# MEPS Programme - New Horizons for Low Power Electric Propulsion Systems

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**Abstract: MEPS (Micro-Satellite Electric Propulsion System) is a development and qualification programme jointly supported by the European Space Agency (ESA) and the Israeli Space Agency (ISA). The programme aimes at the qualification of a novel propulsion system based on a low power, low cost Hall Effect Thruster. The system consists of a dual thruster/cathode subsystem, a Power Processing Unit (PPU), Propellant Management Assembly (PMA), feeding lines and a suitable Xe tank and is conceived as a 'plug and play' system that can be easily installed on a number of small space platforms. It is intended to provide a prompt, effective response to the market needs, where small microsatellite platforms can highly benefit from a low-cost, low-mass propulsion system. MEPS is going to pave the way to a new class of affordable and capable space missions, adopting the "All-In-One" paradigm, being an effective solution for drag compensation, orbit insertion, orbit maintenance and deorbiting tasks for small satellites operating in Low Earth Orbits.**

## I. Introduction

THE present work describes the status of the system development activities, discussing the most meaningful results obtained in the initial test campaigns and presenting the next steps to reach the full qualification of the system. Initial test campaigns have been carried out separately on the thruster-cathode units and on the power processing unit (at Breadboard level) to assess their performance. Two existing thruster concepts are being evaluated for the target system: Sitael's HT 100, a Hall Effect Thruster based on permanent magnets, and Rafael's CAM-200, a Hall thruster with a non-conventional topology of the magnetic field. Thrust provided is between 5.5 and 14 mN, with a maximum specific impulse of 1250s and a discharge power between 120 and 250W.

Conceived with a design-to-cost approach, MEPS is an affordable system intended to significantly extend the capabilities of mini satellites operating in Low Earth Orbit and to enable new classes of EP-based missions. The MEPS architecture is described in the following section and it is based on extensive trade studies to optimize

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reliability, performance and scalability. It goes without saying that the choice of the architecture is tightly linked to the target mission and therefore several interesting applications are presented as well, showing how they could strongly benefit from a low-power EP system.

The MEPS programme was formally kicked-off in November 2013 and Phase 1 operatively started at the beginning of 2014 [1]. The whole programme is divided in two main phases: Phase 1 was devoted the definition of the system requirements and to the selection of the companies that will carry out the PPU development. Phase 2 includes an extensive test programme on EM level hardware (Phase 2A), followed by the formal qualification of the entire propulsion system (Phase 2B). The programme has entered Phase 2 at the end of 2014, after the successful completion of Phase 1 which was mainly devoted to the definition of the system architecture and requirements. In Phase 2A, which is now ongoing, the full EM propulsion system has to be assembled and tested to verify the functionality of all the components and the compliance with the specifications defined in Phase 1. Phase 2B is instead focused on the QM and, following the system CDR, will lead to the full qualification of the propulsion system.
The present paper starts describing the main features of the selected system architecture, dwelling on the reliability-vs-cost trade-off and its qualification programme. Then a detailed description of the ongoing activities at Sitael and Rafael is provided. Finally, potential applications for MEPS are analysed to highlight once more the importance of developing such a propulsion system with the aim of enhancing the capabilities of small satellites and widening the range of attainable mission scenarios.

## II. System Architecture

MEPS architecture is based on a fully redundant configuration, with two thrusters units (operating once at a time due to power budget constraints), and an internally redundant Power Processing Unit (PPU). A Thruster Switching Unit (TSU) is used to switch the power lines to one of the two thrusters. While this configuration (sketched in fig. 1) privileges reliability, thanks to its high level of modularity, it can be easily converted to a less sophisticated single-branch architecture. Single branch option has no redundancy, but is lightweight and considerably cheaper.

System specifications and system architecture have been defined considering a range of candidate missions that could greatly benefit from the use of low-power EP systems. Possible applications for MEPS are:

- Orbit maintenance of spacecraft in Low and Very-Low Earth Orbit (LEO and VLEO)
- Control of a micro-satellite in a Formation Flying mission
- Spacecraft end-of-life disposal
- Debris removal (by plasma beam interaction with a target debris)

