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UNISAT-7: a flexible IOD platform with orbital maneuvering capabilities

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ABSTRACT

New Space technology for Small Satellites has greatly advanced in the past five years. These progresses shall match with a swift integration and testing phase, to be readily marketable, therefore IOD missions are essential to expedite project outcomes.

GAUSS has started working on Small Satellites since 1990s, with its first satellite, UNISAT, launched in 2000. In 2013, UNISAT-5 was the first platform to accomplish in-orbit-release of third-party satellites, with UNISAT-6 following in less than one year.

UNISAT-7 is the latest addition to the UNISAT series: a 32kg microsatellite designed and manufactured by GAUSS Srl (a spin-off company of Scuola di Ingegneria Aerospaziale, Sapienza University of Roma), built from scratch thanks to the extensive experience gained with past missions. Launch is scheduled in in Q1 2021.

It is the most complex mission ever flown by GAUSS, and it includes several original GAUSS subsystems developed for Earth Observation, sat-to-ground optical links, navigation, power, RF, and Smallsat in-orbit-deployments. All these subsystems are tested in orbit in specific IOD missions.

Moreover, UNISAT-7 integrates a precise ADCS solution and a newly developed low-thrust, electric propulsion system named REGULUS, from Italian Company Technology for Propulsion and Innovation (T4i), which will allow the satellite to modify its final orbit, as well as to execute housekeeping maneuvers for drag compensation.

REGULUS is a propulsive unit based on MEPT (Magnetically Enhanced Plasma Thruster) technology developed inside the propulsion laboratory of the University of Padua. T4i, born as a Spin-off of the University of Padua, industrialized this technology in order to make it fly. REGULUS is T4i very first product that has ever flown into space. Its envelope is 1.5 U of volume, it is equipped with solid iodine propellant and its main features are a thrust level of 0.55 mN and Isp of 550 s at 50 W of input power, and wet mass of 2.5 kg at 3000 Ns of Itot. REGULUS is designed to serve nanosatellite platforms from 6U to 24U and CubeSat carriers.

The integration took place in GAUSS white chamber in Rome in late 2020 and the launch is scheduled in March 2021 from Baikonur as a secondary payload of Soyuz-2-1a/Fregat.

Performances of REGULUS propulsion system are evaluated after the initial commissioning of UNISAT-7.

This key IOD mission paves the way to next UNISAT programs, where GAUSS microsatellites will be able to execute orbital maneuvers before any single CubeSat deployment, in order to efficiently shape customized constellations by using UNISATs as autonomous vehicles for in-orbit-deployment.Provide an informative abstract of no more than 500 words. The abstract should stand alone as a summary of the paper, not as an introduction (i.e., no numerical references). Type the abstract across both columns and fully justified.

INTRODUCTION

Space technologies require extensive, live tests to gain valuable results datasets and thus pivotal credibility for market outreach. Small satellites are the perfect test bed for such experiments. Using Lean-satellite methodology, typical micro-satellite missions can be designed, developed and flown in less than two years. GAUSS has been developing and launching Small satellites since the year 2000, when it was part of the Scuola di Ingegneria Aerospaziale in Rome, as a laboratory of Applied Astrodynamics, where students could practice in the development of Small Satellite missions, before completing their University degree.

The San Marco Project

In 1990 GAUSS research laboratory restarted the research on Small Satellite missions at the Scuola di Ingegneria Aerospaziale, following the successful experience gained by the said Institution with the Italian "*San Marco Project*": a set of Small Satellites that were developed and launched in the sixties and seventies by key figures such as Prof. Broglio, which was Dean of the Scuola di Ingegneria Aerospaziale in Rome. San Marco 1 satellite became the first Italian satellite and it was launched on December 15th, 1964, by a Scout launch vehicle, thus letting Italy become the third Nation to launch a Satellite in Space.

