SGEO Development Status and Opportunities for the EP-based Small European Telecommunication Platform

IEPC-2011-203

Presented at the 32nd International Electric Propulsion Conference,
Wiesbaden • Germany
September 11 – 15, 2011

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SGEO is a highly flexible and modular geostationary platform, able to accommodate a wide range of payload up to 400 kg and 3.5 kW. The system is designed for a 15 years-mission and is compatible to most commercial launchers, offering direct injection to GEO as well as GTO injection and subsequent transfer to GEO by means of a chemical Apogee Engine Module. One of the key-features of SGEO is a unified Xenon based propulsion system composed of two independent electric propulsion thruster assemblies (HEMPT and SPT-100) and the cold gas thruster assembly, which supports all propulsion tasks except transfer from GTO to GEO.

Nomenclature

ADE	=	actuator drive electronic
AIT	=	assembly, integration and testing
BOL	=	beginning of life
CG	=	cold gas
CGTA	=	cold gas thruster assembly
EOL	=	end of life
EP	=	electric propulsion
EPTA	=	electric propulsion thruster assembly
ETSU	=	external thruster switching unit
FCU	=	flow control unit
GEO	=	geosynchronous earth orbit
HEMPT	=	high efficiency multi-stage plasma thruster
HTA	=	HEMP thruster assembly
HTM	=	HEMP thruster module
Isp	=	specific impulse
LAE	=	liquid apogee engine
LEO	=	low earth orbit
PPU	=	power processing unit
PSA	=	propellant supply assembly
PSCU	=	power supply & control unit
SCE	=	support & control electronics
SPT-100	=	stationary plasma thruster
TSU	=	thruster switching unit
XFC	=	xenon flow controller
XTA	=	xenon tank assembly
Δv	=	velocity increment

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I. Introduction

SINCE 2007[1], the small geostationary satellite platform (SGEO) is being developed under the umbrella of European Space Agency's ARTES-11 program by an industrial consortium headed by OHB System AG as prime and supported by the subcontractors LuxSpace SARL, OHB Sweden AB (formerly known as the Swedish Space Corporation) and RUAG Space AG.

Supporting payload mass up to 400 *kg* and payload power up to 3.5 *kW* (EOL), SGEO has a flexible, modular design to accommodate a very wide range of missions with focus on telecommunications. The SGEO satellite has a lifetime of 15 years and will be transferred to a disposal orbit at end-of-life. Considering the launch vehicle accommodation and performance constraints, SGEO is designed for the usage of a wide range of launch vehicles with respect to the two launch scenarios of a standard GTO and a direct-to-GEO injection.

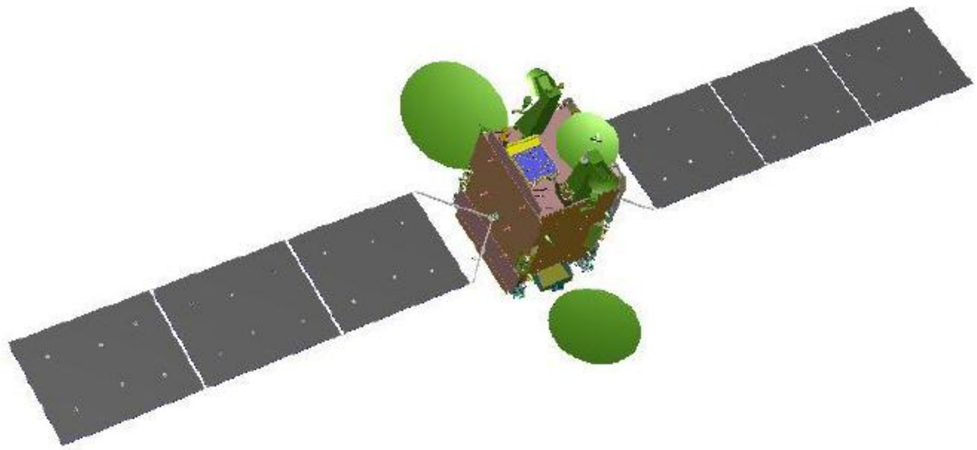


Figure 1: SGEO satellite view

The first SGEO satellite is currently under development for the HISPASAT AG1 (HAG1) mission and drives the satellite baseline design. The contract between OHB and HISPASAT for Phase C/D/E was signed in spring 2009 for the mission HISPASAT AG1, hence making OHB the prime for the entire satellite. In 2010, the mission Preliminary Design Review was successfully completed heading for Critical Design Review in autumn 2011.

