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SATURN: a technological demonstration mission for distributed SAR Imaging

Matteo Battilana, Giulia Capuani, Vito Lamarca, Luca Maioli, Vincenzo Mancini, Maria Lucia Tampellini
OHB-Italia S.p.A.
OHB-I, Via Gallarate 150, 20151, Milan;
matteo.battilana@ohb-italia.it

Fabio Gerace, Davide Giudici, Pietro Guccione, Julien Marini
ARESYS S.r.l.
Aresys, Via Giulio Vincenzo Bona 87, 00156 Rome;
fabio.gerace@aresys.it

Luciano D’Agristina, Domenico Di Lanzo
Airbus Defence & Space Italia S.p.A.
Airbus Defence & Space, Via Dei Luxardo 22-24, 00156 Rome;
luciano.dagristina@airbus.com

Andrea Monti Guarnieri
Politecnico di Milano
PoliMi, Piazza Leonardo da Vinci 32, 20133 Milano;
andrea.montiguarnieri@polimi.it

Alberto Fedele, Roberto Luciani, Francesco Tataranni, Silvia Natalucci
Agenzia Spaziale Italiana
ASI, Via del Politecnico, 00133 Rome;
alberto.fedele@asi.it

ABSTRACT

The OHB-Italia S.p.A-led consortium is in the midst of Phase B of SATURN (*Synthetic AperTure radar cUbesat foRmation flyiNg*), part of ALCOR, an Italian Space Agency (ASI) programme promoting the development of the next generation Italian CubeSats. SATURN is a demonstration mission that features *Multiple-Input-Multiple-Output* (MIMO) technology applied to a Swarm of CubeSats equipped with Synthetic Aperture Radar (SAR) for Earth Observation. MIMO is based on cooperative active sensors, where each one transmits signals and receives the illuminated common area backscatter related to the entire swarm, increasing measurement performances with a trend approximatively equal to the square of the number of sensors. The complete SATURN constellation features 16 mini-swarms, each of 3 CubeSats, spread over 4 SSOs equally spaced by 3 hours of local time. The constellation is designed to provide an average revisit time of 1.5 h and an interferometric revisit time of 1 day worldwide. The aim of this demonstration mission is to verify MIMO technology applied to SAR on a mini-swarm of 3 CubeSats in close formation on a Low Earth Down-Dusk Sun Synchronous Orbit. Using OHB-I’s M^3 Multi Mission Modular platform equipped with a miniaturized SAR Instrument, developed by ARESYS S.r.l. and Airbus Italia S.p.A., our mission is able to achieve a resolution of 5x5 m over a 30 km swath.

Thus, SATURN enables low-cost, scalable SAR missions for affordable access to space for public and private entities, overcoming the single point of failure of one large and complex satellite. Subsequent swarms, deploying from 3 to 48 CubeSats, are expected to bring technological innovations and improve Italy’s competitiveness in the European and global Earth Observation scenario.

INTRODUCTION

SATURN mission represents what is known as a *Coherent SAR Formation*, a term that differs from the connotation “constellation” and identifies a group of units, and therefore sensors, in close formation that simultaneously receive the backscattered signal from the observed scene. The data collected by each satellite in formation, once downloaded to the ground segment, will be coherently recombined to produce a single high-performance SAR image. This technological revolution is designed to overcome the limitations of SAR imaging on CubeSat-sized satellites. In particular, we refer to the high power required by the SAR payload, which is not always compatible with the power available on board, and to the insufficient size of the SAR antenna that can be managed on board, required to resolve azimuth ambiguity in line with nominal performance for this type of mission.

MIMO technology is an evolution of SIMO (*Single-Input-Multiple-Output*) in which only one sensor transmits, and all the others operated in receive-only mode. With SIMO, power gain was proportional to the number of N sensors being used, allowing the antenna size requirement downscaling over an equal number of satellites (in an along-track configuration), maintaining advantages in terms of flexibility, scalability, and robustness. Given that, SATURN foresees an evolution of the SIMO to MIMO concept, where N satellites simultaneously transmit the same frequency linearly modulated signal.

The total contribution is the coherent combination of the signals from the N transmitting satellites allowing an additional improvement in the recombined image SNR. The SAR images that will be obtained, as a combined result of the SIMO and MIMO approaches, will be of higher quality depending on the number of satellites and their position during acquisition.

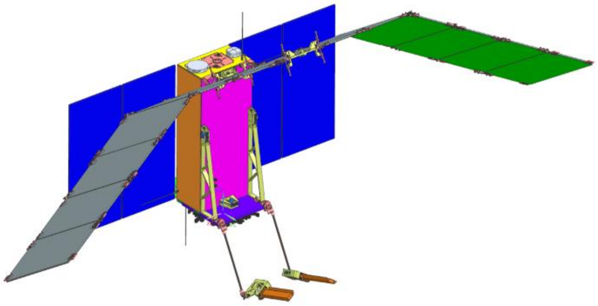


Figure 1: SATURN single satellite based on OHB-I M^3 platform, deployed configuration.

The SATURN demonstration mission starts with three individual satellites, pictured in Figure 1, in swarm and close formation in a configuration called *'along-track train'*, which is necessary to synthesize an antenna of virtual bigger size in the direction of motion.

The purpose is to validate the new technology and subsequently scale it up to a coherent constellation in order to guarantee worldwide coverage and high performance while retaining the design flexibility typical of microsatellites.

MISSION CONCEPT

As anticipated, the demonstration mission is the first step to translating MIMO performance via SATURN on a global scale. Figure 2 shows the mission RoadMap projecting the different phases of SATURN from the demonstration of the technology via a single swarm of 3 CubeSats to the full coherent constellation (16 swarms on 4 orbits).

