Electric Propulsion Applications in the SmallGEO Product Line

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Abstract

Based on Ion acceleration in an electric field, Electric Propulsion (EP) is characterized by high specific impulse at low thrust. If the related maneuver durations are acceptable and sufficient electrical power is available, EP utilization can maximize the payload mass of a satellite. In the early development of the Small GEO platform [1], OHB applied Hall-Effect Thrusters in a solely EP based orbit control system [2] to enable such mass savings and direct launcher injection. At that time transfer durations to GEO of no longer than a few weeks were accepted by the commercial telecommunication market calling for Chemical Propulsion (CP) for the transfer. About 5 years later, transfer durations in the order of up to six month are considered by one of the largest fleet operators SES, in case major overall system costs savings including the launcher can be achieved [3]. In October 2013, ESA, SES and OHB established the Electra program Phase B1 in the frame of ARTES-33, a public-private partnership aimed at developing a full-electric propulsion small satellite platform [4]. The SmallGEO-FLEX platform development for Electra will nearly double the P/L capacity of the SmallGEO-FAST platform based on chemical propulsion at even lower launch mass.

This paper presents the OHB SmallGEO product line with focus on EP applications including the implementation on Heinrich-Hertz and Electra missions. The mission and system design will be discussed with emphasis on the specific challenges of EP accommodation.

1. SMALLGEO PRODUCT LINE

The SmallGEO family of satellites are designed for small and efficient geostationary missions with a launch mass of 2 to 3.5 tons. The applications include the full range of telecommunications, but the platforms are flexible to be adapted to Earth observation or optical communications.

The SGEO product line configurations and key characteristics are defined in Table 1.

SmallGEO configuration	**Fast Classical**	**Fast Hybrid**	**Flex**
Propulsion	Full CP	CP + EP NSSK	Full EP
P/L mass [kg]	300	450	700
P/L power EOL [W]	4000	3600	8000
Launch mass [kg]	3400	3400	<3000
Transfer time	Few days	Few days	3 – 6 month
First mission	EDRS	Heinrich Hertz	Electra
Launch	2016	2018	2018

Table 1: Small GEO configurations

The SGEO prototype under qualification for the HAG1 mission for launch in 2015 is close to the characteristics of the Fast Hybrid configuration, but includes a more sophisticated EP system capable of all propulsive tasks after the GTO transfer.

The SGEO Fast configurations are derived from this prototype with the Fast Hybrid configuration providing increased payload mass performance by adding the EP system for NSSK as compared to the Fast Classical.

The new Flex configuration basically doubles the payload performances at even lower launch mass by performing all propulsive maneuvers with electric propulsion. Due to the low trust however several months are needed for the transfer to GEO as compared to a few days for the Fast configurations.

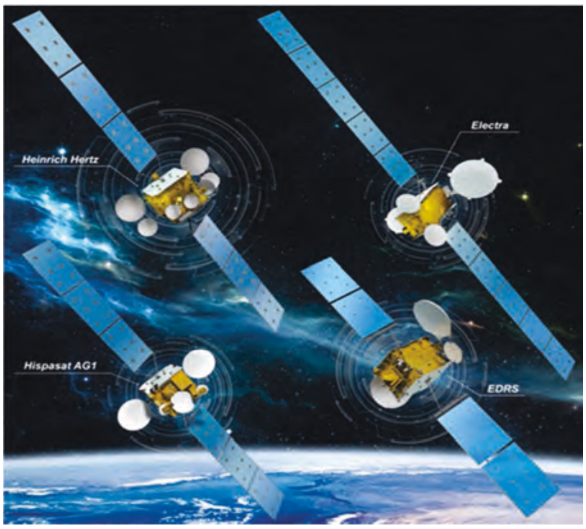

Figure 1: Small GEO satellites

2. EP SYSTEM CHARACTERISTICS

An overview of EP technologies in general suitable for the envisaged GEO applications, which have been qualified or are planned to be qualified in the next few years is provided in Table 2. A classification is provided in terms of technology and anode power with the basic performance characteristics range indicated for the first typical product listed. These technologies include

- Gridded Ion Thrusters (GIT) including different types in terms of Ionization process and size
- Hall Effect Thrusters (HET) of different size
- High-Efficiency Multistage Plasma Thrusters (HEMPT)