II. System description

SGEO is being developed with emphasis on commercial cost-effectiveness, system performance, and new technologies to optimize the payload-to-platform ratio.

The architecture of SGEO has been designed to account for a direct GEO injection or a GTO injection. The sole difference between the launch types lies in the implementation of a chemical propulsion system for GTO transfer. The main propulsion system is based on the combination of the electric propulsion thruster assembly (EPTA) and the cold-gas thruster assembly (CGTA) using Xenon as propellant.

The envelope of SGEO is independent of the propulsion system and the platform body dimensions are 2.3 *m* x 1.9 *m* base area and 2.5 *m* height.

A direct injection launch allows keeping the dry mass of the platform at 1,100 *kg*, while a GTO injection launch increase its dry mass to 1,300 *kg* excluding the payload mass of up to 400 *kg*.

The power subsystem is based on a regulated main bus distributing 5 *kW* (BOL) generated by the triple-junction GaAs solar cells disposed on steerable solar arrays deployed after orbit acquisition. Up to 4.1 *kW* (BOL) are available for Payload in nominal mode and 3.5 *kW* at EOL including margins.

A. Mission Analysis

The SGEO platform will be first used within the HAG1 mission for which the maximum allowed launch mass is 3200 kg. The orbit control functions are shared by the different propulsion assemblies as follows:

- The chemical propulsion system (CPPS) is used for injection of the satellite from GTO into GEO into a defined stable position in GEO.

- The electric propulsion thruster assembly (EPTA) is used for final station acquisition of the satellite in GEO, station keeping and momentum dumping for the operational lifetime, satellite repositioning and transfer into graveyard orbit.
- The cold gas thruster assembly (CGTA) is used for detumbling of the satellite after launcher ejection in case of high rotation rates as well as for attitude control in satellite safe modes during operational lifetime.

The propellant budgets are based on the satellite mass budget frame and are reported in Table 1.

S/C mass [*kg*]	
Dry mass	1700
BOEP mass	1970
Launch mass	3200
Propellant mass	1500
Bi-prop	1295
He	5
Xe	200

Table 1 Mass Budget Summary

The BEOP (beginning of EP operation) mass represents the worst case mass at the beginning of the EP phase after completion of the CP phase.

The GTO to GEO transfer is based in the nominal case on a 4 burn strategy using LAE for main thrust and four RCT thrusters for simultaneous attitude stabilization. The analysis has been conducted considering the losses due to maneuver efficiency, orbit dispersions and thrust direction errors. The different values of Δv required to perform the GTO to GEO manoeuver with respect to the launchers adopted have been evaluated. In the worst case launch scenario the nominal Δv required for the manoeuver is 1543 *m/s*,

The transition from IOT position into final GEO position is performed by use of the EPTA. The propellant budgets accounts for Station Keeping and Momentum Dumping account for 15 years lifetime, starting after In-Orbit Testing.

The xenon budget analysis has been based on the worst case GEO insertion for the electric propulsion subsystem. All mission phases have been analyzed taking into consideration also the losses due to thruster's misalignment and xenon leakage during the whole mission duration. The Δv for the full EP mission is about 1426 *m/s* for the nominal HEMPT case including cant angle and manoeuver efficiencies and excluding margins. The total xenon needed for the mission is 126 *kg* incl. 5 *kg* for cold gas use, which leaves about 69 *kg* of margin taking into account 5 *kg* residuals.

In case of LAE failure, the 10-N RCT thrusters will be used to perform the GTO to GEO transfer. As a worst failure case, the early failure of the LAE before any application of Δv to the satellite is considered. Due to the lower *Isp*, the lower thrust and the higher cant angle assumed for the RCT compared to the LAE, the total Δv that can be applied with the nominal propellant mass is only about 90%. For station acquisition an additional Δv of about 160 *m/s* needs to be applied by the EPPS compared to the budget for nominal use as shown in Table 2.

