The EXCITE IOD/IOV Mission

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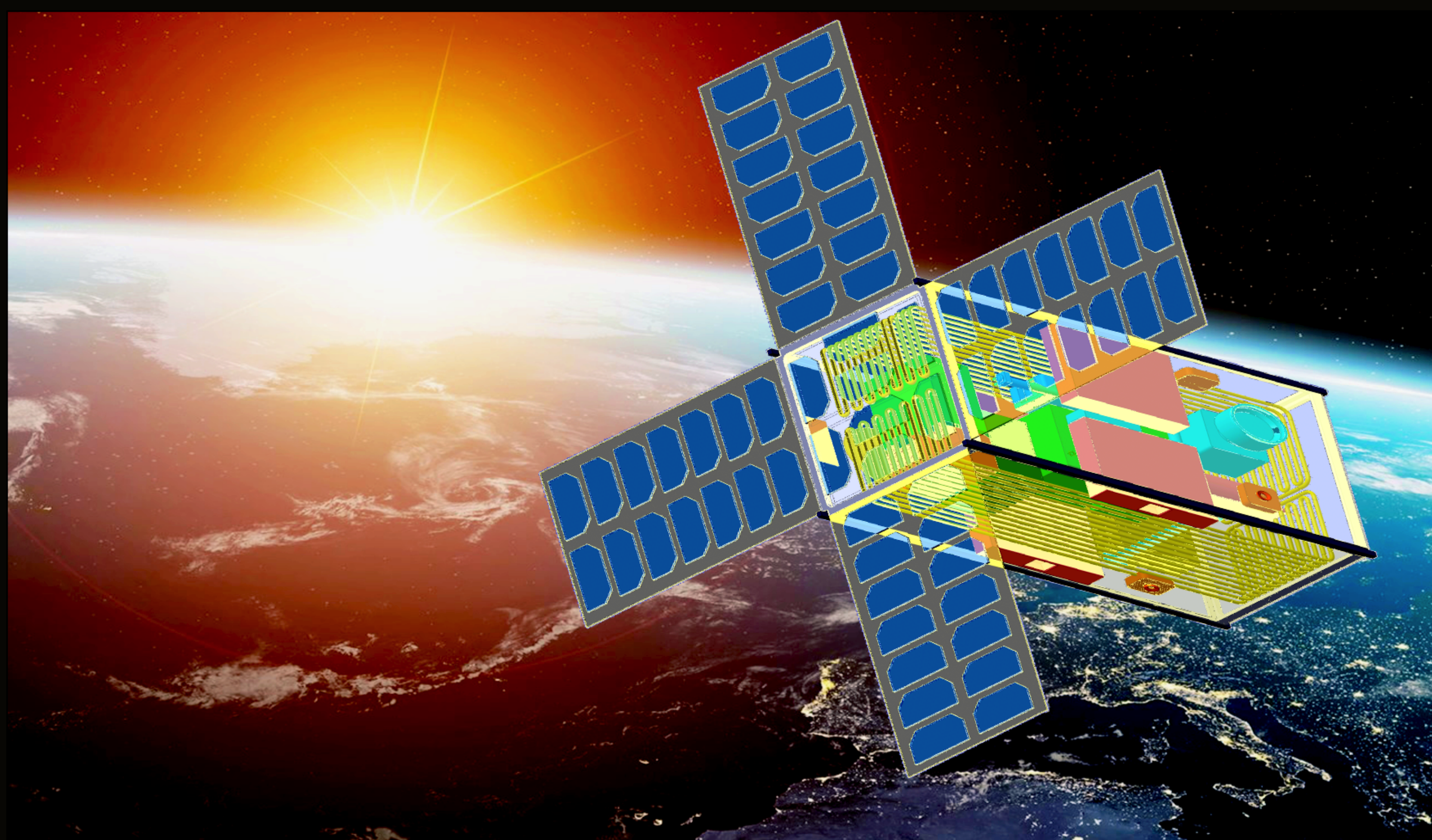
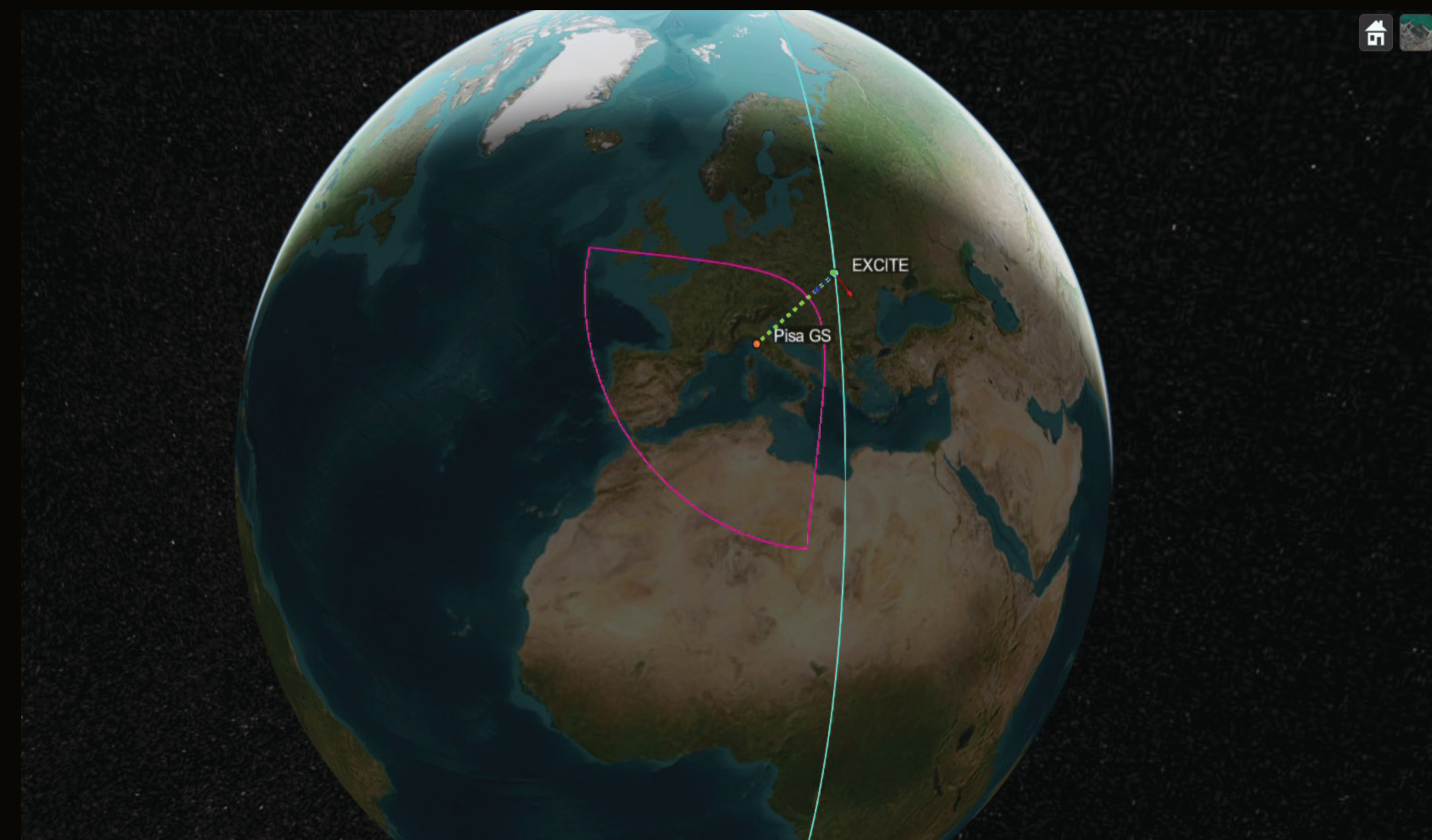




