SITAEL's HT400 Hall Effect Thruster for Constellation Applications

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C. Ducci[1], H. Raiji[2], D. Pedrini[3], T. Misuri[4], L. Onida[5]
SITAEL S.p.A, Via Alessandro Gherardesca 5, Pisa, 56124, Italy

Abstract: SITAEL's HT400 is a Hall-Effect Thruster based on permanent magnets with a nominal power of 400 W, but capable of high-performance operation in a power range from 300 W to 800 W. An Engineering Model of the HT400 has been tested in SITAEL facilities with a total firing time of about 600 hours, exhibiting stable performance, with an estimated total impulse of ~450 kNs. An upgraded magnetically shielded design of the HT400 has been realized, and was coupled with the HC3 and underwent a short performance characterization campaign in July 2019. The estimated total impulse capability of > 1000 kNs will allow for satellites of broadband constellations to autonomously reach their high operational altitudes starting from the typical deployment altitudes of medium lift launch vehicles, and can enable kick-stages to perform constellation satellite deployment, in addition to also being an attractive solution for LEO-GEO space tugs. SITAEL's in-house capabilities of being able to produce the most critical components of the propulsive subsystem have been exploited to develop the dedicated Power Processing Unit (PPU) and hollow cathode 'HC3'. HC3 has been designed to provide a current up to 3 A and operates at mass flow rates between 0.1 mg/s and 0.3 mg/s, with an expected lifetime > 10000 hours. The PPU has been designed to power the thruster over its operational envelope of 300 W-800 W, assuring full performance for a non-regulated bus voltage from 24 V-36 V. This synergetic and parallel approach to the development of all the critical blocks of the propulsive subsystem guarantees a highly reliable, highly performing system. The present paper introduces activities currently ongoing at SITAEL dedicated to the development of a TU EQM based on the HT400 and HC3, and presents a roadmap for the realization and qualification of a plug and play Thruster Unit capable of satisfying high total impulse requirement missions. A preliminary propellant feed system architecture using OTS solutions is presented: this robust architecture can be adapted to a wide variety of mission requirements and is easily modifiable on a case-by-case basis to take into account system requirements on reliability, redundancy, mass and volume. Reference mission scenarios applying a HT400-based propulsion system as the orbit control solution for a hypothetical broadband satellite are analyzed in order to derive performance parameters such as firing time, propellant consumption and total impulse.

[1] Chief Electric Propulsion Design Engineer, Propulsion Division, cosimo.ducci@sitael.com.
[2] Propulsion System Engineer, Propulsion Division, harshraj.raiji@sitael.com.
[3] Electric Propulsion Engineer, PhD, Propulsion Division, daniela.pedrini@sitael.com.
[4] Division Head, Propulsion, Propulsion Division, tommaso.misuri@sitael.com.
[5] Analog Electronic Designer, Space Instruments and Avionics Division, luca.onida@sitael.com.

Nomenclature

ADC	=	Analog to Digital Converter
AIT	=	Assembly, Integration and Testing
BOL	=	Beginning of Life
CAN	=	Controller Area Network
DAC	=	Digital to Analog Converter
DC	=	Direct Current
DR	=	Digital switch closure channel telemetry
EBB	=	Elegant Bread Board
EM	=	Engineering Model
EMI	=	ElectroMagnetic Interference
EOL	=	End of Life
EPS	=	Electric Propulsion System
EQM	=	Engineering Qualification Model
FDIR	=	Fault Detection, Isolation and Recovery
FPGA	=	Field Programmable Gate Array
FU	=	Filter Unit
HET	=	Hall Effect Thruster
HK	=	HouseKeeping
HV	=	High Voltage
Isp	=	Specific Impulse
Kr	=	Krypton
LCL	=	Latching Current Limiter
LEO	=	Low Earth Orbit
MAIT	=	Manufacturing, Assembly, Integration and Testing
MEO	=	Medium Earth Orbit
MS	=	Magnetically Shielded
MUX	=	MUltiPlexer
OBC	=	On Board Computer
OCS	=	Orbit Control System
OTS	=	Off The Shelf
OVV	=	Over Voltage
PMA	=	Propellant Management Assembly
PS	=	Power Supply
S/C	=	Spacecraft
STM	=	Structural Thermal Model
TBC	=	To Be Confirmed
TH	=	Thermistor
TU	=	Thruster Unit
TVAC	=	Thermal Vacuum
UNV	=	Under Voltage
Xe	=	Xenon

