Solar cubE onE – A smallsat to explore the complexity of solar flares and monitor solar peak activity

Lorenzo Pattanaro[1*], Antonio Turi[1], Francesco Berrilli[2], Luca Giovannelli[2], Daniele Urban[3], Silvia Natalucci[3]

[1]*Argotec S.r.l., Via Luigi Burgo 8, 10099, San Mauro Torinese (TO), Italy, +39 011 765 0567,*
lorenzo.pattanaro@argotecgroup.com
[2]*Università Degli Studi Di Roma Tor Vergata, Via Cracovia 50, 00133, Roma (RM), Italy,* +39
067259 4552, *francesco.berrilli@roma2.infn.it*
[3]*Agenzia Spaziale Italiana, Via del Politecnico snc, 00133 Roma (RM), Italy. +39 06 8567 647*
daniele.urban@asi.it

Abstract

The Sun is the astrophysical object which exerts the greatest influence on Earth and its surrounding. Solar particles and electromagnetic radiation emissions significantly impact space assets and manned space exploration missions. Specifically, solar flares expose astronauts to dangerous acute biological doses, cause outages of satellite operations, and, in the most extreme form, even blackout the electrical grid on the ground. Despite the increasing interest in solar flare activity in the last decades, new observations continue to disclose significant and unforeseen outcomes on such phenomena. Nevertheless, solar flares persist as an intricate challenge within astrophysics, encompassing substantial unanswered queries. The UV region of the spectrum presents another crucial aspect of solar emission. This high-energy radiation causes alteration of the upper atmosphere of Earth while X and Gamma-rays fluxes influence the ionosphere.

Solar cubE onE (SEE) mission fits in this context to unveil solar mechanisms behind high energy phenomena within the Sun. SEE will study solar emissions in the X and Gamma regions with a high acquisition frequency and Mg II emission doublet at 280 nm, all within a cost-effective smallsat. In particular, the Mg II index is a proxy of solar activity, its variations are related to the solar magnetic cycle evolution. The scientific data obtained will complement other missions currently studying the Sun, like the Solar Orbiter, IRIS-NASA, Aditya-L1, and Parker Solar Probe. Indeed, SEE will provide scientific data with an unprecedented frequency.

SEE is equipped with a novel UV solar telescope able to capture the spatial information on the solar structures responsible for the UV emissions. This optical payload operates at 280 nm with a 2 nm bandwidth. The second payload is a miniaturized version of an X-ray and gamma-ray detector based on silicon photomultiplier (SiPM) technology.

SEE deals with a peculiar constraint on the maximum radial velocity in the Sunward direction. Indeed, due to the solar telescope's narrow band, particular attention shall be paid to the orbital shift caused by the Doppler effect. Two observation modes are foreseen, a nominal (no-flare) and a fast (flare) mode. In the nominal mode, SEE measures Gamma and X-ray emissions with the highest duty cycle possible while the UV payload acquires periodic images. In the fast mode, when a solar flare is detected, the UV image acquisition frequency is enhanced for the entire duration of the solar flare. SEE is expected to be launched within 2027, near the peak of solar cycle 25. The expected mission duration is about two years to acquire at least a complete spectrum of emissions during one solar year. Indeed, the focus on the high-energy portion of the spectrum ensures a high sensitivity concerning variations in solar activity.

The SEE mission is currently in its preliminary design phase, under development by a consortium led by the University of Roma Tor Vergata as the Prime contractor. This mission is part of the Italian Space Agency (ASI) ALCOR fleet of smallsat. Argotec is responsible for the platform development, integration, and testing. The spacecraft is based on Argotec's HAWK platform, which includes the

Small Satellites Systems and Services Symposium (4S 2024), edited by Max Petrozzi-Ilstad,
Proc. of SPIE Vol. 13546, 135461W · © 2025 The Authors. Published under a Creative Commons
Attribution CC-BY 3.0 License · 0277-786X · doi: 10.1117/12.3061760

heritage acquired in LICIACube and ArgoMoon deep space missions but also the expertise coming from LEO missions, namely the IRIDE constellation.

