SSC09-III-9

Compact Optical Payload for Daily Survey of Vegetation from Small Satellites

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ABSTRACT

Recent advancement of optics fabrication, metrology and detectors are the basis for the development of a new compact instrument designed to provide daily revisit for the analysis of vegetation. The instrument has been optimized to improve multispectral imaging capabilities with respect to Spot-Vegetation, while minimizing mass and power to be accommodated on a small satellite. The new technologies used for this instrument allow shrinking the mass and reducing the power consumption of a factor 5 with respect to Spot-Vegetation. The new instrument is designed to fly on Proba-V, a small satellite developed to ensure continuation of the Spot-Vegetation products.

The paper gives an overview of the payload, presents its performance and explains which innovations allow a very compact design. In particular, the paper presents the technology used for the fabrication of mirrors, the approach used for their alignment, and the tests results obtained so far on the first prototype of the telescope. A section of the paper describes the InGaAs detector developed for the SWIR channel, a long linear array able to operate uncooled. The paper concludes with a description of the mission, of the payload accommodation on the small satellite, and of the data produced.

INTRODUCTION

Vegetation is a multispectral imager flown on Spot-4 and Spot-5, French satellites for Earth Observation and defense. The instrument, with its wide field of view, is capable of covering a swath of 2200 km. The large swath, combined with selection of a polar low Earth orbit, guarantees a daily revisit. Vegetation, through the operations on board of two subsequent Spot satellites, has provided in the last 10 years continuous stream of data about the status of vegetation. Spot-5 lifetime expires in 2012. Pleiades, the next French satellite for Earth Observation, is solely dedicated to high resolution imaging and will not embark any instrument providing vegetation data. BELSPO, the Belgian Federal Science Policy Office, supported the development of an instrument to ensure continuity of vegetation data that could be flown on a Proba type satellite, a small satellite developed by the Belgian Verhaert Space.

The peculiarity of the development consists in the fact that the mass, power and volume of the Vegetation instrument flying on Spot accounts alone for the mass, volume of power budget of the entire Proba satellite, namely 130Kg. The challenge of this development is to produce an instrument responding to the same User Requirement of Vegetation, but with an overall mass less than 30Kg. A number of new technologies have been developed since the nineties, when Vegetation was first conceived. This paper describes what type of innovations and design approach made possible to meet the challenging requirement of ensuring continuity of vegetation data from a small satellite.

DESIGN APPROACH

The Vegetation Instrument flying on board of Spot-5, consists in four dioptric telescope, each telescope is dedicated to a spectral channel, namely Blue (460 nm), Red (658 nm), Near Infrared (834 nm) and Short Wave Infrared (1610nm).

Reviewing the design of Vegetation was soon evident that the room for improvement to reduce the size of the optics was very limited, if we based the solution on a full dioptric system. A solution based on dioptric was too large and massive to be accommodated on the platform of a small satellite. The optical fabrication of mirror advanced significantly in the last 10 years, giving the hope that a solution to squeeze the mass from 130Kg down to the required 30Kg could be found by using a reflective telescope.

Advancement of SWIR detector was another area where it was possible to find significant mass saving. Recently developed detectors based on InGaAs technology, instead of MCT used on Vegetation, are able to deliver the necessary Signal to Noise performance at room temperature, giving the possibility to avoid massive and power thirsty cooling systems.

The evolution of solid state memories and EEE components gave the final help to meet the requirements of mass, volume and power.

The Project, named Proba-V after the name of the platform, at the moment of writing is at the completion of its Phase-B. The design of the payload is quite advanced, an Engineering model of the telescope has been built, and the InGaAs detectors are in fabrication.

INSTRUMENT DESCRIPTION

Telescope Design

An extensive study and trade-off work was undergone to identify a solution that could meet not only technical challenges, but that could also been developed and tested within a tight budget of a small satellite mission. A solution that was identified as a good compromise between performance, design complexity and cost is based on three identical reflective telescopes using high aspherical mirrors in a TMA (Three Mirrors Anastigmat) configuration. The fully reflective optical layout is not affected by chromatic aberration and each telescope can accommodate all spectral bands. It will be necessary to use three telescopes mounted on a stable optical bench with squinted line of sights to cover the field of view of 105 degrees, meaning that each telescope is required to cover a field of view of at least 34 degrees to ensure also an overlap between different spectral imagers.

Figure 1 shows the raytracing of one TMA, Figure 2 shows a section of the telescope and of the mounting structure.