I. Introduction

Approximately 7,000 small satellites are expected to be launched over the next decade in LEO and MEO for broadband communication, earth observation and information applications, with 80% of these satellites being distributed across 50 constellations[1]. The provision of a compact, low mass autonomous propulsive subsystem would grant the satellites of these constellations with independent orbit maneuvering capabilities, thereby broadening their possible applications and/or extending their lifetime, and resulting in more responsive and integrated constellations. In order to address this market trend and provide a low cost European solution, SITAEL is currently focused on the development and qualification of a 400 W-class Hall Effect thruster compatible with both xenon and alternative propellants. The HT400 is also ideal for kick-stages that could be employed for deployment of satellites that form part of a constellation. The 400-W class HET of SITAEL was tested and characterized with Xe in 2012 (accumulating over 600 hours of firing). In order to increase the total impulse capability of this thruster to serve more demanding missions with longer lifetimes, focus was shifted to the realization and characterization of a magnetically-shielded version of this 400 W-class thruster. The magnetically shielded 'MS' HT400 EQM has been coupled with a hollow cathode HC3 EM and undergone a short performance characterization with Xe. The total impulse capability of this new magnetically shielded version of the HT400 is estimated as double that of the non-magnetically shielded version (>1000 kNs versus ~450 kNs): this is a very important feature since the foreseen operative altitude of the operational and foreseen broadband megaconstellations is high; the high total impulse capability of the MSHT400 can be exploited so that satellites at very low launcher deployment altitude can autonomously reach such high target altitudes. This paper then presents a roadmap to realizing and qualifying a 'plug and play' Thruster Unit based on a HT400 and two HC3's in cold redundancy, and specifies the development status of the PPU that has been designed to be coupled with the HT400-based TU. SITAEL also proposes a feed system architecture consisting of space-qualified OTS components, which can be adapted to a wide range of mission scenarios.

II. SITAEL'S HT400, HC3 and PPU

1. HT400

SITAEL realized and characterized an EM of the first HT400 in 2012, executing ground tests in SITAEL vacuum chambers with Xenon and Argon with a SITAEL 1.5 kW PPU. The accumulated firing was about 600 hours in SITAEL's vacuum chambers, and the thruster performance was derived by operation for a few minutes at each working point**,** with the thruster exhibiting stable performance. Since the magnetic field influences the plasma properties inside the channel, the topology of the magnetic field can affect the erosion rate of the walls that is one of the main constraints on the HETs lifetime; therefore, SITAEL then pursed a magnetically-shielded 'upgraded' version of this thruster, an EM of which was realized and characterized with Xenon in July 2019, coupling it with an EM of SITAEL's HC3, a hollow cathode which was designed and developed for the HT400. This improved configuration gives an improved lifetime performance due to the reduction/ elimination of channel erosion, being able to provide an estimated >1000 kNs total impulse, as compared to the estimated ~450 kNs estimated total impulse of the original design of the HT400.

The thruster is composed of four principal subsystems: the structure, the ceramics, the anode and the interfaces. The propellant is injected through the fluidic interfaces of the thrusters, and is uniformly distributed inside the discharge channel as soon as it reaches the anode, where the processes of ionization and acceleration towards the channel exit takes place. The structure is a cylindrical frame designed to connect the various components together and to resist all the mechanical loads applied to the thruster (for example during environmental test campaign/ launch phase). The ceramic parts of the thruster are the discharge channel and some insulators inside the structure: their primary function is that of electrically insulating the anode and the plasma from the thruster. The anode collects and distributes the propellant correctly within the discharge channel and collects the discharge current produced by the ionization of the gas during the thruster operation. CAD views of the magnetically shielded HT400 are shown in Figure 1.

Figure 1. 3D rendering of the HT400 thruster.

2. HC3

HC3 features the architecture of a typical orificed hollow cathode. The cathode is made of an active thermionic emitter (or insert), enclosed in a tube and held in position by a graphite spacer and a tungsten spring. The tube, made of tantalum, terminates with an orifice and is surrounded by a heater, whose function is to warm the emitter up to thermionic emission values to trigger the discharge. The assembly is then enclosed by the so-called keeper, a further electrode used to ignite the cathode and to protect the internal parts from the bombardment of high energy ions formed in the plume, which tend to erode the exposed surfaces. The emitter material selected for HC3 is lanthanum hexaboride (LaB_6), which guarantees robustness, high current density and long life, despite the fact that it operates at higher temperature with respect to barium-based emitters due to a higher work function.

The main cathode dimensions derive from a trade-off between multiple factors, which include the overall geometrical envelope, the discharge power, the ratio between emitter heating with respect to orifice heating, the emitter operating temperature, and the operating lifetime. To perform this tradeoff, the results from a numerical model developed at SITAEL were used to assess the dependence of the cathode operating parameters on the functional dimensions (mainly orifice and emitter geometry).