The SEE mission will offer new data about solar emissions and events, further affirming that smallsats platforms play a crucial role in advancing solar research and space weather predictions.

1 INTRODUCTION

The SEE mission is situated within the framework of the Italian Space Agency (ASI) ALCOR [1] program, which is primarily focused on supporting and ensuring the continuous development of micro and nanosatellites. This initiative aims at facilitating the advancement of a space economy centred around this category of satellites and at strengthening European leadership in the sector.

The mission presented afterward is in its preliminary design phase, under development by a consortium led by the University of Roma Tor Vergata as the Prime contractor. The members of this consortium are:

- University of Roma Tor Vergata (Prime contractor) in charge of the organizational set-up and scientific aspects of the mission.
- Istituto Nazionale di Fisica Nucleare (INFN) focusing on the X and Gamma rays instrument design.
- OPTEC S.p.A. focusing on the UV imager design.
- Sapienza University of Rome focused on the mission analysis.
- Argotec S.r.l. responsible of the overall technical coordination of the project execution, assuring the fulfilment of the system engineering tasks.
- NEXT Ingegneria dei Sistemi S.p.A. in charge of the Ground Segment design.

1.1 Scientific Relevance

Solar radiation exerts a multifaceted influence on various aspects of space weather, terrestrial phenomena, satellite operations, and astronaut safety.

On Earth, solar radiation interacts with the atmosphere, driving weather patterns, affecting climate dynamics, and influencing the ozone layer. This interaction has implications on environmental factors such as air quality and global climate.

In space, spacecrafts are vulnerable to the effects of solar activity. Solar flares and CMEs can cause disruptions to satellite communications, navigation systems, and power grids. Additionally, increased solar radiation during solar storms can pose radiation hazards to astronauts onboard spacecraft and during extravehicular activities (EVAs).

1.2 Ultraviolet Radiation

Earth’s atmosphere is mainly affected by three major factors:

- Day-night cycle
- Variations in solar irradiance due to orbital factors, such as the distance from the Sun
- Solar emissions variability, particularly in the UV and higher energy ranges

While the first two contributions are easily assessed due to their intrinsic determinism, currently, there is no predictive model of Solar Spectral Irradiance (SSI).

Solar variability in the ultraviolet (UV) and high-energy regions of the electromagnetic spectrum holds greater importance compared to variations in integrated solar power, represented by Total Solar Irradiance (TSI). For instance, the TSI exhibits a marginal increase of approximately one-tenth of a percent between the maximum and minimum levels over the solar cycle. However, the relative changes in TSI are not uniformly distributed across the solar spectrum. In fact, wavelengths below

400 nm contribute approximately 9% to the overall change, with nearly 32% of the radiation variation occurring below 250 nm throughout a solar cycle. This underscores the significance of understanding solar variability, particularly in UV wavelengths, for a comprehensive assessment of its effects.

1.3 Solar Flares

Solar flares represent one of the most prominent and dynamic phenomena in our solar system. Along with a steady rise in high-energy radiative flux, these energy bursts are frequently accompanied by strong fluxes of solar energetic particles, primarily electrons and protons, and occasionally by coronal mass ejections. The profound impact of solar flares on space weather and our technological infrastructure makes their study crucial. Firstly, solar flares emit electromagnetic radiation across a wide range of wavelengths, from radio waves to gamma rays, affecting communication systems, GPS navigation, and power grids on Earth. The sudden increase in X-rays and ultraviolet radiation during a flare can disrupt radio communications and navigation systems, posing risks to astronauts and satellites.

Secondly, the release of energetic particles during solar flares can pose hazards to both manned and unmanned space missions. These particles, accelerated to near-light speeds by the flare's intense magnetic fields, can penetrate the spacecraft, damaging onboard electronics.

Furthermore, the study of solar flares provides invaluable insights into fundamental astrophysical processes allowing also to predict [2] and mitigate their effects on our technological infrastructure as well as to improve astronauts' safety during space missions.

