

Description and status of the Very High-Resolution payload for Earth Observation of the Italian Space Agency

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ABSTRACT

The Italian Space Agency is developing a Very High-Resolution (VHR) optical payload in the framework of the PLATiNO (mini Piattaforma spaziale ad Alta TecNOlogia) multi-satellite constellation program for Earth Observation. VHR is a new compact multi-spectral payload realized by Leonardo and Officina Stellare for small-size spacecraft operating in the VNIR spectral range (450-900 nm) and with multi-spectral and panchromatic Ground Sampling Distances (GSD) better than 3 m and 1 m, respectively, from reference LEO orbit altitude.

This work presents the high-level optical technologies of the Italian industrial supply chain deployed for the VHR payload. The optical design foresees a 50 cm telescope with a three-lens optical corrector to retrieve an aberration-free and diffraction limited focal plane, ensuring sharp images in all spectral bands and in all observing scenarios. The physical architecture of the detector combined with the telescope high optical quality allows super-resolution image reconstructions.

The payload is currently undergoing the Phase D of the Program with the Manufacturing, Assembly, Integration and Test of the Proto-Flight Model, which are here described and detailed jointly with the Optical Ground Support Equipment used. The advanced optical design and tight alignment tolerances have led to the development of innovative techniques and procedures to meet the high demanding optical requirements.

The heritage developed within the stringent manufacturing and integration requirements of VHR program strengthens the excellence of the Italian Space Agency and its industrial partners in the panorama of Earth Observation space missions.

Keywords: Earth Observation, Multispectral Satellite, High-Resolution, Optical Design, MAIT.

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1. INTRODUCTION

Earth Observation (EO) is one of the main activities of the Italian Space Agency (Agenzia Spaziale Italiana, ASI), from the development of new space programs to their in-orbit operational management. EO has crucial applications in environmental monitoring, climate [1], air quality monitoring, marine protection, emergency management, hydrogeological risk, soil moisture, precision agriculture, urban planning, infrastructure monitoring, deforestation, fires, volcanoes [2], etc. This large variety of applications requires the deployment of several satellite constellations embarking different payloads with various observation technologies. In the framework of the PLATiNO (*mini Piattaforma spaziale ad Alta TecNOlogia*) Program, ASI is developing a mini-satellites constellation with multi-spectral, hyper-spectral (HYP) [3], Very High-Resolution (VHR) and Synthetic Aperture Radar (SAR) compact payloads.

VHR is the payload with the highest spatial resolution ever realized by ASI for EO [4]. To meet the stringent alignment criteria dictated by its innovative optical design, the Italian industrial supply chain, led by Leonardo S.p.A. and involving Officina Stellare S.p.A., developed cutting-edge optical technologies for both the manufacturing and integration phases. This work describes the instrument optical design (Section 2), the Manufacturing, Assembly, Integration and Test (MAIT, Section 3) with the Optical Ground Support Equipment (OGSE), and it concludes with the planned activities for the next future (Section 4).

2. INSTRUMENT OPTICAL DESIGN

VHR in an EO optical push-broom payload designed for high-resolution observations in the Visible and Near Infrared (VNIR) spectral range, operating from a nominal orbital altitude of approximately 515 km. The mission lifetime is planned to be at least 3 years, extendable up to 5 years. Leonardo S.p.A. developed the optical design of the payload to satisfy the demanding requirements specified by ASI.

The VHR payload has a mass of approximately 100 kg, allowing the use of a small/medium size platform to embark it. This mass is inclusive of payload opto-mechanics, the Video Acquisition Unit (VAU) connected to the FPA, the Internal Control Unit (ICU), FMA, star trackers, radiator, heaters, thermistors and harness. An overview of VHR payload is reported in Figure 1 (left).

The payload spectral bands are listed in the following Table 1. A scheme of the optical layout is reported in Figure 1 (right).

Table 1. VHR payload spectral bands.

Band	Central wavelength [nm]	Bandwidth [nm]
B1 – Blue	485	70
B2 – Green	560	70
B3 – Red	655	70
B4 – NIR	825	120
Panchromatic	625	175

The Across-Track (ACT) and the Along-Track (ALT) Ground Sampling Distance (GSD) will be no greater than 2 m in the VNIR spectral range, and better than 0.5 m in the Panchromatic channel. The acquired swath will be 8 km in both directions. The achievement of these requirements led to the development of a Ritchey-Chretien type telescope with a primary mirror of 50 cm diameter and a focal length of about 4 m, and therefore a focal ratio of approximately $f/8$. The half Field-of-View (FoV) of the telescope is about 0.63° .