The cathode was conceived to provide 1-3 A current with a mass flow rate in the range 0.1-0.3 mg/s. The ignition is obtained after a heating phase with a heater power lower than 100 W and by means of an applied keeper voltage lower than 300 V. CAD views of HC3 are shown in Figure 2. A complete description of HC3 is provided in Ref. [2].

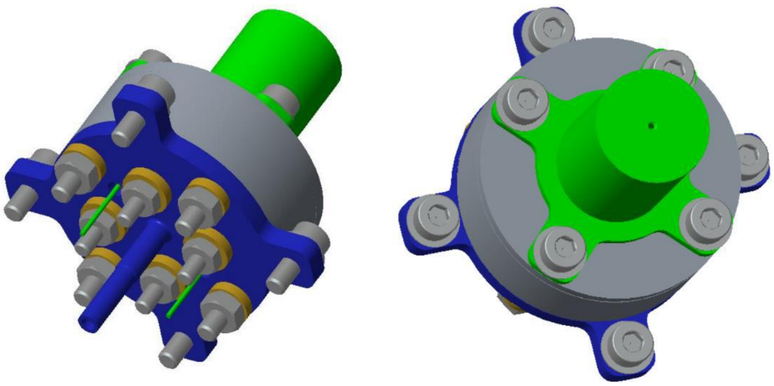

Figure 2. 3D rendering of the HC3 cathode.

3. PPU

The PPU, designed and developed to be compatible with a Thruster Unit based on the MSHT400 and HC3, serves the following functions:

- to transform orders from the satellite to the propulsion subsystem command and control;
- to report to the satellite the propulsion subsystem status and health with main propulsion data;
- to deliver to the thruster the needed power supply;
- to deliver to the PMA the needed power supply;
- to execute the subsystem required control/command logic;
- to keep the satellite electronics safe from a failure coming from electric propulsion subsystem.

The PPU will enable the full operation of the thruster in its complete thrust range for a nominal input power range of 350 W - 800 W, ensure full performance for an unregulated power bus voltage from 24V to 36V and will be composed of the following functional blocks (shown in Figure 3):

- Power Section composed of:
  - Input Power Bus switch and protections;
  - Input EMI filter;
  - Anode isolated DC/DC converter (equipped with a dedicated Filter Unit);
  - Cathode igniter/keeper isolated DC/DC converter;
  - Cathode heater DC/DC converter.
- Control Section composed of:
  - Input EMI filter;
  - Input UNV/OVV Protection;

- HK isolated DC/DC converter;
    - FPGA control and command (ADC, DAC and MUX);
    - PMA valves drivers and power distribution.
- All power and signal interfaces between the two internal main sections and between the PPU and the external subsystems (Platform, TU and PMA).

The power section will be connected directly to the unregulated power bus; it will include an internal protection, while the Control section will be protected by an external distribution Class 1 LCL (TBC).