1.4 Mission Motivation

Charged particles, including electrons, protons, and heavier ions, undergo acceleration to high energies, emitting hard X-rays and gamma-rays. As this radiation cannot penetrate Earth's atmosphere, it can only be detected from space.

Furthermore, the high-energy phenomena under scrutiny entail particle energies reaching many GeV, temperatures ranging from tens to hundreds of millions of degrees, densities as low as 100 million particles per square centimeter, spatial scales spanning tens of thousands of km, and magnetic containment times varying from seconds to hours. Replicating these conditions in Earth-based laboratories is impracticable.

For these reasons, SEE has been designed to shed light on the most intense solar phenomena, while also serving as a complement to other missions currently studying the Sun, such as Solar Orbiter, IRIS-NASA, and Parker Solar Probe. Investigating the quasi-periodic oscillations in the X-ray and Gamma-ray signals of flares paves the way for understanding the underlying physical processes that drive flares and their radiative and particle emissions.

2 HIGH-LEVEL MISSION PROFILE

The main goal of the SEE mission is to improve the understanding of the behaviour of the Sun in a spectral region of strong astrophysical and geophysical importance by acquiring X and Gamma rays fluxes and observing the solar disk in a narrow UV band (2 nm). The data produced will complement useful data in the Space Weather context.

The operative orbit selected for the mission is a dawn-dusk Sun-synchronous orbit (SSO). The main driver for this choice arises from the will to maximize the Sun observing time and from a specific constraint due to the narrow band of the imager. This bandwidth imposes a radial velocity towards the Sun lower than 4 km/s to maintain the orbital shift caused by the Doppler effect at an acceptable level.

2.1 Mission Phases

The current baseline foresees an operational life of at least 1 year (with 1 year of possible extension) resulting in a 2.5 year of maximum mission duration. As the study of solar flares is one of the main goals of the mission, the objective is to conduct scientific operations during the peak of the solar cycle (2023-2028), when the frequency of solar flares is the highest. Consequently, SEE is expected to be launched as a rideshare targeting the begin of the operational phase in 2027.

The SEE mission is developed into four different mission phases:

1. *Launch and Early Orbit Phase (LEOP):* this phase starts as soon as SEE is released from the deployer. During LEOP the satellite is expected to operate some scheduled tasks to be performed autonomously. This phase ends with the beginning of a communication window with the ground station.
2. *Commissioning Phase:* this phase is subdivided into platform commissioning and payloads commissioning. The health, status, and performances check of all the subsystems and payloads takes place during this phase.
3. *Operative Phase:* this phase is the core of the SEE mission. During this phase, the satellite carries out the scientific operations. In a contingency-free scenario, these operations will be interrupted only by eclipse periods of small duration and occurring for a few months per year thanks to the Dawn-dusk SSO.
4. *End Of Life Phase:* this phase prepares the end of the SEE mission. During this phase, the satellite undergoes passivation, which reduces the momentum of the reaction wheels and discharges the batteries. As it lacks a propulsion system, the satellite is powered off after passivation and naturally decays, disintegrating in the Earth’s atmosphere.

2.2 Operative Phase ConOps

The SEE operative phase encompasses two possible scenarios, contingent upon the presence of a solar flare. During nominal operations, SEE will conduct measurements of X and Gamma rays with an unprecedented temporal resolution (> 10 kHz) and a multi-wavelength approach, while periodically capturing images of the solar disk in the UV range. In the event of a solar flare, the operational structure remains unchanged, with the only difference being an increased image acquisition frequency. The signal measured from the X and Gamma rays detectors will be used as a trigger, activated by intense solar flares. Thus, solar flare detection is delegated to the satellite increasing its on-board autonomous capabilities, and optimizing valuable scientific data collection, while minimizing the need for ground-based intervention.

Figure 2-1 shows a schematic view of the ConOps for the two possible scenarios: out of flare and in flare conditions.