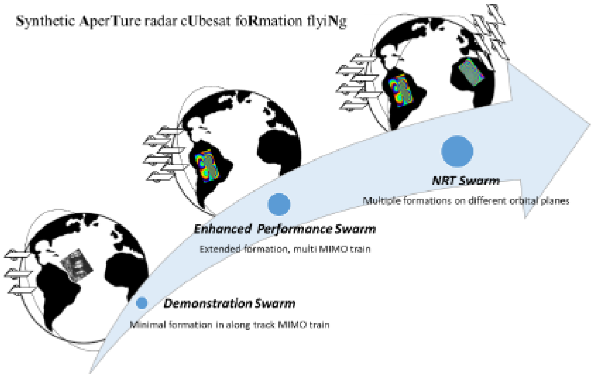


Figure 2: SATURN mission RoadMap

At each stage of the mission, target applications were identified and the key performances that SATURN is able to guarantee were evaluated, reported in Table 1.

Table 1: SATURN roadmap summary for provided services and expected performances.

Mission Phase	Target/Application	Performances
Demonstrative Swarm 3 CubeSat M^3 in along-track train configuration	SAR imaging of highly reflective targets: - *Manmade* - *Urban & Peri urban* - *Maritime Surveillance* - *Ship Detection* - *Oil Spillage*	*Image Size:* 30 x 50 km *Resolution:* 5 x 5 m *High Resolution:* 1.5 x 1.5 m
Enhanced Swarm Multiple Swarm trains on the same orbital plane	- Single Pass Interferometry - Landslides	*Image Size:* 30 x 50 km *Resolution:* 5 x 5 m *High Resolution:* 1.5 x 1.5 m *Interferometry*
	- Ship detection of wide Swath	*Image Size:* 360 x 50 km
Full Constellation Multiple Enhanced Swarm trains on different orbital planes	High Resolution, High Sensitivity Imaging for Near-Real time applications: - Maritime Surveillance over open sea - Emergency management	*Image Size:* 30 x 50 km / 360 x 50 km *Resolution:* 5 x 5 m *High Resolution:* 1.5 x 1.5 m *Interferometry*

The SATURN demonstrative mission involves the following mission architecture, pictured in Figure 3:

- *Space Segment*: consisting of 3 CubeSats equipped with a SAR payload in close formation.

- *Ground Segment*: defined by a commercial Ground Network consisting of a Flight Operation Segment (FOS) with its S-Band Antenna and the Payload Data Ground Segment with X-Band antennas.

- *User Segment*: for data exploitation to commercial and scientific users.

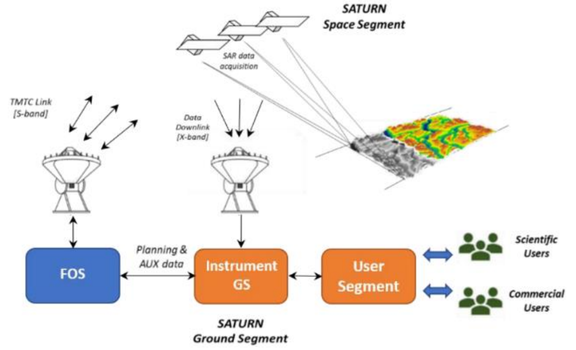


Figure 3: SATURN mission System Architecture

Orbit Coverage

A baseline orbit, an SSO Frozen at 480 km altitude with descending character and Local Time 06:00 a.m., a Down-Dusk, was identified for the mission (as Back-Up solution 460 km & 500 km has also been considered). The reasons for this choice are many but the driving ones are listed here:

- The frozen condition inherently allows interferometric acquisitions, for which it is necessary to observe the same target with a maximum repeat ground tracking error on the order of hundreds of meters.

- The use of Sun-synchronous orbits (SSOs), which combine altitude and inclination such that the satellite passes over any point on the Earth's surface at the same local solar time (nearly the same light or dark conditions day after day). This allows for a choice of time window for observations, accessibility to high latitudes, and limited variation in altitude and velocity. The Down-Dusk SSO was chosen to minimize the effects of drag on the satellite as a function of flight configuration (the SAR antenna and solar panels are aligned with velocity), allowing to move within a more conservative perimeter. Nevertheless, the satellite is designed, projected in view of a constellation over multiple SSOs and therefore is capable of operating in scenarios with different local times without affecting performance.

- The frozen condition maintains a constant altitude profile over the Earth, allowing to see targets at the same latitude at the same distance from the satellite. In addition, a tight longitudinal ground trace control is guaranteed because there are no longitudinal variations of the ground trace due to perigee rotation.

- The frozen condition guarantees ample flexibility on constellation single orbital plane design as well as an immediate understanding of how the performances evolve according to the number and relative distance of mini swarms positioned on the same plane.

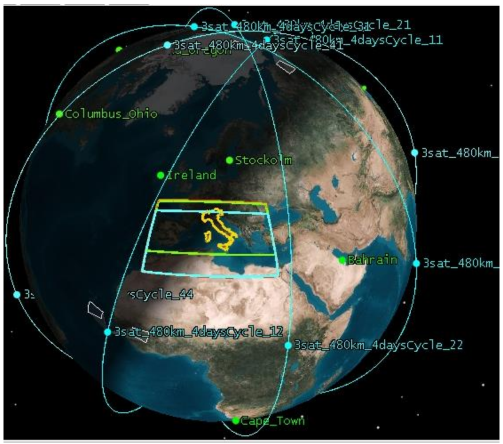


Figure 4: SATURN Full Constellation & Area of Interest, simulation in STK

Regarding the last point, it can be seen that mission performance increases as a function of the number of CubeSats used. In particular this is evidenced by evaluating specific figures of merit such as Typical Revisit Time and Interferometric Revisit Time. Taking the Area of Mission Interest as a reference (highlighted in Figure 4) and computing the figures of merit defined above, it becomes evident how the number of swarms impacts the goodness of these values. The whole, as is evident even from the subsequent images, also projects globally.

Table 2: Area of Interest Figure of Merit wrt N° of Mini-Swarm in the Constellation.

