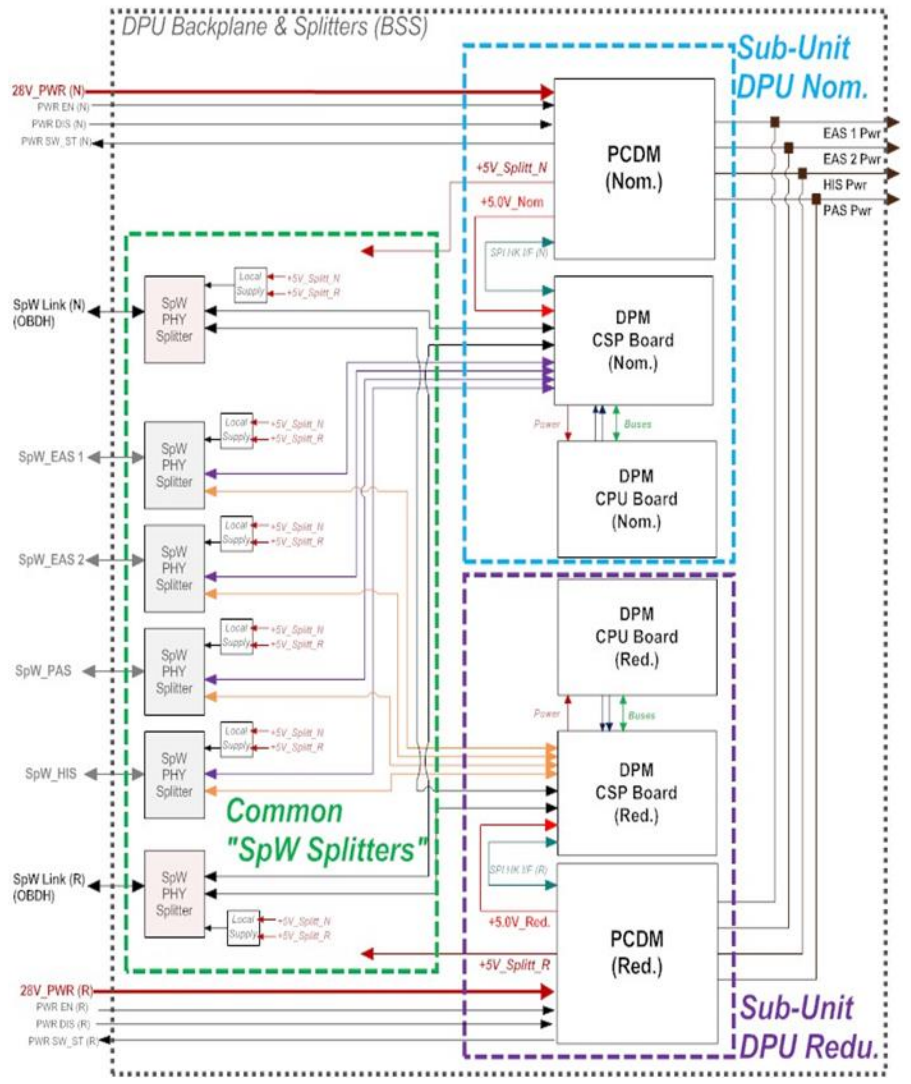


The SWA Data Processing Unit (DPU) is the "heart" of SWA. It represents the primary SWA interface with the S/C.

The DPU:

1. Implements data command interfaces with the S/C via prime/redundant SpW and prime/redundant power interfaces;
2. Is interfaced with EAS, PAS and HIS sensors via SpW;
3. Is in charge of supporting EAS and PAS with power, functionality control, temporary storage, communication and computational capability;
4. Supports HIS with communication to the S/C.