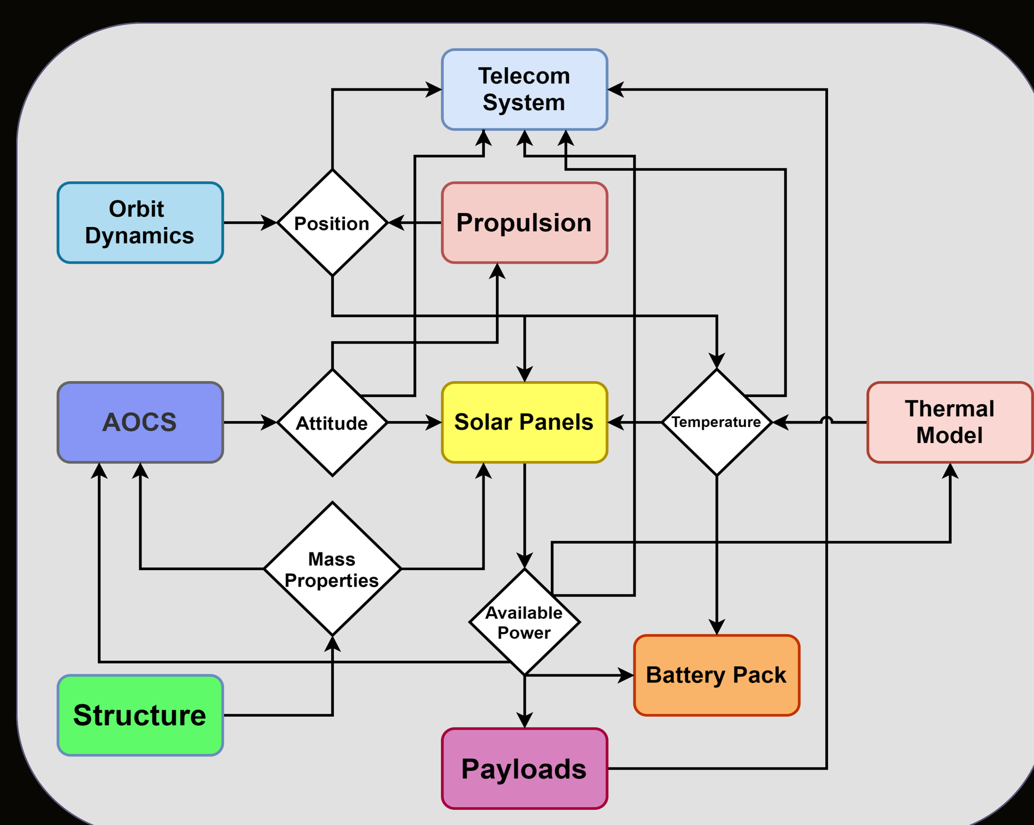
EXCITE - "EXtended Cubesat for Innovative Technology Experiments" - is a technology demonstration mission selected by ASI in the frame of the ALCOR programme. Based on a custom-designed 16U CubeSat platform featuring a full-composite structure, EXCITE is aimed at in-orbit demonstration/in-orbit validation of a number of innovative small spacecraft technologies in the domains of:

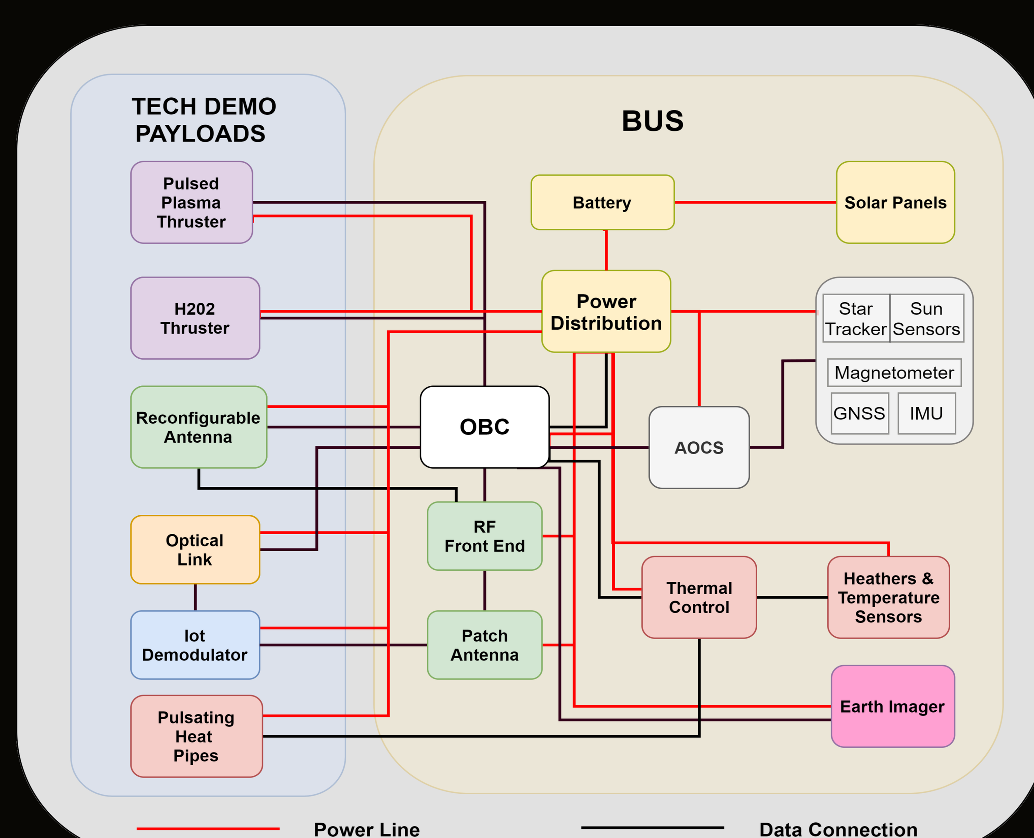
- chemical propulsion,
- electric propulsion,
- thermal management of significant heat loads in limited volumes,
- COTS GPU computing for IoT applications,
- steerable, integrated S-band antennas.