The required exceptional optical quality, up to an ideal Modulation Transfer Function (MTF) of 0.22 for the telescope assembly and an optical distortion less than 1%, coupled with the required spectral cross-talk between the various spectral band less than 3%, led the development of a 3-lens corrective optical system in order to have an aberration-free and diffraction limited focal plane. In addition, a space qualified high-precision Focus Mechanism Assembly (FMA) will be employed to obtain high-contrast and sharp images in all observing scenarios.

An internal baffling system is employed to reduce the straylight in the optical path. All internal surfaces have been blackened with Aeroglaze to minimize spurious reflections. Straylight simulations, including ghosts, scattering,

roughness and contamination, have led to the need to use very high-quality optical elements, with surface roughness better than 2 nm. These analyses also established strict particulate cleanliness requirements, ranging from 500 ppm for mirrors to 100 ppm for lenses and filters achieved within ISO 8 to ISO 6 cleanroom. Furthermore, enhanced reflective silver coating for the mirrors and anti-reflection coating for the lenses were implemented to maximize the throughput of the instrument achieving up to 82% transmission over the VNIR spectral range.

The push-broom acquisition strategy required the use of a CIS-125 linear detector produced by Teledyne and operating in Time Delay Integration (TDI) mode, whose pixels have a small size of 5 microns. Two panchromatic bands shifted by 1/2 pixel are constructively realized in the detector sensing surface allowing the application of super-resolution techniques to improve the image details reached by the satellite [5]. The other four multi-spectral bands are scanned by the satellite orbital motion as reported by Figure 2.

The instrument can be operated in Nadir pointing attitude or with a Ground Motion Compensation (GMC) maneuver to increase the stripe performances and the Signal to Noise Ratio (SNR). Yaw and Roll maneuvers are foreseen to offer acquisition mode flexibility and maintain the ground-track projection on the Focal Plane Assembly (FPA) aligned along the nominal TDI (column) direction. The detector is equipped with a multi-spectral strip filter.

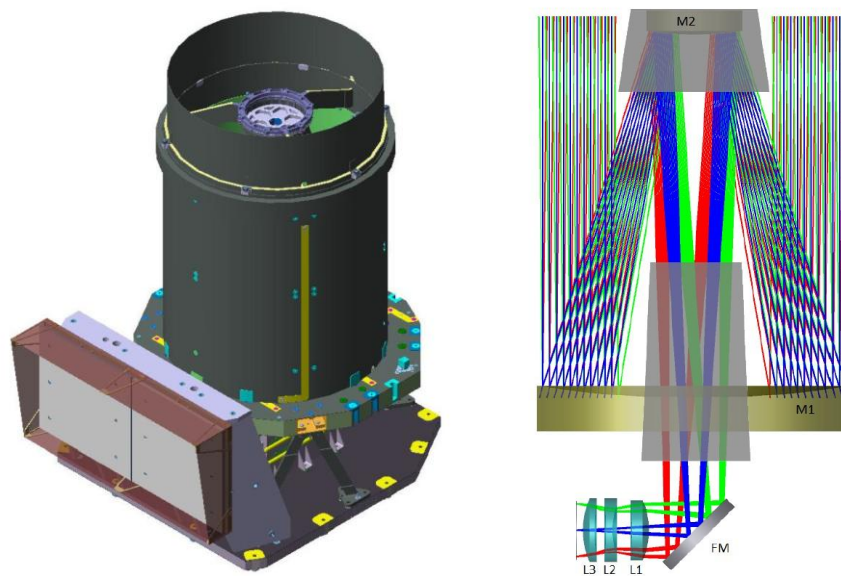


Figure 1. Left: VHR payload Instrument optical head overview. Right: VHR payload optical layout scheme.