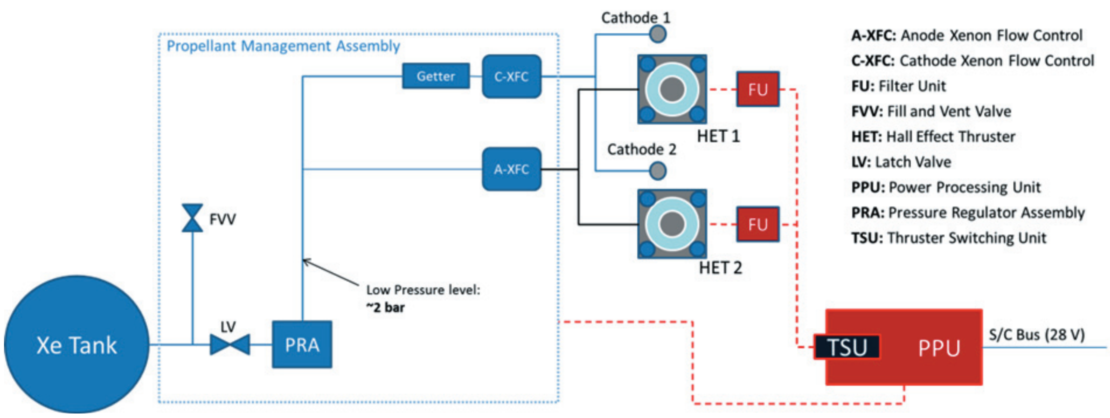


**Figure 1: MEPS sytem architecture**

Applications like orbit maintenance for VLEO satellites require a highly reliable system and in such case the baseline configuration is likely to be the most suitable one. However, missions such as EOL satellite disposal or the use of EP systems on large constellations of satellites entail a higher risk tolerance at system level allowing for the trading off between reliability, mass, volume and ultimately costs. In the latter case, a single-branch configuration might be preferable. Given the wide range of potential applications and market needs, every sub-component (thruster, tank, PPU, PMA) will be separately qualified to enhance the flexibility at system level.. Of course, a low-risk, low-cost delta-qualification will be needed for any variation of the system configuration from the adopted baseline.

## III. Development and Qualification Programme

MEPS system, designed with the target of abating recurring costs and enabling new intriguing possibilities for small satellites, is expected to be ready to fly in a three-year timeframe. In the next months, intensive test campaigns will be conducted on both thruster units (HT 100 and CAM200) with the ultimate aim of identifying a winning configuration. Testing activities on thruster EQMs will include cold-start cycles, shock and vibration tests and thermal and a full lifetest to precisely assess the lifetime of the two devices. In parallel a series of system-level coupling tests will be carried out. The development and qualification programme details and timeline are illustrated in Figure 2. It has to be noticed that the starting TRL of the different components is not the same. While the PPU and the PMA are going to be developed from scratch for this specific system (thus reaching an EM level at the end of Phase 2A), the thrusters are already in a more advanced development state (EQM). For this reason a complete set of tests can be performed on the thruster units in Phase 2A, with no need to wait the QM manufacturing. In principle, if the thrusters successfully pass all tests (thermal cycles, shock&vibration test, lifetest), their configuration can be frozen as is and the QMs will be just a replica of the EQMs. The only difference will be in the rigorous tracking of the manufacturing, assembly and test processes, that will be carried out strictly following the ECSS standards for flight hardware qualification.