In case of HEMPT failure, the mission can be completed by using the SPT-100 thrusters. As a worst failure case, the early failure of the HEMP thrusters before any application of Δv to the satellite is considered. The total Δv is slightly lower compared to the nominal case as a slightly favorable cant angle could be accommodated for the SPT-100. Because of the SPT-100 lower specific impulse, the HEMPT failure is the driver case for sizing the Xenon mass.

Mission case	**Total Δv [*m/s*]**	**Thruster *Isp* (*s*)**	**Required Xe mass [*kg*]**	**Margins [*kg*]**
Nominal	1426	2300	126	69
LAE Failure case	1586	2300	140	55
HEMPT failure case	1357	1500	179	16

Table 2 Xenon budget

On SGEO, the maximum loadable Xenon amount within the baseline Xenon tanks is 220 *kg* leaving another 10% margin compared to the baseline loaded mass of 200 *kg*.

B. Architecture

Figure 1and Figure 2 show the familiar geometry of most geostationary telecommunication satellites applied on SGEO: the payload antenna boresights are parallel with the positive Z (nadir) axis, while the Y-axis points south. The X-axis is aligned with the orbital velocity vector. The apogee engine nozzle, if present, protrudes from the negative Z (zenith) side of the satellite.

The design of the SGEO satellite follows strictly a modular approach including the Core platform module, the Propulsion module, the Repeater module and the so-called Antenna farm. The propulsion module is composed of a chemical propulsion system (CPPS) and the EPTA/CGTA unified Xenon system[2]. Each propulsion subsystem is redundant at subsystem level.

In GEO, 3-axis attitude stabilization is performed through momentum exchange with a set of reaction wheels, while in nominal case the EP thrusters or, in failure case, the cold gas thrusters are used to dissipate accumulated angular momentum from the wheels. Orbital maneuvers and station-keeping rely on EP thrusters fired sequentially, such that the resultant thrust vector over time passes through the satellite's center of mass. Sequential firing of several thrusters is preferred over simultaneous firing in order to spread the power load and avoid overtaxing the battery.

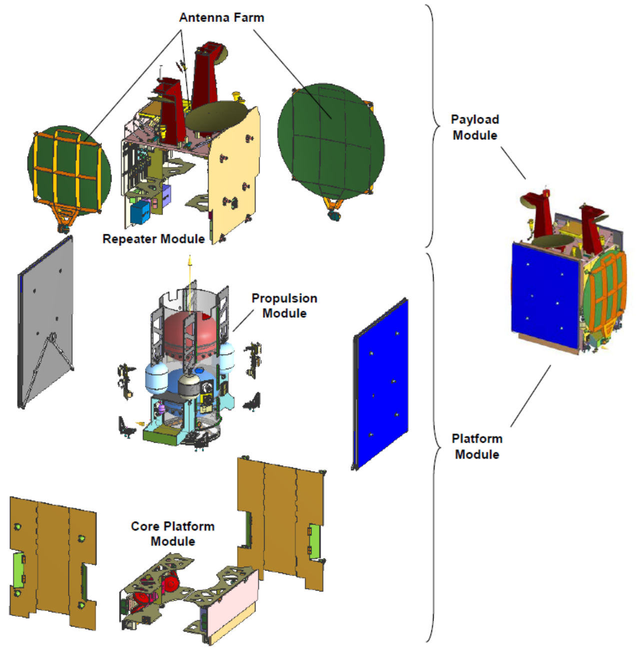


Figure 2: SGEO modular concept

C. Accommodation

The SGEO satellite structure is built around a composite central tube into which the bi-propellant CPPS propellant tanks are installed. The other structural elements are mostly made of composite materials for minimizing the weight of the platform.

The CPPS helium tanks and the xenon tanks are symmetrically placed around the central tube and as close as possible to its walls in order to minimize the excursion of center of gravity (CoG). The CPPS liquid apogee engine (LAE) is installed at the launch vehicle adapter while the 8x 10 *N* thrusters (4N+4R RCT) are located on the base deck for controlling the attitude of the satellite during LAE firing procedures.

The EP thrusters are mounted in pairs on the East and West Panels, with thrust directions symmetrically ordered around the nadir vector. In nominal operations each thruster has thrust vector components in the directions orthogonal to the orbital plane and tangential to the satellite velocity vector in inertial space. Such an accommodation has been preferred against the complexity of thruster orientation mechanism as currently used on other telecommunication platforms.