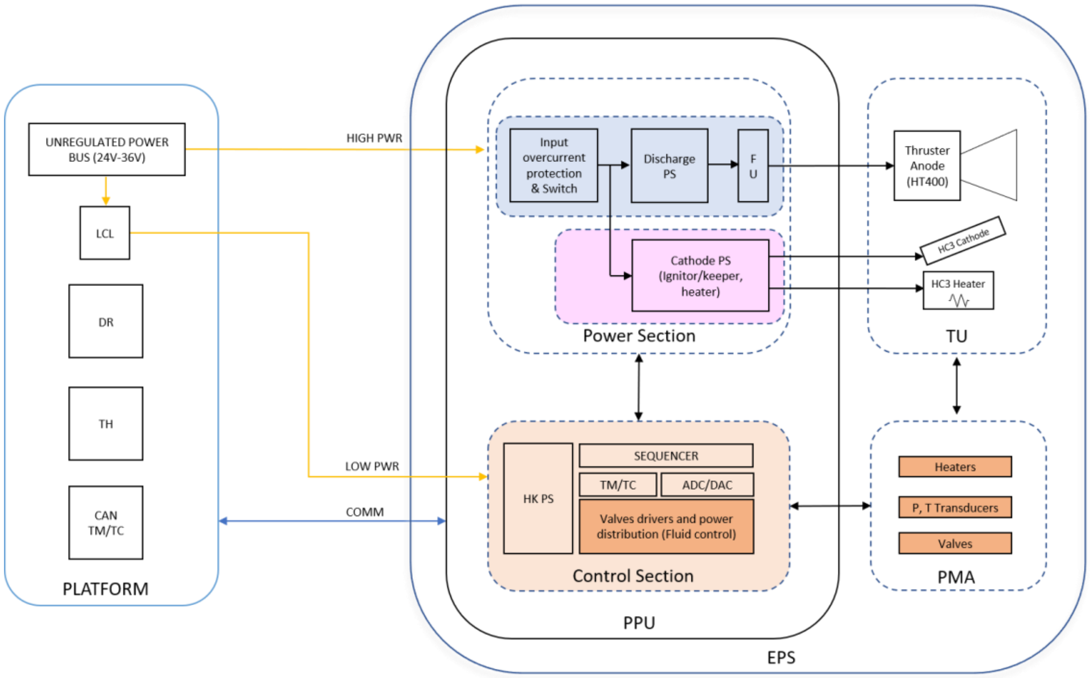

Figure 3. PPU architecture block diagram.

III. ONGOING ACTIVITIES AND DEVELOPMENT ROADMAP

Table 1 presents a roadmap of the development and qualification activities planned for a TU based on HT400 and HC3.

Table 1. HT400-based TU and PPU development roadmap.

	2018		2019				2020			
Activities	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
HT400 EM MAI										
HC3 EM MAIT										
[HT400 EM+ HC3] EM Performance Characterization Campaign										
[HT400 + 2 × HC3] TU EQM Design										
TU EQM Thermomechanical Analyses and design optimization										
HT400 EQM and HC3 EQM MAI										
PPU EBB Design										
PPU EBB MAIT										

	2018		2019				2020			
Activities	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
HC3 STM MAI						■				
TU EQM (*) MAI						■	■			
TU EQM + PPU EBB Functional, Performance Characterization (**)							■			
TU EQM Environmental Testing (***)							■	■		
TU EQM Functional, Performance Characterization (**)								■		
TU EQM endurance test with Kr									■	
PPU EM Design								■	■	■

(*) TU EQM is composed of 1 × HT400 EQM, 1 × HC3 EQM and 1 × HC3 STM.
(**) Foreseen with both Xe and Kr.
(***) Foreseen tests include sine-random, shock and TVAC.

1. Characterization campaign

An EM of the upgraded thruster design 'MSHT400' was realized in Q2 2019. This MSHT400 EM was coupled with an HC3 EM was characterized with Xe in July 2019 in SITAEL's IV4 vacuum facility.

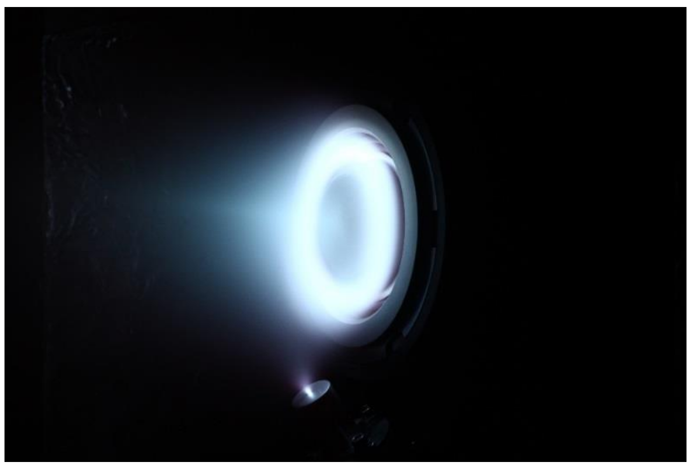

Figure 4. HT400 and HC3 firing with Xe at SITAEL's IV4 facility in July 2019.

The thrust and specific impulse for discharge powers up to 644 W and discharge voltages up to 350 V were acquired during the July 2019 campaign. The primary objectives of the test, which were obtaining repeatable ignitions at low cathode mass flow rates, and testing a completely magnetically shielded configuration were accomplished. Currently ongoing activities foresee the realization of a slightly modified discharge channel and magnetic field topology to optimize thruster performance.

2. TU EQM Design

In parallel, in Q1 2019, SITAEL also started the preliminary design of a 'plug-and-play' TU based on HT400 with two cathodes in cold redundancy. At the same time, a PPU EBB was designed. The preliminary design of the TU EQM and the cathode was optimized on the basis of worst-cases thermomechanical analyses. A 3D rendering of the TU EQM assembly is shown in Figure 5. The proposed Thruster Unit is composed of the MSHT400, along with two HC3's inclined at 50 degrees (could be subject to change depending on ongoing testing activities and design optimization) to the central anode axis, and are foreseen to be integrated on an aluminum baseplate to form the TU. The appropriate fastening elements allow them to maintain their relative position with respect to each other. The cathode brackets are interfaced with the baseplate by means of M4x8 5 bolts. Each HC3 is interfaced with the brackets through 4 M3x6 bolts, equispaced on a diameter of 36 mm. MSHT400 is fastened to the baseplate by means of 6 M4x8 bolts, equispaced on a diameter of 79.3 mm. A ceramic breaker is fixed to the baseplate through a mechanical support (2 M2.5x6 bolts). The fluidic interfaces to the HC3 and the MSHT400 are baselined at 1/16 inches outer diameter, but can be modified.