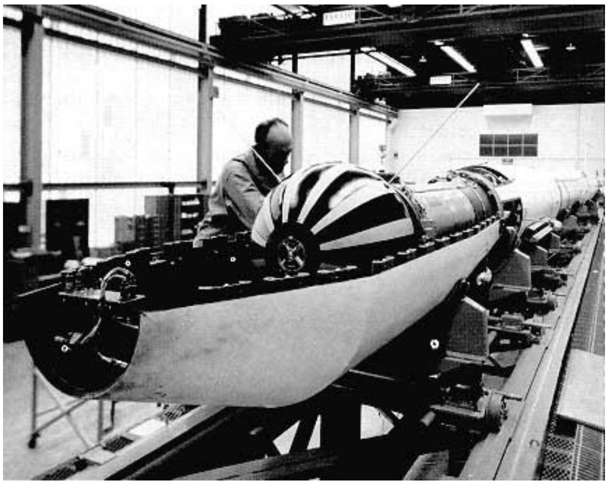

Figure 1: San-Marco 1 integration inside the fairing of the Scout Launcher

The UNISAT Series

In 1990 Prof. Filippo Graziani, at the time full Professor of Astrodynamics of the Scuola di Ingegneria Aerospaziale, acknowledged the importance of hands-on experience for an aerospace engineer, which shall run in parallel with theoretical engineering studies. He then created the GAUSS laboratory, acronym for *Gruppo di Astrodinamica dell'Università "La Sapienza"*, where students could practice what learned in class, with a real-world project. In year 2000 the first UNISAT-1 micro-satellite was launched, using a newly civilian-converted SS-18 ICBM "Dnepr" launcher, and every two years a new UNISAT micro-satellite was developed and launched by a group of students. The students' work ranged from the preliminary mission design to the integration of the satellite at the launch site, continuing with the telemetry, tracking and control of the satellite.

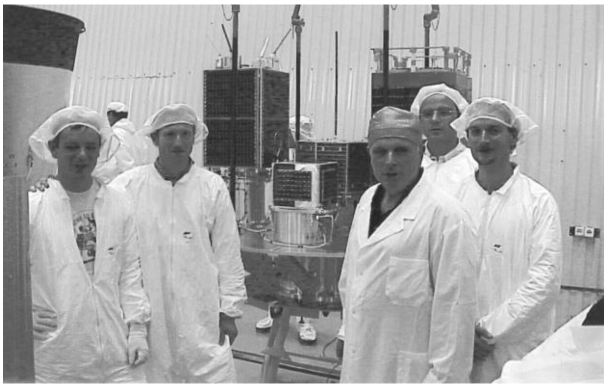

Figure 2: The UNISAT-1 integration team in Bajkonur launch site

The UNISAT series of educational Small Satellites included UNISAT-1, UNISAT-2, UNISAT-3. In 2006 UNISAT-4 failed to reach orbit due to a launcher malfunction. GAUSS then designed the "EduSAT" micro-satellite in cooperation with the Italian Space Agency, and it was launched in 2011, using the same Dnepr launcher, this time from Dombarovsky launch site, in the Orenburg Oblast region of Russia.
The last satellite developed by GAUSS as a University laboratory was UNICUBESAT-GG, a 1U CubeSat which was launched by the ESA VEGA maiden launch in 2012 and its mission was to test gravity gradient stabilization through the use of an extendible boom.

GAUSS as a private Company

GAUSS became a private Company in 2012, with the establishment of GAUSS Srl (*Group of Astrodynamics for the Use of Space Systems*) which aimed at preserving the heritage gained in twenty years of research on Small Satellites. The first satellite launched by GAUSS Srl was UNISAT-5 in 2013. The use of COTS components, pioneered with the first UNISAT missions, helped GAUSS engineers to further reduce overall mission costs while maintaining a certain level of reliability.

GAUSS UNISAT PLATFORMS

GAUSS' first Small Satellite project was UNISAT-5, the first space platform on the market to offer in-orbit deployments for both CubeSats and PocketQubes, then acting as a technology demonstrator for GAUSS and third-party payloads[1]. Third-party satellites are carried inside the satellite, then deployed after reaching final

orbit. The satellite integrated GAUSS' designed GPOD CubeSat deployers as well as P-POD deployers from Cal Poly, USA, while for the PockeQube release the MRFOD deployer was developed, in cooperation with Morehead State University, USA. The satellite was launched on November 21st, 2013 using a Dnepr LV.
With a turnaround of less than one year GAUSS realized UNISAT-6, which was launched on June 19th, 2014, by a Dnepr record cluster mission of 32 satellites.