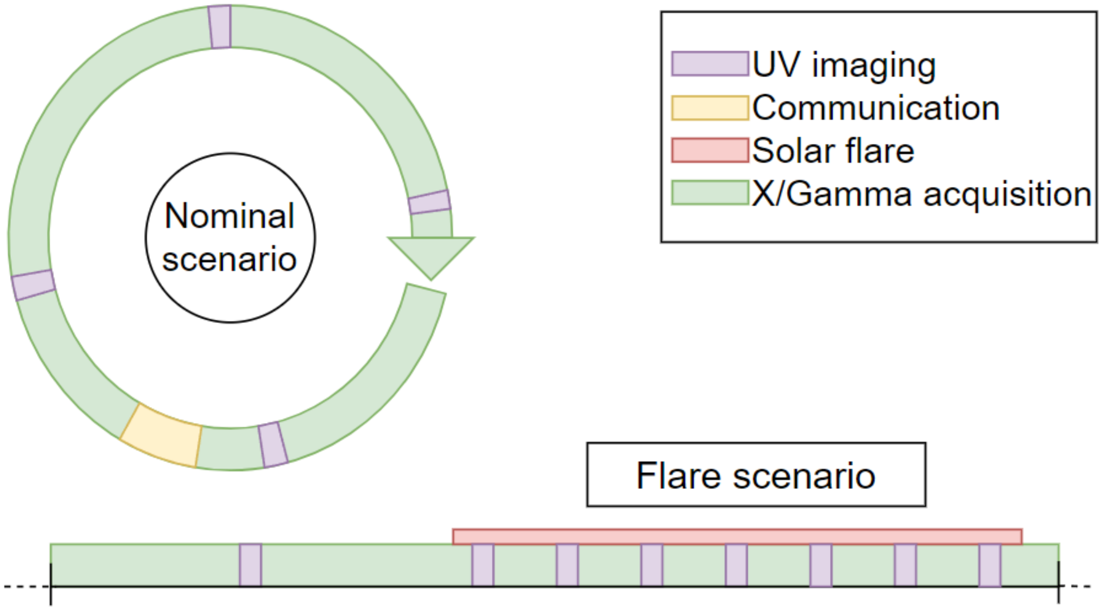

Figure 2-1: Operative phase Concept of Operations

3 PLATFORM OVERVIEW

This section provides an overview of the current baseline platform. Argotec is responsible for the platform development, integration, and testing. The spacecraft is based on Argotec's HAWK platform, which includes the heritage acquired in LICIACube and ArgoMoon deep space missions but also the expertise coming from LEO missions, namely the IRIDE constellation.
The SEE spacecraft is depicted in Figure 3-1 in its stowed configuration and Figure 3-2 in its deployed configuration. Table 3-1 reports the main figures of merit of the platform.

Figure 3-1: SEE stowed configuration

Figure 3-2: SEE deployed configuration

In its current state of design, the SEE spacecraft is fully compliant with the 12U CubeSat standardized form factor.

The approach for the design of the space segment foresees a wide use of recurrent units to ensure strong flight heritage and high reliability. Nevertheless, due to the peculiar aspects of the mission, both payloads are custom units, developed within the SEE project.

Table 3-1: SEE platform characteristics

Mass [kg]	< 25
Maximum stowed dimensions [mm]	344 x 226 x 226
Platform generated power [W]	> 65
Platform store energy [Wh]	>180
On-board storage memory [GB]	16
Payload mass fraction [%]	40
Lifetime [y]	> 2.5

3.1 X and Gamma rays instrument

The X and Gamma rays instrument is selected to achieve the scientific objective of monitoring solar flare signal quasi-periodic fluctuations from soft-X to Gamma ray energy range. The instrument is composed of four different channels covering an energy ranging from 1.5 keV to 3 MeV as following:

- 1.5 – 12 keV (GOES-B band)
- 3 – 25 keV (GOES-A band)
- 30 – 300 keV
- 300 – 3000 keV

The unprecedented temporal resolution (up to 10 kHz) of this instrument is dedicated to distinguishing the particle acceleration mechanism during solar flares(e.g., [3])which is still not fully understood. The 4 mm side sensor and 80 mm long collimator provide an acceptance angle of 6 deg. The X and Gamma rays instrument is also exploited to detect an incoming solar flare. Soft X-rays can be used to forecast the onset and decline of solar flares through the variation in the radiation intensity. This is crucial for the SEE mission since it enhances its autonomy respect to ground contact, reducing ground segment costs.

