PROBA
(PROJECT FOR ON-BOARD AUTONOMY)

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ABSTRACT *– Proba is an ESAmission dedicated to in-orbit technology demonstration, earth environment monitoring and preparatory earth observation. Proba is a small spacecraft equipped with a selected set of technologies providing advanced on-board functions to support mission operations with minimum ground involvement. This spacecraft autonomy is exercised and demonstrated in realistic scenarios through the utilization of the payload instruments.*

1 - INTRODUCTION

Proba is a mission included in the ESA's General Support Technology Programme [Teston 1999]. The project is currently in its final phase: the integration of the flight spacecraft. This mission is part of an overall effort to promote technological missions using small spacecraft. The next step is a follow-on project (Proba 2) which is included in the next phase of the GSTP and is due to start in 2000.

An industrial team led by Verhaert Design and Development (Belgium) is responsible for the project. It is supported by several European subcontractors and suppliers. The payload instruments are provided to the industrial team under ESA's responsibility.

This paper presents a description of the Proba mission, the spacecraft and ground segment design, and the payload instruments.

1.1 - PROBA MISSION SUMMARY

1.1.1 - Launch and Orbit

Proba is planned to be launched in 2001 on a PSLV from Antrix (India). It will be injected directly into its final polar, sun-synchronous orbit at an altitude of 817 km, 98.7 degrees inclination. The orbital drift (away from sun-synchronism) amounts to about 2 degrees per year and is compatible with the PROBA mission requirements. There is thus no need for on-board propulsion.

Navigation of the spacecraft is performed autonomously on-board by the Attitude Control and Navigation Subsystem (ACNS) with a combination of GPS measurements and orbit propagation. The spacecraft is kept three-axis stabilised by means of attitude measurements provided by an autonomous star tracker and by on-board control through a set of reaction wheels and magneto-torquers.

1.1.2 - Payload Instruments

The payload of Proba is composed mainly by a spectrometer (CHRIS), 2 Earth environment monitors (DEBIE and SREM) and 2 imagers (WAC and HRC). These instruments have been selected because they put severe requirements on the spacecraft technology in terms of ACNS, data handling and resources management in addition to scientific interest. For example, the spectrometer uses the spacecraft high accuracy slewing capabilities to perform multiple images of the same scene on Earth from different viewing angles. Also, the planning and the execution of the spectrometer and the imagers observation requests use the on-board flight dynamics function of Proba.

2 - PROBA SYSTEM DESCRIPTION

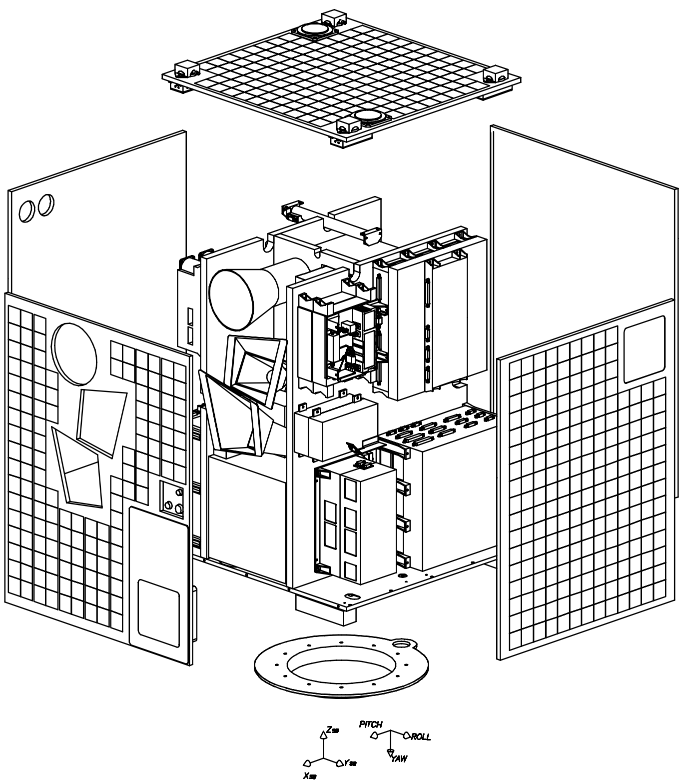

Figure 1: Exploded view of PROBA demonstrating the internal H-assembly with the units and the outer panels with the body mounted solar cells.

Proba has a weight of about 100 kg and belongs to the class of micro-satellites. Its structure (Figure 1) is built in a classical manner using aluminium honeycomb panels. Body-mounted Gallium Arsenide solar panels provide power to the spacecraft and a Li-Ion battery is used for energy storage. A centrally switched 28 V regulated bus distributes the power to the units and instruments. A high performance computer provides the computing power to the platform and a Digital Signal Processor (DSP) based computer with a solid state recorder provides the processing power to the imaging payload. The telecommunications subsystem is omni-directional using CCSDS-compatible up-link and down-link for S-band communications with the ground. The set of ACNS units support Earth and inertial 3-axis attitude pointing as well as on-board navigation and manoeuvring computations. The spacecraft platform provides full redundancy.

Whereas commonly available units and well-proven concepts are used for the communication subsystems and part of the power subsystem, the system design of Proba is innovative in many respects, especially in the areas of attitude control and avionics. A core of technologies aiming at the demonstration of spacecraft autonomy is accommodated in the attitude control and the avionics subsystems and forms an integral part of the Proba system design. They are for example, a GPS receiver for navigation and attitude determination, an autonomous star tracker for attitude determination, a high-performance computer, a DSP for on-board scientific data processing and analysis, and a solid state mass memory.

Table 1 provides an overview of the PROBA platform specifications and Figure 2 presents a block diagram of the PROBA spacecraft.