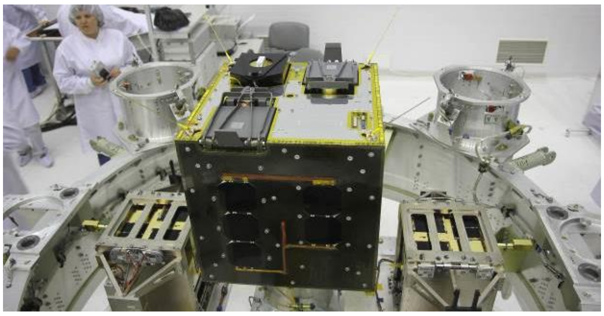

Figure 3: UNISAT-6 after integration on Dnepr LV

Four CubeSats were deployed, among them was the first Iraqi satellite, TigriSat, and one of the first prototypes for the Spire CubeSat Constellation, LEMUR-1. After the success of the CubeSats deployment mission, UNISAT-6 was used to test GAUSS space bus and ground segment and procedures. UNISAT-6, as well as its predecessors, included several subsystems assembled using COTS components that were carefully selected for their reliability after positive outcomes from environmental tests such as TVAC and vibration tests (shock, sine, random). The use of COTS components with minimal modifications to increase reliability in space along with redundant systems has allowed GAUSS to reduce costs per platform, while ensuring an overall high level of reliability per mission. UNISAT-6 has been actively operating from GAUSS ground station for more than six years, well beyond the designed life expectancy for the platform.
The heritage and experience obtained by the design, development, launch and ground operations of these satellites were essential for the design of GAUSS latest satellite, UNISAT-7.

LEAN SATELLITE PHILOSOPHY

GAUSS adopted a strategy of lean-satellite development and manufacturing for the original subsystems created for this mission[2,3]. This meant to have a swift prototyping cycle to arrive to the flight product, with several test phases in different stress conditions. During the design and manufacturing of the electronic boards, GAUSS engineers sought to abide to most of ECSS guidelines whenever possible, with the aim of keeping a balance between added reliability, production costs and procurement times, as some ECSS rules find a better application to larger missions. First functioning prototypes are prepared using development boards, when available, to speed up hardware development and initial coding processes.

UNISAT-7

The latest Small Satellite mission designed, developed and assembled by GAUSS is UNISAT-7. It is a 31,5kg, octagonal shaped micro-satellite. It is based on heritage gained with past UNISAT missions. Its development started in 2015 and the design was altered multiple times as a launch delay and subsequent launcher switch from the initial Dnepr LV to the Soyuz-2 LV required modifications and a review of the entire project.
The satellite was launched on March 22nd, 2021 by a Soyuz-2 / Fregat LV from Bajkonur Cosmodrome, which released the platform into a circular 550km, Sun Synchronous Orbit.

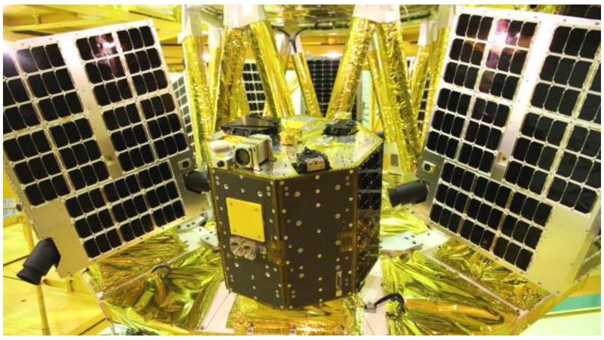

Figure 4: UNISAT-7 after its integration on the Fregat LV in Bajkonur

UNISAT-7 is a huge leap in terms of system complexity compared to UNISAT-6, as there are more than 28 individual subsystems that provide telemetry for their own diagnosis to the central OBC and to ground. The main missions are the in-orbit release of nano- and pico-satellites and IOD technology tests for GAUSS and third-party payloads.

Figure 5: UNISAT-7 mission patch

UNISAT-7 has carried in space and automatically deployed five smaller satellites: two CubeSats and three PocketQubes. GAUSS' customized solutions for deployment were used to release these satellites in orbit, as several were of a peculiar size. Two CubeSats were released on March 25th, at around 10:10PM UTC: BCCSAT-1, a 1U CubeSat from Thailand, and FEES, a 1/3U from Italy. Three PocketQubes were released on March 24th, 2021 at around 10:50AM UTC: DIY, a 1p PocketQube from Argentina, SMOG-1, a 1p from Hungary and STECCO, a 5p from Italy. One GAUSS GPOD CubeSat deployer hosted the two CubeSats, one custom GAUSS MRFOD deployer hosted the 5p STECCO PocketQube and another MRFOD deployer contained the remaining two PocketQubes.

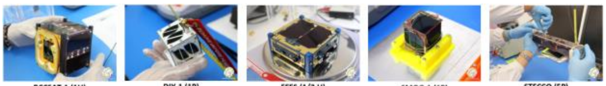

Figure 6: The five satellites released in orbit by UNISAT-7

All the satellites have been successfully received by their respective owners and radio amateurs worldwide since May 24th, 2021 onwards.

UNISAT-7 SYSTEM ARCHITECTURE

UNISAT-7 includes more than 30 subsystems that provide their own telemetry to the main OBC. To address this added complexity, the satellite features two main electronic buses[4], one deputed for the satellite critical systems and the other assigned to the management of the payloads for the in-orbit demonstrator missions.