3.2 UV imager

To achieve the science requirements dictated by the SEE mission, periodical acquisitions of full disk images is needed to allow to detect the magnetic structures responsible for solar UV variability. Specifically, the focus is on the variability of the Mg II emission doublet at 280 nm. The Mg II index (core-to-wing ratio) is commonly used as a proxy for the spectral solar irradiance variability from the UV to EUV, which is mainly associated to the solar magnetic cycle [4]. This index is computed from the ratio of the fluxes of the highly variable Mg II h and k emission cores (chromosphere origin) to that of the weakly variable nearby wings (photosphere origin).

Therefore, SEE is equipped with an innovative UV solar telescope, developed and built by Optec S.p.A., specifically designed to meet the scientific requirements while facing the challenge of miniaturization dictated by the volume constraints of a CubeSat platform. The telescope is composed of 2 spherical mirrors and 3 spherical lenses. Figure 3-3 shows the preliminary optical layout of the telescope in a schematic view.

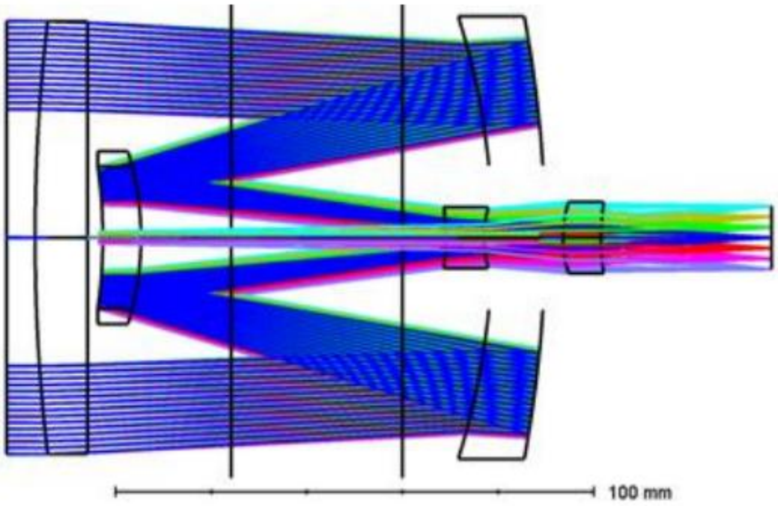

Figure 3-3: UV imager schematic view of the optical layout

The compact design allows to fit the UV telescope in less than 2U volume. Considering the distance from the Sun, a 1.1 deg FoV has been chosen for the design of the sensor to get the entire solar disk. The straylight due to surface microroughness is one of the major challenges in the development of the imager since the scattering is more sensitive in the UV wavelength range.

3.3 On Board Computer & Data Handling System

As the central core of the satellite, the Argotec FERMI OBC has the responsibility on the control of the various subsystems and on the data handling through the On-Board Software (OSW). In addition, in case of contingency, the OBC is able to trigger the Fault Detection Isolation and Recovery (FDIR) functionalities, to preserve the health status of the spacecraft. Its hybrid architecture is based on two main components: CPU and FPGA that guarantee flexibility in the processing software.

The OSW architecture is organized over multiple layers each of them designed to be independent from the layers below and the ones above. Thanks to this modularity each layer is designed, tested, and maintained separately, simplifying the OSW management and bug fixing. Moreover, this allows for the reduction of the changes needed to integrate mission-specific tasks and functionalities, simplifying software component reuse across different missions and platforms. Figure 3-4 shows a representation of the SEE OSW architecture.

Thanks to the implementation of the platform abstraction layer, the OSW can be run on multiple platforms and simulation environments. This feature allows for less expensive hardware during test campaigns while maintaining a highly representative simulation.

Argotec Fermi OBC gained heritage during ArgoMoon and LICIACube missions which both successfully flew in Deep Space. The Fermi OBC is shown in Figure 3-5.