System		**Description**
Orbit	LEO Altitude 817 km Sun-Synchronous (right ascension node at 345 degrees) Near-polar (inclination 98.7°)	Optimisation for the requirements: • Best orbit for main imager • Good orbit for other payloads • Selection of low cost launcher with flight opportunity in a short time.
	Operational Lifetime	2 years for consumables (battery and solar cells)
Mechanical	Dimensions	600 x 600 x 800 mm
	Mass	< 100 kg
Thermal	Passive thermal control	
ACNS	Attitude control	3-axis stabilised providing high accuracy nadir and off-nadir pointing capabilities.
	Sensors	Cold redundant dual head advanced star trackers, redundant 3-axis magnetometers, GPS receiver.
	Actuators	4 Magnetorquers, 4 Reaction Wheels
	Absolute Pointing Accuracy	Better than 360 arcsec
	Absolute Pointing Knowledge	Better than 125 arcsec.
Avionics	Processor	Cold redundant radiation tolerant ERC32 RISC processor
	Memory	8 Mbyte RAM, 2 Mbyte FLASH
	Interfaces	RS422, TTC-B-01, analog and digital status lines, direct high speed interface to Telemetry.
	Uplink Communications	Hot redundant S-band receivers, 4kbps
	Downlink Communications	Cold Redundant S-band transmitters, 1 Mbps
	Communications Packet Standard	CCSDS
Power	Solar Panels	5 body mounted GaAs panels, 90W peak power
	Battery	36 Li-ion cells, 9Ah, 25V
	Power Conditioning System	28V regulated power bus, redundant battery charge and discharge regulators, power distribution system and shunt regulators.
Software	Operating System	VxWorks
	Data Handling/Application Software	Newly developed for PROBA

Table 1 : PROBA platform specifications overview

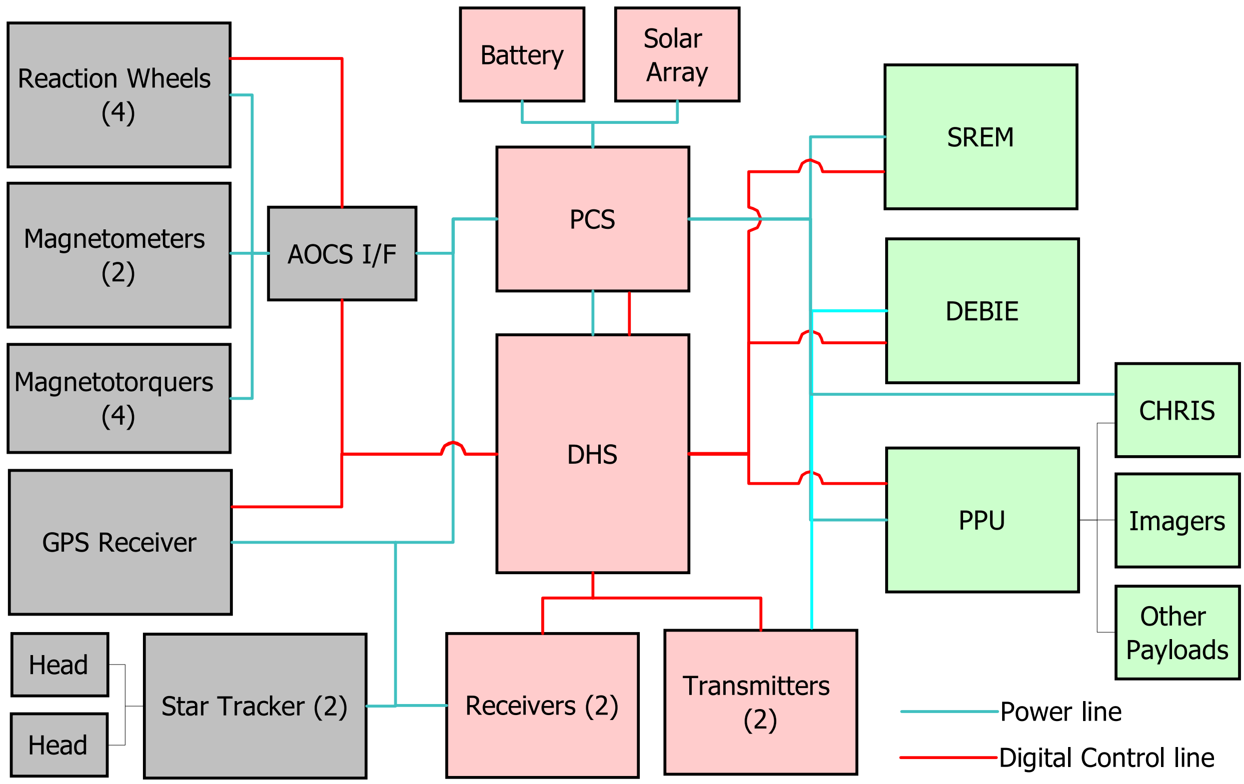

Figure 2: PROBA block diagram showing the AOCS units (left), the power and avionics Units (centre) and the payload units (right). Power and digital commanding and control interconnections between the units are shown. Other interconnections such as analog and digital monitoring lines are not shown.

2.1 - Mechanical and Thermal

The PROBA structure was designed to meet the following requirements:

- to provide a carrying structure compatible with the ASAP5 and PSLV launcher requirements
- to accommodate mainly off-the-shelf units and payloads with frozen mechanical design
- to provide easy unit access and modularity compatible with a flexible integration and checkout approach
- to be reusable to maximum extent for other technology demonstration missions.

The carrying part of the structure is composed of 3 aluminium honeycomb panels mounted in an H-structure and a bottom board. Almost all units are mounted on these inner panels. The nadir pointing bottom board of the spacecraft acts as the interface with the launcher. The outside panels have body-mounted Gallium Arsenide solar cells.

The thermal control of the spacecraft is completely passive, by an appropriate choice of the different paints, by the application of Multi-Layer-Insulation and by control of the conductive links between the different units and the carrying structure.