N° Mini-Swarm	Typical Revisit Time	Interferometric Revisit Time
1 Swarm	20.4 hours	4 days
16 Swarm	1.4 hours	1 day

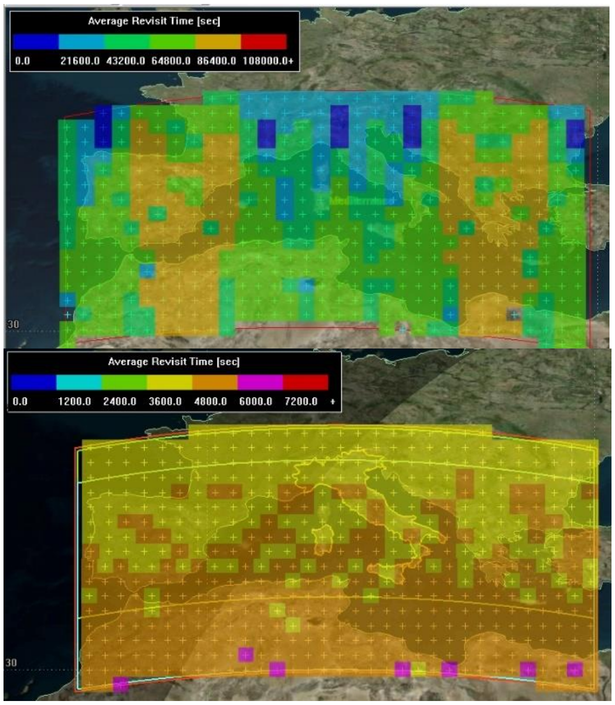


Figure 5: Typical revisit time for the AoI, 1 swarm (top) and 16 swarm (bot), simulation in STK.

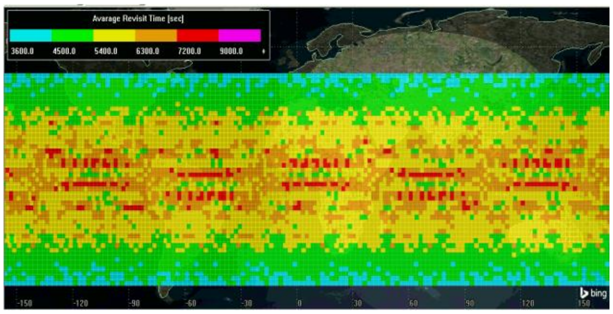


Figure 6: Typical revisit time Worldwide for the Full Constellation, simulation in STK.

Mini-Swarm Management

To be compliant with SAR payload specifications and for MIMO to work properly, the 3 satellites must travel in an along-track train. This results in very stringent constraints on the relative distances of the three satellites. The overriding measure is that of relative along-track distance, in which case a range has been defined in which one can move that will guarantee the performance of the SAR antenna while avoiding mutual collision avoidance risks. This range varies between 180 m and 550 m, in which a distance of 200 m was chosen as the baseline; this value allows to acquire with 3 SAR antennas an excellent azimuth resolution and possibly have a value already suitable to the swarm to be implemented with additional sensors, up to 6/7.

With this baseline along-track distance the 3 CubeSats have to move in a tube of about 800 m length and 200 m radius, in Figure7. Moving now to an LVLH reference for each satellite, the offset errors that the satellites can have in the 3 directions: radial, cross-track, and along-track, can vary by a maximum of +/- 5 m. These constraints require very careful swarm control in which one must manage the 3 satellites consistently to avoid violating the constraints and maintain an attitude such that SAR acquisition is correct.

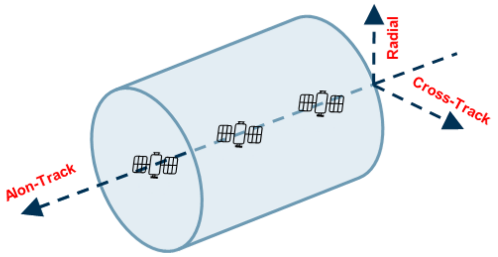
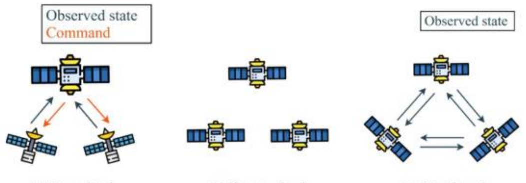


Figure 7: SATURN mini-swarm domain.

The state of the art for control in close distance formation involves 3 architectures: Centralized, Decentralized and Distributed, the advantages and disadvantages of which are shown in Table 3. Each architecture can also follow a Leader-Follower approach, where one of the satellites is designated as the leader and defines the trajectory while the others as followers emulating it; a behavioral approach where control weights are defined for each satellite (collision avoidance, goal seeking and formation keeping) and the trajectory is calculated individually for each of these satellites; and a Virtual Structure approach, where the entire swarm travels as a constrained grid [1].

Table 3: Swarm Control Architecture State of Art.

Centered	Decentered	Distributed
PRO Cost-Efficient for Small Constellation. Quick State Update.	*PRO* Inter Satellite Link (ISL) not necessary. High Autonomy	*PRO* High Reliability Low State Latency High Reactivity
CONS Single Point of Failure Need for ISL Lack of Failure Tracking	*CONS* Low efficiency for close up formation. Coordination Problems.	*CONS* Need for ISL Need for a common clock.

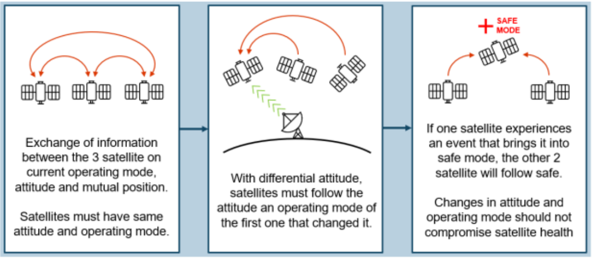


(a) Centralized (b) Decentralized (c) Distributed

It was decided to adopt distributed control as the basic design for the following reasons: centralized training control exposes the project to a single point of failure. This means exposing the system to a risk that can be easily circumvented with a distributed approach; a centralized project implies a significant increase in data flow in the inter-satellite communication link that can be avoided with a distributed approach; contingency phases would in any case require management functions nominally part of a distributed training control; the need to propel synchronously to avoid formation divergence.