It was very clear already from a first analysis that a fully reflective telescope with a field of view of 34 degrees was source of many challenges: manufacturability of mirror #3 with its very low f-number (below 0.7) was challenging to test; mirror #1 has a large deviation from a spherical mirror making unfeasible to use any postpolishing, and finally the alignment of the three mirror required the development of an alternative approach because the position of their vertex and axis of symmetry ruled out conventional alignments based on optical methods.

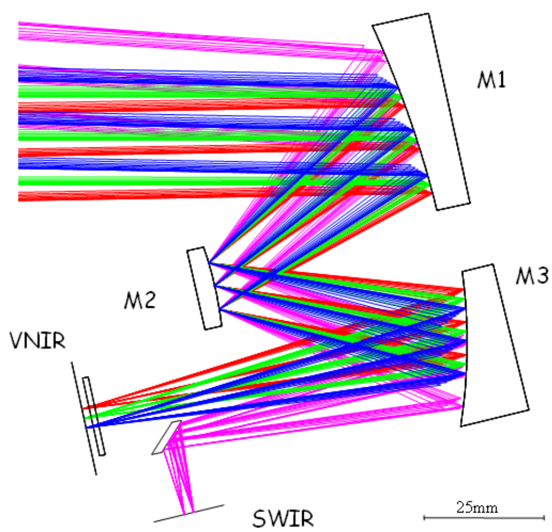

Figure 1- TMA Raytracing

Work done at AMOS in cooperation with optical and mechanical engineers at OIP, the Instrument Prime, resulted in a design where all aspects above were reviewed until a solution within the reach of the current state-of-art of manufacturing capabilities could be found. The work consisted in finding a good balance between the achievable mechanical tolerance using Single Point Diamond Turning (SPDT) and the final optical performance. All mirrors have been successfully manufactured and tested. The alignment of the mirrors is currently in progress. Preliminary results show that the complex operation alignment is under control. Further work to establish final performance of the telescope is in progress at the moment of writing.

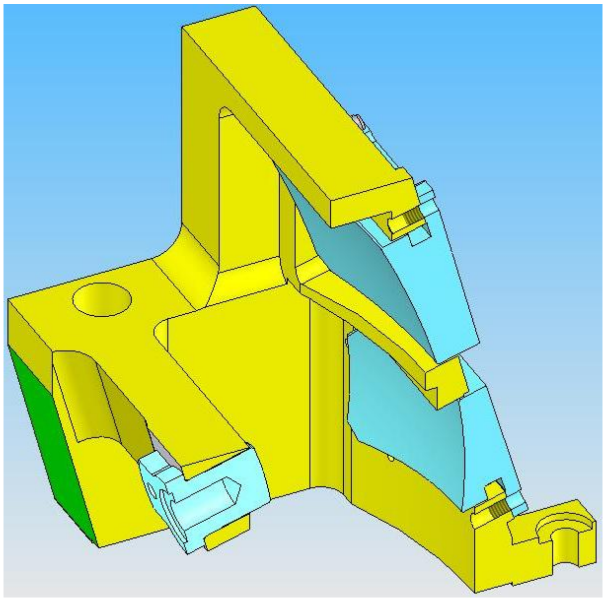

Figure 2 - TMA Mechanical Design

SWIR Detector

The User Requirement ask for a SWIR channel to be used for distinguish burn scarves from flooded areas. Large format MCT detector currently used is very expensive and requires massive and power thirsty cooling systems. XenICs recently developed an InGaAs detector partially meeting the Vegetation Requirements. Further development started to bring the format of the detector from the existing 512 pixels to 3000 pixels, the required format to cover the large field of view. Furthermore, a specific design of the ROIC (Read-out IC) gave the possibility to optimize full well capacity and read-out for the Vegetation requirements. The development of a detector of 3000 pixel of 25μm each requires using almost the full wafer. The InGaAs is a very brittle material, handling a linear array as long as the wafer was considered a not negligible risk; furthermore, the yield of a detector free of defective pixels in such long array was expected very low. To circumvent these two problems, a solution based on three detector of 1024 mechanical butted has been selected. Figure 3 shows the mechanical layout of the selected configuration. The green lines are the InGaAs photodiodes, the white straps indicates the ROIC.