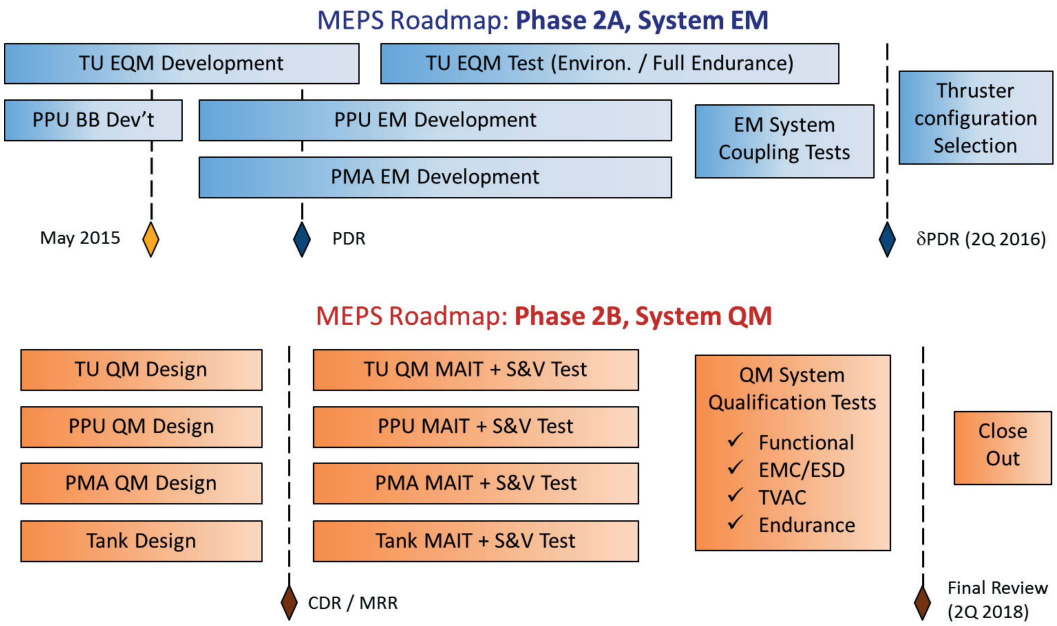


**Figure 2: MEPS development and qualification plan**

All the qualification tests will be performed at sytem level, with the exception of the shock and vibration tests that will be performed at equipment level. Here follows a more detailed description of the components that constitute MEPS.

### A. Sitael Low Power Hall Thrusters

Sitael's HT 100 Hall Effect Thruster (HET) is the smallest and lowest power-consuming HET ever developed in Europe [2]. HT 100 has been conceived for application on mini- and micro-satellites with limited onboard available power and volume. Its most relevant design feature is the use of permanent magnets instead of electromagnets for the generation of the required magnetic field. This design choice resulted in an extremely compact device that has an overall weight of 436g.

The thruster has a nominal operation point of 175W / 8mN but can effectively operate in a wider power range, from 120W to 250W. Thruster efficiency is up to 36%, with specific impulse that can be as high as 1450s. Thrust provided ranges from 5 to 15 mN.

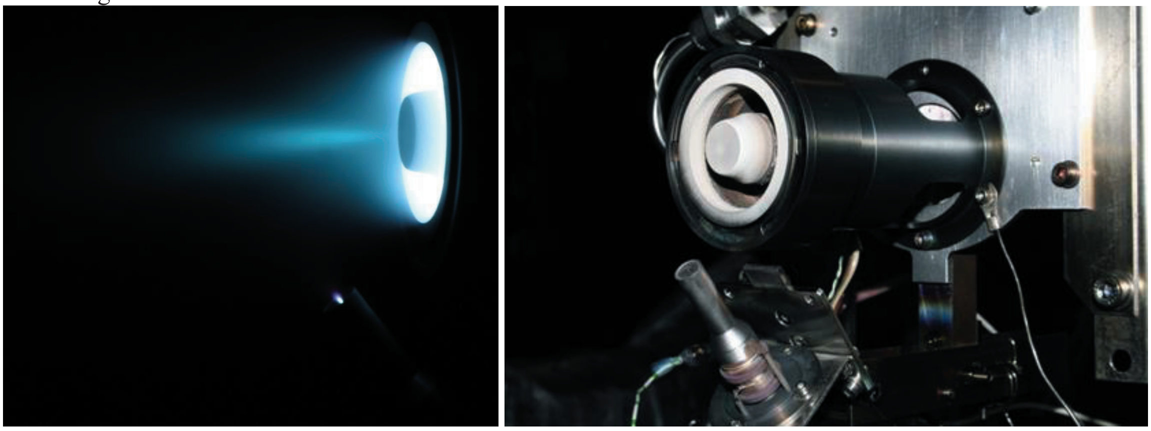

**Figure 3: Sitael HT 100 Thruster**

### B. Rafael Low Power Hall Thrusters

Rafael's CAM200 Hall effect thruster, presented in Figure 4, is a unique and unconventional Hall thruster as it consists of a co-axial anodes. The use of co-axial anodes in low power Hall effect thrusters has already been proven to overcome the associated limitations such as ion loss to the inner thruster walls and insufficient degree of ionization [3,4]. As such Rafael's CAM200 Hall thruster exhibits unparalleled performance in terms of thrust, specific impulse and efficiency.

