EIS, A UNIQUE HYPERSPECTRAL PATHFINDER MISSION COMBINING THE COMPACT ELOIS INSTRUMENT AND THE INNOSAT SMALLSAT PLATFORM.

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ABSTRACT

The new mission EIS is an IOD/IOV mission as a part of the European Union "Horizon 2020" program and combines the innovative ELOIS hyperspectral instrument with the flight-proven InnoSat platform to form a low-cost but still agile and high performing hyperspectral imaging mission. OHB-Sweden is mission prime, responsible for the platform systems, payload integration, AIT and in space operations, while AMOS is payload prime and responsible for the instrument delivery and data validation. The target orbit is a LEO SSO orbit on 630 km and the design lifetime is 5 years. The platform, based on already flight proven architecture, is enhanced with very high pointing performance and stability, an X-band link for the high data-rate required by the payload, and provided with orbit transfer and maintenance capability via FEEP thrusters. ELOIS is a state-of-the-art instrument featuring several innovative optical, mechanical, and electrical designs. The instrument provides very high radiometric and SNR performances while being very small and light-weight, and has a much lower power demand than comparable imagers. This makes it an excellent instrument for low-cost smallsat imaging missions. The mission will be controlled from the OHB Sweden Mission Control in Kista, Sweden. The combination of the InnoSat platform and the ELOIS instrument has the potential of being a powerful demonstrator for future hyperspectral missions with a wide range of applications.

1 INTRODUCTION and BACKGROUND

As a part of the European Union initiative "Horizon 2020 in-orbit demonstration/in-orbit validation (IOD/IOV) missions", ESA has implemented a contract for a high performance IOD/IOV mission, currently named EIS – ELOIS IOD Satellite. OHB Sweden has been awarded the contract for mission prime with responsibility for the development and delivery of the platform with all necessary interfaces to the payload, as well as for the payload integration, system verification and satellite operations for one year.

AMOS has been pre-selected by the European Commission to provide the ELOIS payload for the EIS mission. ELOIS (Enhanced Light Offner Imaging Spectrometer) is a hyperspectral instrument presently being developed under a GSTP contract from ESA.

Hyperspectral Earth Observation is a fast-evolving field requiring high performance imaging spectrometers. Since 2010, AMOS has initiated a series of developments demonstrating the feasibility of miniaturizing very capable hyperspectral instruments. ELOIS represents a breakthrough in terms of SWaP (i.e. Size Weight and Power) and radiometric performance made possible through the convergence of a series of technological innovations such as free form optics, high precision slits and multi-blazed diffraction gratings combined, thanks to a unique optical design, into a compact full aluminum instrument.

The EIS mission uses OHB Sweden's successful InnoSat micro satellite platform. The InnoSat platform has proven itself worthy in a large variety of missions from a commercial (GMS-T, in orbit since 2021), scientific (MATS, launch 2022) or institutional nature (AWS, launch Q1 2024).

2 MISSION CONCEPT

The ESA and European Commission (EC) main mission objective is to demonstrate and validate the ELOIS instrument performance in orbit. The EC supports this through ESA in a 1-year operational phase with an optional extension of 1 additional year. The satellite and payload are designed for a 5-year lifetime which should allow for the EIS mission to be operated beyond the first two years. Hence, OHB Sweden and AMOS also regard the commercial validation of a low-cost hyperspectral imaging service as a secondary objective.

The orbit selection is driven by the payload design. A low Earth Sun-Synchronous Orbit is the baseline with an altitude of around 630km and a 5-day ground repeat track. The local time of ascending node would ideally be around 23:30 such that the satellite passes from North to South in the sunlit phase of the orbit.

3 SPACE SEGMENT DESIGN

The EIS spacecraft consists of an InnoSat micro satellite platform, upgraded with certain mission critical enhancements, and an ELOIS payload. The satellite is projected to be in the 120 kg range including the 42 kg ELOIS instrument.

3.1 Platform

The main platform architecture is similar to previous InnoSat satellites but incorporates a number of new features and enhancements resulting from the ELOIS instrument requirements. The electrical power subsystem comprises of the Power Conditioning and Distribution Unit, a battery and 2 deployable solar panels. Only 2 panels are used to minimize the inertia hence maximizing the agility of the spacecraft. The avionics are grouped together with the radios for communication around the Data Handling Subsystem and consist of all AOCS sensors and actuators.

Historically, payload data on InnoSat missions was transmitted over S-band (i.e. MATS) with maximum speeds of about 5 Mbps. The ELOIS instrument, collecting a large number of spectral bands across the VIS-SWIR spectrum, has a much higher data rate, in the order of 500 Mbps, so this calls for the incorporation of an X-band link capable of efficiently downlinking a sufficient amount of data. The platform will incorporate a DVB-S2 capable X-band radio with data rates in the range of 100 to 150 Mbps. The DVB-S2 protocol provides flexibility to optimize the link budget during the pass. A directional high gain antenna is used to complete the RF link.