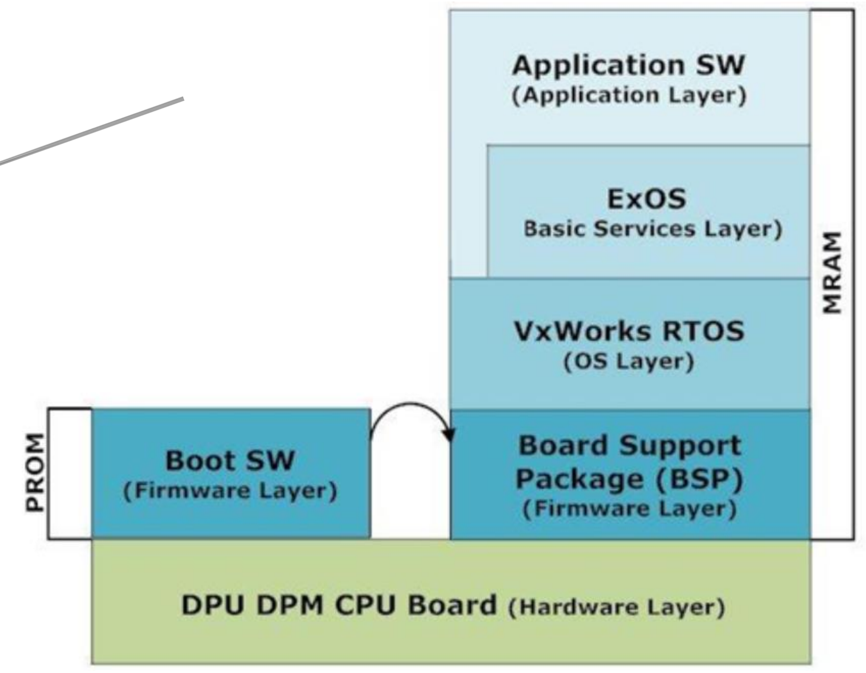
◄ DPU: Data Processing Unit - design

The SWA DPU is comprised of a number of elements shown in figure on the left:

- 1 x Backplane and SpW Splitter (BSS) front-end I/F circuits;
- Sub-Unit 1 (DPU Nominal) and Sub-Unit 2 (DPU Redundant) each composed of:
  - Power Conditioning and Distribution Module (PCDM);
  - Data Processing Module (DPM), composed of:
    - Communication and Scientific Data Processing (CSP) board;
    - Central Processing Unit (CPU) board.

The CSP board is based on two RTAX2000 FPGAs (primary and secondary) and a 2.5Gbit SDRAM mass-memory needed for buffering the scientific data coming from EAS and PAS. The CPU board is based on the Leon2FT ASIC AT697F by ATMEL, running at 100MHz and working under the VxWorks Real Time Multitasking Operating System.

DPU: Data Processing Unit - software



The overall SWA DPU SW consists of two different independent executable SW images (◄ Figure to left), each loaded on the prime and redundant sides of the DPU:

a) the BOOT SW (BSW);
b) the Flight SW (FSW).

The BSW performs the basic hardware initialization and checks the status of processor and memory.

The FSW is structured in different Software Layers controlling TC validation and execution, TM, DPU and sensors' state, tasks execution and inter process communication, Scientific Data Processing, exchange of information among the subsystems and between the DPU and S/C, etc...

The access between the above Software Layers and all DPU internal HW and physical interfaces of the system is provided by the Board Support Package (BPS) software.

DPU: Data Processing Unit – data crunching: moments

The Scientific Data Processing Software (SDPSW) is the component of the FSW in charge of processing data collected by EAS (1 and 2) and PAS sensors.

Moments of particle velocity distribution function f(v) are the most concise scientific information to characterize plasma status.

