Solely EP based Orbit Control System on Small GEO Satellite

IEPC-2007-274

30th International Electric Propulsion Conference, Florence, Italy
September 17-20, 2007

H. Lübberstedt*, Th. Miesner, A. Winkler
OHB-System AG, D-28359 Bremen, Germany

P. Rathsman, J. Kugelberg
Swedish Space Corporation, SE-17104 Solna, Sweden

Abstract: SGEO offers a highly flexible and modular geostationary platform, able to accommodate a wide range of payloads in the range of 300 kg and 3 kW. SGEO is the first Western satellite relying solely on electrical propulsion for all orbit control tasks after direct injection into geostationary orbit. Optional, an Apogee Engine Module based on chemical propulsion will provide the perigee raising manoeuvres in case of a launch into geostationary transfer orbit. This approach extends the possible launcher candidates respectively increases the payload capacity of SGEO.

Nomenclature

AEM	=	Apogee Engine Module
ARTES	=	Advanced Research in Telecommunications Systems, ESA Telecommunication Program Lines
DLR	=	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
ESA	=	European Space Agency
EP	=	Electrical Propulsion
EPPS	=	Electrical Propulsion Subsystem
GEO	=	Geostationary Earth Orbit
GTO	=	Geostationary Transfer Orbit

I. Introduction

The objective of the Small Geostationary Satellite initiative (SGEO) is to establish a general purpose small geostationary satellite platform which will be competitive in the commercial telecom market for small platforms, and which may also be used for institutional applications. The SGEO Phase B within the framework of the ESA ARTES-11 program has started early 2007 planning for a launch in 2010.

A number of advanced and new technologies will be implemented in order to provide a competitive edge in the telecommunication market and to obtain the heritage expected by many customers. On the other hand, the design of the SGEO platform is largely based on existing well proven technology and thus relies strongly on the legacy from existing satellites. This approach provides a competitive advantage in the near-term market as well as in the future product evolution. The SGEO product portfolio ranges from Satellite platform delivery up to in-orbit delivery of turn-key systems including satellite and ground control station[1,2].

* Mission & AOCS Engineer, SGEO, mail-to: luebberstedt@ohb-system.de.

II. SGEO System

SGEO offers a highly flexible and modular geostationary platform, able to accommodate a wide range of payloads in the range of 300 kg and 3 kW. The system is designed for up to 15 years lifetime and a fast recurring delivery time of 18 to 24 months. ITAR free subsystems & components based on European technologies are envisaged.

SGEO is compatible to most commercial launchers and offers two launch scenarios:

1. Direct injection to GEO on Soyuz (Kourou) , Zenit (LandLaunch and SeaLaunch) and Proton.
2. GTO injection and transfer to GEO with a chemical Apogee Engine Module (AEM) on Ariane V (as secondary passenger), Soyuz, Zenit, Proton, Atlas and Delta.

In case of direct injection the pure EP based orbit control system allows to minimize the launch mass to a magnitude of 1300 kg. In case of GTO injection the hybrid propulsion system still allows to keep the launch mass in the range of 2400 kg. The satellite configuration for a typical TV-Broadcast mission is outlined in Figure 1.

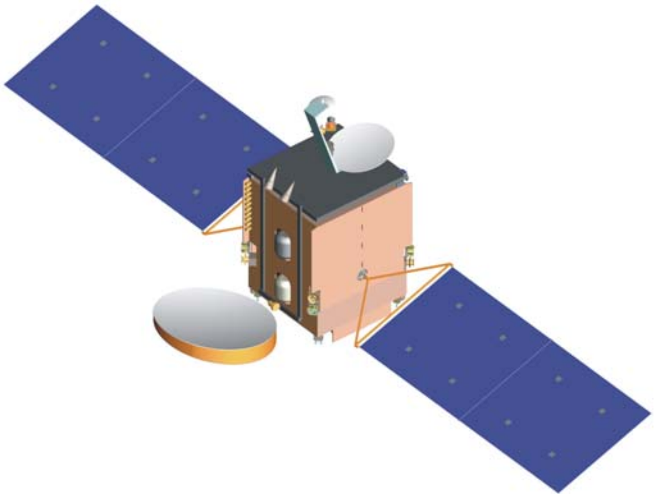

Figure 1. SGEO in-orbit configuration (GTO option)