Following this, a hybrid approach between behavioral and virtual structure was chosen. This is both because the satellites in the swarm must maintain a well-defined geometry (the along-track-directed train with relatively fixed distances) and because each satellite will have intrinsic rules that more closely define its behavior and how it reacts to events in formation.

The mission architecture therefore sees the need for an ISL that will be implemented on board to enable mutual communication between the CubeSats. In particular, the satellites constantly exchange: current operating mode SAT and AOCS; current attitude, via quaternions; time and orbital position obtained from the GNSS; thrust level of the propulsion system.



Exchange of information between the 3 satellite on current operating mode, attitude and mutual position.

Satellites must have same attitude and operating mode.

With differential attitude, satellites must follow the attitude an operating mode of the first one that changed it.

If one satellite experiences an event that brings it into safe mode, the other 2 satellite will follow safe.

Changes in attitude and operating mode should not compromise satellite health

Figure 8: Nominal formation control summary

A formation control strategy was established that would independently manage the nominal mission modes and attitude, minimize the risk of collision between units, identify any uncooperative units, and above all guarantee the maintenance of the swarm within geometric constraints. A representative summary can be found in Figure 8.

Nominally then, the 3 satellites exchange various vital information via ISL. The satellites must maintain the same attitude and operating mode, following the needs communicated by the ground or the satellite that first triggered a change. The ground, which can communicate with both the individual units and the swarm, dictates the objectives to be executed. If a satellite exceeds one of the safety thresholds for control or proper operation, actions are ended for a counteraction.

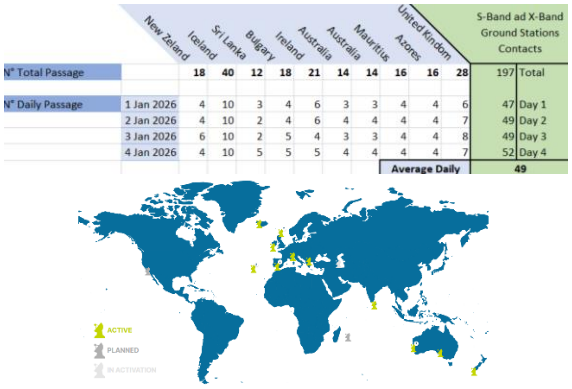
A strategy is also in place in the event of a unit contingency, which can occur for a variety of reasons such as attitude mismatch or propulsive phase. Through this management structure, it is therefore possible to ensure not only that all units are kept synchronously in the same orbit, but also that they are able to acquire correctly.

Ground Segment

The SATURN satellite has two communication links, the S-band providing telemetry and commands for satellite operations, and the X-band for downloading image data. Routine operations of the space segment are supported by the LeafSpace ground network, which consists of several ground stations capable of communicating in both necessary bands.

The possibility of the simultaneous downlink of the 3 satellites of the single swarm on the ground stations, both in S-band and X-band, is being evaluated. The finalization of this possible solution will be the subject of several iterations with the ground network supplier.

In any case, the LeafSpace ground network allows the amount of data collected by the SAR payload to be downloaded. The amount of daily contacts needed to share information with Ground depends strictly on the amount of images collected. The simulations carried out to verify the number and duration of contacts for the individual ground stations confirm the compatibility with the ground network, with a typical duration of passes of about 7.2 minutes and about 3.3 passes per orbit. The number of daily passes for the individual stations and for the entire LeafSpace ground network [5] are shown in Figure 9.



		New Zeland	Iceland	Sri Lanka	Bulgary	Ireland	Australia	Australia	Mauritius	Azores	United Kindom	S-Band ad X-Band Ground Stations Contacts	
N° Total Passage		18	40	12	18	21	14	14	16	16	28	197	Total
N° Daily Passage	1 Jan 2026	4	10	3	4	6	3	3	4	4	6	47	Day 1
	2 Jan 2026	4	10	2	4	6	4	4	4	4	7	49	Day 2
	3 Jan 2026	6	10	2	5	4	3	3	4	4	8	49	Day 3
	4 Jan 2026	4	10	5	5	5	4	4	4	4	7	52	Day 4
										Average Daily		49	

Figure 9: Ground Network Performances

SATELLITE OVERVIEW

The characteristics of the mission, specifically the close formation needs dictated by the SAR, and the requirements dictated by the payload such as the level of power peaks necessary and a large antenna, impose constraints at the satellite level that do not always allow the desired performance to be achieved, especially for commercial use. The concept behind the SATURN mission is the distribution of large resources over a swarm of several CubeSats.

Several compromises were made on the overall architecture in order to develop a CubeSat system (standard CubeSat components) that conforms to the desired performance.

The most challenging requirements of the mission are as follows:

- SAR RF peaks require more power than the battery can provide.
- swarm operation must be synchronized to follow the same tag operation time and not diverge.
- the error of position, velocity and attitude must be low to allow SAR processing at a high level of precision.
- SAR antenna and solar panel will have a complex deployment architecture to comply with the standard CubeSat dispenser.

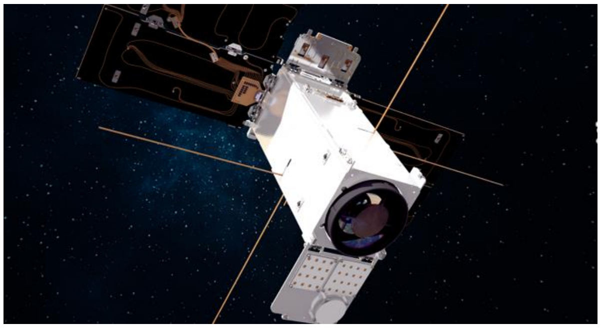


Figure 10: M^3 platform for IRIDE constellation [6].