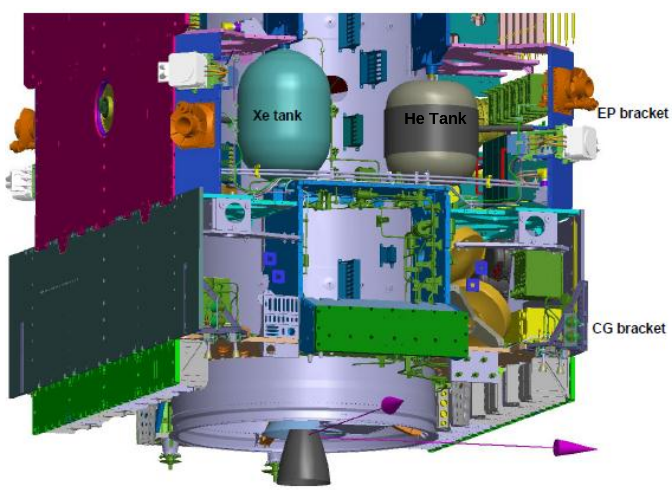


Figure 3: Propulsion module accommodation

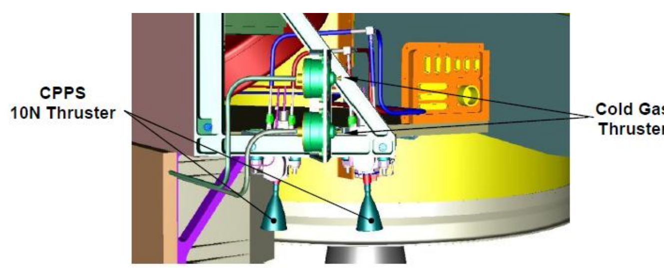


Figure 4: CGT accommodation

Power reduction due to sputtering phenomena on solar arrays has been found negligible[3].

The 8x cold gas thrusters (4N + 4R CGT) are located on the outside of the RCT on brackets on the anti-nadir panel of the spacecraft. The thrusters are placed in the East and West planes in pairs (nominal and redundant branch), canted 55° with respect to the x-axis, intentionally offset from the spacecraft center of mass for detumbling the satellite after separation from the launch vehicle. CG can also be activated to orientate the satellite towards the sun whenever it becomes necessary to enter the safe mode (i.e. reaction wheels not available).

III. Xenon Propulsion Subsystem Description

The baseline version of the SGEO propulsion subsystem for in-orbit operations is shown in Figure 5. From a technological point of view, it is divided in two groups, the EPTA and the CGTA, both operating with a two-tanks unified xenon propellant supply assembly.

The EP subsystem is divided into two groups: the nominal branch (EPTA 1) is composed of four HEMP thrusters while the redundant branch (EPTA 2) is composed by four SPT-100.

The subsystem design permits the simultaneous firing of one thruster from each branch (but not adjacent thrusters), although the baseline operation foresees to fire one thruster at any given time. The system does not allow the CGTA and the EPTAs operating at the same time, to avoid pressure spikes on the EP system due to the high mass flow rates used during CG operations (~200 *mg/s*).

The XTA is composed by two tanks, connected by a shared manifold, filled through a central fill/drain valve connected to the PSA. The total volume provided by the tanks is around 60 *l*. For reason of volume efficiency, the xenon is stored under high pressure in supercritical condition (nominal beginning of life pressure of 186 *bar* at 50°*C*). Heaters and thermistors are used to control the temperature of the tanks, to avoid undesirable mass shifting among them.

The PSA provides pressure regulation and a central distribution system to multiple thruster branches (and types) with different flow requirements[4]. The current design reduces the pressure from 186 *bar* to 2.2±0.11 *bar* at the outputs.