Class	Typical Product	Power* [kW]	Thrust [mN]	Isp [s]
GIT 0.6 kW	RIT-10, T5	0.6	<20	>3300
HEMPT 1.4 kW	HEMPT-3050	1.4	>40	>2300
HET 1.4 kW	SPT-100, PPS-1350	1.4	>80	>1500
GIT 4.5 kW	XIPS RIT-XT T6	4.5	>160	>3500
HET 4.5 kW	SPT-140, PPS-5000 XR-5	4.5	>270	>1700

Table 2: EP systems characteristics classified by technology and *anode power

The small European GIT 0.6 kW systems have flown first on Artemis in 2001 [5]. A similar class US system XIPS-13 (450 W, 18 mN, 2350 s) has flown on several Boeing 601 platforms since 1995. The bigger 4.5 kW XIPS-25 systems are used in the Boeing 702 platforms. RIT-XT is under development. T6 is under qualification for Bepi-Colombo designed for higher Isp at lower thrust (140 mN).

HET 1.4 kW SPT-100 systems are broadly used in several Russian (Yamal, Express) and Western platforms (Eurostar, Spacebus, SSL-1300) as well as on HAG1 [6]. PPS-1350 has flown on SMART-1 to the moon [4]. US HET 4.5 kW systems (XR-5) have been flown on AEHF, while SPT-140 and PPS-5000 are under development.

HEMPT-3050 is undergoing ground qualification and is planned to be launched on Heinrich Hertz [7].

All these systems are throttable within a certain range and therefore can be adapted to the available power. For the 4.5 kW systems, a second operational point at reduced power of typically 3 kW is qualified for most systems.

A major driver in EP system accommodation is the plume of the high energetic ions. The half cone angle including 90% of the ion current for HET is typically around 45 deg as compared to less than 20 deg for GIT.

The EP plume impacts on the satellite include erosion, change of transmission properties, forces and torques, surface heating, electrostatic charging, magnetic disturbances and electromagnetic interferences. These effects need to be considered in the S/C design. In particular sputtering of the solar arrays drive the EP thrusters accommodation [2].

3. EP APPLICATIONS IN GEO MISSIONS

Due to its low thrust, electric propulsion was mainly used for station keeping in GEO to counteract perturbations in longitude, eccentricity and in particular inclination, which is the biggest contribution. The related net ΔV for station keeping is in the order of 1 m/s per week. The station keeping maneuvers are typically performed twice each day on at least 5 days per week leading to a net ΔV of about 0.1 m/s per maneuver. Considering a satellite mass of 2 tons and effective thrust levels in the order of 30-60 mN lead to maneuver durations in the range of 1-2 hours. These thrust levels correspond to a HEMPT respectively a HET system at 1.4 kW with a cant angle to the N/S axis of 45 deg. As there is some flexibility in the maneuver duration requirement which is basically driven by the available electrical energy, thrust level is less critical and higher specific impulse can save fuel mass.

Such medium power station keeping EP systems are further applied (e.g. on SGEO/ HAG1 [2]) for

- Final GEO Station acquisition,
- Intermediate repositioning, and
- Transfer to graveyard orbit at end of mission.

For these kinds of maneuvers the orbit altitude is changed below or above the GEO belt in order to apply an East or West drift. A minimum radial distance of about 50 km is required to ensure safety with respect to other GEO S/C while higher distances are used to increase the drift rate to accelerate the total maneuver duration in case of repositioning. To apply a drift rate of 1 deg/ day, the related ΔV need is in the order of 3 m/s. The thrust level is driven by the need to acquire or leave the GEO slot without interfering to the neighboring slots. For a 2 ton S/C an effective thrust level about 40 mN is required.

Nominally or in case of anomalies of the launcher [5] or the CP system, even orbit topping maneuvers with ΔV in the order of some 100 m/s have been performed with station keeping EP systems. Assuming to run two 1.4 kW engines in parallel without any cosine losses would lead to thrust durations of 1-2 month for a 200 m/s maneuver.

For high ΔV manouvres like the transfer from GTO which are in the range of some 1000 m/s, higher thrust levels are required in order to minimize the transfer time. With state-of-the-art 4.5 kW systems, thrust levels in the order of 160 mN up to 270 mN can be achieved. Running two such engines in parallel the GTO duration can be limited to several month for a 2-ton S/C.

These generic order-of-magnitude considerations are summarizes in Table 3.