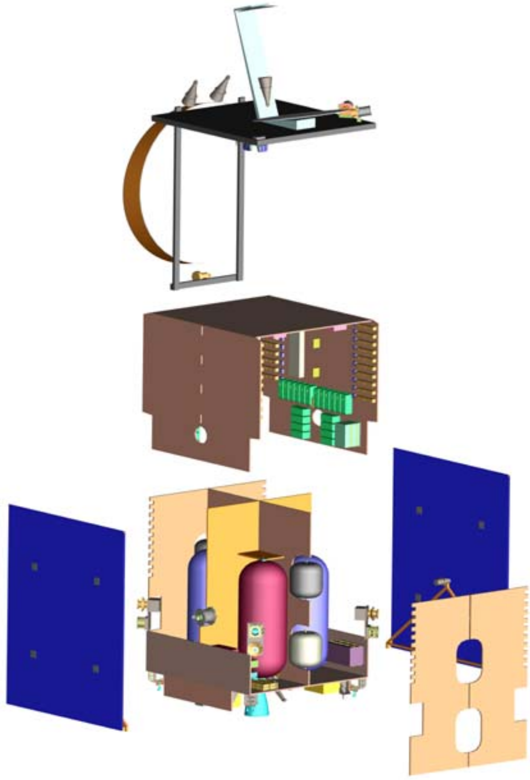

Figure 2. SGEO launch configuration - exploded view (GTO option)

The modular approach with platform, repeater and antenna modules as shown in Figure 2 allows to optimize the AIV flow and finally to save costs and time. The platform module basically houses all elements which are related to the satellite bus and is designed as generic as possible. In case of GTO injection, the elements of the AEM are additionally integrated, in particular the four bi-propellant tanks as shown. The 4 tank concept leads to a compact and scalable GTO platform. The shear web structure maximises flexibility and scalability of payload accommodation.

The On-Board Data Handling (OBDH) design follows the System on Chip philosophy making use of LEON, MIL-STD-1553B and IP Cores. This allows to have software independent telemetry and telecommand capabilities for S/C operations. The TM/TC transceiver unit receives commands from the satellite control ground station and transmits satellite status data to the ground station.

The orbital position is acquired via ground-based tracking, although an on-board GPS receiver is planned to be flown on SGEO to demonstrate autonomous orbit determination on-board. The Attitude and Orbit Control System (AOCS) features star trackers based on Active Pixel Sensors and stabilization via reaction wheels. The AEM includes one main engine and eight reaction engines to control the apogee manoeuvres. The Electrical propulsion subsystem (EPPS) is described below.

III. Mission Analysis & EP thruster configuration

With the exception of the transfer from GTO to GEO, which will be performed by launcher respectively the AEM, the SGEO Electrical propulsion subsystem (EPPS) will perform all orbital manoeuvres. This includes:

- Station acquisition to account for the injection errors of the launcher respectively the AEM,
- Station-keeping during 15 years,
- Intermediate repositioning, if needed,
- Transfer to graveyard orbit at end of mission as well as
- Momentum management during all phases except during GTO-GEO transfer.

To enable these tasks, a fully redundant system consisting of two branches with 4 EP thrusters each is baselined. The thruster layout as illustrated in figure 3 is chosen such that the centre of mass (CoM) movement during the lifetime is bounded by the eight thrust vectors, with an additional margin to ensure that torques can always be generated for wheel unloading.

On the Geostationary Earth Orbit (Radius ~ 42164 km, Eccentricity ~ 0°, Inclination ~ 0°) the orbital slot is typically defined by a box of following dimensions: longitude ~150 km, latitude ~150 km and Radial ~75 km. To enter or leave the GEO slot the semi-major axis of the orbit is changed using a tangential thrust. The satellite starts to drift in longitude. In order to stay clear of neighbouring satellites a certain minimum thrust level is needed.

A perfect geo-stationary orbit does not exist in reality. Instead, a number of orbital perturbations are continuously experienced by a GEO satellite, leading to a steadily changing orbit:

- The non-spherical shape of the Earth' gravitational potential (tesseral terms) causes the longitude drift. In addition, the zonal terms contribute to the inclination vector drift.
- Solar radiation pressure causes an eccentricity vector drift.
- Solar and lunar gravitational perturbations cause the inclination vector drift and contribute to the eccentricity vector drift.