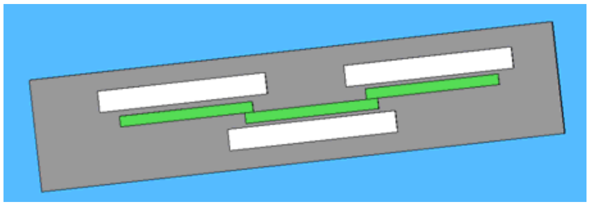

Figure 3 - SWIR Detector Layout

The mechanical butted solution, while solving the problem of handling and cosmetic, left the engineers at XenICs with the problem of the alignment of the three detectors within the tight mechanical tolerances. As part of the development, a number of dummy arrays have been assembled to check the feasibility of the alignment and to verify the achievable accuracy.

Figure 4 - TMA on the Test Set-up

Optomechanical Design

The material selected for the telescope is a special aluminum alloy. The material was selected to obtain an optical quality and a surface roughness compatible with the WFE (wave front error) and in field straylight requirements. The drawback of aluminum is its high CTE (coefficient of thermal expansion). The strict requirement of geolocation, only a fraction of a pixel, requires high thermo-mechanical stability. The accommodation on the Proba-V platform poses severe constraints on the thermal environment. Furthermore, thermal control systems based on active cooling and/or heat pipes were ruled out because out of reach for a small satellite. To obtain the stability requirements to comply with the geolocation requirements using only passive thermal design was another design challenge to the edge of feasibility. The thermo-mechanical concept, shown in Figure 6, is based on a simple idea: use the high conductivity of aluminum to reduce, if not eliminate completely, the thermal gradients within the optical pallet. The whole optical pallet has been design in each small part to rapidly dissipate any accumulation of heat and still being able to passively cool the detectors to their operative temperature. We are obviously very eager to discover if the thermal concept will be fulfilling his tasks. Because the criticality of the thermal stability, the work planned for the phase C/D will contain and early thermal model to run thermal tests as soon as possible in the development.

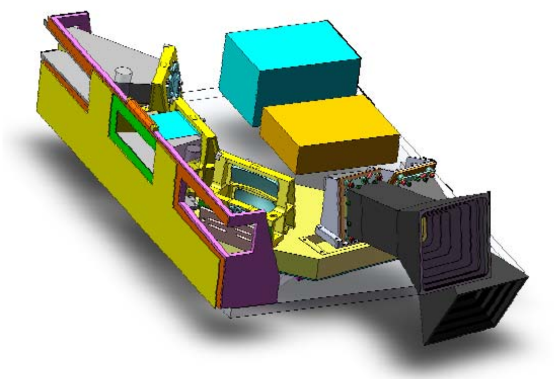

Figure 5 - Payload Mounted on the Optical Pallet

Data Compression

The massive amount of data produced by the instrument is beyond the capabilities of the bandwidth available on board of a small satellite. Data are reduced by using a lossless data compression algorithm implemented in a specific electronics. The data compression ratio obtained using standard CCSDS compression algorithms is shown in the following table.

Table 1 - Compression Rates

Spectral Band	Compression ratio
Blue	10.8
Red	7.2
NIR	5.4
SWIR	2

Payload Performance and Design Parameters

Table 2 reports the payload expected performance versus design parameters requirements stemming from Vegetation. It can be seen that the Ground Sampling Distance is significantly improved from Vegetation. The improved capabilities of this instrument have been welcomed by the Users because it gives the possibility to ensure continuation of Vegetation data (1 Km GSD) and at the same time offers the possibility to match the resolution of the instruments presently flying whose GSD is 300m, MERIS , MODIS, TERRA. This will enhance the scientific return of the mission, because the user expects to extract more information by complementing Proba-V data with those coming from other missions.

Table 2 - Main Instrument Parameters

Parameter	Vegetation	Proba-V
Mass (Kg)	160	28
Volume (m)	1.0 x 1.0 x 0.7	0.7 x 0.4 x 0.3
Swath	2250 km	2250 km
GSD @ Nadir (m)	1165	100 (VNIR) 200 (SWIR)
GSD @ Max Swath (m)	1700	360 (VNIR) 690 (SWIR)
MTF @ GSD	0.3	0.3
Spectral bands		
Blue	450nm, FWHM 42nm	460nm, FWHM 42nm
Red	645nm, FWHM 70nm	CWL 658nm, FWHM 82nm
NIR	834nm, FWHM 121nm	834nm, FWHM 121nm
SWIR	1665nm, FWHM 89nm	1610nm, FWHM 89nm
SNR @ L2 (W/m2/sr/µm)	1km product	300 m product
Blue (L2=111)	188	502
Red (L2= 110)	333	597
NIR (L2=106)	393	611
SWIR (L2=20)	333	405 (600m product)
Geolocation accuracy		
Absolute (m)	300	300
Multitempora l (m)	500	300
Multispectral (m)	1000	300
Power (W)	<200	36

At the moment of writing all the mechanical parts of the telescope have been manufactured and tested. Test results show that all components are well within the specification. The telescope has been assembled. It was possible to observe a first interferogram after only a few days of work dedicated to the alignment. This indicates that the alignment procedure was well defined and easy to implement. Fine alignment and performance test are in progress.