The primary goal of the mission is to test/validate in orbit a number of small spacecraft technologies developed by UniPi researchers and by local SMEs. As a secondary objective, EXCITE will implement advanced bus technologies developed at UniPi in a high-performance 16 U Cubesat platform. The spacecraft and the mission are developed by regional academic/industrial partnership located in Tuscany with the University of Pisa (Prime) and four local SMEs: Aerospazio Tecnologie Srl (electric propulsion), CRM Compositi Srl (structures), IngeniArs Srl (OBDH) and MBI Srl (telecom and networking).

With respect to original attributes of CubeSat projects, which emphasized simplicity, low-cost, and high-risk, in recent years there has been a growing demand for improved performance across various aspects such as pointing accuracy, power generation, and data downloading. For this reason, the proposed research activity is focused on the development of optimization methodologies to improve the capabilities of these platforms.

Being such an highly compact and integrated structure, finding an optimal design for a Cubesat with so many highly coupled design variables results in a non-trivial mathematical problem. Managing such a high-dimensional optimization problem effectively requires advanced optimization techniques capable of handling large-scale, multidisciplinary design optimization (MDO) problems. Due to this fact, gradient-based algorithms have been considered in the presented research, using an open source python library provided by OpenMDAO (Open-source Multidisciplinary Design Analysis and Optimization) that offers a robust framework for tackling such optimization challenges. By taking into account derivatives of the objective function and constraints with respect to the design variables, gradient-based algorithms can efficiently navigate the design space to identify optimal solutions. Moreover, in order to address multiple-objectives and generate an optimized design in terms of mass, cost, risk and scheduling of the in orbit demonstrations, genetic algorhytms such as NSGA-II have been utilized.





The optimization problem is currently encompassing several disciplines including orbital dynamics, attitude control, communication and power distribution. The orbital propagation takes into account eclipse effects, drag and J2. A thermal model is still under development and might impact considerably the final design of the spacecraft.

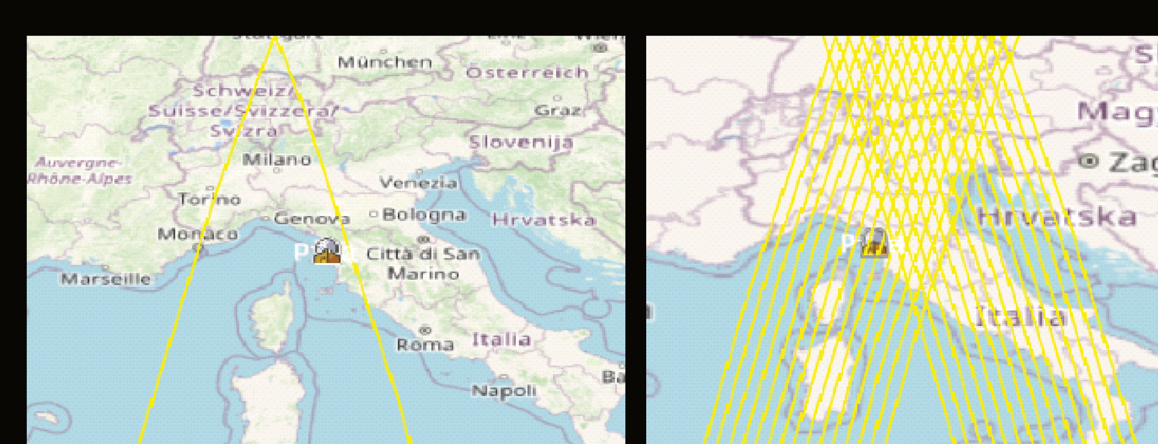
At each iteration of the design process a new set of design variables is generated, then fed into the spacecraft model and propagated for the desired mission duration. The scheduling of the In-Orbit Demonstrations will affect particularly the attitude modes of the spacecraft and therefore the input power coming from the solar panels and the input thermal balance. For this reason, a proper validation of all the models (disciplines) of the spacecraft will be performed before proceeding with the final formulation of the objective functions for the optimization problem.