Figure 5. 3D rendering of the HT400-based TU.

3. TU EQM Thermomechanical analyses and design optimization

The TU EQM model shown in Figure 5 has been subjected to thermal analyses with the following operating conditions:

- **Case 1: Cold condition**- In this condition, none of the thruster components are active. Boundary conditions assumed are a free space temperature of 3K, and temperature of the interface with the satellite as -10°C.
- **Case 2: Startup condition**- In this condition, only the cathode heater is active. Boundary conditions assumed are a free space temperature of 3K, and temperature of the interface with the satellite of -10°C.
- **Case 3: Operation at 400 W discharge power** - In this condition, the thruster is operating at 400 W, 300 V. Boundary conditions assumed are a free space temperature of 3K, and temperature of the interface with the satellite of 30°C.
- **Case 4: Operation at 600 W discharge power** - In this condition, the thruster is operating at 600 W, 300 V. Boundary conditions assumed are a free space temperature of 3K, and temperature of the interface with the satellite of 30°C.

Table 2 reports the conductive heat fluxes of the TU components towards the satellite interface for each of the aforementioned cases.

Table 2. Conductive heat fluxes from the TU to S/C interface.

TU components	**Case 1 Cold condition**	**Case 2 Startup condition**	**Case 3 Operation at 400 W discharge power**	**Case 4 Operation at 600 W discharge power**
Mechanical components	1.42 W	4.109 W	3.689 W	4.192 W
Pipework	0.04 W	0.506 W	0.393 W	0.437 W
Harness (cathodes + anode)	2.24 W	9.489W	7.939 W	8.802 W
TOTAL	3.70 W	14.1 W	12.021 W	13.43 W

The analyses confirm that the maximum temperature of the thruster components is within the limit values with margins. For operation at a discharge power of 600W, corresponding to Case 4 in Table 2 , the maximum total conductive heat flux to the spacecraft interface is 13.43 W. The computed temperature distribution for the thruster operating at 600 W discharge power is shown in Figure 6.

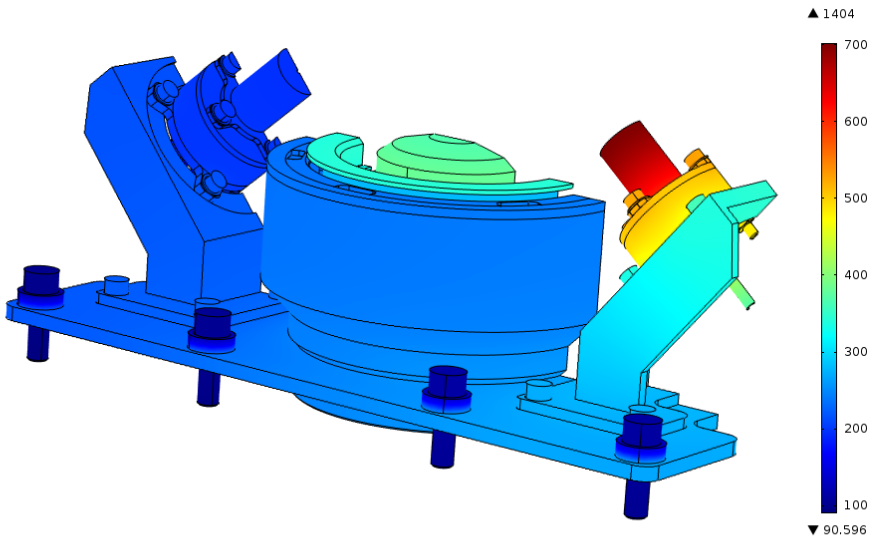

Figure 6. Computed Temperature distribution (in °C) over the TU for operation at 600W discharge power.

Mechanical analyses were also carried out, using ECSS standards[3] as a reference, and showed positive results; the static analysis was carried out considering ±50 g acting simultaneously along all axes , random vibration analyses was carried out using an out-of-plane input of 18.88 gRMS and in-plane input of 12.89 gRMS.