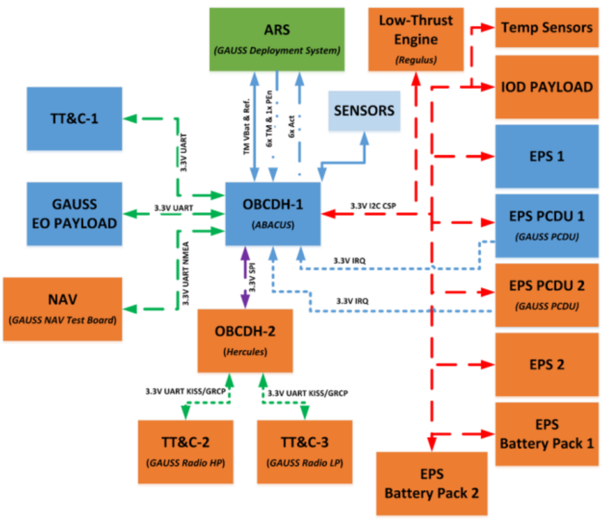

Figure 7: System Architecture of UNISAT-7

The UNISAT bus proved to be very flexible as several peculiar IOD payloads, which had selective power requirements, were added to the system architecture only during the last development reviews. This required the design of auxiliary subsystems to manage, control and power the IOD payloads.

UNISAT-7 ATTITUDE DETERMINATION AND CONTROL

UNISAT-7 integrates a precise ADCS solution that was specifically tailored to the mission needs, and the moments of inertia of UNISAT-7 flight model. It is based on attitude determination using Sun sensors, Earth sensors, internal and externally deployed three-axis magnetometers, and an inertial measuring unit that includes precise rate gyros. The attitude control is executed by the operation and dynamic control of three large reaction wheels positioned parallel to the three main platform axes, and three magnetorquers for detumbling and wheels desaturation. Several operative modes are available, like Y-Thompson, magnetic fast detumbling, Nadir pointing of a specific platform axis, velocity vector pointing, controlled spin. The pointing accuracy of UNISAT-7 ADCS is less than 1° in both sunlit and eclipse parts of the SSO orbit, with a detumbling rate of 30°/s. Pointing during the activation of REGULUS engine is foreseen to be about 2°. All configuration parameters for the ADCS, as well as the operation logs are accessible via the main ABACUS on board computer, which is connected to the UART debug port of the ADCS.

UNISAT-7 POWER ARCHITECTURE

REGULUS low-thrust engine nominal required power is 50W, therefore the power system architecture of UNISAT-7 was heavily modified to sustain such load for a significant period. Power per solar panel and battery capacity were increased, and a new power subsystem was devised to manage, convert, and monitor power to payload subsystems such as REGULUS.

UNISAT-7 power bus consists of a dual-EPS power system connected to six solar panels, each containing two independent solar cells strips: one for the main bus, the second for the payload bus.

Average total generated power is 45W.

Two Li-Ion battery packs for a total of 154Wh capacity are reserved for the payloads operation, whereas one 77Wh battery pack is dedicated to the main UNISAT bus.

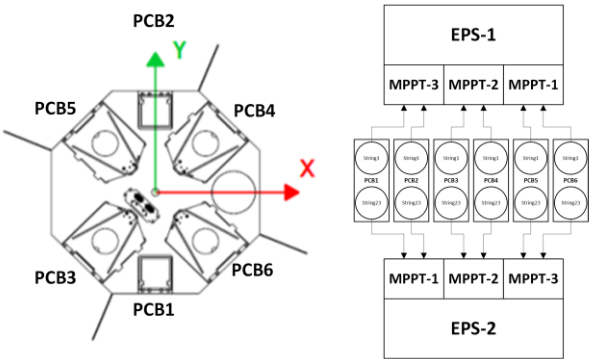

Figure 8: schematic of power generation in UNISAT-7

Regulated power channels of the two EPS systems are connected to critical subsystems, such as main UHF radio and ABACUS main on-board-computer.

The PCDU Subsystem

The PCDU subsystem (*Power Conditioning and Distribution Unit*) is GAUSS' new addition designed to manage, power, and diagnose payloads present on the satellite. It is a very flexible subsystem as every power channel can be customized in its electrical parameters, and several safety measures are implemented in the board to increase mission reliability. A current limiter is present on all power channels and power good signals are present for all the DC/DC converters used to generate each channel's power.
This subsystem is directly connected to the payload battery packs.