2.2 - Attitude Control and Navigation System

The autonomy requirements for the PROBA bus and the requirements imposed by the selected payloads have led to the implementation of a complex ACNS. The main requirements on the PROBA ACNS are:

1. Provide 3-axis attitude control including high accuracy nadir and off-nadir pointing and manoeuvring capabilities in accordance with the selected Earth observation instrument requirements
2. The ACNS software shall control the spacecraft based only on target oriented ground commands (i.e. commands specifying the targets longitude, latitude and altitude). The spacecraft sensors shall acquire all required information autonomously.
3. Provide technology demonstrations of GPS attitude and the use of Computer-Aided Software Engineering tools for the development of the ACNS software.

To meet these requirements, PROBA has been fitted with a high-accuracy double head star tracker, with a GPS receiver and with a set of reaction wheels for the nominal ACNS operation. This set of sensors and actuators is complemented with the magnetotorquers and 3-axis magnetometers to be mainly used for momentum dumping and during the initial attitude acquisition operations after separation or non-nominal events (Figure 3). Finally, the core of the ACNS subsystem consists of the ACNS software.

The autonomous star tracker is the main attitude determination sensor during nominal mission phases. It provides full-sky coverage and achieves the high accuracy required in Earth observation. The sensor can autonomously reconstruct the spacecraft's inertial attitude starting from a "lost in space" attitude without any prior estimates of the spacecraft orientation. This is done with a typical performance of a few arc-seconds up to an arc-minute. The attitude can be reconstructed at relatively high inertial rates, which allows the ACNS software to perform gyro-less rate measurements which are sufficiently accurate to control large-angle precise and stable manoeuvres. The star tracker selected for PROBA is provided by the Technical University of Denmark.

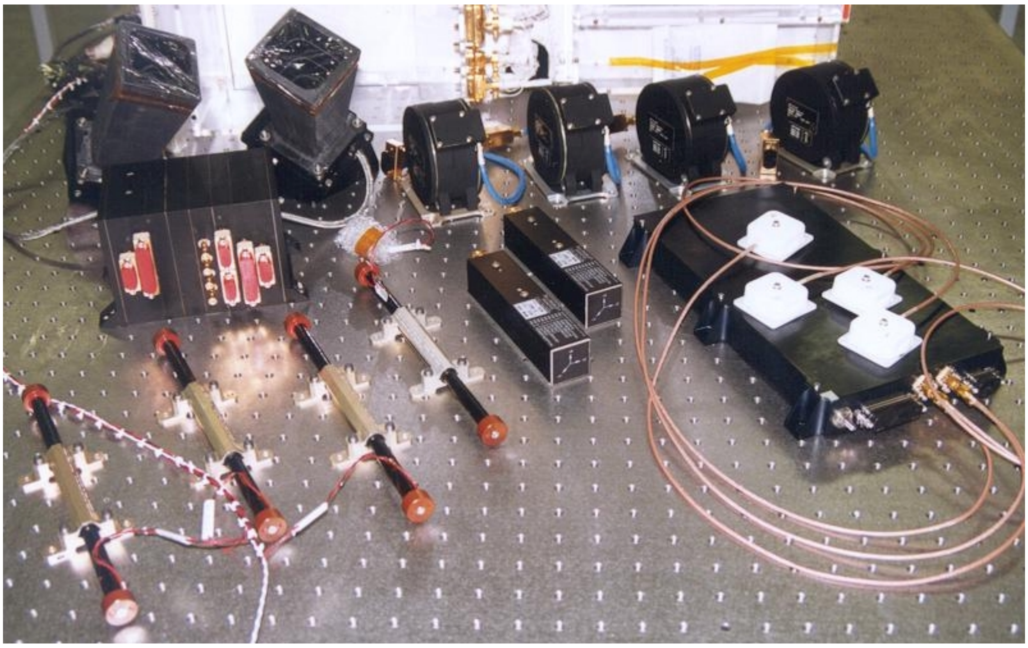

Figure 3: ACNS sensors and Actuators: 4 magneto-torquers, dual head star tracker, 4 reaction wheels, 2 magnetometers, GPS receiver

Knowledge of the PROBA orbit is acquired autonomously with a GPS receiver, supplied by SSTL (UK). The provision of range data from GPS satellites (or pre-processed position, velocity and time measurements from the GPS receiver software) will allow on-board determination of the osculating orbital elements of the spacecraft and a correlation of on-board time with Universal Time Coordinated (UTC) required in the various on-board ephemeris generators. Knowledge of the orbit will allow pointing the spacecraft to any orbit-referenced attitude (including the normal-mode nadir pointing) without the need for an Earth sensor. In addition, using an on-board Earth-rotation ephemeris calculator, pointing to any user-selected Earth coordinates is also possible. The GPS receiver thus forms a crucial component in the on-board autonomy demonstration. In case of GPS failure, the ACNS software obtains the navigation data from NORAD two-line elements automatically uplinked by the ground. Finally, the GPS receiver will be used for the GPS-based attitude determination demonstration.

During nominal operations, the generation of control torques is ensured by four Teldix (Germany) reaction wheels mounted in a tetrahedron configuration. Their storage capacity is 0.04 Nms and their maximum torque capability is 5 mNm at 1500 RPM. As already indicated, momentum dumping is ensured by two redundant, three-axis magnetometers and by four magneto-torquers.

All ACNS sensors and actuators are controlled by the ACNS software (developed by Université de Sherbrouck) running on the central ERC 32 computer and provides complete flight dynamics calculation functions, including:

- Navigation function: the autonomous estimation of the orbit using GPS measurements and the autonomous determination of attitude using the advanced star sensor.
- Guidance functions: the prediction of orbital events (eclipses, next target passages, next station passage etc) and the on-board generation of the reference attitude profile during imaging. These functions provide essential support to the on-board mission planning system.
- Control function: the execution of the attitude control commands for attitude acquisition and hold.

In performing these functions, the ACNS software has to deal with further complications such as latency of the detectors and synchronisation between the different on-board clocks.

