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Development of a calibration facility for small EO Sat as PROBA V

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Abstract— **Today more and more small Earth Observation satellites are under development. All of them are very ambitious and needs accurate on ground calibration. A typical case is PROBA V payload where to ensure the continuity of Vegetation data, an instrument responding to the same user requirements as Vegetation was build, but with an overall mass of about 30 kg, instead of the 130 kg of VGT. Because a very high level of performances is required these need to be verified and calibrated with a high level of accuracy. This paper presents the calibration facility developed for the testing of small Earth Observation payloads as PROBA V. The facility needs to address the geometrical and radiometric calibration of the payload. To achieve this, a 400 mm clear aperture off axis collimator with a dedicated focal plane is developed for the geometrical calibration and a 300 mm integrating sphere calibrated at the LNE is used for the radiometric calibration. To access all the Field Of View, the payload is placed on a rotating tip tilt table allowing rotation of +/- 180° for across track Field Of View scanning and +/-10° for along track scanning. The payload is surrounded by thermal shroud to provide the required thermal environment.**

Keywords: Calibration, Optical ground support equipmenst, collimator integrating sphere

I. INTRODUCTION

Earth Observation (EO) payloads required geometric, spectral and radiometric calibrations in orbit conditions prior their launch. The CSL (Centre Spatial de Liege) has developed a facility able to carry out these optical calibrations for small EO payloads. This facility consists in vacuum chamber of 3 m diameter and 5 m height. This facility allows to work at 10^{-6} mbar. Inside the chamber a manipulator (Mechanical Ground Support Equipment MGSE) is put on damped optical table fix on a seismic block. This MGSE is able to scan FOV of +/- 180° across track and +/- 10° along track. The MGSE is able to manipulate payloads of 1 m³ and several hundred of kg. The chamber as several thermal lines that allow to cool down to 20 K and warm up to 400 K (temperature range large enough for EO payloads). Thermal tent of different sizes are available to surround the payload. Additionally to these GSE (Ground Support Equipments), optical stimuli are located around the payloads.

After a presentation of the PROBA V payload and test requirements, the different GSE are described and their performances are presented.

II. PROBA V DESCRIPTION

The optical design of the PROBA-V telescopes involves only reflective elements assembled in a TMA telescope which allows a significant reduction of mass and complexity for a multispectral imager with a wide field of view. However the mirrors are off-axis and aspherical bringing manufacturing and alignment difficulties. The optical layout is presented in Figure 1.

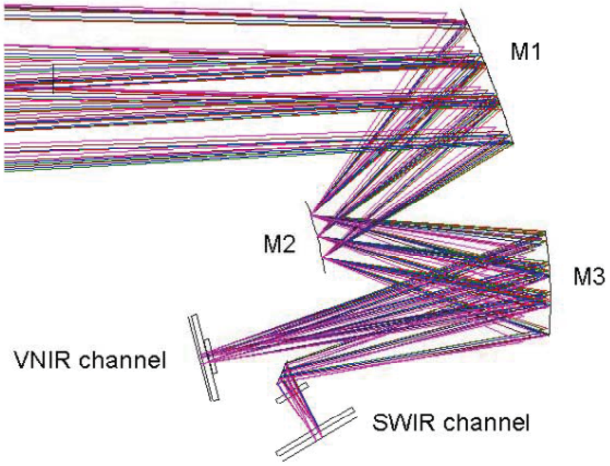

Figure 1. Optical design of the PROBA V TMA

The instrument is composed of 3 such TMA telescopes. Each TMA contains 4 spectral bands: 3 bands in the visible range (462.5 nm, 655 nm, 842.5 nm) and one band in the SWIR spectral range (1600 nm). Each telescope covers a field of view of 34° and their optical axes are positioned at 34° to cover a large field of 102°. The concept of the instrument with the 3 TMAs is presented in Figure 2.