The design of the TU was validated, and currently, efforts are underway to manufacture and assemble EQM's of the HT400 and HC3. The PPU EBB was also manufactured in parallel, and is currently undergoing testing. The aim is to realize an EQM of the TU, which is foreseen to consist of a HT400 EQM, an HC3 EQM and a HC3 STM. The aim is to then perform functional testing and performance characterization of the TU EQM with both Xe and Kr, and a fraction of this test will be performed by coupling the TU EQM with the PPU EBB. This test will be followed by environmental testing, after which another functional test and a performance characterization will be carried out. Finally, an endurance test campaign with Kr is also foreseen. The PPU EM design is expected to be completed by Q4 2020. The large number of vacuum facilities and laboratories available at SITAEL makes it possible to test, verify and couple all the propulsion system items in-house, considerably boosting the design, development and qualification processes.

IV. HT400-BASED PROPULSION SUBSYSTEM

In order to support the operation of the proposed TU based on the magnetically shielded HT400, SITAEL has designed an EPS architecture based on proportional flow control, which is highly flexible, based on space qualified parts that can be adapted to a wide range of mission scenarios: the proposed architecture schematic is shown in Figure 7 and a 3D rendering of the architecture is shown in Figure 8.

Isolation from the high pressure tank assembly is done by means of high-pressure latch valves in cold redundancy. Filling and venting activities of the fluidic circuit are done by means of the fill and drain valve upstream of the high pressure latch valves. The main advantage of the proportional flow control technology is that the proportional flow control valve is able to regulate in real-time the flow rate from the high-pressure range directly to the required flow rate range. This reduces the number of propellant feed system components, therefore reducing the overall subsystem weight and cost. The objective of the solenoid valves is to provide thruster/cathode isolation in the low pressure branch. Downstream of the solenoid valves, calibrated orifices are used to perform fine flow control in the inlet paths of the TU. The orifices are be grouped together in a Flow Restrictor Assembly. The pressure transducers and temperature sensors are used to perform health checks on the system, to perform FDIR operations and to provide to the OBC the required telemetry to perform propellant gauging. Heaters will be used to maintain the PMA fluidic circuit (excluding the tank) within a temperature interval of 20-25°C. The fluidic components integrated on two faces of a baseplate can be provided by SITAEL as a compact, fully welded assembly. The proposed architecture is based on space-qualified OTS components, and is fully redundant, thereby making it highly reliable and ideally suited to long duration missions. This proposed architecture can be modified according to mission-specific requirements.

The physical envelope of the components of the proposed HT400-based propulsion subsystem is shown in Table 3. The mass budget of the proposed HT400- based propulsion subsystem, for both a fully-redundant (shown in Figure 7 and Figure 8) and single-string architecture is presented in Table 4. The propellant tank/s mass and envelope is not considered in the aforementioned budgets, since this will depend strictly on the mission-specific total impulse requirement and the type of propellant.

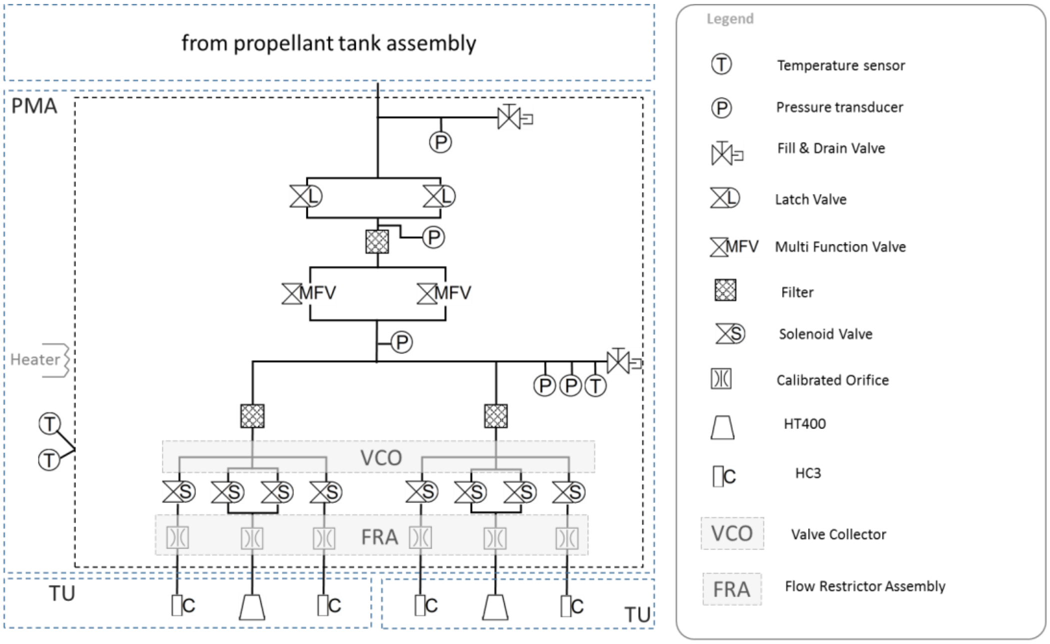

Figure 7. Proposed HT400-based EPS architecture.