Pointing to geographical Earth references will either be to a fixed target (e.g. during ground station overfly for antenna pointing or during utilisation of one of the imagers) or in a scanning motion over a 19 km user-selected target area during the CHRIS imaging mode. Each of the five scans over the target area are executed back and forth at 1/3 the nominal nadir push-broom velocity in order to increase the radiometric resolution. A detailed description of the ACNS can be found in [de Lafontaine 1999].

2.3 - Avionics

The avionics is composed by:

- a high-performance redundant central computer (DHS) responsible for spacecraft telecommand and telemetry, all spacecraft computing tasks and interfaces to every unit of the spacecraft,
- a Payload Processor (PPU) with a solid-state recorder and a DSP for payload processing and data storage,
- a redundant set of S Band receivers and transmitters.

2.3.1 - DHS

The DHS unit was designed to integrate in a single redundant unit all the core functions of the spacecraft avionics (Figure 4) and to provide sufficiently high-performance computing to support not only the traditional attitude control and data handling tasks but also spacecraft autonomy (i.e. the processing normally performed on-ground has been migrated on-board in the case of Proba). It is provided by SIL (UK).

To this end a high-performance RISC processor, the ERC 32, has been used. The ERC 32 is a radiation tolerant (> 80 Krad) SPARC V7 processor providing 10 MIPS and 2 MFLOPS with a floating-point unit. A memory controller includes all the peripheral functions needed by the processor, such as the address decoders, the bus arbiter, the EDAC, 2 UARTS, 3 timers and a watchdog. The chip set is manufactured with the MHS 0.8 micron CMOS/EPI radiation tolerant technology.

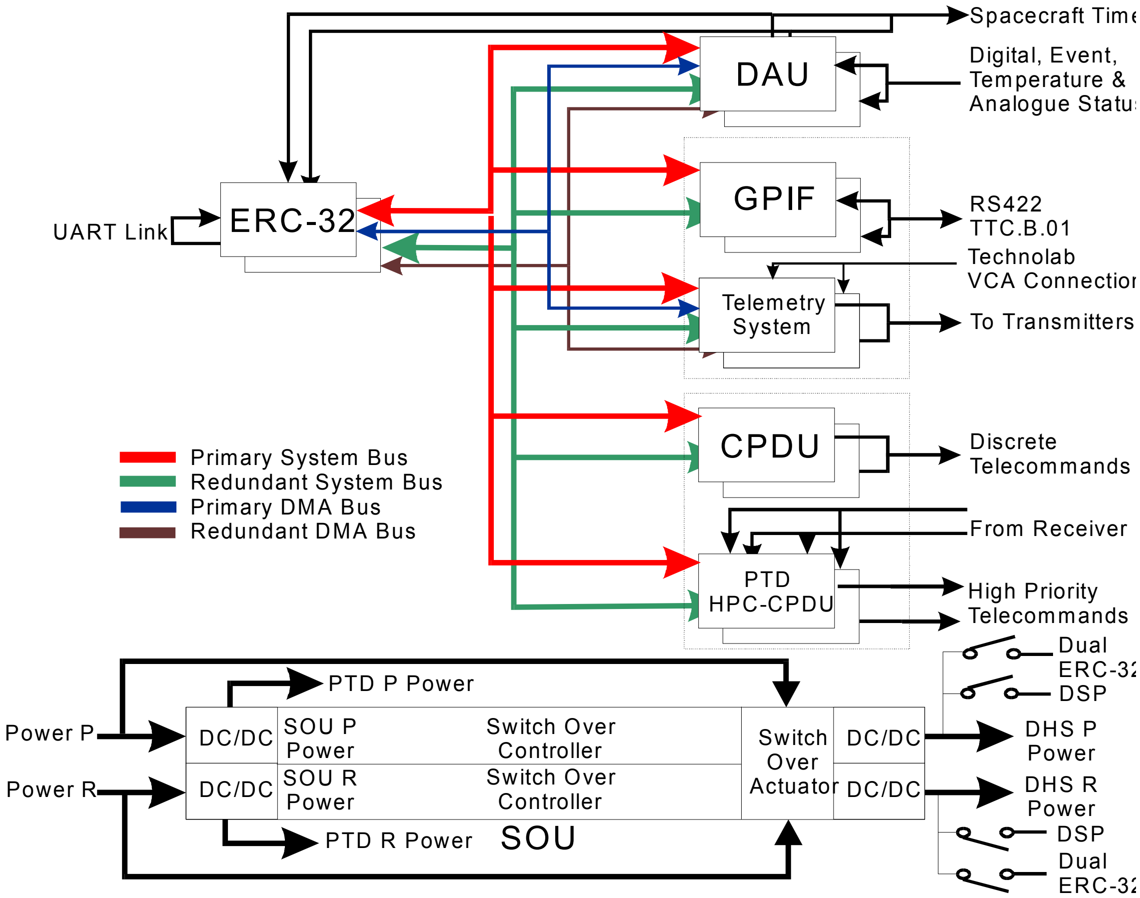

Figure 4: DHS block diagram

The DHS includes 2 of these processors. They are normally used as cold redundant hardware. However, in order to cope with potentially higher processing demands, it is also possible to run the DHS in dual processor mode, where both processors are running concurrently and exchanging data with high speed serial links.

The other functions of the DHS are:

- 2 hot redundant telecommand decoders supporting COP-1 packet telecommanding and direct (MAP-0) ground commands,
- cold redundant spacecraft interfaces, RS-422 or TTC-B-01 for data exchange, pulse, analog, digital, … for commanding, house-keeping and time distribution,
- 2 cold redundant telemetry generators, each supporting 3 Virtual Channels,
- a reconfiguration unit performing the reconfiguration of the DHS in case of software and hardware failure or transient (e.g. Latch-up)

2.3.2 - PPU

The PPU is mainly the computer controlling the imaging instruments (provided by MMS UK). It includes a DSP, the TCS21020 for high capability data processing and improved usage of the on-board mass memory through compression.
The TCS21020 is a radiation tolerant (> 100 Krad) 32 bit DSP. It is fully compatible with the ADSP 21020 from Analog Devices. It provides 15 MIPS and 45 MFLOPS. The chip is manufactured by the TEMIC/MHS 0.6 micron SCMOS/2RT+ process.