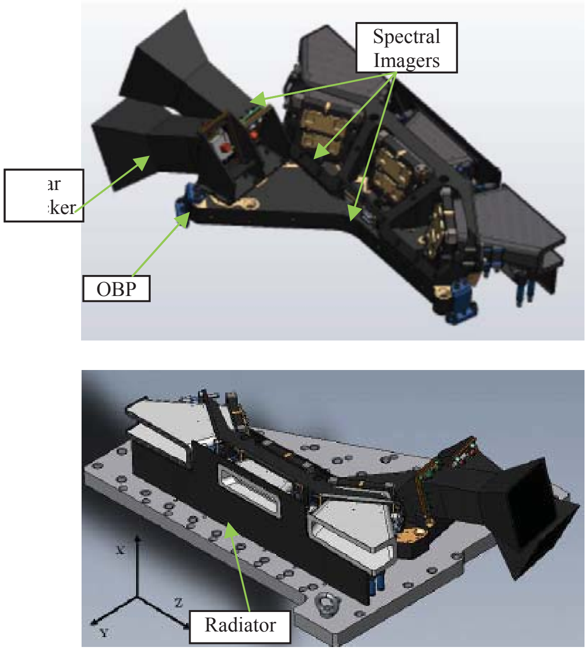

Figure 2. Concept of the PROBA V instrument

III. TEST REQUIREMENTS

The major requirements for EO payloads are to know where the instrument is sighting (geometrical localization and registration) and how much light and which color it receives (spectro radiometric calibration). The geometrical calibration is carried out by using a collimator with slits in its focal plane. These slits are used for the Modulation Transfer Function evaluation (MTF), the Ground Sampling (GS), distortion and absolute geometrical calibration. Slits are horizontal and vertical to collect the across and along track performances.

The radiometric calibration consists in an absolute calibration, a relative calibration, an interband calibration, a dark field, linearity and signal to noise ratio versus temperature. The expected absolute calibration should be better than 5%, while the relative and flat field better than 2%.

During the qualification tests the payload needs to be cool down to -40°C and warm up to +60°C. This is achieved by a set of 6 shrouds feed by regulated LN2.

The MGSE needs to cover the FOV of the three Spectro imagers (SI) (ie 104 arc degrees). Additionally to these FOV the MGSE needs to access the two faces of the alignment cube located at 120 and 210 arc degrees from the central SI axis. This means that the range in rotation must be -57° to + 230°. To access the different spectral fields the MGSE needs to have a tip-tilt axis of -3° to + 2° range.

Finally, since small satellites are considered, small amount of money is available. To cope with this major constraint, the here below described GSE are not necessary optimized for PROBA V, but are built with available hardware at CSL coming from former project. This cost saving approach divided the price of the GSE by a factor 5. Additionally, the set up is appropriated for other small EO satellites. Most of them have similar requirements.

IV. GENERAL TEST CONFIGURATION

The set up is implemented in FOCAL 3 facility. FOCAL 3 (acronym of Facility for Optical Calibration At Liège) is composed by two stainless steel vessels located in a class 10 000 clean room (following US standard: FED-STD-209E). Focal 3 consists in one main vertical cylindrical chamber of 3 m diameter and 2.8 m height and an auxiliary horizontal axis chamber of 1.2m diameter and 5m length. Class 100 is used for PROBA V. Two optical benches are installed respectively in the main chamber and in the auxiliary chamber. Both benches are put on the same seismic block which is actively controlled thanks to 5 air cushions.

A general implementation is presented in Figure 3. The collimator OGSE (Optical Ground Support Equipment) is located in the auxiliary chamber, while the Integrating sphere OGSE, the Mechanical GSE and the Thermal GSE are in the main F3 vacuum chamber.