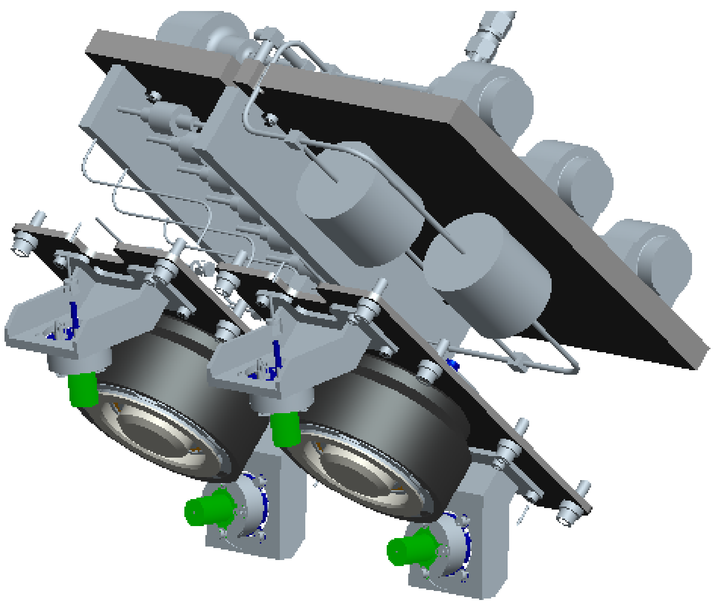

Figure 8. 3D rendering of the proposed HT400-based propulsion system.

Table 3. Physical envelope of the HT400-based propulsion subsystem units.

Unit	Length (mm)	Width (mm)	Height (mm)
Thruster Unit	163	102	80
Propellant Management Assembly	297	256	130
Power Processing Unit	410	250	150

Table 4. Mass budgets for a fully-redundant and single-string EPS architecture.

Unit	Mass [kg]	
	Fully-redundant architecture *(as shown in* Figure 6 *and* Figure 7*)* **(2×TU, 2×PPU)**	**Single-string architecture (1×TU, 1×PPU)**
Propellant Management Assembly	4.18	3.49
Thruster Unit	5.54	2.77
Power Processing Unit	12	6
Total dry	21.72	12.26
Total dry mass with 20% margin	26.06	14.71

V. CASE STUDIES

Reference mission scenarios applying a HT400-based propulsion system as the orbit control solution for a hypothetical broadband satellite are analyzed in order to derive preliminary performance parameters such as firing time, propellant consumption and total impulse. Table lists the features of various broadband constellations which are foreseen to be launched and of which deployment activities have already started.

Table 5. Features of currently operational and foreseen broadband constellations[4].

Constellation	Country	No. of satellites	Operational Altitude [km]
Laser Light	USA	12	10,000
Samsung	Korea	4600	1500-2000
Boeing V-Band	USA	2956	1000
LeoSat	USA	108	1432
O3B	Luxembourg	27	8000
SpaceX Starlink	USA	4425	1200
Hongyan	China	300	1100
ViaSat	USA	20	8200
Telesat LEO	Canada	117	1000
Yaliny	Russia	135	600
Lucky Star	China	156	1000
Astrome Technologies	India	600	1400

Given the high operational altitude of the constellations listed in Table 5, the use of an HT400-based propulsion system will enable the satellites to autonomously reach the target operational altitude from the typical deployment altitude of medium lift vehicles (approximately 600-700 km), assuming the BOL wet mass of these satellites to be approximately equal to 350 kg. Using the operating point of the HT400 acquired during the July 2019 campaign at 615 W discharge power, 300 V discharge voltage, Table 6 presents the performance parameters of a HT400-based propulsion system for reference mission profiles that could be probable profiles of a satellite of a broadband constellation.