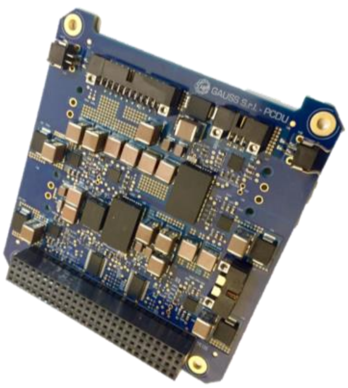

Figure 9: The PCDU subsystem

UNISAT-7 AUTOMATIC RELEASE SYSTEM

UNISAT-7 features the ARS System (*Automatic Release System*), deputed for the management of the deployment of the five satellites, the first mission of UNISAT-7. The system is based on the experience from past satellites, but it was greatly overhauled to enhance reliability of this critical part of UNISAT-7 mission. The ARS System is compatible with several opening mechanisms: thermal cutters, TiNi Frangibolt® and ERM Ejector® devices.
The CubeSats deployer door was fixed with a Frangibolt® mechanism while the two GAUSS MRFOD PocketQube deployers were fixed with a custom-designed thermal cutter, that was devised to be fully compatible with the ARS System, while providing an adequate retaining force during the launch phase.

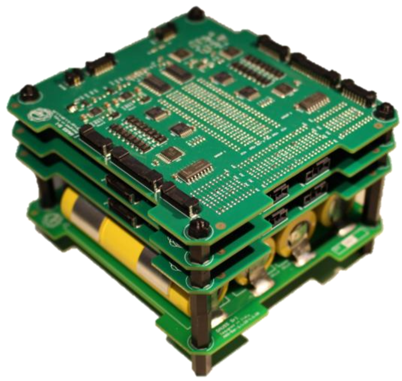

Figure 10: The ARS System fully assembled

The ARS system is composed of a hard-wired logic, a set of driver daughter boards used to provide the required power to the opening mechanisms, and a LiFePO4 battery pack. It is completely independent in terms of power from the satellite bus, and it features several safety mechanisms, like full redundancy on all critical components and a secondary power channel connection to the main satellite battery pack, for redundancy. The hard-wired logic acts as a timer for the opening event, and it does not include any discrete components (MCU etc.) that may be impacted by space environment. Dual telemetry is available on all deployer doors. The release event is divided into specific groups of deployers, it is automated and commanded by this timer, with a repetition cycle executed until the door is open. Manual override can be commanded from ground.
The timer scheduling was manually set at ground during the development of the FM system of UNISAT-7. The ARS system was successfully verified in vibration stress tests using flight qualification levels and in thermal vacuum tests.

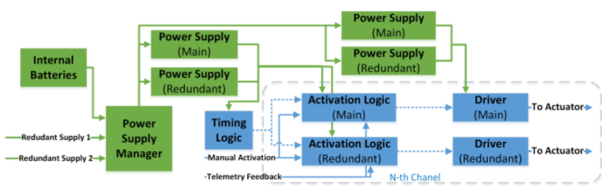

Figure 11: The logic architecture of ARS system

UNISAT-7 IOD MISSIONS

UNISAT-7 includes several payloads developed by GAUSS and other Companies, that will be tested once in orbit and after a period of satellite commissioning. GAUSS engineers have aided in the process of space qualification of the third-party payloads that were integrated in UNISAT-7: hardware requirements for components selection and system interoperability were given to each payload owner, in order to have a fully compliant payload, ready to be tested with the engineering model of UNISAT-7 electronics.

Protection was added by GAUSS engineers with the application, where needed, of bicomponent epoxy resin to strengthen component adhesion on PCB boards in delicate areas.

The main IOD mission will be the REGULUS engine by Technology for Propulsion and Innovation SpA (T4i), an Italian company based in Padova, specialized in electric and chemical propulsion systems for in-space and access to space applications for Small Satellites. REGULUS is an ambipolar low-trust engine, whose technology derives form the Magnetic Enhanced Plasma Thruster (MEPT) technology, integrating all the subsystems into a complete propulsion unit of 1.5U with a total mass of 2.5 kg.

A second third-party payload is Pluto in Space (PiS) developed by RAME Srl, an Italian Company specialized in RF solutions. This payload will test an Narrow Band Internet-of-Things protocol developed for ground-to-space applications, to retrieve from space data coming from IoT transmitters on ground, with minimal modifications compared to the regular terrestrial NB-IoT transmitters currently available on the market. It will use a software-defined-radio programmed with several automated scripts for the reception and decoding of signals from IoT transmitters that will be activated by ground personnel during suitable passes of UNISAT-7.

With regards to GAUSS payloads, the satellite includes several systems specifically designed for the mission, that will be tested as part of GAUSS IOD campaign to qualify several payloads for space use in Small Satellites.

OPT0 and OPT1 Imaging Systems

Two new Earth observation (EO) systems have been integrated into UNISAT-7, their name are OPT-0 and OPT-1. They have been developed completely in-house, using COTS and open-source components, and all firmware has been written internally by GAUSS personnel. These systems were designed to provide compressed pictures in RGB.