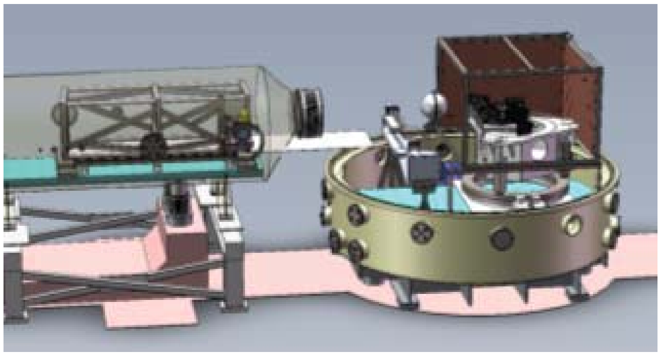

Figure 3. Concept of the PROBA V calibration facility. The seismic block is colored in pink, the optical benches in blue.

V. COLLIMATOR

A. Collimator requirements and goals

The collimator OGSE has to provide to the payload a collimated beam with a diameter larger than 200 mm in the PROBAV spectral range of 400 to 1800 nm. The collimator will be used to calibrate instrument MTF, the relative and absolute localization and the on ground sampling interval.

B. Collimator design

To fulfil these requirements the collimator consists in a 400 mm off-axis parabola with a 2 m focal length. This provides a magnification of 20 with respect to the PROBA V TMA. For the MTF, on ground sampling and relative localization slits are placed along and across track for VNIR and SWIR detectors (see Figure 4.) The slits are able to scan the detector pixel in both directions by means of two translation units.

For the absolute calibration a camera is positioned in the focal plane and collects the retro reflected light from the different cubes. Additionally to the payload cubes, a small mirror materializes the optical axis of the collimator. The source consists in a small integrating sphere feed by 3 optical fibres, one for the flux monitoring and two for the sources. There are two sources, one 20W Laser Diode for the absolute localization and one Energetic plasma source for the other tests. Figure 5. presents a CAD drawing of the source pack.

A stainless steel truss supports the parabolic mirror cell and the focal plane. The truss is painted with Z306.

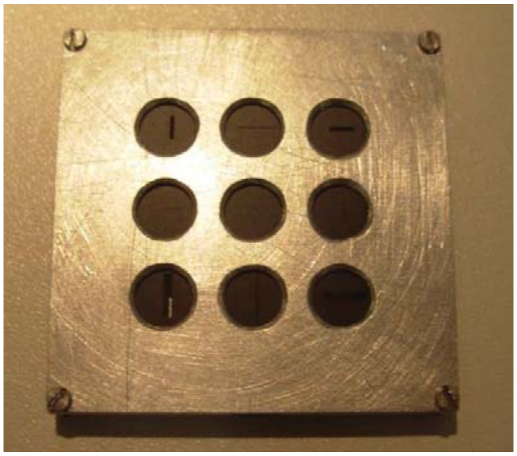

Figure 4. Collimator slits

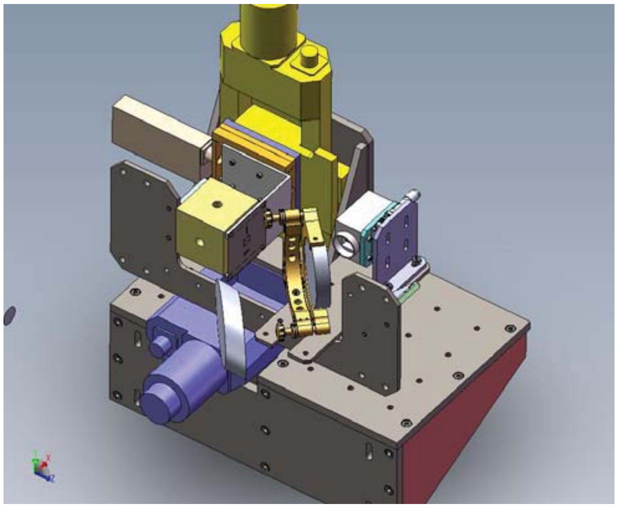

Figure 5. Collimator source pack. The yellow cube is the source and the grey one corresponds to the camera. The folding mirror and the beam splitter are also represented