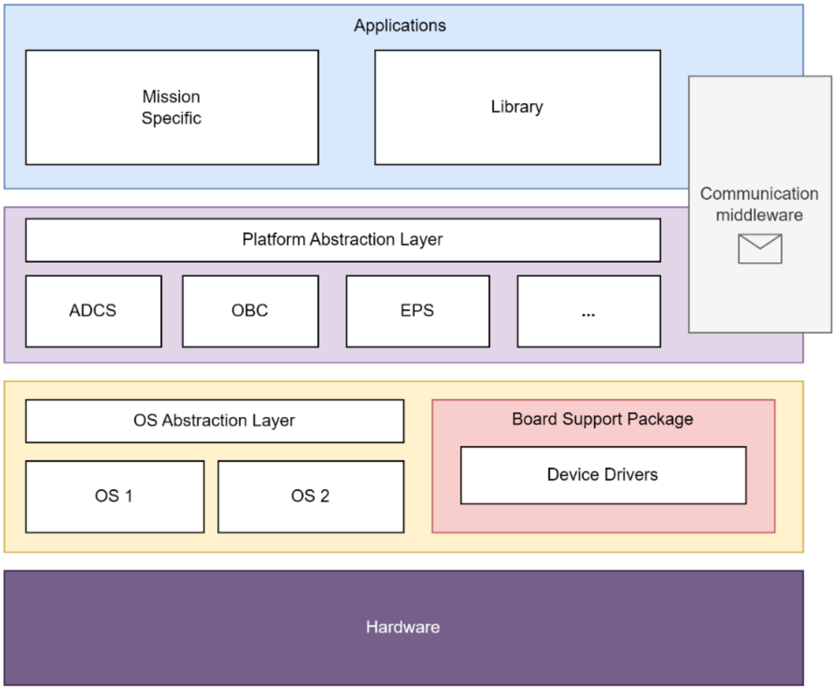

Figure 3-4: OSW layer architecture layout

Figure 3-5: Fermi OBC

3.4 Electrical Power System

The EPS subsystem oversees the generation, conversion, storage and distribution of electrical power to the various subsystems. The SEE EPS is constituted by the following items:

- The Solar Panel Array (SPA)
- The battery packs
- The Power Conditioning and Distribution Unit (PCDU)

Figure 3-6 shows a high-level block diagram of the SEE EPS architecture.

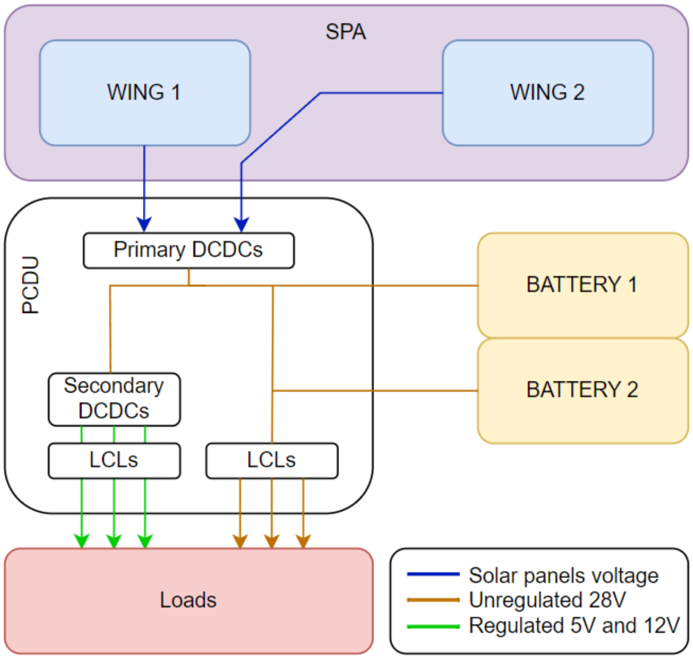

Figure 3-6: SEE EPS architecture

The SPA is composed of two double deployable wings and is a recurrent design from LICIACube. The maximum generated power (84 W @BOL, T_{cold}) is managed by the Argotec ZEUS PCDU equipped with a Maximum Power Point Tracking (MPPT) algorithm to maximize the power received by the solar panels, and with a Battery Charging Regulation (BCR) algorithm to correctly charge the Lithium-ion batteries and avoid related stresses. Moreover, each output line is protected by individual LCLs for overcurrent events.