The first EO payload, OPT0, is a narrow field of view, long focal distance, miniaturized system composed of a 12Mpix RGB CMOS, a COTS refractive lens assembly modified for space use and a Raspberry 3B+ OBDH. Total frame size at 600km is 37km x 27km, with a GSD of 9m/px. The angular field of view is 3,5° x 2,6°, verified at ground and max resolution is 4056 x 3040 pixels. The OBDH is operated through a custom firmware that automates all the operations of picture shooting, housekeeping, and system-level diagnosis. OPT0 is connected to the main OBC via one of the GAUSS breakout boards, that oversees powering of the system and creating a data connection with the main OBC when OPT0 is active. The lens assembly is a COTS component that was specifically modified at the assembly factory to remove any lubricant or standard substances which are not suited for the space environment. Since the OPT0 camera assembly (CMOS + lens) needed to be mounted outside of the main satellite structure, a customized shell was designed, made of anodized aluminum. Its purpose is to protect the sensitive assembly from the vibrational stresses of the launch, and to maintain the relative positions and distances of all components that constitute the assembly. The shell includes several low-outgassing dampening elastomers, which are designed to mitigate the vibrations envelope passed from the satellite structure to the assembly.

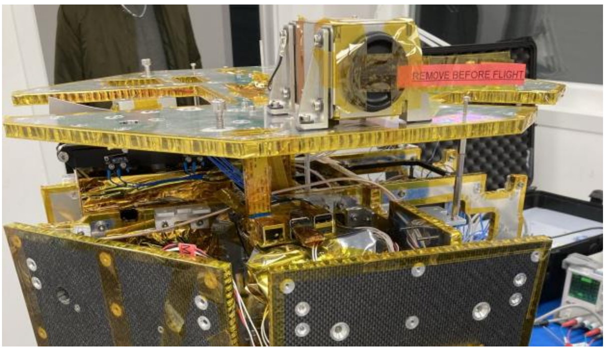

Figure 12: The OPT0 system visible on the +Z panel of UNISAT-7 Flight Model

OPT0 has been positively tested in a complete vibrational test campaign using launch qualification levels, and no image degradations or hardware damages were discovered.

OPT1 is a wide field of view EO system that will be utilized to take pictures of the Earth during the activation of the REGULUS engine, as this system is fixed to the -Z side of the satellite. It is composed of a 5Mpix CMOS RGB camera, a fixed fish-eye lens and a Raspberry Zero OBDH. The field of view of the OPT1 system is 155°. Both systems have an advanced picture processing algorithm that stores, organizes, compress, and split the image file for subsequent download to the ground. A preview scripting algorithm is present on both cameras, to download a preview mosaic of all the pictures taken, in order to aid the ground operator in the selection of the most suitable image for download.

Both EO systems have three shooting modes: single, multiple, and burst mode: the first takes a single picture, the second takes several pictures with a user-selectable pause between each picture, the third is used to take a specified number of pictures in the shortest time period.

Figure 13: The first preview mosaic webp image downloaded from UNISAT-7 on May 20th, 2021

OPT1 has been already successfully activated in space, housekeeping telemetry has confirmed the nominal status of the hardware and its connections, and a preview mosaic (Figure 13) has been downloaded. The mosaic image shows three pictures: the first was commanded during final assembly test in GAUSS headquarters for test purpose, the second was shot during a night pass with the camera pointed to outer space, while the third image was commanded on May 20th during the morning pass, and GAUSS received a telemetry confirmation of the command execution just moments after the transmission.

All pictures executed by OPT0 and OPT1 are first compressed in jpg using hardware compression present on the OBDH processors, then recompressed into *webp* image format using Google's *cwebp* routine to further reduce file size while maintaining the same image quality level as the jpg output. The reduction in file size can reach up to 90%, depending on the subject and the details present in the image. This reduction guarantees that the preview mosaic image con be downloaded during a single satellite pass, thus expediting the selection of the high-resolution image that will be downloaded next.

Figure 14: The OPT1 camera assembly EM

EARENDIL Payload

UNISAT-7 includes a sat-to-ground optical link research payload named EARENDIL (*Experimental Astronautic Research for Nadir Directional Light*) which will involve joint operations with GAUSS space debris Observatory "CastelGAUSS", located in Castelgrande, Southern Italy. It integrates two high-power, high-efficacy and high luminous flux LEDs with known spectral signature, that will be activated when the spacecraft will pass over the observatory on cloudless nights, and when the satellite is in complete eclipse. The total electrical power required for the LEDs is 50W, and the total lumen output is over 8000lm. Luminous efficacy is over 150lm/W at the set voltage. CastelGAUSS Space Debris Observatory will track UNISAT-7 pass, and several long exposure pictures will be taken, to sense incoming light emitted by the payload. The LEDs will blink at a set rate to limit thermal issues and allow heat transfer with the aluminum shell, which also acts as a light reflector to focus the beamwidth on the perpendicular axis.