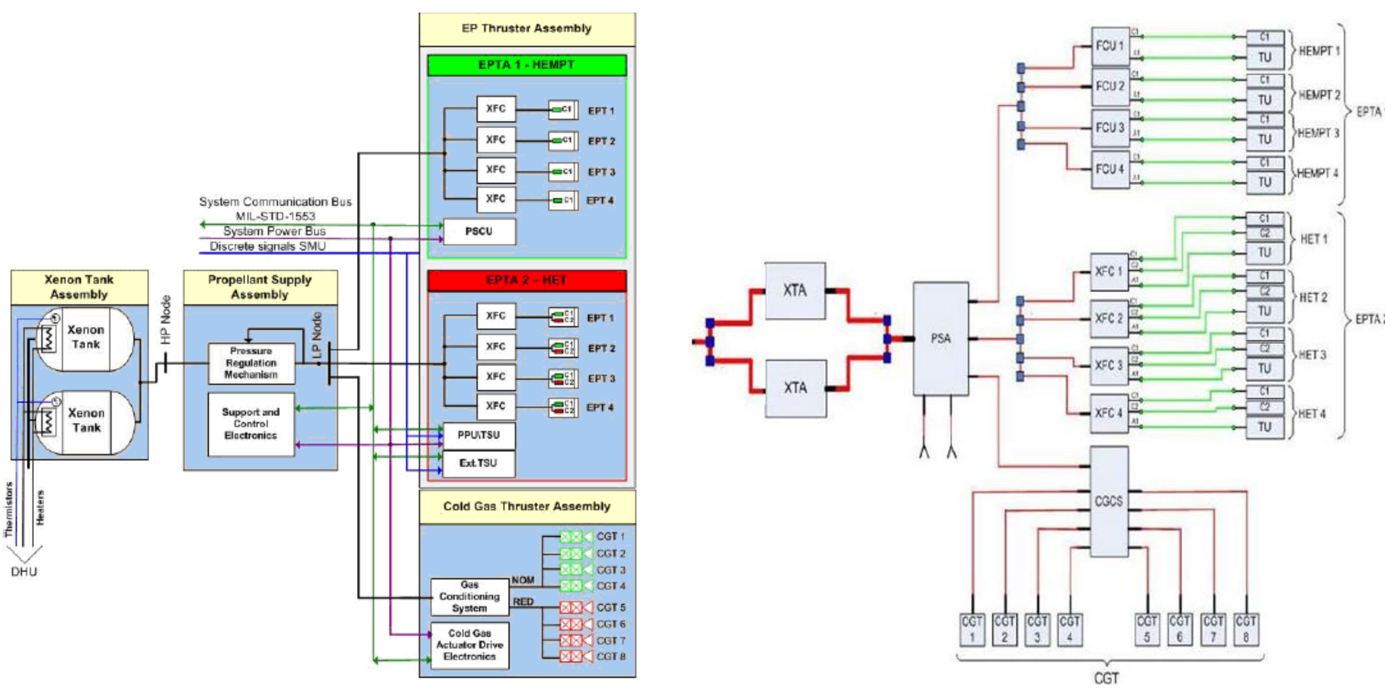


Figure 5 Functional and hydraulic diagram of the propulsion subsystem

Since the flow requirements are large for the CGTA and low on the electric thrusters, the baseline PSA uses a bang-bang regulator approach similar to the one used on SMART-1. Therefore, using the two cavity system, the mass flow rate can be adapted to the requirement of the active propulsion subsystem. The PSA includes a plenum volume which acts also as a pressure stabilizer, while latch valves are used to insulate the EPTA 1 branch since it has screwed connections to the FCU inlet interfaces. The PSA is controlled by the satellite management unit through a dedicated electronic hardware.

To minimize the risk for potential propellant leakage, all the rest of the Xenon tubing from the PSA to the XFCs of the EPTA 2 and to the CGTA system are welded.

The EP thruster bracket will hold all the thruster assembly components for easy insert and removal during platform AIT. The thermal radiation into the baseplate is kept as small as possible to prevent overheating of the XFC located on the opposite side of the thruster bracket. The XFCs themselves are thermally insulated from the thruster interfaces.

All the assemblies are internally redundant at component level.

The development status of the XTA and PSA has already approached the phase D. Both have successfully passed the critical design review. Moreover, the XTA has passed all the critical tests of the qualification campaign except the cleanliness, pressure cycling and burst tests, which are not considered critical.

D. EPTA 1

The HEMPT system is a new development in the frame of the DLR project HEMPTIS (HEMPT In-orbit-verification on SmallGEO)[5]. The HEMPT assembly (HTA) consist of three main sub-components: four HEMP thruster modules (HTM), including the thruster, the neutralizer and the FCU, the PSCU and the internal harness. The HTM compact design is obtained by mounting the HEMPT and the neutralizer on one side of the support structure, while the FCU is mounted on the opposite side. The FCU is used to control the propellant flow through the neutralizer and through the thruster anode.