It was decided to structure the mission based on the design of the M^3 Multi Mission Modular platform (Figure 10), a CubeSat platform developed by OHB-Italia originally for an optical payload but with excellent adaptability capabilities, such as hyperspectral or SAR application.

The modularity of the platform and its heritage developed in the field of the EAGLET-2 and IRIDE missions, allows the platform to meet mission requirements by providing a solid foundation from which to answer stringent requirements.

Platform Configuration

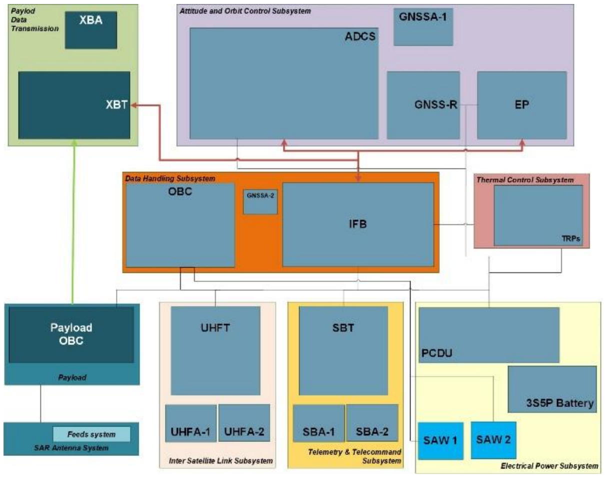


Figure 11: SATURN Spacecraft Architecture.

The M3 platform was adapted to the needs of the mission to provide the payload with all the necessary media and interfaces for proper data acquisition and transmission to the Ground Segment. The platform, whose architecture is shown in Figure 11, includes the following units:

- On Board Data Handling Subsystem (DHS), comprising:
  - On Board Computer (OBC)
  - Interface Board (IFB)
  - On Board Software (OBSW)
- Electrical Power Subsystem (EPS), including:
  - Battery (BAT)
  - Solar Array Wings (SAWs)
  - Power Conditioning and Distribution Unit (PCDU)
- Attitude and Orbit Control Subsystem (AOCS), inclusive of:
  - Attitude Determination Control System (ADCS)
  - GNSS Receiver and Antenna
  - Electrical Propulsion (EP)
- Telemetry & Telecommand (TMTC) Subsystem, for communication between Satellite and Ground Station Network.
- Inter Satellite Link (ISL) subsystem, for swarm management and pre-acquisition SAR calibration.
- Thermal Control Subsystem (TCS) for Platform and Payload temperature management, which includes heater and thermistors.
- Structure (STR) including panels, brackets, support.

- Harness.

In the figure below, a preliminary platform configuration, which also includes the SES, is shown: the upper layer accommodates all the platform subsystem, the lower layer accommodates all SAR electronic modules.

Spacecraft Configuration

The complex architecture of the SAR antenna, and its deployment mechanism (hinges, HDRM, ...) constitutes a very complex design constraint with respect to the envelope required by the CubeSat Dispenser.

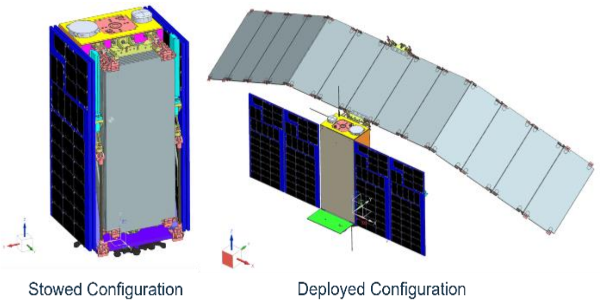

Stowed Configuration
Deployed Configuration

Figure 12: Stowed and Deployed Configurations.

A process of optimizing the configuration of the platform made it possible to ensure compatibility with respect to the maximum envelope of 30 x 30 x 60 cm. As already done in OHB-Italy CubeSat projects, an 8" IF RING has been selected as Launch Vehicle mechanical interface, proving to be the optimal solution for SATURN mission.

The SAR antenna is deployed with an inclination of 120° from the -Z axis to allow a nominal offset angle of 30° from the nadir during observations. This angle, which can span a range of 15-45° due to satellite off-nadir, allows for proper MIMO acquisition and increased coverage for observations.

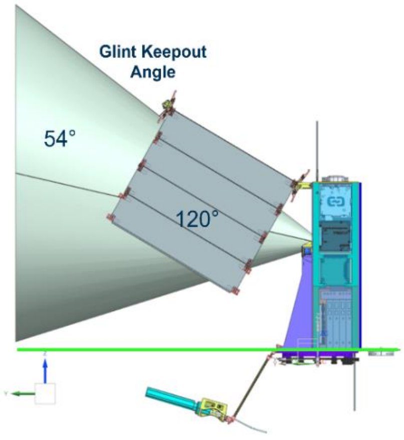


Figure 13: Star Tracker Occultation

The 120° deployment angle also allows the Star Tracker, which boresight is directed along +Y, to not be occulted by any body and glint/reflection over the structure, as depicted in Figure 13.

Power Subsystem

To overcome the power peak problem, a battery pack with a capacity of at least 800 Wh would be necessary. To reduce mass and envelope, a hybrid electrical power subsystem has been designed: in addition to LiFePO4 battery pack (3S5P configuration, 178Wh), that assures enough energy for the operations of the payload, a SuperCap bank will provide the desired power peak to the RF amplifiers. To avoid modification to the already qualified EPS, the SuperCap module has been located inside the SES, and will be directly managed by the SAR On-Board Computer: before each acquisition, the SuperCap bank will be recharged with low current.

The solar panels were also sized to support the satellite power demand for each application and during each operational phase.