The mass memory is 1.2 Gbit and uses three-dimensional packaging technology for high-density storage.

The PPU provides also several additional interfaces for other on-board experiments, interfaces to solid state gyroscopes (SSG), an interface to an extra star tracker (PASS), and an interface to a house-keeping bus.
This latter will be used on PROBA to measure temperatures and radiation dose in remote locations of the spacecraft. It uses a collection of devices called SIP (for Smart Instrumentation Point) which are small modules of 15 mm/7,5 mm/5 mm, weighing less than 3 g. They use advanced packaging and include the temperature and total dose sensors, the Analog to Digital converter, and the bus interface. The SIPs were developed by Xensor Integration (NL).

The PPU controls also the imagers (indicated Micro Cameras on Figure 5) covered in the payload section of this paper.

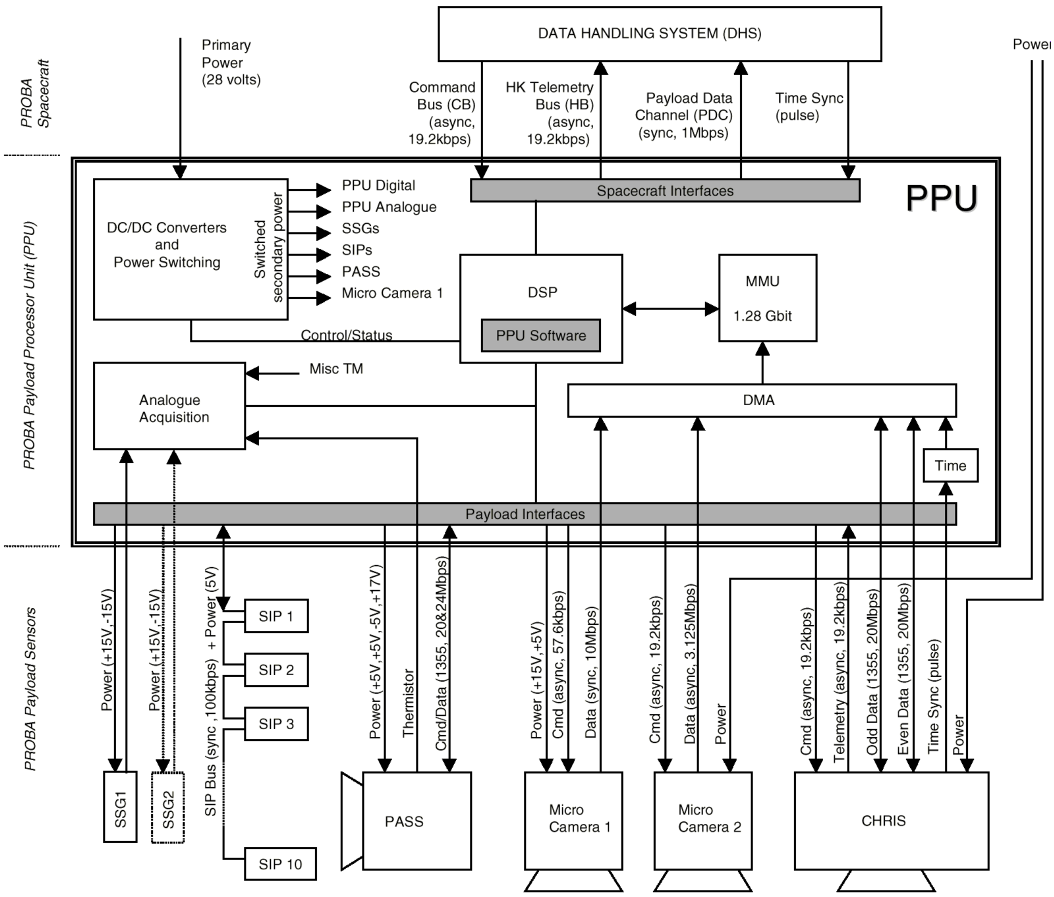

Figure 5: Block diagram of PPU and attached payloads

2.3.3 - TT&C

The S band link capacities are 4 Kbit/s for the packet telecommanding and a maximum of 1 Mb/s for the packet telemetry. Standard ESA modulation scheme (PSK/PM) is used for the uplink and BPSK for the downlink.

Off the shelf units from SIL (UK) have been used for TT&C support.

Two hot redundant receivers are connected through a combiner/diplexer to Zenith and Nadir antennas providing omni-coverage commanding of the spacecraft.

Two cold redundant transmitters are connected through a switching unit to Zenith and Nadir antennas providing also omni-coverage telemetry of from the spacecraft.

2.4 - Power

The basic power consumption of the platform is 35 W. The excess of power will be allocated to the payload. The duty cycle of the instruments will be calculated on board taking into account the available power and energy but also the scientific requests and the available data storage.

The body mounted solar arrays will provide a worst case (end of life, summer solstice) peak power generation ranging from 45 to 67 W per panel. Averaged along the sunlit part of the orbit, the power generation at bus level will be 85 W. The solar arrays are built with 22 strings of 39 to 41 cells grouped in 6 sections. The cells are of a standard size of 3.8x3.5 cm with integrated diode. The panels are provided by Officine Galileo (Italy).

The 9 Ah Li-ion battery will be used mainly in eclipse as the peak power demands in day phase will be almost all covered by power from the arrays. The duty cycle of the instruments will not create a Depth of Discharge higher than 20 %.
The battery is built using standard Li-Ion cells that are screened and matched. Ground testing has demonstrated the compatibility of the battery with the 2 years mission of PROBA.
The battery weights 2.2 kg. It is provided by AEA (UK).