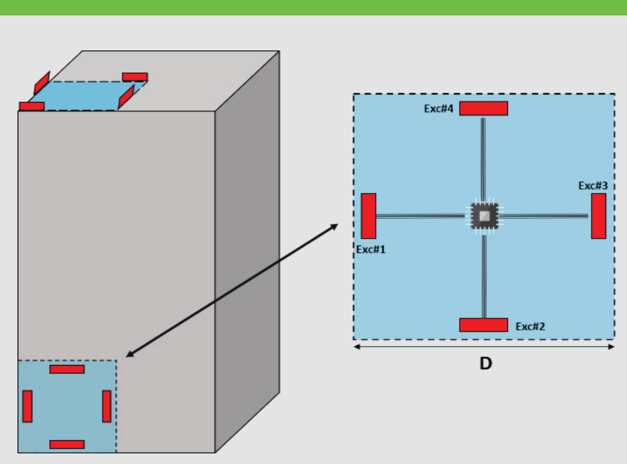
A propulsion system on a Cubesat improves the mission design flexibility and also provides adjustability to any orbit insertion error after the deployment of the satellite. For this reason, the amount of propellant and the orbital maneuvers schedule will be crucial design variables for the optimization of EXCITE.

Furthermore, the scheduling of orbital maneuvers is essential for maximizing access time on specific ground stations. By carefully planning and executing maneuvers, the CubeSat can align its ground track with the desired ground station passes, thereby maximizing communication windows and data downlink opportunities.

For example, using the H202 propulsion system, assuming 1 kg of propellant mass, it will be possible to perform a Hohmann transfer from 550 km altitude to 500 km, using about 40% of total propellant mass. Then the rest of the propellant might be used to compensate the drag losses, extending the mission duration, or for a faster de-orbit at the end of the spacecraft lifetime.

The figure below shows the ground track pattern for a 15 days propagation, the first image focuses on minimizing the average revisit time over the Pisa ground station by flying at 555 km altitude (left image), while the second one (right image) maximizes the coverage over the italian territory, by just setting the orbital altitude at 570 km.



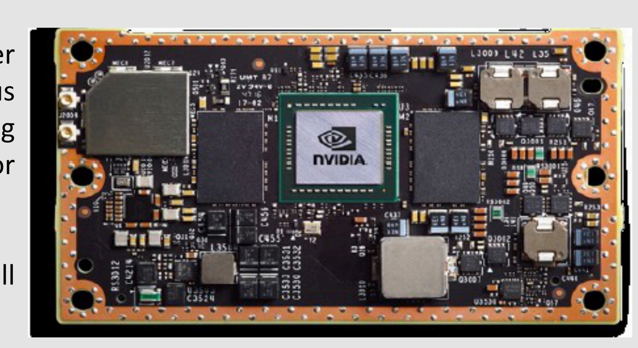


The reconfigurable antenna is an integrated, electronically steerable unit based on exciters distributed on suitable spacecraft surfaces, allowing for extreme compactness and low mass. The experiment can be performed anytime, provided visibility with the GS is ensured and the instantaneous power balance on board allows for the RF front end operation.