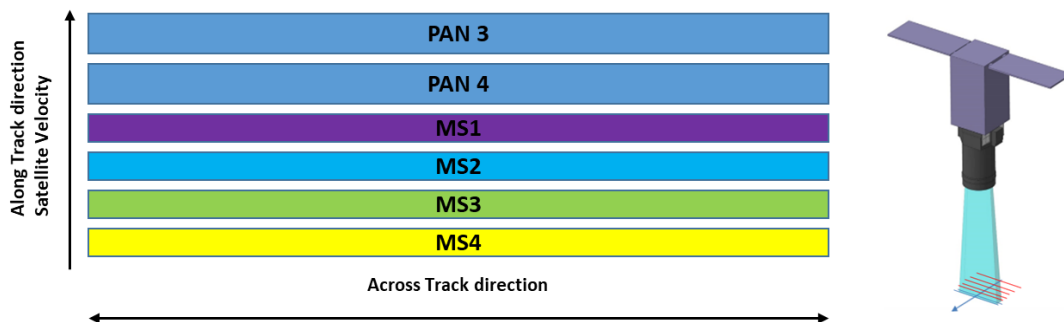


Figure 2. VHR push-broom acquisition strategy with two panchromatic bands and four multi-spectral broad bands.

3. MANUFACTURING, ASSEMBLY, INTEGRATION AND TEST

Manufacturing, Assembly, Integration and Test (MAIT) Phase proved to be equally complex, driven by the challenge of satisfying the payload's stringent optical and environmental requirements.

The two hyperbolic mirrors have been manufactured from blanks of low-expansion glass and their shapes have been lightened with a honeycomb-like structure developed to maximize the cell dimensions and to minimize the ribs thickness, the optical surface thickness and the total final weight, reaching a value for the latter equal to 1/3 of the non-lightened structure. A sketch of M1 lightning is reported in the following Figure 3 as an example. The optical surfaces were rough-finished and polished with extremely high-precision planetary machines.

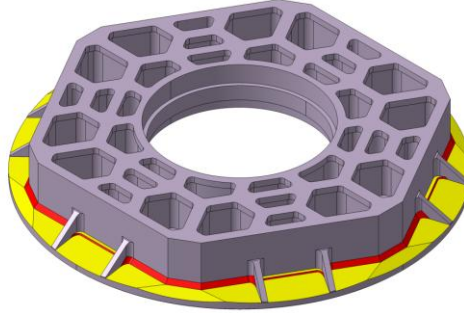


Figure 3. M1 lightened mirror.

As shown in Figure. 1, the M1 mirror is mounted on three bipods attached directly to the optical bench. The M2 mirror, supported by three vanes, and held in place by a Carbon Fiber Reinforced Polymer (CFRP) tube. The folding flat mirror (FM) is bonded to a Titan support and positioned at the rear of the optical bench.

The three lenses of the corrector, fabricated from radiation-hardened glasses, are bonded into a Titanium barrel, which is subsequently mounted onto the rear of the optical bench.

The tolerances involved for the telescope alignment are very tight and require the following step:

1. The optical bench is taken as a global reference frame;
2. M1 is aligned with respect to the optical bench;
3. FM and lens corrector subassemblies are integrated in the rear part of the optical bench;
4. M2 is aligned with respect to M1;
5. MTF and best focal plane are determined by interferometric measurements;
6. The detector is integrated and tested within a thermal vacuum chamber.

These phases are described below together with the OGSE developed for this purpose.

Optical bench reference frame

The optical alignment workflow initiated with the determination of the mechanical reference frame (MRF) of the optical bench by using a reference optical cube bonded in its front part and a service lamina mounted in its rear part, measured via an high-precision theodolite, as reported in Figure 4. This metrology setup achieved an alignment precision on the order of few arcseconds.

Primary mirror M1 alignment

The next step involves aligning M1, which is supported by a dedicated fixture and moved by a hexapod. The mirror is centered using a Centering Measuring Machine (CMM), while its tip/tilt is adjusted by comparing the autocollimator

measurements between the service lamina and the rear surface of the mirror, as shown in Figure 5. Finally, the mirror is bonded to the bipods using a special space-qualified glue. The Wavefront Error (WFE) of the primary mirror is characterized with its optical axis perpendicular to the direction of gravity vector and the optical bench is rotated in 90° steps to average the measurements and exclude the contribution of the WFE distortion given by gravity. This measurement sequence was performed both before and after curing cycle inside the Thermo-Vacuum Chamber (TVAC).

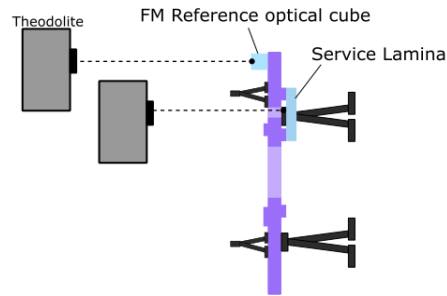


Figure 4. Schematic concept of the mechanical reference frame characterization of the optical bench.