Development on the thruster, that is a derivative of the Simplified-CAMILA Hall thruster [5], commenced in 2012 with the design, manufacture and experimentation of several development models (CAM200-DM) [6]. Recently, in 2014, Engineering Models (EM) of the thruster were fabricated and are currently undergoing extensive experimentation to prove thruster capabilities. Representative measured thruster performance parameters are presented in Table 2.

| Power [W] | Thrust [mN] | Isp [sec] | η [%] |
|---|---|---|---|
| **100** | 5.6±0.15 | 970±50 | 26±2 |
| **200** | 11±0.3 | 1450±60 | 38±3 |
| **300** | 16.4±0.5 | 1590±70 | 43±3 |

**Table 1: Rafael's CAM200-DM measured performance**

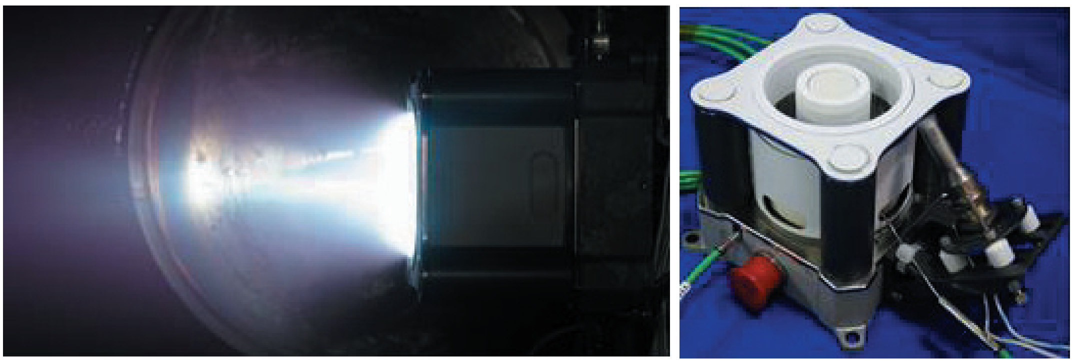

**Figure 4: Picture of CAM200-EM**

Currently an engineering model (EM) of CAM200 is assembled and performance tested. CAM200-EM is presented in Figure 5.

### C. Rafael Low Current Heaterless Cathode

Rafael's heaterless hollow cathode, presented in Figure 5, is an impregnated tungsten based electron source capable of delivering current from 0.4 A to 1.5 A. In contrast with conventional heater-utilizing hollow cathodes, that take minutes to ignite and require a designated heater power supply, the heaterless cathode can be ignited within seconds and does not require any additional power supplies.

Rafael has designed and fabricated several development models that were used to improve design capabilities and optimize cathode performance and lifetime [7]. As part of the process speacial manufacturing processes were developed to allow for the use of a variety of materials and geometries for optimal cathode thermal design. In addition, unique startup hardware and corresponding startup schemes were developed to properly initiate cathode operation.

Current development activities include experimentation and implementation of new materials, startup sequence optimization and additional engineering adjustments as a preparation to engineering model manufacture.

**Figure 5: Rafael's heaterless hollow cathode**

### D. PPU Development Status

Since a PPU for such a propulsion system is being developed here for the first time, a Bread Board has been manufactured before starting the EM design, in order to assess any potential issue before starting a longer and more expensive design and manufacturing phase. In addition, a dedicated test campaign has been carried out in November 2014 with the aim of acquiring relevant data to determine the electric impedance of the two thrusters (Rafael CAM-200 and Sitael HT 100) and to characterize their electrical behaviour. Such data have been instrumental in the process of PPU Breadboard design.

A Breadboard power processing unit has been assembled at the beginning of 2015 and has been successfully tested in combination with the Sitael's HT 100. The first coupling test proved the correct operability and sequencing of the anodic power module. An additional coupling test with the the complete set of power and control modules (which includes the cathode power supply) is going to be performed in June/July 2015, to fully validate the PPU design before starting the development of the EM model.