However, given the criticality of the SAR antenna demand, an energy budget was made considering not only the nominal orbit (480 km LTDN 06:00 a.m.) but also those variants for the entire constellation, both in terms of Local Time and altitude. The two pivotal nodes representing the best and worst illumination conditions, i.e., SSO Down-Dusk and Noon-Midnight were considered. In both cases, the satellite predicts an attitude that prefers solar pointing, the difference being:

- the *Down-Dusk* orbit is the best case, the satellite maintains a nominal Nadir Pointing attitude (minimum drag), keeping the SWAs pointed at the sun for the duration of the orbit, except for the acquisition and orbital maintenance phases. In addition, the duration of the longest eclipse, which occurs only during summer periods, was evaluated in a conservative approach.

- the *Noon-Midnight* orbit is the worst case, representing the worst lighting conditions with the longest eclipse duration (about 35 minutes on average). This aspect forces the mission attitude to be constantly Sun Pointing (worst case for drag) to accumulate as much energy as possible, changing attitude only during the acquisition and orbit maintenance phases.

A qualitative representation of mission arrangements for orbits is represented by the following two figures. It can be guessed that with respect to attitude condition and sunlight phase duration the orbit with LTDN 12:00 (Noon-Midnight) is confirmed to be the worst case.

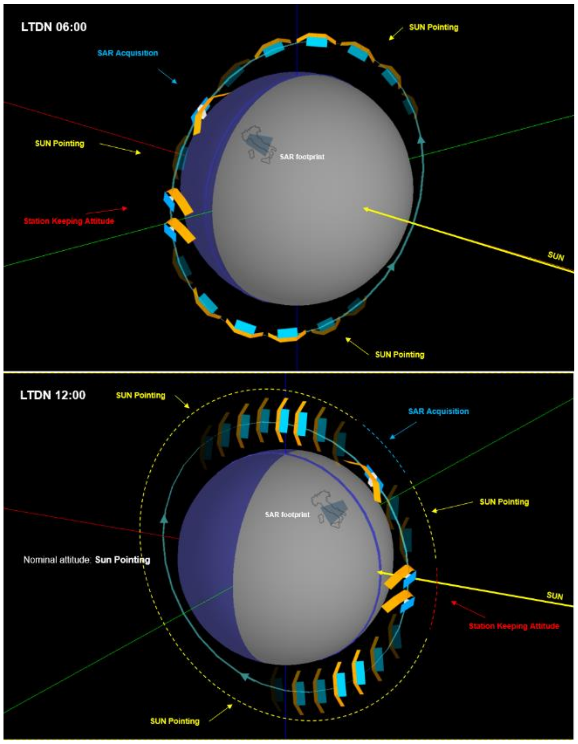


Figure 14: SATURN Down-Dusk Orbit (Nominal) top, Noon-Midnight Orbit bottom nominal phase operation.

Therefore, the following worst-case inputs have been used:

- Minimum Sun Activities.
- Eclipse Duration for LTDN 12:00 (35 min).
- 1 Solar Array String Power @ EOL, Sun Point (85°C).
- Worst Case MPPT Efficiency.
- Assumed no Input power during Firing Time for 5 minutes, even if the thruster accommodation guarantee a near Sun Pointing attitude for propelled phase across the equator.
- X-Band Transmission according to the worst-case time required to download 2 High-Res SAR Images with 100 mbps data rate: 3 minutes.
- No input power considered during both acquisition and download phases.
- System Margin: 20%.

With the provided inputs, the overall number of available acquisitions for the worst case is summarized in Table 4.

Table 4: Number of images for different Acquisition / Download scenarios.

Image Number for different conditions		
Consecutive Acquisition 30 x 50 km	2.8	Acq. Only
Consecutive Acquisition 30 x 33 km	4.2	Acq. Only
Consecutive Download 30 x 50 km	4.2	Down. Only
Consecutive Download 30 x 33 km	6.3	Down. Only
Consecutive Acq.+Down. 30 x 50 km	1.7	Acq. + Down.
Consecutive Acq.+Down. 30 x 33 km	2.5	Acq. + Down.

GNSS Performance

To reach the desired performances, the in-orbit relative position of the three satellites should be controlled with a maximum error of ± 5 m. A calibration of all the sensors is required before each acquisition, starting from the knowledge of relative distance between the spacecraft.

To meet these needs, it was decided to adopt a POD system using the GNSS already on board. Precise Pointing Positioning (PPP) is achieved by post-processing the satellite data on the ground. Through this post-processing it is possible to obtain a much more accurate estimate of the relative positions of the three sensors, both for upstream calibration and to improve the image characteristics downstream of the acquisition as auxiliary information.

Some software has already been identified to fulfil this task, such as the Bernese GNSS Software [2] that provides post-processing from near-real time to reprocessing, combining GPS/GLONASS Kinematic and reduced-dynamic precise orbit determination for Low Earth orbiters (LEOs). However, subsequent considerations will have to be weighed in the next steps in order to choose the optimal approach.

Inter Satellite Link

An Inter Satellite Link (ISL) is required for nominal constellation management (maintaining orbit and preventing collisions with space debris and between satellites in the same swarm). The drivers for dimensioning the ISL are:

- the relative distance of 200 m between the satellites in the train
- the amount of data exchanged before each acquisition, which was estimated to be in the order of tens of kilobytes.
- ensuring omnidirectional coverage.

For this reason, various analyses were carried out for the displacement of ISL antennas, taking into account UHF/VHF antenna patterns, satellite appendages, relative distances between units and radio frequency compatibility. A preliminary radiation pattern verification was generated to evaluate and check the radiation pattern against SAR antenna and platform constraints. Figure 15 shows the radiation pattern and minimum gain points in the case of the currently analyzed configuration.

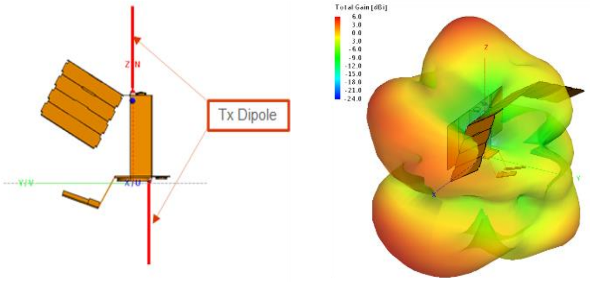


Figure 15: ISL TX preliminary radiation pattern.