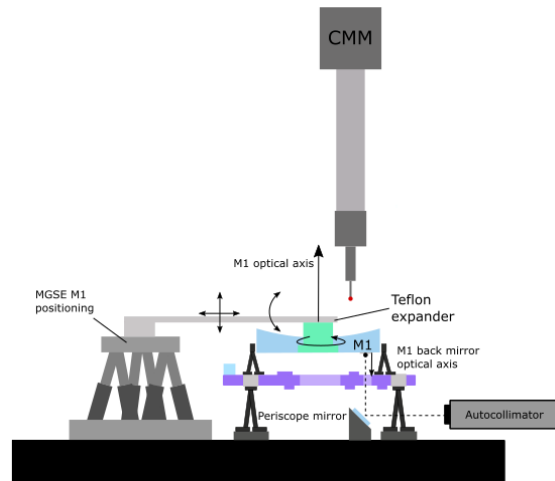


Figure 5. Schematic concept of M1 alignment using an hexapod and measuring it with a CMM and an autocollimator.

Integration of folding mirror FM and lens corrector

Next, the optical bench is inverted to allow the FM with its support and the lens corrector with its support to be mounted. The necessary mechanical precision is ensured by the fact that these elements are installed in their respective seats and guided by positioning pins.

Secondary mirror M2 alignment with respect to primary mirror M1

M2 alignment is the most critical part of the MAIT phase of VHR. The standard method to align an on-axis mirror telescope is based on nulling power, coma and tilt aberration for the axial field by decentering and tilting the secondary mirror following an iterative procedure. Due to the high requirement on optical quality of this telescope, this method is not suitable to match the required performances, therefore the VHR telescope employs a specialized alignment method, based on nulling power, coma and tilt on axis field and nulling astigmatism and tilt on maximum field by decentering

and tilting the secondary mirror. Since the compensator for axial aberration and full field aberration is the same, the procedure does not fully compensate for the aberrations, but it finds the best position of secondary mirror that can balance the performance on axis and in field, and thereby maximizing the achievable MTF. The used setup is shown in Figure 6. The alignment of M2 is performed using the hexapod and a support tool and it is monitored using a FISBA interferometer working in autocollimation thanks to a large flat service mirror. At the end of the procedure M2 is glued into the crown and the curing in TVAC is performed.

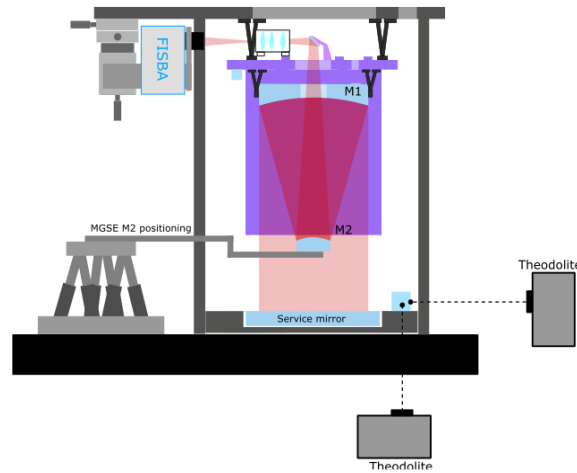


Figure 6. Schematic concept of M2 alignment with respect to M1 using an hexapod and monitoring it using a FISMA interferometer.

Interferometric measurements

To determine the final MTF of the telescope and identify its best focus position, interferometric measurements are acquired using the FISBA interferometer with the telescope oriented in both Zenith and Nadir (pointing upside and downside) configurations. This procedure effectively isolates and eliminates the gravitational-induced deformation terms and provides the nominal performance that the telescope will exhibit in orbit under 0g conditions.

Focal Plane Assembly integration

The final part of the telescope integration is the mounting and alignment of the integrated FPA (filter, detector and FMA). This phase required the development of a large collimator system shown in Figure 7 with an exit pupil larger than the entrance pupil of VHR.