The units are being developed by THALES Electron Devices (HEMPT 3050 and neutralizer), by Astrium (PSCU) and by Bradford Engineering (FCU). The HTA is currently undergoing the Critical Design Review. In Table 3 the EM performance of the HEMP thruster is reported in comparison with the SGEO qualification requirements.

In the HEMPT subsystem design several thrusters can operate with a common anode power supply (PSCU), thus eliminating the need for any thruster switching unit. The thruster activation is obtained by applying propellant flow to the neutralizer and to the anode of the selected thruster. In Figure 6 a schematic diagram of the EPTA 1 is shown.

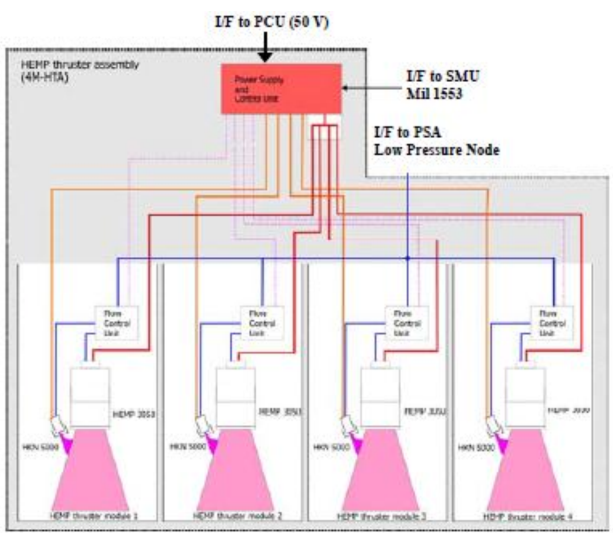
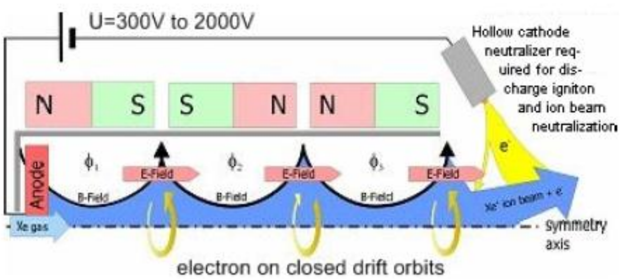


Figure 6 The subsystem design of the HEMPT propulsion branch

Parameter	Endurance test data (EM3)	SGEO Qualification Requirement
Nominal thrust	≥ 44 *mN*	≥ 44 *mN*
Isp	≥ 2300 *s*	≥ 2300 *s*
Total Impulse	0.8×10^6 *Ns*	≥ 1.14×10^6 *Ns*
Discharge Voltage	1000 *V*	-
Xenon mass flow rate	≤ 1.89 *mg/s*	< 1.9 *mg/s*
Operational duration	~ 4000 *h*	> 4800 *h* in-orbit operation > 7200 *h* ground qualification level
Restarts cycles	> 200	> 6500 in-orbit operation > 9800 ground qualification level
Thruster Power	1400 *W*	≤ 1400 *W*

Table 3 Qualification status of the HEMPT

In Figure 7 a detailed scheme of the HEMP thruster 3050 configuration is shown. The thruster cross section highlights the three permanent magnets around the ceramic cylinder: the magnetic configuration of the thruster is optimized to achieve an high ionization efficiency and to decrease the plume divergence angle[5]. In the same Figure 7 a picture of the thruster engineering model number 3 (EM3) is reported. The picture was taken during the endurance test in which the thruster reached about 4000 *hr* at nominal SGEO working conditions.



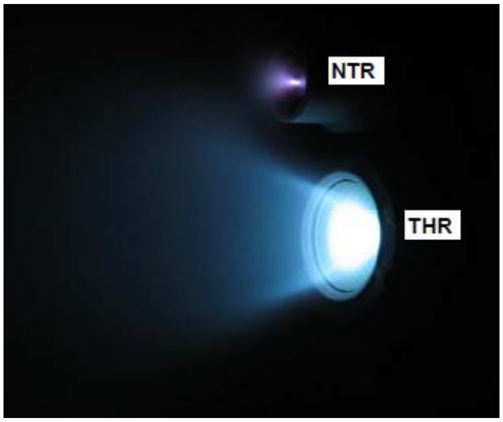


Figure 7 HEMPT 3050 - Schematic diagram and picture

The test was completed successfully, a detailed analysis and the recorded data are reported in concurrent works[6]. The HEMPT qualification model will undergo a full qualification on ground during phase C/D.

