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## Metrology on-board PROBA-3: The Shadow Position Sensor (SPS) subsystem

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**Summary.** — PROBA-3 is an ESA Mission whose aim is to demonstrate the in-orbit Formation Flying and attitude control capabilities of its two satellites by means of closed-loop, on-board metrology. The two small spacecraft will form a giant externally occulted coronagraph that will observe in visible polarized light the inner part of the solar corona. The SPS subsystem is composed of eight sensors that will measure, with the required sensitivity and dynamic range, the penumbra light intensity around the coronagraph instrument entrance pupil.

### 1. – Introduction

PROBA-3 [1] is an ESA mission whose technological purpose is demonstrate the efficiency of formation-flying technologies (FF) [2] forming a giant, externally occulted, Lyot coronagraph (ASPIICS [3] - Association of Spacecraft for Polarimetric and Imaging Investigation of the Corona of the Sun), that will image the inner part of the corona in visible polarized light, from 1.08 to 3  $R_{\odot}$ . Two satellites, the Coronagraph S/C (CSC, 340 kg) and the Occulter S/C (OSC, 200 kg and 1.4 m diameter) will orbit around the Earth in a highly-elliptical orbit, at an altitude between 600 and 60,530 km, and up to 59° inclination, aligning with the Sun and creating an artificial eclipse during observations.

The orbital period is 19.38 hours and, at the apogee, the two satellites will keep a nominal distance of 144 m and will fly in a rigid formation for eight hours. During the

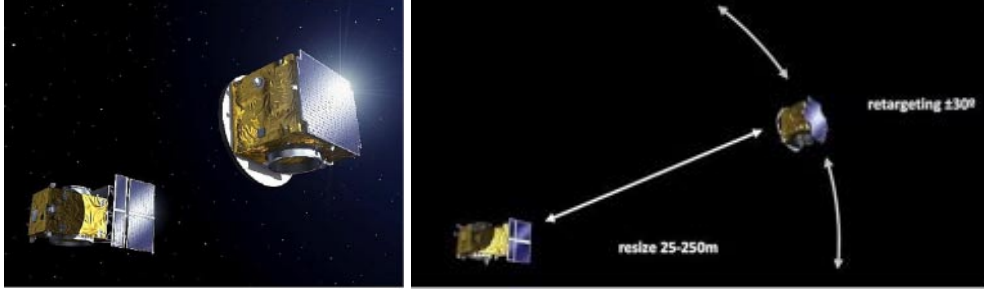


Fig. 1. – Positioning of the two spacecraft during observations (not in scale) and FF demonstration maneuvers performed with reference to the Sun direction.

remaining time the two satellites will fly in a loose, "safe" configuration so to avoid any risk of collision. The launch is programmed for 2020 from Kouroua and the mission will last 2.5 years, including 4 months of commissioning, and, at its end, the spacecraft will naturally de-orbit in atmosphere.

The autonomous Guidance, Navigation and Control system will use data from several metrological systems to maintain the FF; between these, the last and more accurate is SPS (Shadow Position Sensor) [4, 5], who is required to verify the centering of the CSC with respect to the umbra cone and return its 3D position with an accuracy of  $500\ \mu\text{m}$  for a lateral displacement and of 50 mm for a longitudinal one inside a *requirement box* of  $20 \times 20 \times 200\ \text{mm}^3$ . Outside of this volume, but inside a *goal box* of  $100 \times 100 \times 1000\ \text{mm}^3$ , SPS is required to return a 3D relative position measurement with reduced performance.

## 2. – SPS electronics design and models

SPS measures the illumination level on eight  $3 \times 3\ \text{mm}^2$  SiPM (Silicon Photomultipliers) arranged on a circle of 55 mm radius around the coronagraph entrance pupil and runs a dedicated on-board algorithm that compares the light measured on sensors to a third order pseudo-paraboloid [6] whose parameters are re-configurable.

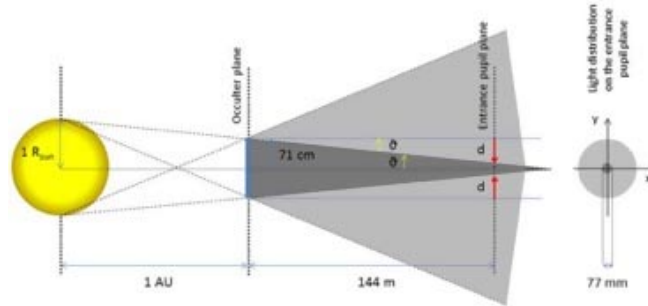


Fig. 2. – Visualization of penumbra (light gray) and umbra (dark gray) in the direction connecting the two spacecraft and on the entrance pupil plane.

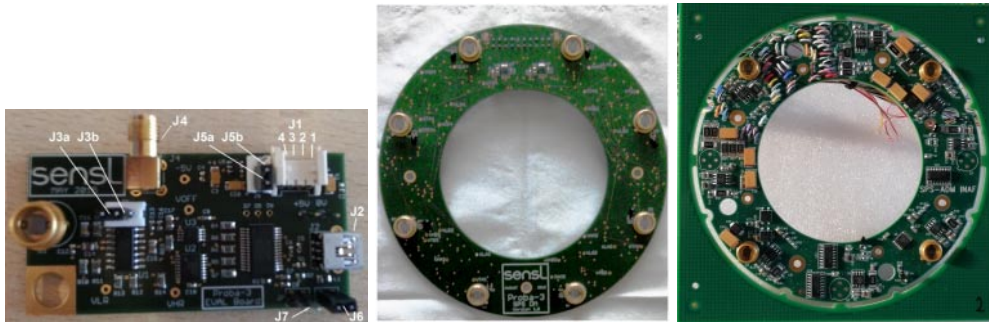


Fig. 3. – The single-sensor *Evaluation Board*, the *Development Model* (DM) and the *Advanced Demonstration Model* (ADM).

The SPS sensors are split in two sets (A and B) that can be switched on and off independently and can be fed alternatively from a nominal or a redundant power source ensuring, at the same time, an electrical isolation between sources by means of SSRs (Solid State Relays) and optocouplers.

A transimpedance stage converts the SiPM current into a voltage covering with margin the *goal box* dynamic range (*Low Gain*), then, an amplification  $\times 5$  enhances the resolution in the *requirement box* (*High Gain*). A 12-bit serial ADC, working at 4.16 MHz, samples these signals at a rate of 32.5 ksp/s, then an FPGA operates a running average on the digitized data and provides the proper value, LG or HG, to the algorithm.

Extensive electrical and functional tests [5] have been performed on the previous development models EB and DM, see fig. 3, and the lessons learned led to various changes, *e.g.* a power switching section, differential transmission lines and a stable voltage reference on-board. After these changes in the design at CDR stage, INAF decided to produce the ADM and test it in Florence and Catania laboratories, anticipating the *Engineering Qualification Model* (EQM) and *Flight Model* (FM) delivery.

### 3. – Conclusions

We have described the consolidated design of the SPS subsystem on board the PROBA-3 Mission after the CDR milestone. An ADM will be used to confirm the design changes deriving from previous models tests and to practice test activities and procedures useful for the EQM and FM qualification campaign.

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