C. *Collimator AIV and performances*

The collimator is interferometricaly aligned with a 400 mm Auto Collimator Flat (see Figure 6.). The Wave Front Error is 63 nm RMS. The camera is aligned with respect to the back reflected beam. A small flat mirror is put in the beam (outside the useful beam for PROBA V) to get the materialization of the collimator optical axis. This reference is then referenced with respect to the position of the instrument reference cubes. Indeed, this is necessary since the beam splitter introduces astigmatism and modifies the position of the return beam versus the entrance pupil position. A template with the initial position of the beams is recorded and will be compared to the return beam position of the payload cubes. The measured repeatability is better than 1 arcsec.

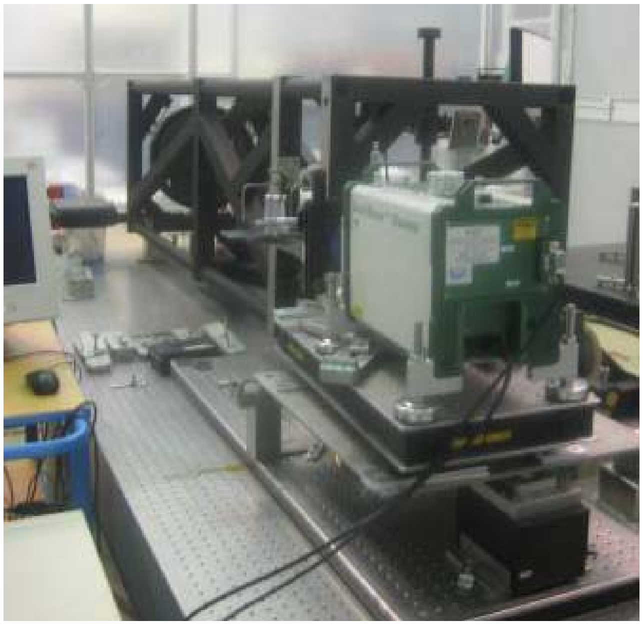

Figure 6. Collimator alignment set-up

Finally, the Collimator OGSE has been integrated in the F3 auxiliary chamber. The alignment after transfer is controlled with the help of the image of the small integrated alignment mirror, a LD source and the camera. The optical axis of the collimator is set perpendicular to the local gravity by means of a levelled theodolite.

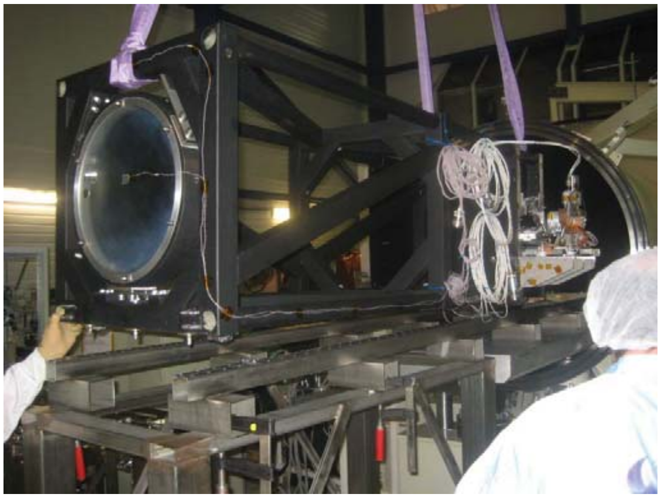

Figure 7. Collimator integration in F3 auxiliary chamber

VI. INTEGRATING SPHERE

A. *Integrating sphere requirements and goal*

For the radiometric qualification, there is a need to provide a flat field calibrated luminance in front of the instrument. This OGSE will allow not only to perform the absolute calibration but also to provide the flat field response of the instrument and the linearity.