E. EPTA 2

The SPT-100 EPTA 2 branch is composed by four subassemblies, each consisting of the SPT-100, the XFC, the Filter Unit, the Hot Interconnecting Box, which are powered and controlled by the PPU and the ETSU. Due to its flight heritage, the SPT-100 is considered to be a safe and robust backup solution to the newly developed HEMPT.

In the EPTA 2 the PPU has an internal TSU that allows the selection between two thruster subsets. As the SGEO requires the switching between four thrusters, an additional ETSU has therefore been added into the subsystem design after the TSU. To avoid the re-qualification of the existing PPU, the ETSU has separate discrete control of the switching functions and status monitoring which is provided by the SMU. In Figure 8 the subsystem design is outlined.

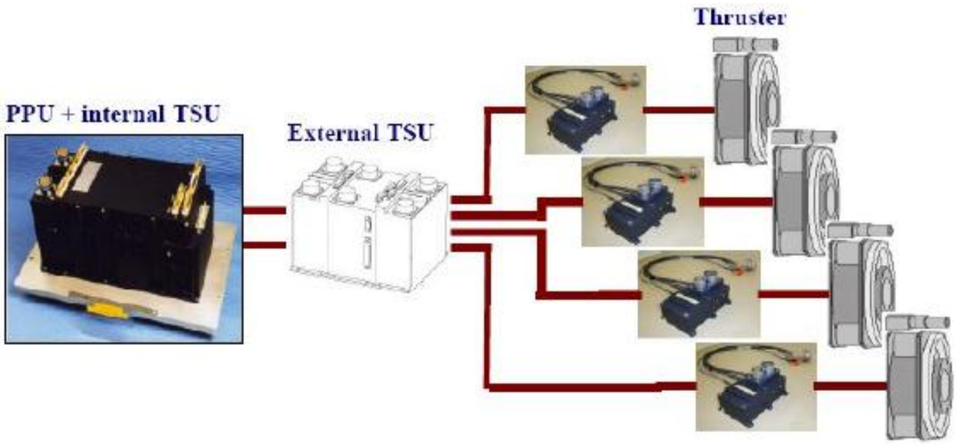


Figure 8 The subsystem design of the HET propulsion branch

The qualification status of the SPT100 is presented in the next Table 4 in comparison with SGEO qualification requirements. According to the justification provided by Snecma and EDB Fakel based on the available heritage and design knowledge, considering the SGEO operational points, a delta-qualification for the SPT-100 and for the cathode was deemed unnecessary.

Parameter	Qualification Value	SGEO Qualification Requirement
Nominal thrust	83 *mN*	75 *mN*
Isp	1553 *s*	≥ 1500 *s*
Total Impulse	$2.69x10^6$ *Ns*	≥ $1.08x10^6$ *Ns*
Discharge Voltage	300 *V*	-
Xenon mass flow rate	5.39 *mg/s*	-
Operational duration	9066 *hr*	4051 *hr*
Restarts cycles	8883	> 7200 in-orbit operation
Thruster Power	1500 *W*	≤ 1350 *W*

Table 4 Qualification status of the SPT-100

Snecma is fully responsible of providing the EPTA 2. In May 2009 Snecma was awarded the contract for the development and procurement of the complete EPTA based on the SPT-100 from EDB Fakel, Russia. The first two flight branches (proto flight and flight models) are approaching final delivery to OHB Sweden at present time[7].

F. CGTA

In the current CGTA design the propellant is supplied by a separate outlet line from the PSA while the fill and drain valves are shared with the electric propulsion subsystem. The CGTA constitutes a stand-alone subsystem that includes all necessary components for both nominal and redundant operation. This includes dedicated electronics to drive actuators, to acquire sensor data, to provide communication to the spacecraft via MIL-STD-1553B and for supplying conditioned power to the CGTA hardware. The CGTA branches will be primed with xenon before launch so that the cold gas system will be immediately operational. In the next Figure 9 the CGTA architecture is presented.