The functions of the PCS are:

- conditioning and distribution of power to users by means of a 28 Volt regulated bus, four non-switchable power lines to the essential sub-systems and twelve switched power lines to payloads and non-essential sub-systems (PDU),
- sourcing of the power from six solar array sections and control by a Sequential Switching Shunt Regulator (S3R),
- sourcing of the power during eclipse or peak power loads, from one battery through two Battery Discharge Regulators (BDR),
- battery monitoring and management (BME),
- battery charging by means of two Battery Charge Regulators (BCR)

Failure tolerance of the PCS is provided by:

- redundant PCS interfaces, BDRs and BCRs,
- majority voting of 3 independent voltages in the Main Error Amplifier controlling the BCR, the BDR and the S3R,
- each of the 6 sections being made of one shunt transistor and two output diodes in series and a seventh "section" connecting a resistor across the power bus,
- redundant End of Charge detection in the BME,
- over-current output protection in the PDU.

The PCS also protects the spacecraft against a power bus under-voltage by turning off all switched power outputs in case of bus or battery under-voltage.

The PCS is controlled by the on-board computer through a redundant 16-bit memory load interface (TTC-B-01) and discrete ground commands. It is provided by SIL (UK).

2.5 - Payloads

2.5.1 - CHRIS

The larger instrument is a Compact High Resolution Imaging Spectrometer (CHRIS) provided by Sira Electro-Optics Ltd (UK) (Figure 6). The scientific objective is to provide multi-spectral data (up to 62 bands) on Earth surface reflectance in the visible/near-infrared (VNIR) spectral band (415 to 1050 nm) with a spectral sampling interval ranging between 2 and 10 nm at high spatial resolution (25 m at nadir). The instrument will use the PROBA platform pointing capabilities to provide Bidirectional Reflectance Distribution Function (BRDF) data (variation in reflectance with view angle) for selected scenes on Earth surface. The instrument will be used mainly to provide images of land areas, and will be of interest particularly in recording features of vegetation and aerosols.

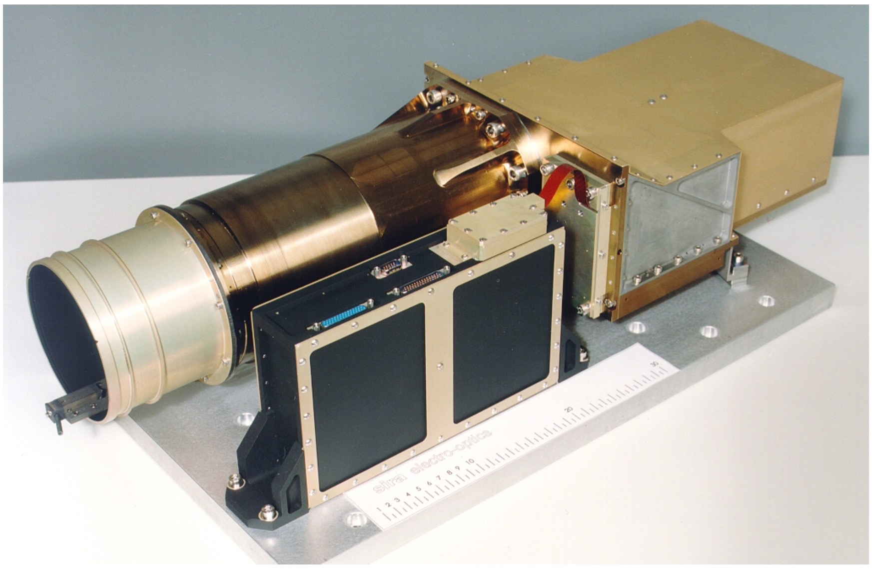

Figure 6: CHRIS instrument

The objective is also to validate techniques for future imaging spectrometer missions possibly on agile small satellite platforms, particularly with respect to precision farming observations, regional yield forecasting and forest inventory.

The instrument is an imaging spectrometer of basically conventional form, with a “telescope” forming an image of Earth onto the entrance slit of a spectrometer, and an area-array detector at the spectrometer focal plane. The instrument will operate in a push-broom mode during Earth imaging. The detector is a thinned, back-illuminated, frame-transfer CCD. CCD rows are assigned to separate wavelengths, and CCD columns to separate resolved points in the Earth image.
The platform will provide slow pitch during imaging in order to increase the integration time of the instrument. This increase in integration time is needed to achieve the target radiometric resolution, at the baseline spatial and spectral sampling interval.

The platform will process imaging demands from ground control specifying:
- target location - requiring roll manoeuvres to point across-track for off Nadir targets,
- viewing directions for each target in one orbit - requiring pitch manoeuvres to point along-track,
- spectral bands and spectral sampling interval in each band,
- spatial sampling interval.

The platform will perform the required pitch and roll manoeuvres and transmit control signals to CHRIS to initiate and terminate imaging, with the required spectral and spatial characteristics.

In-flight calibration for radiometric response, using a dark scene on Earth or the calibration device, will also be supported by CHRIS and the platform.

The digitised data from CHRIS will be stored in a mass memory unit, processed and compressed with a DSP and transmit to ground on command.