North/South (N/S) station-keeping to counteract the inclination vector drift is the biggest contribution (> 70 %) to the delta V budget needed for GEO operations. Therefore a thrust vector with a low angle to the N/S axis alpha (see figure 3) is preferred in order to achieve a high fuel efficiency.

The operational concept for SGEO as outlined in figure 4 foresees two manoeuvres per day around the orbital nodes each consisting of two single thruster firings. The thrusters are used sequentially due to power constraints. Each thruster of the active branch is typically used once per day.

Key drivers leading to the baseline SGEO EP configuration are fuel efficiency, accommodation constraints, in particular plume impingement as well as design complexity, risks, resources and costs as further described in the following subsections.

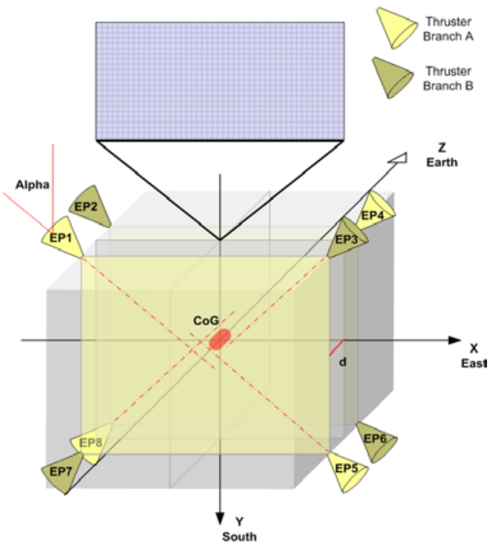

Figure 3. 8 EP-Thruster Layout

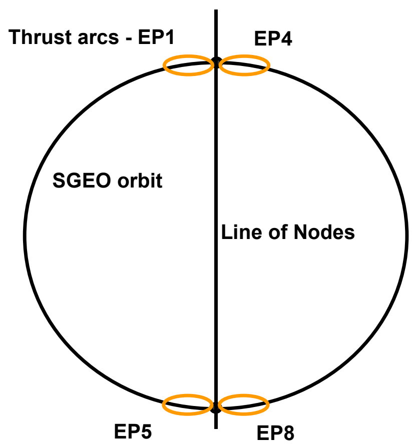

Figure 4. Operations scheme

A. EP thruster candidates

The European EP thruster system candidates considered for SGEO are summarized in Table 1. Main drivers are the qualification status and heritage. As key constraint the maximum input power to the EP system is limited to 1500 W. The Hall Effect Thruster (HET) system PPS-1350 has the most advanced qualification status followed by the Gridded Ion Engine (GIE) systems RIT-10 and T5. The High Efficiency Multistage Plasma Thruster system HEMP-T[3,4] is a new development, which is planned for in-orbit demonstration on SGEO. In case of GIE, parallel operation of two thrusters is considered in order to increase the system thrust level.

Thruster	Type	Power† (W)	Thrust (mN)	Isp (s)	Plume half cone‡ (°)
PPS-1350	HET	1500	75	>1500	< 45
RIT-10	GIE	600	15	>3300	< 20
T5	GIE	600	15	>3300	< 20
HEMP-3050	HEMP	1500	45	>2500	< 45

Table 1. Overview of European EP thruster system candidates

B. Ion plasma plume impact on the satellite

The Ion plasma plume of the electric thrusters interact with the satellite in several ways:

1. Sputtering leads to erosion of the impacted surfaces. Further the transmission properties are modified and the roughness of the surface may be increased.
2. The momentum exchange between incident ions and the impacted surface leads to forces and torques
3. The low efficiency of the ions momentum exchange process leads to heating of the impinged surfaces
4. Electromagnetic interferences in particular the interactions of the plasma jet with the electromagnetic waves of the payload communication link
5. Electrostatic charging, magnetic disturbances and general electromagnetic interferences

These effects leads to thruster layout constraints in particular item 1 with respect to the solar arrays and item 1 and 4 with respect to payload antennas. Further item 2 drives the AOCS requirements. As the divergence of the EP thruster plumes is considerable as shown in table 1, a layout principle as sketched in figure 5 with an N/S-angle alpha in the order of 45° is used. The Ion plasma plume interactions with the satellite are currently being analysed in detail. Preliminary results indicate the feasibility of the configurations considered.