The battery pack is required to store the electrical energy required to survive eclipse events and supply for short duration peak powers when required. SEE employs two 8s1p Argotec ELEKTRA battery units. Indeed, the HAWK platform can be equipped with multiple ELEKTRA battery units in parallel, thus increasing the capacity and robustness of the system.

3.5 Communication System

The Communication system oversees the reception of the telecommands from ground to operate the platform, as well the downlink of the telemetries and scientific data collected during the science operations. Specifically, the SEE Communication system will operate in the S-band for both telecommand uplink and telemetry downlink with the utilization of four S-band antennas appropriately mounted on two opposite spacecraft faces. This ensures a possible link with the ground station regardless of the spacecraft's orientation. This is critical for the SEE mission since, as shown in Figure 2-1, during a communication window in a solar flare scenario, the satellite continues to

perform scientific observations to maximize scientific returns. This implies that the antennas will not be pointed towards the ground station during solar flares. Nevertheless, thanks to this architecture, the mission control center will still be capable of communicating with the satellite to check its status or send commands while the scientific data will be transferred in the next communication windows.
The downlink of scientific data is instead demanded to a high-data rate X-band transmitter to assure a complete downlink of the data.
The use of both a X-band and a S-band radios is the current baseline for the Argotec HAWK LEO platform; thus, this choice aligns with the philosophy of cost reduction through the use of recurrent components and architecture.
Figure 3-7 shows the high-level block diagram of the SEE Communication system with its components.

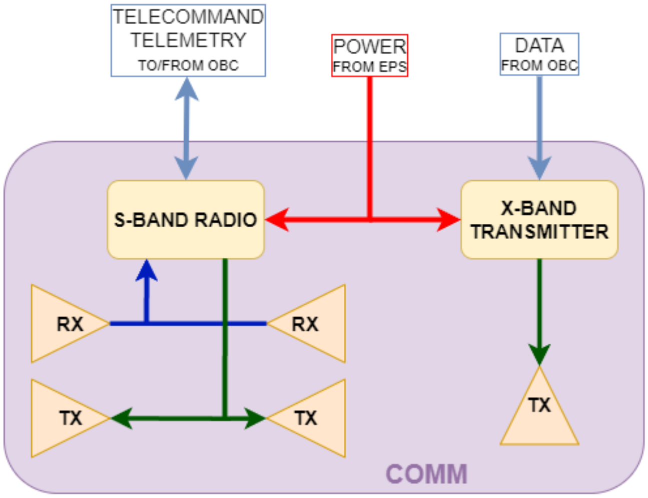

Figure 3-7: Communication system functional block diagram

3.6 Attitude Determination and Control System

The ADCS is responsible for the acquisition, determination, maintenance, and control of the spacecraft attitude. The ADCS suite for the SEE mission includes the following components:

- An electronic control board responsible for the attitude determination algorithms and control laws.
- A star tracker employed to assure fine pointing of the platform.
- 4 sun sensors to perform a coarse pointing and to acquire the Sun direction during the spacecraft Safe Mode.
- A gyroscope unit to estimate the angular velocity of the spacecraft.
- A GNSS to obtain the spacecraft velocity and position used to perform orbit determination other than target pointing.
- 3 reaction wheels (plus 1 optional for redundancy) to stabilize the satellite along the three axis and to perform attitude changes foreseen by the different operative modes or commanded from ground.
- 3 magnetorquers to desaturate the reaction wheels and to be able of performing detumbling of the satellite without necessarily oversizing the reaction wheels.

Figure 3-8 reports the ADCS high level architecture highlighting the workflow from sensing to actuation.