	∆V [m/s]	Thrust level [mN]	Duration
Station keeping (twice per day)	0.1	30 – 60	<1-2 hrs
Repositioning (apply drift of 1 deg/ day)	3	40 – 80	1–2 days
Orbit topping	200	80 - 160	1–2 month
GTO transfer	2000	320 - 540	3-5 month

Table 3: Generic low thrust maneuver characteristics for GEO missions considering 2000 kg S/C mass

A major advantage performing the GTO Transfer with EP is the high flexibility of the system to accommodate a broad spectrum of different launch and transfer scenarios ranging from sub GTO with apogees below 20000 km up to super-synchronous injections with apogees up to 80000 km as illustrated in Figure 2. SGEO Flex can accommodate low thrust ∆V up to 4000 m/s leading to a high flexibility in launcher selection. Launcher overcapacities can be used to minimize transfer time by means of increasing the apogee respectively lowering inclination and increasing the perigee.

As opposed to station keeping, for GTO transfer the thrust level drives the transfer time and to derive the most suitable EP system, the P/L mass to GEO needs to be considered including the launch scenario taken into account the time constraints.

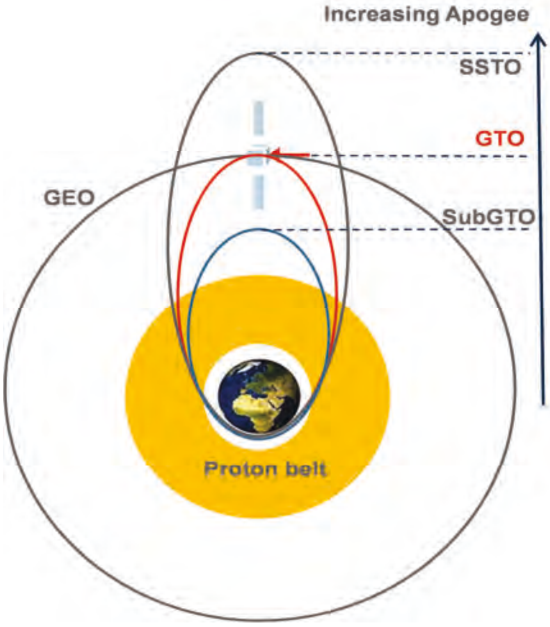

Figure 2. GTO transfer schematic

A key requirement for the EP transfer in particular for low sub-GTOs is the radiation environment which is driven by the proton belt ranging from about 1000 km up to 10000 km. For the total non-ionising dose the GTO environment dominates the GEO environment.

4. HAG 1

The first SmallGEO mission "HISPASAT Advanced Generation 1" planned to be launched in 2015 will supply Spain, Portugal, the Canary Islands and South America with multimedia services providing Communication capacity of up to 24 transponders in Ku-band and 3 transponders in Ka-band.

The P/L is complemented by the innovative REDSAT elements including an active direct radiating array antenna providing 4 reconfigurable uplink beams in Ku-band and an advanced on-board processor.

The HAG1 satellite will have a launch mass about 3.2 t including a payload around 400 kg and 3.5 kW at end of life.

On HAG1 all orbital maneuvers after transfer from GTO to GEO are performed by electrical propulsion. For the GTO transfer a dedicated bi-propellant system is implemented. For a mission with direct injection to GEO by the launcher, the CP system could be omitted leading to an EP only propulsion platform.

Figure 3: HAG1 –all propulsive tasks in GEO with EP

The Electric propulsion system consists of two redundant branches with 4 fixed 1.4 kW HET each accommodated in the E/W corners of the satellite [2]. This configuration does not need mechanisms and allows relatively high thrust efficiency, but requires thruster accommodation close to the centre of the S/C near the P/L module.

Due to the central EP thruster configuration, parts of the EP plasma plumes could cross the payload RF beams from the deployable East/West reflector antennas. A dedicated ARTES 5.1 project with the purpose of modeling and testing potential EMC issues concluded that no degradation of the communication links are to be expected [8].

The layout of the solar arrays have been adapted to prevent detrimental effects of the EP plasma plume.

Overall the EP system increases the P/L to launch mass ratio by about 4 % as compared to the CP based platform SGEO Fast classical. For the 3-3.5 ton class satellite this corresponds to 100 – 150 kg of P/L mass, which is equivalent to an increase of up to 50%.

5. HEINRICH-HERTZ

The Heinrich Hertz mission aims to explore and test new communications technologies in space including verification of hardware and software as well as scientific experiments. Further it shall serve as test-bed of pre-operational SatCom services for German (public-sector) users.

The Heinrich Hertz (H2) satellite will have a launch mass about 3.4 t including a payload up to 450 kg.