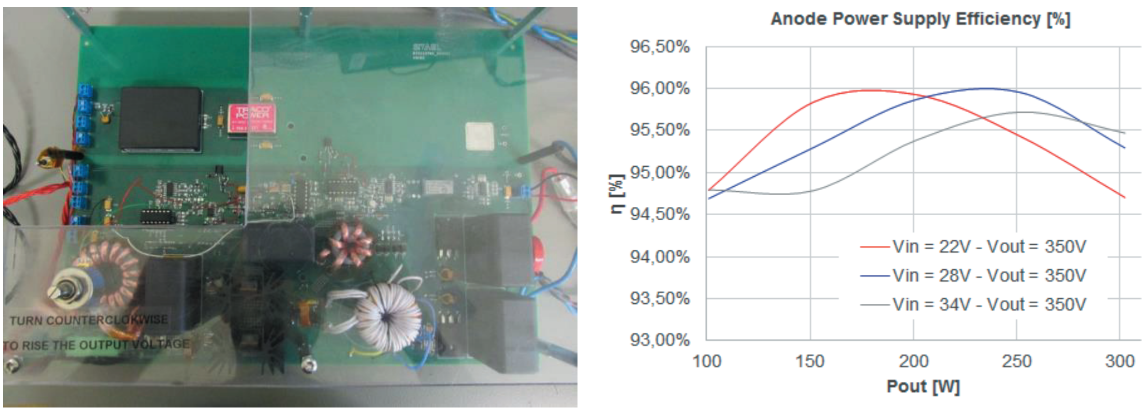


**Figure 6: MEPS PPU Bread Board**

### E. PMA and Tank Development Status

In the framework of MEPS development program, Rafael also develops a PMA to suit the EP system. It is a redundant sub-system consisting of pressure reducing and flow control components, as well as a DXFC to control the anodic power of the active thruster and its cathode.

A Xenon tank will supply the propellant, at high pressure. It will hold at least 10 kg. of Xe, thus enabling very high demand mission. The propellant tank is considered to be built using COPV technology, or either conventional materials, like Titanium.

## IV. Target Applications

MEPS started in late 2013 to fill a niche in the space market by providing a low-cost, low-power and integrated subsystem that can extend the intrinsic benefits of electric propulsion to small platforms operating in low Earth orbit. Among the many potential applications of low-power, HET-based propulsion systems, LEO communication satellite constellations, VLEO Earth observation missions and de-orbit applications seem to be the most promising near-term scenarios.

As a matter of fact, the recent interest of the private sector for LEO-HTS large constellations of small satellites has raised the need of low-cost and efficient propulsion systems for constellation deployment and maintenance. Telecommunication and EO constellations would benefit from the high Isp of EP-based systems increasing the payload mass or reducing the launch mass. However, a minimum thrust level of several mN (usually around 10mN) is needed to perform debris collision avoidance manoeuvres within a few hours. This requirement is of paramount importance in LEO altitude regions as the historical practice of abandoning spacecraft and upper stages at the end of mission life has allowed roughly 2 million kg of debris to accumulate in orbit [6]. In this context, the uncontrolled growth of space debris population (~5% per year) has to be avoided to enable safe operations in space for the future. Active Debris Removal (ADR) missions such as the Ion Beam Shepherd (IBS) would highly benefit from the MEPS system given the high specific impulse provided (>1100 s) and, for contactless deorbiting strategies, the low-divergence ion beam (<55° @ 95% of the total ion beam, but with the larger part of highly energetic ions contained in a much narrower cone).

Another important application for MEPS-like systems is drag-compensation for VLEO satellites. Hall thruster have a higher thrust density w.r.t. other EP devices (i.e. ion engines) and can provide sufficient thrust to maintain a satellite at heights lower than 250 km, allowing for high-res imaging of Earth surface.

Last but not the least, an electric propulsion system can also be a winning option for de-orbiting tasks as it is possible to complete the manoeuvre with substantial savings in propellant mass. In this case, at the end of mission life, the available power can be switched from the payload to the electric thruster, which then acts breaking the satellite and lowering its altitude until the denser layers of the atmosphere quickly complete the disposal process.

MEPS is a candidate solution for Rafael's LiteSat microsatellite. This is a new development microsatellite, achieving sub-meter resolution with an incredible low body volume (34x34 cm), thanks to an integrated design concept.

Thanks to the MEPS propulsion, it can compensate the 300 – 350 km altitude orbit drag and is designed to be part of large constellations, providing dense coverage of target areas. Most of the MEPS design requirements were derived from this mission needs.

## V. Conclusion

The paper presented the current status of MEPS programme. Thruster EQM testing is ongoing, both at Sitael and at Rafael. In parallel the Power Processing Unit has been designed and manufactured at BB level, in order to validate its electronic architecture through coupling tests with the thruster. In the following year all the system components will be developed at EM level, while the two thrusters are going through intensive environmental and characterization tests to fully assess their performance. The ultimate target is to have an electric propulsion system that is space qualified according to ESA/ISA standards in three years from now. Such a system, operating at low power levels (<250W) with excellent performance in terms of specific impulse and efficiency, is expected to fill an important niche in the market of small satellites, allowing to perform 'traditional' tasks with significant propellant savings and even opening up novel mission scenarios which are not attainable with other means of propulsion.

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