Payload Data Volume

Starting from the data volumes that each type of acquisition entails, summarized in Table 5, an analysis was carried out to confirm the validity of the selected ground network and to be compliant with the mission requirements on the number of contacts.

Table 5: Payload Data Volume for single images.

Image Number for different conditions		
Sensitivity Option	2.1	Gbit
High Resolution Option	9.4	Gbit
Average Value Option	5.8	Gbit

The preliminary parametric analysis was calculated based on the following inputs: data volume of single image, number of acquisitions per orbit, downlink data rate, and downlink strategy.

The table below indicates the number of ground contacts needed to download respectively 2 – 5 – 10 images with different downlink data rates. It is assumed to communicate with a single satellite at a time.

Table 6: Ground Contacts required based on number of average image size acquired, triple ground station communications.

	Triple satellite: Number of Ground Contacts needed		
Downlink Data Rate	2 images Acquired	5 images Acquired	10 images Acquired
100 mbps	4.1	10.3	20.5
200 mbps	2.1	5.1	10.3
350 mbps	1.2	2.9	5.9

The results highlighted that the produced instrument data volume is compatible with the selected ground network.

Mass Budget

The current design foreseen an overall mass of about 38.7 kg (including margins) composed by the following contributes:

- 11.8 kg for Platform Subsystem.
- 15.5 kg for SAR Payload including SES (SAR Electronic Subsystem) and SAS (SAR Antenna Subsystem).
- 10.0 kg for Satellite Structure, including the 8” interface ring for the launcher.
- 1.4 kg for Harness.

PAYLOAD OVERVIEW

Confirmed by ESA study “*Distributed SAR for Space 4.0*”, the interest for such innovative payload arose since the early studies about formations of SIMO and MIMO SAR that are formed by multiple active sensors, each of them transmitting its own signal and receiving the backscatter of all the sensors. An example of a well-designed MIMO-SAR is the one schematically represented in Figure 16, proposed for a ground-based Radar [3]. In that case, the combination of Nt = 3 transmitters and Nr = 3 receivers – properly placed, allow the generation of Nr × Nt = 9 phase centers, that is 9 samples, properly spaced along-track.

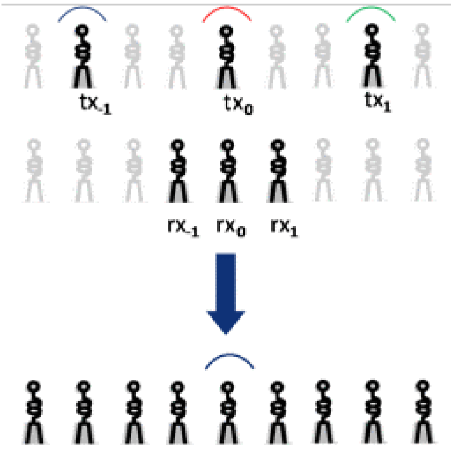


Figure 16: MIMO SAR example with 3 transmitters and 3 receivers, equally displaced phase center is achieved.

The immediate advantage of such MIMO configuration is a hardware simplification, where N Tx/Rx elements are used to get the performances of the N^2 real array.

Clearly, the MIMO antenna architecture can be extended to a distributed system, resulting in a close formation of all active sensors. The goal is the same as for the SIMO concept previously discussed: to make a robust, scalable formation of small – or tiny – satellites, still achieving High Resolution and Wide Swath coverage. However, in the MIMO case, the power gain is enhanced by a factor N, with respect to the SIMO, then N² with respect to the single element, due to the superposition of N transmissions.

Instrument Overview

The SATURN instrument is a X-band SAR equipped with a reflect array antenna, composed by 13 panels, conceived to work in single Polarization (HH Pol) and acquiring data in Stripmap mode. This instrument has been developed by ARESYS S.r.l. and Airbus Italia S.p.A.

During imaging, the SAR acquires the echo signals scattered by the imaged scene in response to the transmitted pulses, processes them (RF → IF, IF sampling, DDC, I&Q extraction and BAQ compression), and then merges this data with timing and auxiliary information (required for processing) to generate the SAR Raw data. The SAR provides the hardware and functionality required for on-board characterization /calibration purposes so enabling the image quality requirements fulfilment over the entire mission duration. Moreover, system characterization and calibration strategies are also strictly required to handle the different sensors intrinsic mismatches.

The three formation flying SARs are kept in-time and in-frequency synchronized to execute acquisition at full performance. The formation can perform both SIMO and MIMO acquisitions by independently selecting the number of Transmitters and Receivers. The radar parameters are configurable so allowing the capability to meet different set of performances among resolution, swath, NESZ (Noise Equivalent Sigma Zero) and ambiguity level.

The SATURN instrument high-level architecture consists of two main subsystems:

- SAR Electronics Subsystem (SES), which is distributed on four different modules:
  - SAR Board Computer,
  - Hi-Power Module, integrating SuperCap,
  - RF section including Up/Down converter (UDC) and TRMs Assembly
  - GPS Disciplined Oscillator (GPSDO).
- SAR Antenna Subsystem (SAS), which is composed by:
  - 13 panels
  - 2 slot-array feeds, composing the feed subsystem, deployed outside the CubeSat (focal length F=750 mm)
  - Deployment mechanisms for both Antenna and Feed System

To improve the performance within the frequency band and increasing the illumination efficiency, the reflect-array panels are arranged symmetrically w.r.t. S/C in three segments: five panels are placed in the centre and four panels on each side. The side panels are tilted on the horizontal plane by an angle β and again this angle is optimized to guarantee optimum RF performances.
This optimization process is a trade-off that considers the following needs:

- to provide the highest illumination efficiency.
- to minimize the spill over losses.
- to design a simple and reliable deployment mechanism that increases the Feed focal length.