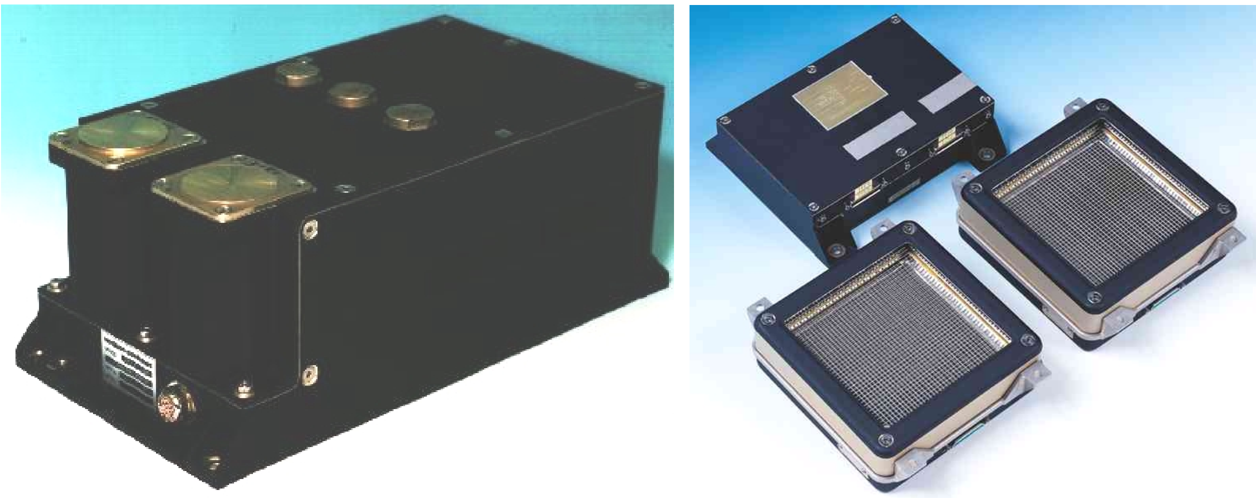

Figure 7: The SREM (left) and DEBIE (right) payloads. Both the processing unit and the 2 sensors of DEBIE are displayed.

2.5.2 - SREM

The primary objectives of ESA’s Standard Radiation Environment Monitor (SREM) are for space environmental technology research. That is, to derive understanding of the environment which is a hazard to future missions, develop models for engineering, and collaborate in research on the effects of radiation on space systems. However, the SREM data are also available for scientific studies such as particle sources, transport and loss, energisation of radiation belt particles. These activities are strengthened by the availability of SREM data from many different spacecraft.

The path of PROBA will cover the “polar horns”, where energetic electrons of the outer radiation belt are transported to low altitudes, as well as the South Atlantic Anomaly (SAA) with its enhanced proton fluxes (the inner part of the inner radiation belt). PROBA will also be exposed to energetic particles from the sun during energetic events, and cosmic rays. These latter environments are modulated by the earth's magnetic field. With SREM, mapping (1), temporal variations (2) and possibly directional measurements (3) of these particles populations will be carried out. The measurements of SREM will also be correlated with on-board degradations caused by radiation on the electronic parts, the CCDs, the solar cells.

(1) Through continuous operation of SREM, the models of the radiation belt positions, the particle fluxes and the geomagnetic shielding will be compared, updated or renewed for various electron and proton energies, and for cosmic rays.

(2) Through long-term operation of SREM, the radiation belt flux variations (storm injections, radiation belt motions), the solar particle event variations, the variation in geomagnetic shielding in response to storms, and the long-term variations in the SAA and Cosmic Rays (CR) fluxes will be studied. The measurements will be correlated with other spacecraft STRV, SOHO, GOES, etc.

(3) Using the manoeuvring capability of PROBA, the anisotropy of the radiation environment at low altitude can be measured. PROBA will be rotated such that the SREM points locally vertically

(up and down), and collects particular angles at different locations. In the SAA, PROBA will be slewed up to ±45°. In order to obtain good statistics, this procedure should be performed repeatedly and over a period of time to see long-term flux variations, and during high solar activity to observe possible short-term atmospheric influences. Finally, since the SREM has measurement channels for high-energy protons and heavy ions, asymmetries in cosmic ray fluxes may be observed.

SREM was developed by Contraves (Switzerland).

*2.5.3 - **DEBIE***

The DEBris In-orbit Evaluator (DEBIE) detector (Figure 7) on PROBA will measure for the first time the small size particulate fluxes in a polar type orbit. Information on the sub-centimetre size meteoroid and space debris population in space can only be gained by the analysis of returned material (for lower orbits) or by in-situ measurements.

DEBIE, developed by Patria Finnavitec (Finland) uses a combination of impact ionisation, momentum transfer and foil penetration for the detection of impacting particles. Mass and velocity of the impacting particle can be deduced from the recorded signals. The lower detection threshold is about 10^{-14} g.

Two separate sensors facing in different directions (velocity direction and normal to the orbit plan) are mounted on the external walls of PROBA. According to the present models a few impacts per day are expected. The impacts measurements will be sent to ground at each contact together with the time and the sensors attitude and location at the time of the impact.