The instrument requires a high absolute and relative pointing accuracy which in turn is requiring high performance AOCS equipment and software. The standard InnoSat AOCS equipment is thus complemented with a high-performance gyroscope and star-trackers. The gyroscope is lightweight and based on fiber optic technology. The 2 star-trackers are oriented orthogonally and are mounted directly on the optical bench of the payload for the best thermo-elastic stability.

To deliver an agile platform the use of CMGs (Control Momentum Gyro) has been considered. In comparison with the use of conventional reaction wheels on InnoSat, CMGs provide a much higher torque resulting in faster slews. For this current mission the slew rate provided by the reactions wheels (>1 deg/s) is sufficient and the additional effort to incorporate CMGs in the InnoSat platform and the associated risks, are not justified by the IOD/IOV nature of the project. They are however an excellent way of improving the agility of the spacecraft by adding CMGs in future missions in addition to the reaction wheels.

The EIS satellite comes with four Field-Emission Electrical Propulsion (FEEP) thrusters providing up to 1.2 mN of thrust at 160W for orbit maintenance (phasing, altitude), orbit raising and collision avoidance maneuvers. As FEEP thrusters are throttleable devices, specific EIS operating points have been selected balancing power consumption and performance needs. The choice for FEEP technology is justified by its performance in line with the EIS mission requirements (deltaV, power consumption etc.) as well as a high TRL level, accommodation flexibility and its low-cost whilst being able to use multiple FEEP's for system redundancy.

Onboard command scheduling is performed with Mission Timeline (PUS 11) or Position Scheduler (PUS 22). This allows for flexible and hands-off payload operations. The position schedule will be useful in particular for planning of ground contacts and calibration observations.

The EIS mission shall be implemented within a relatively low budget and essentially following a COTS equipment philosophy that is the trademark of InnoSat. With these enhancements, OHB Sweden's InnoSat product will be well positioned for any similar EO mission requiring high data throughput, agility and stability, typically required for hyperspectral missions.

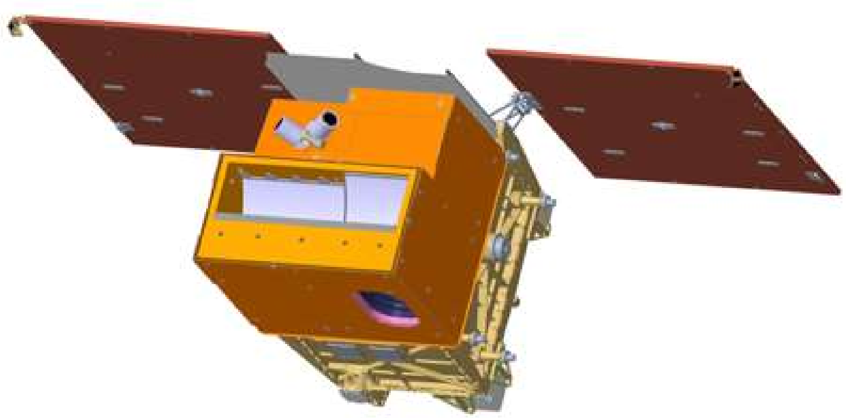

Figure 1 ELOIS payload (with orange cover, entrance pupil and radiator) on top of the InnoSat platform. The deployable Solar Arrays are visible with a Sun shield in between, as well as the Star Trackers mounted on the payload.

3.2 Payload

AMOS, leveraging its extensive experience in optical design and advanced optics manufacturing, has developed a state-of-the-art hyperspectral instrument dedicated to smallsats and named ELOIS.

ELOIS is taking advantage of an innovative diffraction grating, ruled on a freeform surface, and combined with highly aspherical mirrors into a smart optical design to achieve a very small form factor. This design offers increased flexibility and throughput performance as it combines imaging, de-magnification and dispersing functions in a system with only three power surfaces enclosed in a compact volume. This solution offers a reduction of about a factor 4 in volume compared to standard Offner-Chrisp spectrometers for equivalent performance. In addition, AMOS' design achieves very low distortions with excellent keystone and smile performances. This is especially important for instrument covering a very large swath as our ELOIS. In comparison with well-known institutional missions such as EnMap or Prisma, ELOIS is 10 times smaller while offering a 2 times larger swath (70 km) and comparable performance.

Thanks to a very small F-number (i.e. F/2.1) and a complex multi-blazed grating optimized over the entire spectral range, our spectrometer achieves high radiometric performance. The 140mm pupil diameter of the instrument, the optimized efficiency of the grating and the large full-well capacity of selected detectors contribute to a high Signal-to-Noise Ratio (SNR - up to 400). The complete optical chain achieves a Modulation Transfer Function of 0.8 in the VNIR and 0.65 in the SWIR, allowing for a total MTF budget of about 0.3 including smearing, jitter, sensor, manufacturing and thermo-elastic errors.