Thermal Design

The thermal design of the payload has been optimized to minimize the thermal gradients on the optical bench and to eliminate, as far as possible, any gradient within each telescope. The material for the telescope and the optical bench is aluminum; this solution has the advantage of being completely athermal, but the drawback of thermo-elastic deformation due to the coupling of the optical bench with the satellite. Among the various solution, the selected configuration uses only passive cooling. Thermal straps connect the detectors to the optical bench and the optical bench is connected to the radiator mounted on the nadir looking side of the satellite. The thermal analysis performed shows that it will be possible to keep the detectors at the required operating temperature. Thermal gradients within the telescope are expected to be less than one degree. The temperature variation seen by the optical bench in one orbit is less than a couple of degrees.

These modest temperature variations allow to keep thermo-elastic deformations within the requirement to ensure the gelocation requirement.

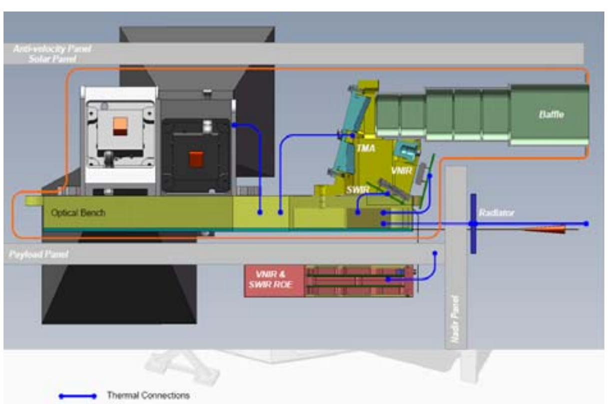

Figure 6 - Thermal Model

Accommodation of the Payload on the Satellite

Figure 7 shows the payload mounted on the Proba-V platform. Given the reduced size of the platform and the H-shape structure, the only practical location of the payload, is on the anti-velocity panel. This accommodation, with respect to a solution with the payload in the middle of the structure, has the advantage of a very simple assembly and clean mechanical interface. The drawback is a larger temperature gradient due to the close vicinity of the payload to the solar panel.

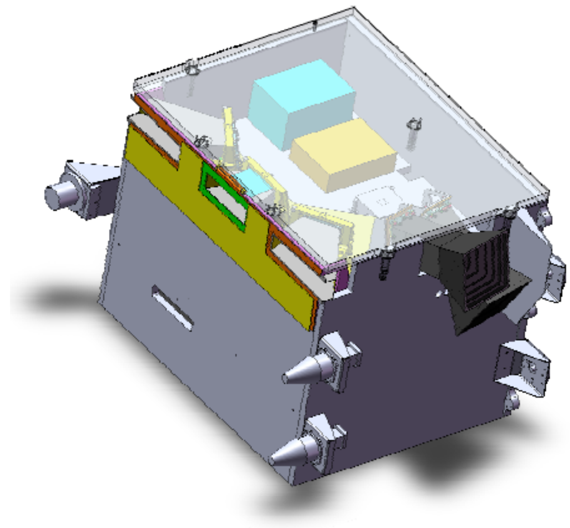

Figure 7 - Payload Mounted on the Satellite

Acknowledgments

The team involved in the design and manufacturing at OIP, AMOS and XenICs is composed by several persons, whose dedication and attention to details is instrumental for the progress of such a challenging project. A long list would be necessary to name all of them. A special mention should go to Avi Blasberger who proposed to investigate a solution based on a TMA. Moshe Blau gave an important contribution with his simple and straightforward mechanical design, essential for any optical design to be successful. A special thank goes to my colleagues B. Harnisch, M. Erdman, and V. Kirschner that reviewed the design and outlined all the hurdles we may encounter in designing and building off axis highly aspherical telescopes.