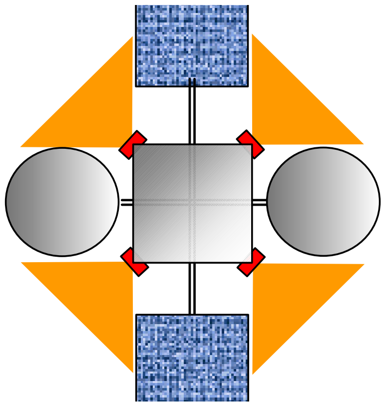

Figure 5. Layout constraints due to EP thruster plumes

C. EP configuration options

The number of thrusters has to be minimized in view of the relatively high resources and costs of an electrical thruster. One optional configuration considered is based on two redundant thruster pairs each mounted on one thruster orientation mechanism (TOM) with two pivotable axes. This configuration saves 4 thrusters at the expense of 2 TOMs compared to the baseline. As these TOMs are relatively complex the system dry mass savings are moderate. Due to accommodation constraints the N/S-angle alpha is larger compared to the baseline. This leads to a lower fuel efficiency and finally to a comparable system wet mass. Both configurations are technically feasible, however the TOMs adds additional complexity to the program.

† Input to EP Power Supply

‡ including 90% of the total ion beam current

IV. SGEO Electric Propulsion Subsystem

The SGEO Electrical Propulsion subsystem (EPPS) consists of five subassemblies as shown Figure 6. The Cold Gas Thruster Assembly is used for initial de-tumbling after separation from the launch vehicle and for safe mode. The EP thrusters are divided into two groups. In the baseline design each group is powered by a separate electronic unit (PPU/TSU), which allows to operate any of the four thrusters within its group as commanded by the AOCS.

The EP thrusters and the Cold Gas Thruster Assembly will be fed with Xe by the same Propellant Supply Assembly. Its main function is to decrease the Xenon pressure from the main inlet tank pressure (High Pressure Node) down to a regulated pressure of 2.2 bar minimum at the outlet (Low Pressure Node). The inlet pressure is at 150 bar maximum (Beginning Of Life) and decreases down to 2.2 bar at End Of Life. The Xe flow rate to each EP thruster is regulated by the Xe Flow Control Unit (XFC). For Xenon storage, the baseline is to use two Xe tanks.

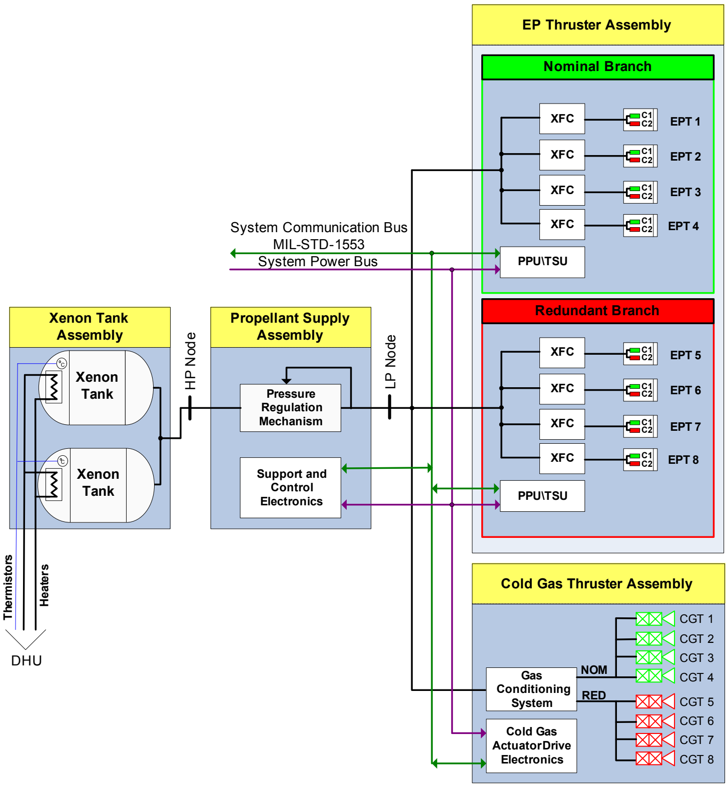

Figure 6. Block schematic of EPPS

A. HEMP-T in-orbit demonstration

The HEMP 3050 is currently under development at Thales supported by DLR and ESA. The thruster exists today as a functioning breadboard[4]. It is intended to perform a ground qualification and thereafter an in-orbit demonstration by implementing it as one of the two EP thruster branches on the first SGEO mission. The HEMP-T assembly configuration foreseen consists of a Power Supply and Control Unit (PSCU), four HEMP 3050 thrusters including neutralizers and four Xenon Flow Control units (figure 7).