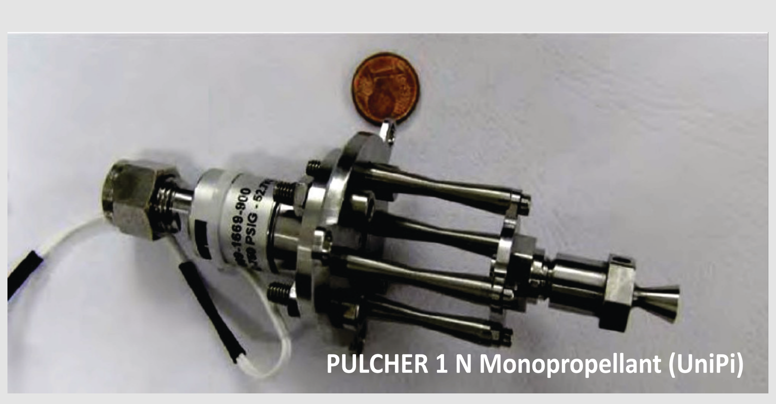
The possibility of using an electronically steerable antenna is particularly interesting because it allows not to rotate the spacecraft while passing over the ground station therefore reduces the number of attitude manouvers to be performed and eventually leds to a reduction of the battery consumption.

The performances will be evaluated with respect to the S-band patch antenna installed as a bus system on the SC.

The IoT Gpu experiment is envisaged as follows:
- a designed IoT signal is transmitted by MBI's IoT ground terminal when EXCITE is passing within its visibility area. In particular, an innovative spread-spectrum waveform named IURA (IoT Universal Radio Access) will be used. The signal collected by on-board telecommunication hardware is demodulated and stored by the GPU.
- when the spacecraft is in view of the mission's ground station, or of another suitable receiving station located elsewhere, the GPU generates a Continuous Wave (CW) signal in S-band that is broadcast by the RF front-end. The receiving ground terminals can perform a detailed analysis of the received beacon for performance assessment and for additional auxiliary scientific purposes.



The possibility to demodulate signals received by the ReconfaAnt experiment will be addressed in the initial phases of the mission design.



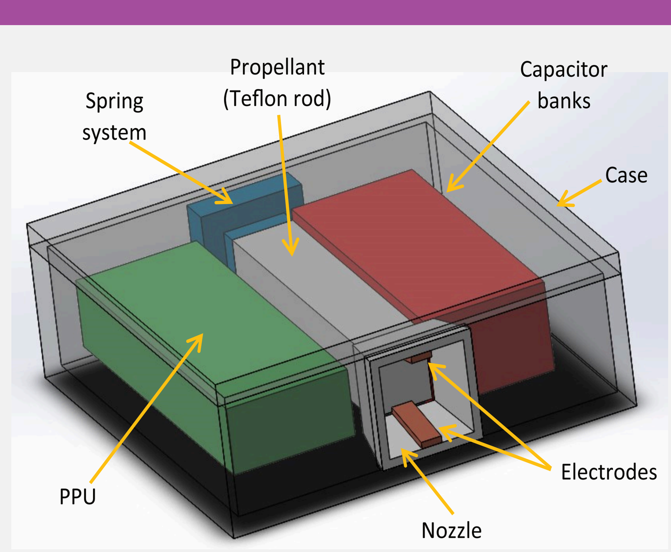
The H2O2 hydrogen peroxide monopropellant propulsion system occupies a volume of about 2U, including a propellant mass of about 2 kg. The demonstration maneuvers are designed to change different orbital parameters in a sensible way, demonstrating both in-plane and out-of-plane maneuvers, while deviating minimally from the nominal flight trajectory. Starting from the nominal orbit at 550 km, the maneuvers envisaged are as follows:

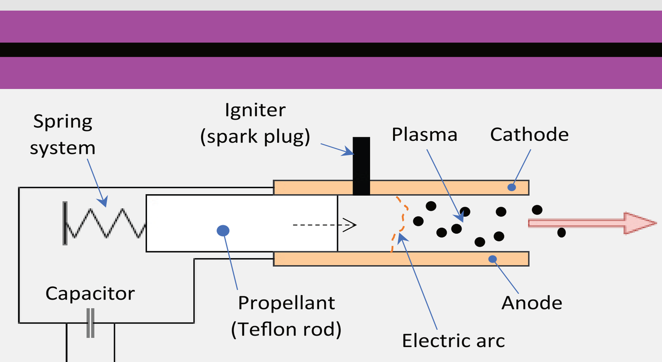
1. apogee lowering to 500 km. The required consumption is about 22% of the initial propellant mass equivalent to 27 m/s of ΔV;
2. apogee raising back to 550 km; propellant consumption and ΔV approximately as before;
3. change of RAAN by 0.5 degrees; the maneuver is best performed providing a 65 m/s ΔV by firing at argument of latitude almost equal to 90 degrees, for a 50% propellant consumption;
4. the remaining propellant is used for the final de-orbiting maneuvering phase.