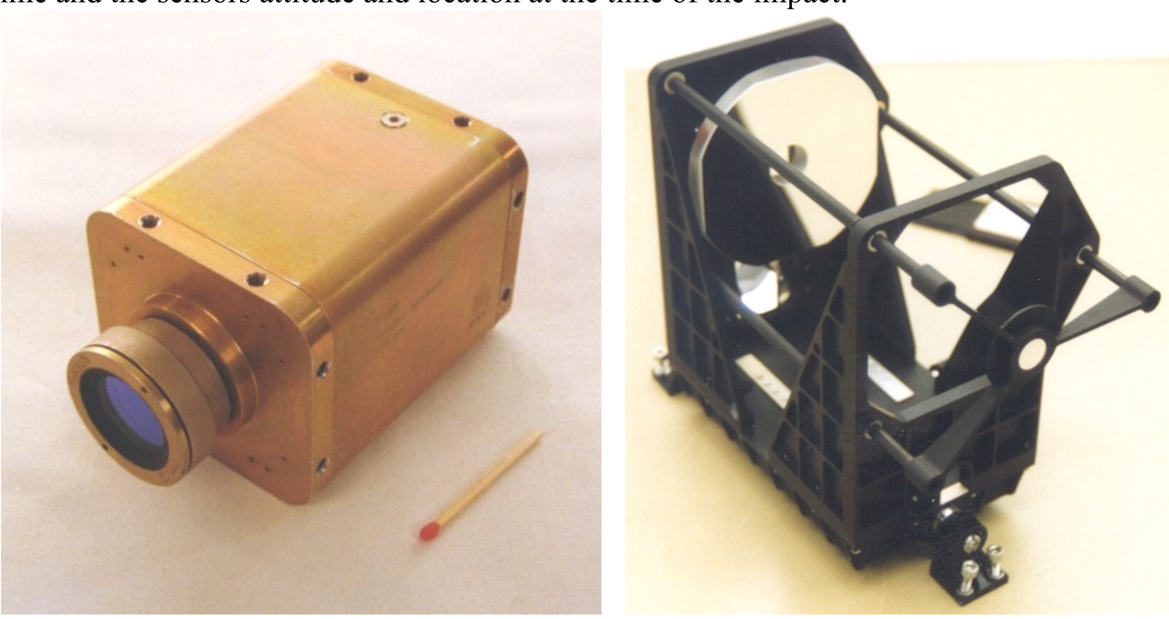

Figure 8: The two imagers to be accommodated on PROBA: the Wide Angle Camera (left) and the High Resolution Camera (right) providing 10 m resolution.

2.5.4 - Imagers

PROBA accommodates two imagers from OIP (Belgium), a Wide Angle Camera and a High Resolution Camera (Figure 8).

In orbit usage of the imagers will be through high level imaging requests which will be scheduled using the fly by prediction and planning functions of the spacecraft. The spacecraft can store and compress hundreds of these images between ground visibility. Images sent to ground will then be distributed using the Web.

WAC is a miniaturised (7x7x6 cm) black and white camera using a 640x480 CMOS Active Pixel Sensor with a field of view of 40 by 31 degrees. Images are digitised on 8 bits before transmission to the spacecraft.

HRC is a miniaturised black and white imager with 10 m ground resolution. The telescope is of the Cassegrain type with an aperture size of 115 mm and a focal length of 2296 mm. The detector is based on a CCD and uses 3D packaging technology. It contains 1024 x 1024 pixels of 14 µm size. The field of view (along the diagonal of the detector) is 0.504°. Images are digitised to 10 bits before transmission to the spacecraft.

2.6 - On-board Software

The on-board software, which is running on the central Data Handling System, is a new development for PROBA. It uses VxWorks as operating system and is implemented in C by Spacebel (Belgium). Apart from the classical functionality of performing the spacecraft control, housekeeping and monitoring tasks, it contains also the autonomy related functionality such as the failure detection, identification and recovery functions, the ACNS software and the on-board mission planner. The latter function plans ground requests for payload operation tasks taking into account the available on-board resources and target visibility as predicted by the ACNS software. The ACNS software, described previously, is produced by the autocoding tool of Xmath and integrated in the rest of the on-board software. The on-board software follows the ESA Packet Utilisation Standard for the communications with the ground. PROBA and its software is designed such that it can be completely reprogrammed in flight.

3 - DEVELOPMENT

The classical ESA development approach has been adapted to the objectives and the constraints of Proba. The project life cycle has been split in 3 main phases, the System Design Phase, the Production and Qualification phase and the Integration and Acceptance phase. Between each phase a peer review is performed by Estec.

The model philosophy adapted for PROBA is based on a Structural and Thermal model and the Proto-Flight model of the spacecraft. The PFM approach at spacecraft level was further supported by partial electrical models of most of the bus units.

In the area of software validation, spacecraft testing and operations preparation, the project has tried to optimise the available resources. This has been translated into the usage of a common environment for spacecraft testing and operations and the production of a Software Validation Facility (provided by SSF Finland) the early phase of the project. This latter tool simulates the entire spacecraft and allows that the on-board software executable code is executed in this facility as if it was running in the real hardware while enhanced testing and debugging capabilities are available. This facility is also connected to the common spacecraft test and spacecraft operations environment to provide a spacecraft simulator for the operation teams.

4 - GROUND STATION AND OPERATIONS

One of the benefits of on-board autonomy is the reduced need for ground operators involvement in the mission operations and the associated reduction in ground-station operating costs. To exploit this to a maximum extend, the PROBA ground segment has been automated as much as possible while maintaining the required facilities limited.

With the ground station located in Redu (Belgium) about 4 times 10 minutes of visibility per day will be available in average.

The station, provided by SAS (Belgium), consists of a portable 2.4-m dish with S-band RF front-end and a control centre with limited facilities. The ground station provides the following functions:

1. Automatic link acquisition based on Norad elements and spacecraft navigation data;
2. Communications set-up protocol for the types of data (and their bit-rates) to be received;
3. Automatic uplink of previously screened observation requests and spacecraft planning commands;
4. Automated call of ground staff in case of detection of on-board anomalies;
5. Automated science data filing, notification of scientists and data distribution.

It is the intention that with the combination of on-board autonomy and the automation in the ground station, the involvement of ground operators during nominal and routine mission phases is limited to routine maintenance tasks on (typically) weekly basis. This ground operator receives after every pass a pass report summarising the spacecraft and ground station status. Furthermore, remote access to the ground station via a local network or via the internet provides the operators with the capability to access the downlinked spacecraft data whenever they wish.

To implement the described automations, the ground segment provides besides classical telecommand and telemetry also operation procedures support. These procedures implement the automatic link acquisition, setup procedures, routine spacecraft operation procedures and (limited) telemetry analysis. The same operations environment will also be used during subsystem and system check-out tests performed during the spacecraft integration and validation phase.

5 - CONCLUSIONS

The Proba mission design fulfils the ESA objectives of in-orbit technology demonstration, earth environment monitoring and preparatory earth observation. Technological units represent a significant part of the spacecraft and provide the advanced capabilities required by the instruments. The instruments will provide valuable scientific or preparatory data.

Proba demonstrates also that micro-satellite can efficiently combine in-orbit technology demonstration and operational missions and also be sufficiently flexible to be reconfigured for other missions.

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