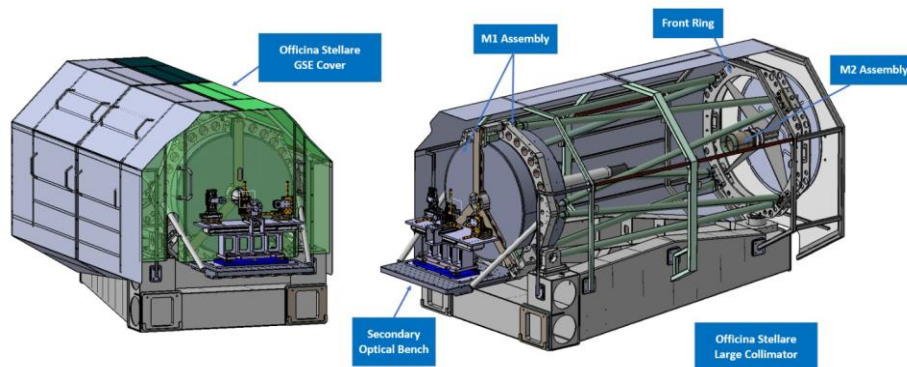


Figure 7. Large collimator system developed for FPA alignment.

To align the FPA, both the large collimator and the entire VHR payload will be placed inside a new, large TVAC chamber, 4 m in diameter and 7 m in length, recently installed at Leonardo facility (Figure 8). FPA tip/tilt will be controlled by a hexapod and monitored directly via the detector in imaging mode in order to minimize the MTF in the whole FoV of the telescope.

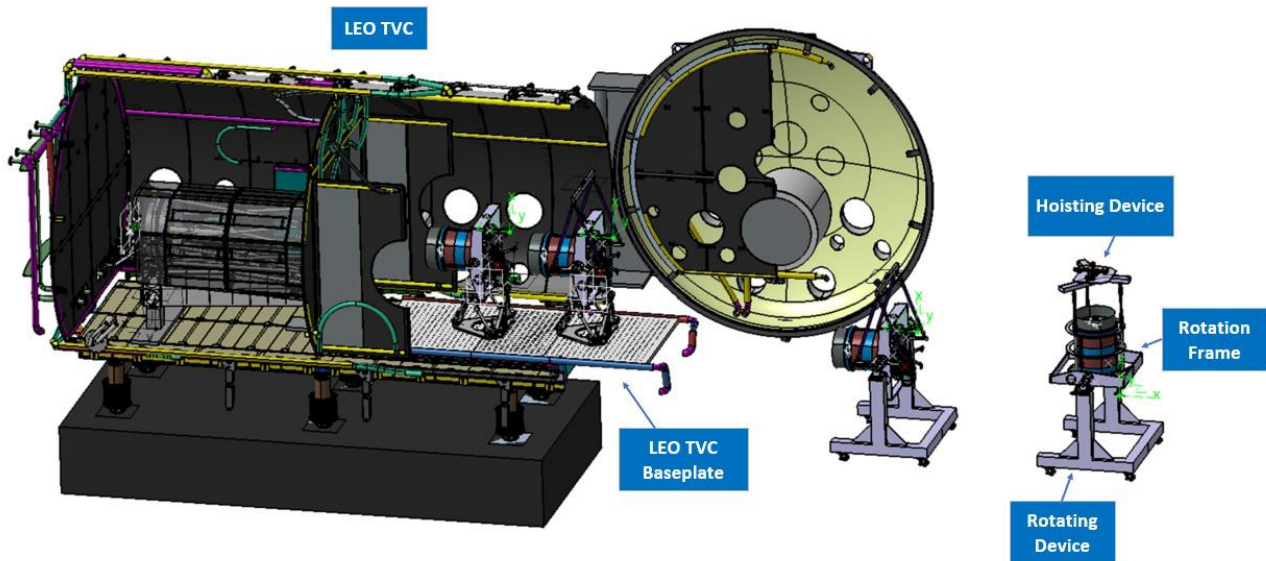


Figure 8. Large TVAC chamber with large collimator and VHR inside for FPA alignment and payload calibration.

4. CONCLUSION

VHR will be the high-resolution payload developed by ASI and the Italian national supply chain in the framework of the PLATiNO program for EO. After the integration of the entire telescope, the alignment of the FPA will be completed in the coming months. All calibration activities for the detector (dark, flat, offset, etc.) and for the entire payload (radiometric, flat, straylight, etc.) will be completed by the end of 2026, using the new large TVAC chamber at the Leonardo facility. At the end of Phase D, the VHR payload will be ready for integration with the platform. The heritage developed within the VHR program has strengthened the excellence of ASI and the Italian industrial sector in the global panorama of Earth Observation.

ACKNOWLEDGEMENTS

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