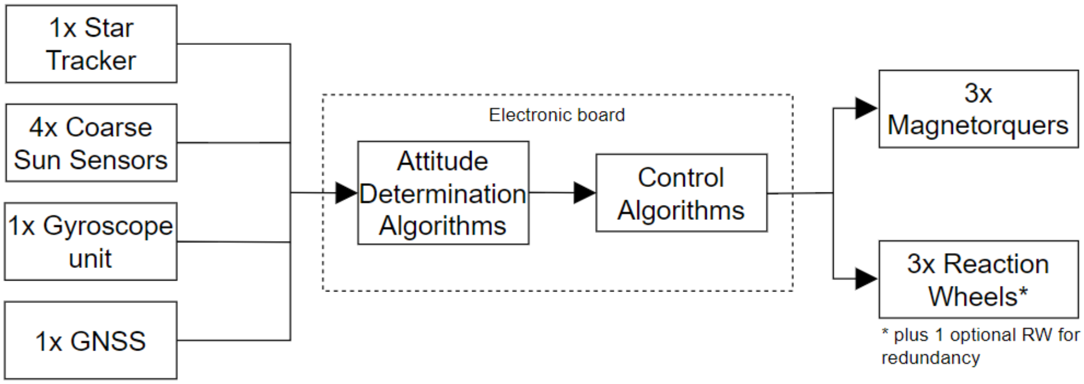

Figure 3-8: SEE ADCS suite block diagram

3.7 Thermal Control System

The platform TCS is fine-tuned on mission specific requirements, but the techniques used are part of the HAWK platform heritage. The baseline design tries to employ as few active techniques as possible to simplify the thermal architecture, reduce the power demand, and increase the reliability of the whole mission. Indeed, the only active techniques taken into account so far are heaters needed during cold cases such as eclipses. On the other hand, the main passive technique employed by the TCS is the usage of different coatings, with different thermo-optical properties, to reject and absorb heat. The coatings are optimized for mission specific fluxes and internal subsystems heat dissipation.

3.8 Structure

The structure is based on company standard 12U structure except for customizations made to accommodate payloads and subsystems interfaces. The satellite structure consists of two bays divided by a plate deck, as showed in Figure 3-9. The lower bay is designed to host the main platform avionics. The upper bay accommodates the payloads, the ADCS components, and the X-band radio, which are units that are mission specific.

Figure 3-9: SEE structure

4 CONCLUSION

The scientific data that SEE will collect will provide a new and complementary perspective on the astrophysical and geophysical aspects of the Sun emissions and events. SEE will also act as a technology demonstrator for new miniaturized technologies in the Space Weather domain.

The various choices made are aimed at satisfying the high-performance requirements, while at the same time respecting the mass and volume constraints imposed by the Platform's form factor. The result is a Platform that pushes the boundaries of the current state of the art for 12U CubeSats in terms of system performances and autonomy . In fact. SEE shall perform its scientific operations especially during the most critical radiation events from the Sun (differently from other satellites, which can be almost switched off or moved to safe mode in such conditions).

In conclusion, SEE will not only pave the way to a new era of solar study but also revolutionize our understanding of solar dynamics.

References

[1] G. Leccese, A. Fedele, S. Natalucci, *Overview and Roadmap of Italian Space Agency Activities in the Micro- and Nano-Satellite Domain*, 73rd IAC, Paris, France, 2022.

[2] Cicogna et al., *Flare-forecasting Algorithms Based on High-gradient Polarity Inversion Lines in Active Regions*, The Astrophysical Journal, 915, id.38, 2021 DOI: 10.3847/1538-4357/abfafb

[3] Zimovets et al., *Quasi-Periodic Pulsations in Solar and Stellar Flares: A Review of Underpinning Physical Mechanisms and Their Predicted Observational Signatures*, Space Science Revies (2021), 217:66, DOI: 10.1007/s11214-021-00840-9

[4] Criscuoli et al., *The Correlation of Synthetic UV Color versus Mg ii Index along the Solar Cycle*, The Astrophysical Journal, 865, article id. 22, 2018, DOI:10.3847/1538-4357/aad809