B. Integrating sphere design

The integrating sphere (see Figure 8.) is a 305 mm diameter Spectralon and vacuum compatible sphere with a 101.6 mm output port. It is feed by two 75 halogen lamps supplied by a stabilized power supply. The lamp housings are cooled by GN2 trough a piping. The output port of each lamp housing has a variable shutter that allows adjusting the radiance output level. The output beam radiance is monitored by two detectors one Si and one Ge to cover the PROBA V spectral band and levels. The integrating sphere is placed on a translation unit to set the IS in working position (in front of the payload) or to place it in rest position (out of the FOV of the collimator and the payload).

Figure 8. Integrating Sphere OGSE

C. Integrating Sphere OGSE AIV and performances

The following performances of the integrating sphere were carried out to acquire a good understanding of the integrating sphere characteristics. Since during operation only the monitoring detectors are used to evaluate the Integrating Sphere output radiance, the signal of these detectors were calibrated versus a stable (10^{-4}) photometer and versus an absolute luxmeter at LNE. These detectors show a good linearity response with respect the output and a good overlap in term of intensity (see Figure 9.). This is required because the halogen lamps have not the PROBA V spectral profile.

This linearity is also verified over the spectral range. This is controlled with a small spectrometer. The results are displayed in Figure 10.

An important parameter to guarantee is the integrating sphere isotropy, since this OGSE is used to define the equalisation coefficient of the instrument. This is realized with the test set up sketched in Figure 11. A small achromatic collimator is placed on a rotating table at 580 mm (working position with respect to the PROBVA V pupil) in front of the integrating sphere output port. The small collimator is fibre linked to a photometer that records the signal.