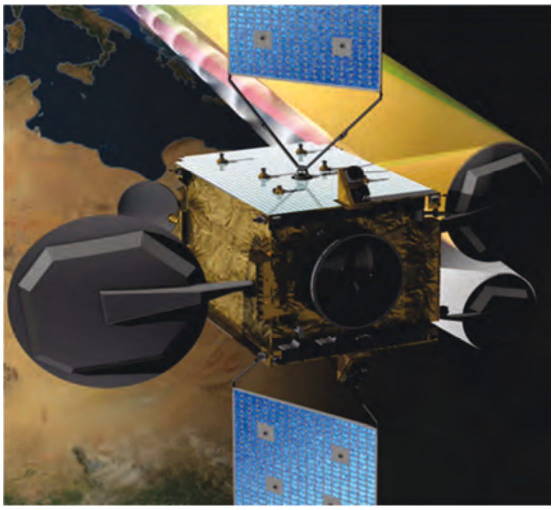

Figure 4: H2SAT – NSSK with EP

Compared to HAG1, the EP system has been simplified to provide only NSSK, while EWSK and momentum management is performed by the CP system. The EP system consists of two redundant branches with 2 fixed 1.4 kW EP thrusters each. The thrusters are accommodated on brackets at the anti-Earth edges of the N/S radiators.

This accommodation has the advantage to increase the N/S P/L radiator area and to minimize the risk of payload EMC effects as compared to HAG1.

The wet mass impact on satellite level is small taken to account the decreased dry mass of the EP system, which leads to a similar P/L to launch mass ratio for H2 and HAG1.

6. ELECTRA

Electra based on the SGEO-Flex platform will be the first European all-EP telecom satellite. The launch is planned for 2018. The first Electra satellite will have a launch mass in the range of 2.5 to 3 tons including a payload around 600 kg and 8 kW at end of life. This performance will place the platform in the same category as current mid-size telecom satellites with typical launch masses around 5 t but placing it within the capabilities of several low-cost launch alternatives.

SGEO-Flex will be compatible with a single launch on Soyuz CSG, Falcon 9, Falcon 9R (Hopper), Atlas 401, Land Launch, Sea Launch, H2A and as secondary passenger on Ariane 5 (under Sylda).

Further two SGEO-Flex type S/C will be compatible with a stacked launch on Falcon 9, Proton and as primary passenger on Ariane 5 (on top of Sylda).

With some P/L limitations also small GEO launchers like Cyclone-4, GSLV and Antares will be possible.

Figure 5: Electra – Full EP propulsion system incl. GTO

The Electra EP configuration is based on two redundant pairs of 4.5 kW EP thrusters mounted in pairs on two articulated EP booms. These mechanisms provide the necessary degrees of freedom to fulfil all propulsive tasks, station keeping and momentum management with only two thrusters. The EP booms are placed at the anti-Earth edges of the N/S radiators.

As the 4.5 kW EP systems provide sufficient lifetime, the Xenon tank can be sized for sufficient capacity to achieve a low thrust ΔV of up to 4000 m/s for GTO transfer to enable a highly flexible launcher selection. As the Xe tank is still small as compared to CP tanks, the tank volume was not a particular design driver on this type of satellite.

The booms provide the additional advantage to maximize the distance of the EP thrusters to the S/C and thereby minimizing the impacts of sputtering and EMC as compared to the SGEO Fast Hybrid configuration. In this way the EP thrusters are also thermally well decoupled from the S/C.

The orbit transfer with EP however increases the time spent in the radiation belts as compared to the SGEO Fast missions with considerably increased total non-ionizing dose levels, in particular for sub GTOs with initial apogee altitudes in the order of 10000 km. The major impact would be the degradation of the solar cells, which is accounted for by cover glass shielding in the design. The total ionizing dose levels are also increased but will be significantly less than the 15-year on-station dose.

Compared to the SGEO Fast classical platform, the P/L performance in terms of power and mass is increased in the order 100% at reduced launch mass enabling the use of smaller launchers respectively dual launch on medium class launchers.

7. CONCLUSIONS

The OHB SmallGEO product line has been presented with focus on the first missions under development including EP applications. HAG1 and H2-Sat use 1.4 kW EP systems for station keeping leading to an increase in P/L mass capacity of up to 50% as compared to the CP based SGEO Fast classical platform.

A major step beyond is achieved by the all EP system to be implemented in the Electra development. This new SGEO Flex platform will provide an increase in P/L mass capacity of 100% and more as compared to the CP based SGEO Fast classical platform. At the same time smaller more cost effective launchers are possible respectively the transfer time penalty can be minimized on medium class GEO launchers due to the high flexibility regarding the launcher injection scenario.

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