Figure 15: the EARENDIL Payload

HERCULES On-board-computer

GAUSS will also test its new On-Board Computer, named HERCULES. It includes an ARM Cortex R4F processor, which integrates two cores working in dual-lockstep mode, making it less susceptible to radiations-caused failures. HERCULES is compliant with the PC/104 CubeSat standard, and it can integrate a daughterboard on the same pcb, next to the processor, thus allowing to save space on small volume missions like 1U or 2U CubeSats.

Figure 16: HERCULES OBC with a GAUSS UHF radio fixed to it in the daughterboard slot

The daughterboard slot is compatible with GAUSS UHF radios, but different subsystems can be customized to be mounted in that spot, thus providing additional features to the HERCULES OBC.

GAUSS UHF radios

GAUSS will also test its two new UHF radios developed for Small Satellites: a 2W TPO (transmitter power output) version and a more powerful 5W version. These two transceivers are connected to the primary antenna system by a new subsystem, that will be tested as well, called 3PST RF switch. It allows up to three transceivers to be singularly connected to the same RF connection (e.g., an antenna system), with safety features that keep a matched impedance by using RF terminations on deselected transceivers, therefore unrequested RF transmissions on unconnected radios will not be reflected back and cause failures.

GAUSS GNSS Receiver

GAUSS has also developed its GNSS receiver navigation solution, to be used on UNISAT-7. It has been tested at ground in GAUSS laboratories using a custom-developed GNSS simulation chamber that was specifically created to evaluate orbital system performances prior to its use within UNISAT-7 mission. GAUSS GNSS receiver allows a refresh rate up to 10Hz, with no COCOM limitations.
GAUSS GNSS receiver was activated minutes after the release of the UNISAT-7 from the Fregat stage, and time to first 3D fix (TTFF) was under three minutes. Thousands of 3D fix points have been successfully downloaded and verified against given positions propagated using NORAD TLE. The GNSS receiver is paired with a L1 active COTS antenna, commonly employed on general aviation aircrafts.

GAUSS Reaction Wheel

A further IOD mission will test a prototype for a CubeSat-compatible reaction wheel developed by GAUSS, that will be tested against an initial angular velocity that will be imparted by the main ADCS system. The reaction wheel has been installed on the top panel, aligned with the +Z vector.

COTS Components tested on UNISAT-7

As with previous missions flown by GAUSS, UNISAT-7 integrates several COTS components that have been selected for their superior reliability at ground. These components have been inspected and modified (where needed) by GAUSS engineers to better withstand space environment. These components have then been verified in TVAC at the School of Aerospace Engineering's LARES-lab directed by Prof. Paolozzi, and in vibrational sessions at external testing facilities. IOD missions for these components have already been executed on UNISAT-7 after its launch, and they are all operating nominally. A series of precise digital temperature sensors, commonly found in web stores and used in do-it-yourself / embedded devices, create a network of temperature sensors that monitor temperatures on all UNISAT-7 panels and near critical parts, such as batteries, the REGULUS engine, and EARENDIL payload. The readings from these sensors are sent over the telemetry beacon every 20s. Other key COTS components that have been already successfully verified in this UNISAT-7 mission include: RTC DIY boards for precise time retaining, USB-UART bridge DIY boards, LiMn coin-shaped and Li-Ion 18650 batteries, high-strength bicomponent epoxy resins commonly available at hardware stores.

UNISAT-7 AND REGULUS

UNISAT-7 will be used to test the first flight model of REGULUS low-thrust engine by Technology for Propulsion and Innovation (T4i)[5]. The use of this engine, coupled with an active attitude control solution, enable housekeeping maneuvers for Small Satellites, as well as orbital parameters changes, like semi-major axis and eccentricity.
REGULUS engine could be used also as an active device for reducing deorbit time, for platforms which would otherwise remain in orbit beyond the ruled IADC's 25 years.
Orbit changes will be assessed using the onboard GAUSS GNSS receiver, as well as by the evaluation of orbital TLEs provided by US NORAD. The power channel allotted to REGULUS has been dimensioned to sustain a continuous engine operation of at least one orbit, and a successive coast phase during which the battery is recharged.
At 50 W of input power, REGULUS can provide a thrust of 0.55 mN with a specific impulse of 550 s, and it is capable of a maximum 0,65 mN thrust, with a specific impulse of up to 650s. Thrust can be set at a desired level via software telecommand, and it is linked to the electrical power consumption.