The opto-mechanical architecture of the payload is intentionally designed as simple and modular as possible, taking full advantage of the all-aluminum approach and Single Point Diamond Turning of optical surfaces and mechanical interfaces. Through various R&D projects, AMOS has developed and demonstrated the specific manufacturing techniques now ensuring a fully athermal solution with straightforward alignment of the optics. This architecture is based on a main optical bench, supporting all the opto-mechanical elements. The Front Telescope mirrors are directly mounted on the bench while the spectroscope and its focal planes are assembled as stand-alone sub-systems on a second-stage board. Our instrument is therefore fully athermal as all elements are made in the same aluminum material. All components can be manufactured in a cost-efficient way with excellent quality and aligned easily thanks to ultra-precise machined interfaces and “snap-together” kind of assembly.

This innovative imager thus achieves an excellent price-quality ratio, obtained thanks to the optimization of several optical, mechanical, electronic and software technologies. As it also consumes less power and requires fewer peripheral instruments, it is ideal for constellations of small satellites.

4 GROUND SEGMENT

OHB Sweden will operate the satellite from its premises in Kista, Sweden, using its own Mission Control Center and related RAMSES mission control software. Ground station services for both S-band and X-band will be procured as a service; no dedicated ground stations are foreseen. Using such a service provides access to a large network of ground stations giving flexibility in planning and timeliness of data.

In the IOD/IOV part of the mission weekly observation requests will be exchanged between the payload and platform teams. These include both observations of interesting targets but also on-ground calibration targets and Moon pointing for calibration. Automated mission planning will map the requests to time-tagged commands for the payload as well as for the AOCS subsystem.

All data received from the spacecraft, both payload data and ancillary platform data (attitude, position, etc.) will be processed in the Mission Control Center, archived and provided to the payload ground segment. The payload ground segment will pre-process the raw data to level 2 and disseminate the final data products to selected end users.

5 DOWNSTREAM APPLICATIONS

With its 200 spectral bands spread over the entire solar spectrum (i.e. from 400 nm to 2450 nm), ELOIS is designed to collect rich and specific information that a standard multispectral camera would not capture. Instead of collecting discrete data contained in a limited number of broad spectral bands, continuous data about the reflected light is collected for each pixel in a set of narrow bands and a so-called "hypercube" can be generated for any location on Earth. This allows for retrieving precise reflectance curves offering an improved discrimination power to easily distinguish different materials (e.g. man-made structures, rocks, etc), identify specific features through their typical spectral signature or detect subtle variations in surface properties of soil, vegetation or water due to changes in the nature, composition, water content, pigments or suspended matter. ELOIS will thus provide an avenue for developing new Earth Observation downstream applications, or improving existing ones, in various fields such as precision farming, mineral exploration, environmental and climate change monitoring, etc. Enhanced detection and identification of a range of crop stress, diseases, pollutants, invasive species, harmful algae blooms, plastic litter, etc will enable more efficient business operations and better management and anticipation of current issues threatening our planet.

In addition, thanks to AMOS unique design and manufacturing technologies for the diffraction grating, radiometric performance can be tailored and favor specific parts of the spectrum in view of targeted applications. Without changing anything else than the grating configuration, AMOS can optimize the SNR and deliver customized versions of the instrument.

6 IMPACT and FUTURE OUTLOOK

First of all, the achievements stemming from the ELOIS development projects have been at the origin of the selection of AMOS as a member of the core team coordinated by OHB System in charge of the payload delivery for the future flagship hyperspectral mission of the EU, the so-called CHIME (also known as Sentinel 10). In this framework, AMOS will deliver to OHB System 13 grating-based spectrometers in the coming years. This shows that technologies developed for small satellite systems can also benefit to large-scale institutional missions.

The EIS mission is planned to be launched in mid- 2024 and AMOS is currently manufacturing the instrument to be integrated by OHB Sweden.

For the 1-year IOD/IOV mission, the aim is to collaborate with a select group of "champion users" from the academic, research, private, institutional or non-profit sectors that will receive hyperspectral data collected over a variety of regions and will have the chance to further process it and demonstrate the added-value of extracted information in various domains.

This pathfinder mission will offer unprecedented capabilities for such a smallsat. It will allow for reaching TRL9 and demonstrating AMOS compact hyperspectral technology in space. The EIS mission also paves the way for further enhancements of the payload. AMOS has indeed initiated the development of the follow-on concept "Rainbow" that will consist in an upgrade of the ELOIS instrument integrating a new focal plane assembly with a single large format detector covering the entire range (i.e. 450 – 2500 nm) and allowing for an improved Ground Sampling Distance of 20m in the VIS as in the SWIR which will represent a major step forward. Active cooling is also contemplated together with further on-board data processing on the Payload Computer currently implemented by DELTATEC for the EIS mission.

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