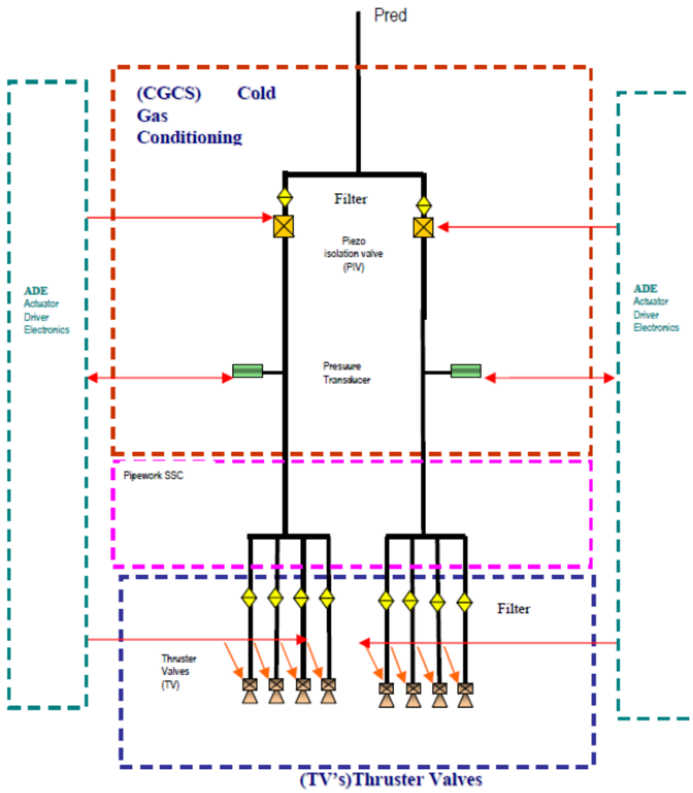


Figure 9 The subsystem design of the CGTA

The CGTA consists of a redundant propellant conditioning module, eight cold gas thrusters, the power and control electronics and the related tubing and harness. The conditioning module provides interfaces to the low pressure side of the PSA and also provides insulation from the upstream propellant when the cold gas thrusters are not operating. In Table 5 the performance characteristics of the CGTA are reported.

The cold gas subsystem is provided by Thales Alenia Space[8].

Parameter	**Expected**	**SGEO Requirement**
Nominal thrust @ 2.2 *bar*	≥ 50 *mN*	≥ 50 *mN*
Isp	≥ 28 *s*	≥ 25 *s*
Total xenon throughput	20 *kg*	≥ 20 *kg*
Max feeding pressure	≥ 7 *bar*	6.9 *bar*
Power consumption	< 20 *W*	20 *W*
Power consumption	< 2 *W*	2 *W*
Qualification media	Xe gas	Xe gas

Table 5 Performance characteristics of the CGTA

IV. Conclusion

SGEO offers a highly flexible and modular geostationary platform designed for a 15 years mission, able to accommodate a wide range of payloads in the range up to 400 *kg* and 3.5 *kW*. The innovative electric propulsion system increases the payload capacity for SGEO and respectively extends the possible launch opportunities. The SGEO EP design provides the capability to perform all orbit control maneuvers after transfer to GEO, which enables a purely EP based S/C in case of a direct injection launch. Nowadays electric propulsion has been widely accepted for station keeping and final orbit insertion of Earth-orbit spacecraft. However operational use for GTO to GEO transfers has not yet occurred except in particular cases or mission analysis[10,11]. The GTO to GEO transfer strategy adopted by HAG1 mission, considering the contingency cases, takes a step forward in that direction, placing SGEO satellite-class as one of the most promising candidates for the use of full-EP subsystem. The newly developed HEMPT system will be flown for the first time on SGEO promising further performance optimization at decreasing complexity. The first SGEO mission HAG1 is approaching CDR with a launch planned in 2013. The SGEO platform is further developed at OHB for ESAs EDRS mission.

Acknowledgments

The authors would like to acknowledge the support of ESA, DLR and the work of the OHB, LuxSpace, OHB Sweden AB (formerly known as the Swedish Space Corporation) and RUAG Space AG design teams and further partners.

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