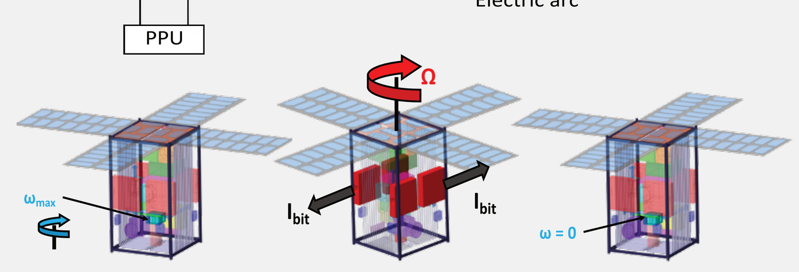
The Pulsating Heat Pipes allow for removal of high localized heat fluxes – a compact, high perfomance solution for thermal management of high power microsatellites.

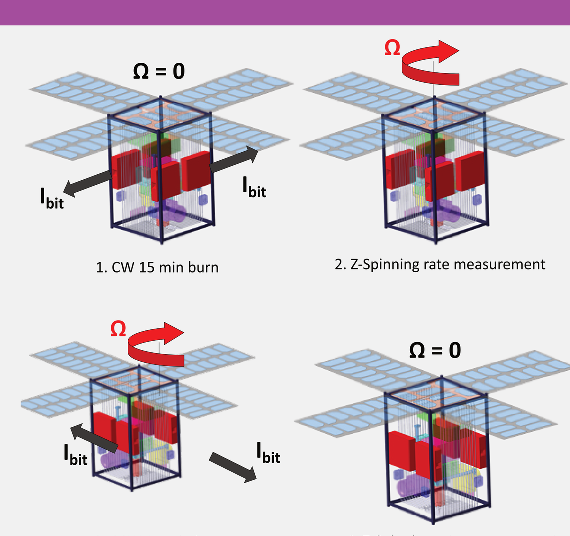
The PHP experiment is totally passive; it will automatically start as soon as proper thermal conditions are established, which will occur almost immediately after acquisition of the nominal Sun pointing attitude and deployment of the solar panels.

A radiator will be mounted on the surface opposite to the solar panels. Each PHP consists of a long capillary pipe wound in parallel segments. Two PHPs will be embedded in the structural panels to transfer the heat generated by the +z face solar cells to a radiator placed on the shadowed -z face. Each PHP will transfer about 10 W of thermal power, to maintain the solar panel at a temperature of 298 to 308 K.









The PPT tests are designed to demonstrate the capability to carry out precision maneuvers. Four independent thrusters will be installed on EXCITE, to generate either pure thrust or pure torque by selecting thrusters in pairs. It is envisioned to perform three experiments:

1. validate the use of PPTs to control the attitude of the satellite in one axis, by spinning up the satellite using a pair of thrusters pairs on opposite sides of the spacecraft body. The burns last 5 minutes in order to reach a spin rate of about 0.8 deg/s. The resulting angular rate measured by the AOCS sensors provides a measure of the impulse delivered. The opposite pairs of thrusters are then fired to spin the spacecraft back to zero angular speed.
2. provide off-loading capabilities of reaction wheels of the on-board 3-axis AOCS, by momentarily taking over the task of the magnetorquers to provide de-saturation torque to the reaction wheel assembly.
3. provide translational thrust, needed e.g. for precise proximity operations (rendez-vous, close formation control), by firing thrusters on the same side of the spacecraft. In the latter case, the spacecraft orientation will be set so to have the thrusters oriented along the orbital velocity direction. Firing for a few minutes at nominal rate (1 Hz) and impulse bit (40 μN s) will provide enough delta-V to change orbital altitude by a few tens of meters, a change that can be easily detected by the onboard GNSS sensors.

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