The refence scenarios 1 and 2 consider the typical deployment altitudes of medium life vehicles (reference scenario 1) and small satellite launch vehicles (reference scenario 2). Reference scenario 1 and reference scenario 2 in Table 6 considers orbit raising to the typical foreseen operational altitude of broadband altitudes (2500 km and 3500 km for reference scenario 1 and reference scenario 2 respectively). Reference scenario 3 and reference scenario 4 in Table 6 considers orbit raising to OneWeb-like and Starlink-like operational altitudes (1200 km) from a launcher deployment altitude of 300 km. Reference scenarios 1,2 and 4 in Table 6 include a constellation performance recovery phase at the constellation operational altitudes in order to maintain constellation coverage characteristics in case of the failure of a satellite in the constellation ; reference scenario 4 in Table 6 includes an inclination change of 10° at the operational altitude. All the reference scenarios include a phase of active EOL deorbiting to a low altitude.

Table 6. Performance of a HT400-based EPS for reference mission profiles of a broadband satellite.

REFERENCE SCENARIO 1 *launcher deployment altitude= 700 km, constellation operational altitude =2500 km*					
Mission Phase	**Phase description**	**Propellant consumption [kg]**	**Firing Time [hours]**	**delta-V [m/s]**	**Total impulse [kNs]**
Nominal orbit acquisition	Orbit raising from 700 km to 2500 km (98° inclination)	24.1	2938.4	803.77	290.64
Constellation performance recovery	180° rephasing (worst-case)	0.83	101.33	30.8	10.016
EOL deorbiting	Active deorbiting to 250 km	31.88	3885.9	1054.3	384.35
TOTAL		**56.82**	**6925.6**	**1888.9**	**685**
REFERENCE SCENARIO 2 *launcher deployment altitude= 500 km, constellation operational altitude =3500 km*					
Mission Phase	**Phase description**	**Propellant consumption [kg]**	**Firing Time [hours]**	**delta-V [m/s]**	**Total impulse [kNs]**
Nominal orbit acquisition	Orbit raising from 500 km, to 3500 km (98° inclination)	38.53	4696.6	1260.3	464.54
Constellation performance recovery	180° rephasing (worst-case)	0.89	108.58	34.53	10.73
EOL deorbiting	Active deorbiting to 250 km	43.03	5244.8	1402.5	518.76
TOTAL		**82.45**	**10050**	**2697.4**	**994.03**

REFERENCE SCENARIO 3 *launcher deployment altitude= 300 km, constellation operational altitude =1200 km*					
Mission Phase	**Phase description**	**Propellant consumption [kg]**	**Firing Time [hours]**	**delta-V [m/s]**	**Total impulse [kNs]**
Nominal orbit acquisition	Orbit raising from 300 km to 1100 km (53° inclination)	14	1706.4	473.26	168.78
Constellation performance recovery	180° rephasing (worst-case)	0.74	90.564	26.699	8.9527
EOL deorbiting	Active deorbiting to 250 km	14.847	1809.6	502.35	178.99
TOTAL		**29.59**	**3606.6**	**1002.3**	**356.72 (***)**
(***) the non-magnetically shielded configuration of the HT400 is also capable of satisfying the total impulse of the presented reference mission profile.					

REFERENCE SCENARIO 4 *launcher deployment altitude= 300 km, constellation operational altitude =1200 km*					
Mission Phase	**Phase description**	**Propellant consumption [kg]**	**Firing Time [hours]**	**delta-V [m/s]**	**Total impulse [kNs]**
Nominal altitude acquisition	Orbit raising from 300 km to 1200 km (53° inclination)	14	1706.4	473.26	168.78
Inclination change	10° inclination change at operational altitude	59.986	7311.2	1982.1	723.14
EOL deorbiting	Active deorbiting to 250 km	11.733	1430	502.35	141.44
TOTAL		**85.71**	**10447.6**	**2957.71**	**1033.4**

VI. Conclusion

A fully magnetically shielded configuration of the HT400 and HC3 was demonstrated to obtain repeatable ignitions at low cathode mass flow rates; in order to optimize thruster performance the campaign is foreseen to be repeated with a slightly modified discharge channel and magnetic field topology., SITAEL's facilities and capabilities are being exploited to obtain a synergetic, parallel development of the critical components of a TU based on the HT400 and HC3, and the PPU capable of driving the TU. The design of the TU EQM has been validated through thermomechanical analyses. The development roadmap is presented, with the aim of carrying out functional and performance characterization of the TU EQM with both Xe and Kr, carrying out environmental testing on the TU EQM, and realizing a PPU EM by the end of 2020. A potential EPS architecture is proposed, with the system-level impacts being highlighted. Through preliminary mission analyses, it is demonstrated that the high total impulse capability of the magnetically-shielded HT400 is ideal for satellites which form part of foreseen broadband constellations.

Acknowledgments

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