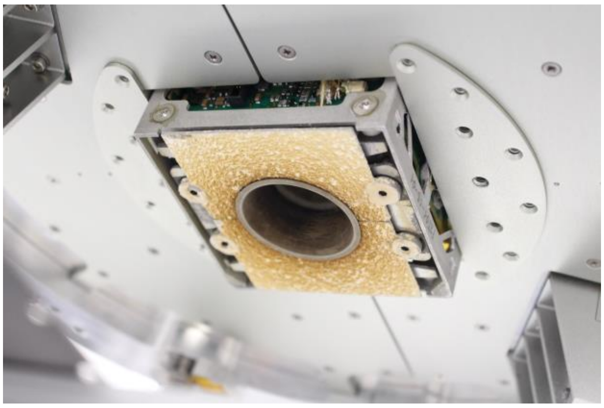

Figure 17: REGULUS low-thrust engine mounted on UNISAT-7 flight model. GAUSS heat transfer plate is visible and surrounds the engine.

GAUSS has worked on thermal aspects with regards to the management of the generated heat when the engine is active. A custom heat transfer plate has been fixed to the engine, and it is connected to the bottom of the satellite: it will enhance heat distribution and thermal radiation. Material composition and surface properties of this heat transfer plate has been carefully selected to maximize conductive heat transfer and thermal emission to outer space.
REGULUS T4i includes its own thermal management system, capable of dissipating 50% of the thermal load through a specific radiator towards space using flight-proven materials and coatings.

REGULUS IOD Mission

GAUSS is working in conjunction with T4i to begin the commissioning of the REGULUS engine. A first test has been already executed and it proved to be successful: GAUSS operators commanded the activation of the power channel dedicated to REGULUS, and the consequent turn-on of the logic of the engine. REGULUS response was nominal, and status as well as housekeeping telemetries were downloaded. This dataset proved the system to be fine, therefore the engine had positively passed the critical event of the launch.
Several tests will be executed, in continuous steps over the coming months, until the full activation of the engine is achieved. During the overall mission, in fact, REGULUS will perform several operations, such as the simulation of orbital operations to spread CubeSats into different orbits, drag compensation, the variation of altitude and final UNISAT-7 decommissioning.

REGULUS performance

REGULUS EP system is a complete and innovative 1.5U-2U electric propulsion system that has been designed to address the mobility needs of nanosatellite platforms ranging from 6U up to 27 U and nanosatellite deployers. Clustering multiple REGULUS systems, we can also provide the necessary performances to bigger platforms up to 150 kg. REGULUS is the first Italian propulsion system based on solid unpressurized propellant (i.e., Iodine) which combines high propulsive performances with compact design and plug & play integration, resulting into a drastically increased satellite versatility at a low cost. The absence of grids and of any other component that can be subjected to erosion results in an augmented reliability and robustness of the system, enabling different and new mission scenarios even beyond LEO missions.

REGULUS can effectively deliver in its flight configuration 3 kNs of total impulse at 0.55 mN of thrust, that means around 60 days of continuous mission.

In such scenario, we have typical mission design that depends on the mass of the system, as in the following table:

Table 1: REGULUS Performances based on mass

Size [U]	Sat. Mass [kg]	Altitude change [km]
6	12	450
8	16	320
12	24	230

While in terms of drag compensation, we can extend a mission in VLEO (300 km circular orbit hypothesis) for at least 20 months.
Different total impulses can be provided under specific customer requests, varying the tank size and thus the overall volume of the propulsion unit.

CONCLUSIONS

UNISAT-7 is one of the most challenging missions ever designed and launched by GAUSS. It integrates several space technologies that will be actively tested in space, proving the flexibility of the UNISAT bus and GAUSS missions for expedited in-orbit demonstrations. The platform includes several COTS components that have lowered the overall mission expense and allowed a swift development of the satellite, while enhancing reliability, compared with previous UNISAT missions, which have proven themselves a reliable option, enduring in operation for over six years of active service.
The integration of a precise ADCS solution coupled with REGULUS low-thrust engine will enable next UNISAT satellites to perform orbital maneuvers for nano- and pico-satellites in-orbit release, as well as for payloads operations, such as Earth Observation systems, which will not be fixed anymore to operate only within the initial orbital parameters, but altitude and eccentricity will become dynamic parameters managed by the UNISAT platform. The possibility to release satellites in different timings and with diverse orbital parameters sets up the basis for an efficient small-satellite constellation building from a single carrier. The presence of REGULUS low-thrust engine will allow an expedited deorbiting process, once UNISAT-7 mission is over.

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