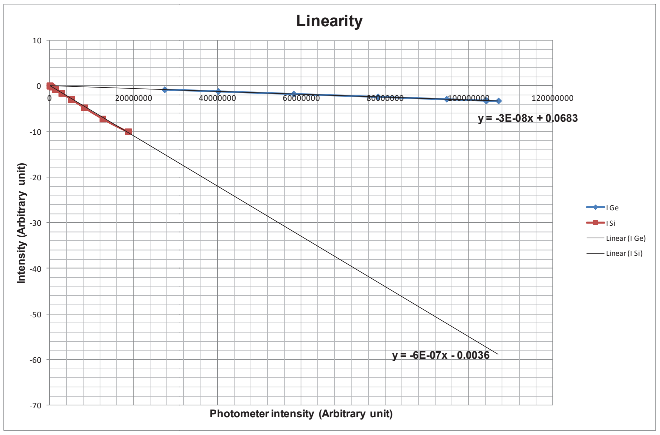

Figure 9. Monitoring detector response versus output port radiance

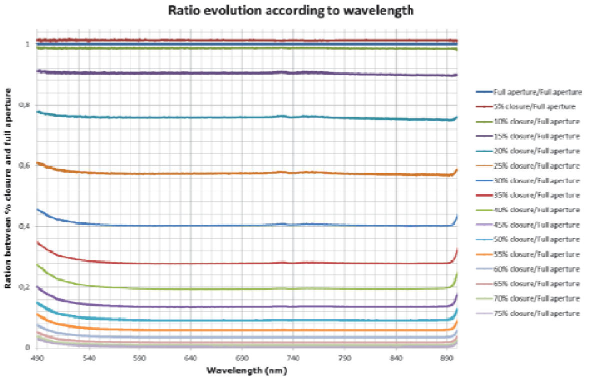

Figure 10. Spectral response versus shutter position

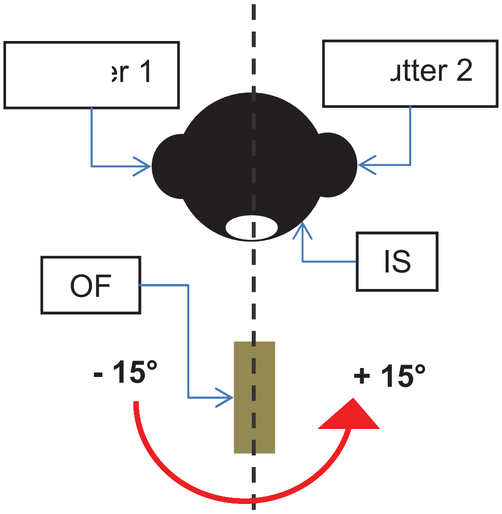

Figure 11. Isotropy test layout

The isotropy results are plotted in Figure 12. where a zoom on the interested field is performed. Whatever the shutter positions are, the Integrating Sphere isotropy is better than 98%. Looking to the field angles larger than 5° indicates that the signal drops and that no straylight below 10^3 is coming from these fields. That allows also to use the integrating sphere to evaluate the Total Integrate Scatter Straylight (see ref [2]).

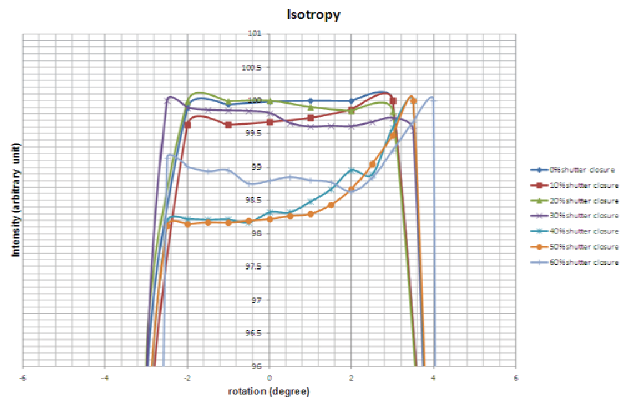

Figure 12. Integrating sphere isotropy with respect to shutter position

Last but not least, the absolute calibration is undertaken at the LNE (Laboratoires National d'Etallonage) Trappes France. The goal of the calibration is to link the IS luminance and the IS spectral radiance between 300 and 1700 nm to the International Unit System. This is performed by using a calibrated spectro radiometer. The final results are presented in Figure 13.

The IS has been calibrated at the same lab as for VGT, this looks the safest way to correlate the radiometric data to VGT with respect to ground calibration.

With available data the aperture can be adjusted to reach the following L level, 0.8 of L2 in the Blue band, 0.85 of L4 in the Red band and L4for the other bands. The levels L2 to L4 are achieved with a shutter position giving correct isotropy of the source and acceptable signal of the monitoring detectors.

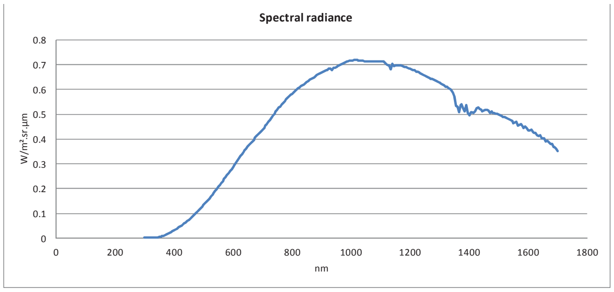

Figure 13. Integrating Sphere absolute spectral radiance calibration

VII. CONCLUSION

This paper presents two OGSE available at CSL integrated in vacuum facility for testing Earth Observation satellite. One collimator for geometrical calibration and one integrating sphere for radiometric calibration. Additional to these OGSE a Mechanical Ground System Equipment is also integrated in the vacuum facility to set the tested payload in front of each OGSE and to scan all the FOV as well as all the spectral bands. A thermal tent is as well developed to achieve the require temperatures on the payload. Finally an Electronic Ground System Equipment (EGSE) is work out to establish communication with all the GSE.

ACKNOWLEDGMENT

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[2] *Y. Stockman, ML. Hellin,* A. *Zuccaro Marchi, M. Taccola, Jorg Versluys, M. François, E. Mazy,* "Conceptual design of a stray light facility for earth observation satellites" ICSO 2012