$$N = \int f(\vec{v})\, d^3v$$

$$NV = \int f(\vec{v})\, \vec{v}\, d^3v$$

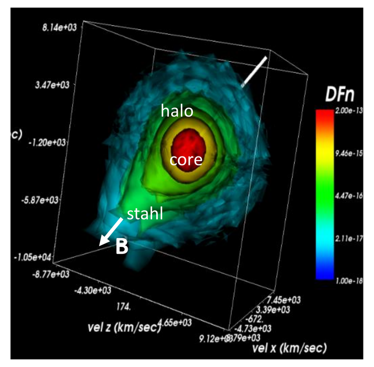
$$\Pi = m \int f(\vec{v})\, \vec{v}\vec{v}\, d^3v$$

$$Q = \frac{m}{2} \int f(\vec{v})\, v^2 \vec{v}\, d^3v$$

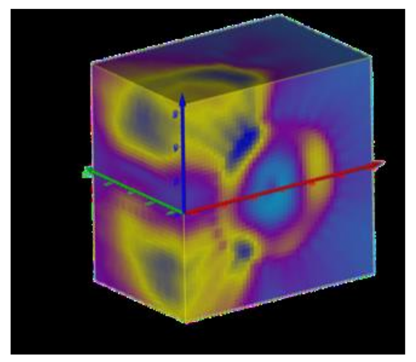
N = number density
NV = number flux density
Π = pressure tensor
Q = heat flux

For the EAS sensor, the resulting 13 parameters are calculated over 3 separate energy ranges and 2 angular regions to create 'partial moments' per sensor head. These support cross calibration of the heads and ability to ignore regions affected by e.g. Photoelectrons.

DPU: Data Processing Unit – data crunching: lossless compression



EAS:
VDF acquired as a cube of counts whose dimensions are: Θ, E, Φ and stored in a one dimensional array (rolling buffer) to be compressed



Best compression ratio reached by re-organizing the acquisition sequence (Θ, E, Φ) in order to reduce jumps in the sequence (10% gain) and further applying a Complex Reordering mechanism to assure the highest degree of spatial continuity among contiguous samples (17% gain):

EAS CR*..........................1.9 - 12.1
PAS CR*..........................3.4 - 17.5

*depending on data product.

Sensor	Telemetry Allocation (bps)	SSMM load (Gbits per 168 day orbit)
SWA/EAS	4345.4	63.1
SWA/HIS	5512.5	80.0
SWA/PAS	4455.4	64.7
SWA/DPU + HK	300	4.35
Total	14613.3	212.1
Project Allocation	14500	210.5

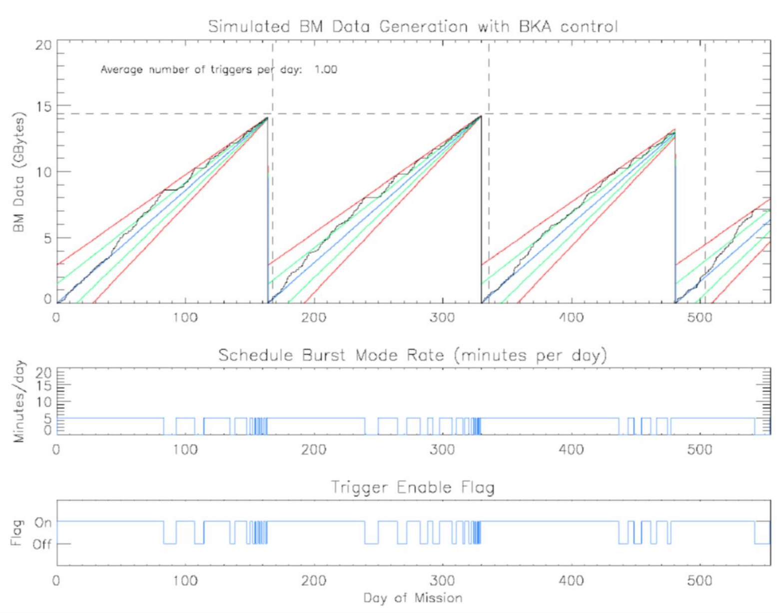
SWA has a very limited telemetry rate.

DPU: Data Processing Unit – the Book Keeping Algorithm (BKA)

The book-keeping algorithm (BKA) is a software tool able to monitor and control the amount of BM used against the pro-rata expectation for any given point along the orbit and for each sensor.

The BKA works with a set of parameters adjustable along the orbit allowing for lessons learnt:

❖ maximum and minimum acceptable data rates (2 red lines in Figure ►)
❖ 're-enable levels' (green lines)



Top panel: the simulated accumulated data rate for the scheduled burst and trigger-captured data (black trace) against the pro-rata orbit average (blue trace), assuming an average trigger response rate of 1 per day.