A slotted waveguide array solution has been selected as best Feed candidate since its main characteristics:

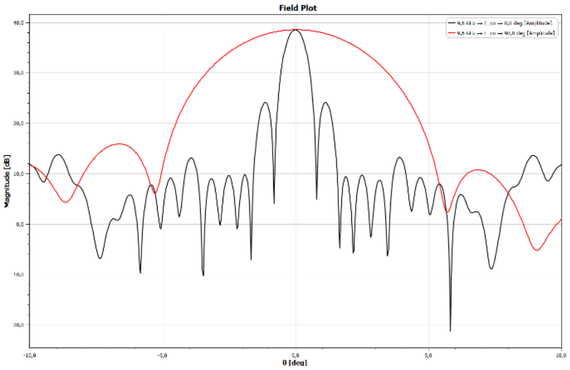
- Reduced losses
- Flexibility in the primary radiation pattern synthesis
- High power handling.

No need for a dedicated external Beam Forming Network since the Excitation Coefficients values of the Array elements (slots) are directly imposed by the proper slots geometry design.

The deployment mechanisms for both the antenna and the two feeds are composed of passive elements both for locking the panel stack at launch and to deploy it on orbit. The only active elements are the two Non-Explosive Actuators (NEA) that fix the stack to the satellite at launch. Three rotations guarantee the feeds correct deployment, before the deployment of the antenna. The antenna performances are summarized in the table below:

Table 7: SAR Antenna performances and Antenna RF Pattern.

	9.4 GHz	**9.6 GHz**	**9.8 GHz**
Peak Direction (dBi)	38.07	38.53	38.09
Losses (dB)	2.42	2.42	2.42
Peak Gain (dB)	35.65	36.11	35.67
HPBW(°) Az Cut	0.71	0.69	0.68
HPBW(°) El Cut	4.32	4.22	4.17
SLL (dB)	-14.69	-14.38	-14.41



Payload Performances

The SATURN SAR performances have been estimated for an orbit altitude of 480 Km and a swarm consisting of three sensors in along-track configuration. An access nominal region between 20 and 40 degrees of incidence angle has been considered with 6/7 independent beams depending on the desired range swath (as anticipated could be expanded up to 15 to 45 degrees).

Moreover, distinct SAR Stripmap options have been analysed to provide different levels of image performance in terms of resolution, swath, NESZ and ambiguity rejection (fully exploiting the SAR radar configurability). The different options cover the generation images within the following performance intervals:

- Geometric resolution: 1.5÷5 m.
- Range Swath: 30÷40 km.
- Azimuth Swath: 33÷50 km.
- NESZ: -5÷-15 dB.
- Ambiguity level: lower than -15 dB.

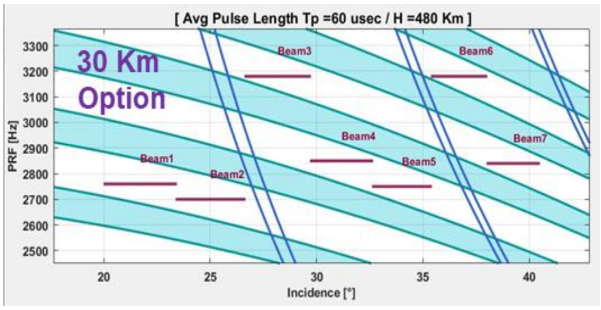


Figure 17: SAR range swath beam allocation, 30 km.

The figures and tables just showed report performance for the 30x50 Km swath and 5x5 meters resolution option.

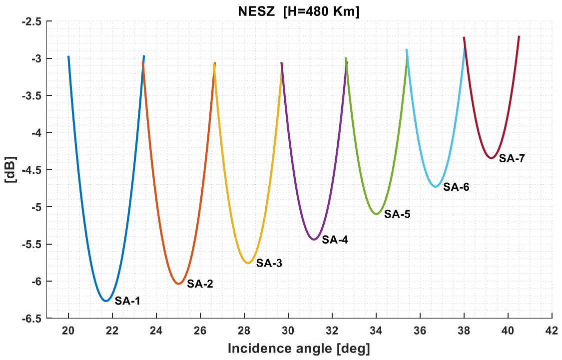


Figure 18: Single Sensor NESZ (before MIMO recombination).

Table 8: Single Sensor and MIMO-3 NESZ.

Sensitivity Option: 5x5 m Resolution – 30x50 Km Swath				
NESZ [dB]	**Single Sensor**		**N=3 MIMO Recombination**	
	Best Case	**Worst Case**	**Best Case**	**Worst Case**
SA-01	-6.3	-3.0	-15.8	-12.5
SA-02	-6.0	-3.0	-15.6	-12.6
SA-03	-5.8	-3.1	-15.3	-12.6
SA-04	-5.4	-3.0	-15.0	-12.6
SA-05	-5.1	-3.0	-14.6	-12.5
SA-06	-4.7	-2.9	-14.3	-12.4
SA-07	-4.3	-2.7	-13.9	-12.2

RESULTS AND CONCLUSIONS

As reported, the simulations on payload performances show that the system is capable to satisfy the mission requirements, in terms of resolution and swath.

Starting from the heritage of the OBH-I Platform M[3], the SATURN spacecraft configuration has been designed, keeping the compatibility with the CubeSat Class, in terms of subsystem and overall mass and envelope. The adaptability of the platform allows to build a solid architecture that fulfils the requirements of the SAR payload while managing to be in a close formation within strict limitations.

Despite the high number of technical challenges in the design of SAR for nano-micro platforms, with a hybrid power system and the application of distributed MIMO SAR concept, the system is capable to acquire the required minimum of daily images on all the orbits foreseen for the Full Constellation. Projecting this demonstration mission to the full worldwide operability.

Being in the core of the Phase B the SATURN mission team is developing and researching to optimize the performance of the spacecraft, working into a goal-oriented perspective.

Acknowledgments

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