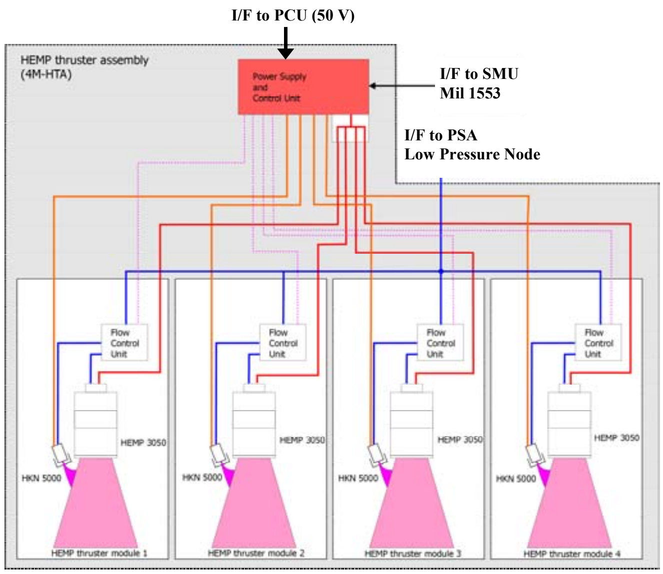

Figure 7. Block schematic of HEMP-T assembly

The key advantages of the HEMP-T technology are the following[3]:

- Erosion-free operation due to magnetic plasma confinement. As the plasma does not get in contact with the walls of the discharge chamber, the lifetime projection is > 18000 hrs.
- Simple operation scheme by switching the Xenon flow on and off with applied anode voltage. There are no transient anode current peaks.
- A low-mass, single-point-failure tolerant PSCU can be used for four thrusters.

V. Conclusion

SGEO offers a highly flexible and modular geostationary platform, able to accommodate a wide range of payloads in the range of 300 kg and 3 kW. The system is designed for up to 15 years lifetime, a fast recurring delivery time of 18 to 24 months with a goal of ITAR free subsystems based on European technologies.

SGEO is compatible to most commercial launchers and offers direct injection to GEO as well as GTO injection and subsequent transfer to GEO by means of a chemical Apogee Engine Module. The solely EP based orbit control system for GEO operations extends the possible launcher candidates respectively increases the payload capacity for SGEO. In-orbit demonstration of HEMP-T technology and GPS will pave the way for further improvements of reliability and cost efficiency of the SGEO platform and its ground segment.

VI. Acknowledgments

The authors would like to acknowledge the support of ESA, DLR and the work of the OHB, LuxSpace, SSC and Oerlikon design teams and further partners.

References

[1]H. Lübberstedt, D. Labuhn, D.Lang, Th. Miesner, A. Winkler, H. Schuff, "SGEO – A Small GEO Satellite System for Telecommunications" Proceedings of the 4S Symposium, Chia Laguna, Sardinia, Italy, 2006, ESA SP-625, November 2006

[2]D.Lang, H. Lübberstedt, Th. Miesner, A. Winkler, H. Schuff, "SGEO – A Small GEO Satellite System for Telecommunications" *Proceedings of the 25th AIAA Int. Communications Satellite Systems Conf.*, Seoul, Korea, 2007, AIAA-2007-3146

[3]Hans-Peter Harmann, Norbert Koch and Guenter Kornfeld, "Low Complexity and Low Cost Electric Propulsion System for Telecom Satellites based on HEMP Thruster Assembly", *Proceedings of the 30th International Electric Propulsion Conference,* Florence 2007, IEPC -2007- 114

[4]Norbert Koch, Hans-Peter Harmann and Guenter Kornfeld, "Status of the Thales High Efficiency Multi Stage Plasma Thruster Development for HEMP-T 3050 and HEMP-T 30250", *Proceedings of the 30th International Electric Propulsion Conference,* Florence 2007, IEPC -2007- 110