The BKA is used by the DPU to assess the rate of generation of science by each sensor over a time range which starts at T_0 and lasts ΔT.

The DPU holds 2 limits per each sensor (changeable in flight):

1. The fractional level, **O**, to which the sensors may be allowed to become overdrawn against the pro-rata allocation;
2. The fractional level, **U**, which the sensor is deemed to have reached becoming underdrawn against the pro-rata allocation.

The DPU will keep under control the volume of data **V(t)** sent to SSMM and accumulated since T_0 and the expected remaining pro-rata data accumulation **A(t)** based on the orbit-averaged allocation A_0:

$$A(t)=A_0 \times (t- T_0)/ \Delta T$$

The DPU will disable optional BM and trigger event capture at any time if:

$$(A_0-V(t)) < (1-O) \times (A_0-A(t))$$

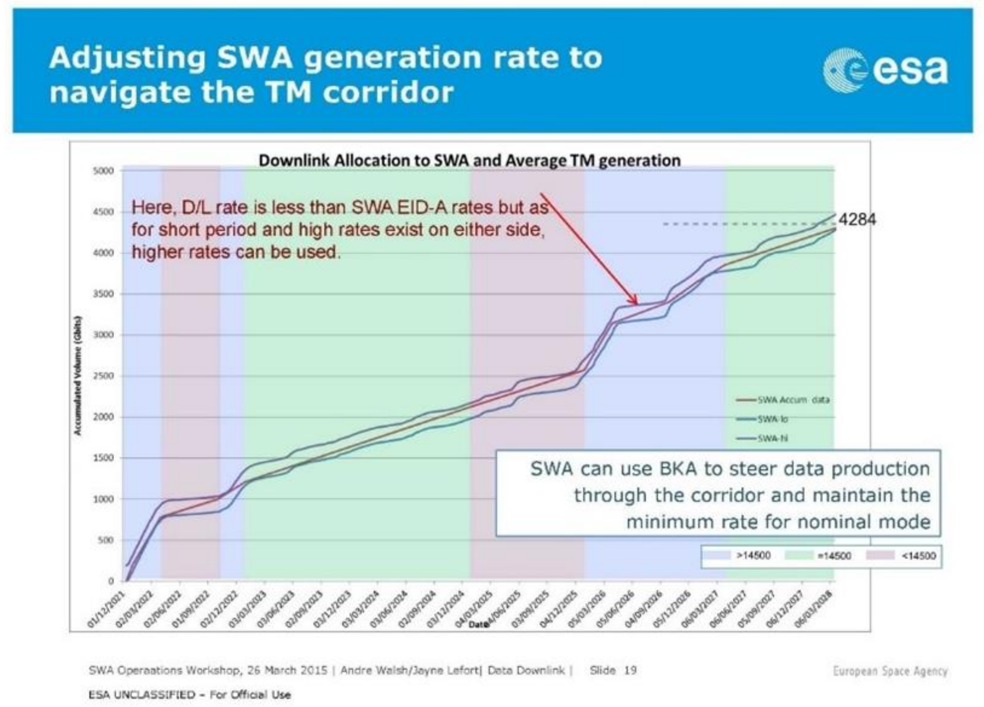
i.e. when the remaining orbit-averaged allocation is less than the remaining pro-rata orbit allocation **A(t)** by a fraction **O**

or when

$$V(t) > A_0[(1-O)(t- T_0)/ \Delta T+O]$$

re-enabling BM and trigger event capture once the excess is reduced, at most, by a factor **MxO**:

$$V(t) < A_0[(1-MO)(t- T_0)/ \Delta T+MO]$$



- BKA scheme readily compatible with the OTC (operations telemetry corridors) concept ►.
- Instead of one single, monotonous, linear gradient per orbit, OCT is made of a number of different gradients defined over a number of shorter time periods and these will need to be commanded as part of the SWA long term science plan.