Operational Concept of the First Commercial Small-Geo Based Mission

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A small European geostationary platform (SGEO) for communications applications is being developed under OHB's lead management. Initiated by OHB, it has been established as a separate component of the long-term ESA schedule under the ARTES-11 program. The technical specifications for SGEO are based on a proposal submitted by OHB-System AG. What sets the SGEO platform apart is its modular structure. As a result, the satellite can be fitted individually in accordance with the customer's specific requirements without any major modifications to the satellite bus. SGEO has been developed as an optimum platform for communications payloads. With its modular design, however, SGEO also provides a cost-efficient basis for other applications such as earth observation or meteorology. The first SGEO mission based on the new satellite platform will be launched with a payload for the Spanish satellite operator HISPASAT as "HISPASAT Advanced Generation 1". HISPASAT AG1 will be placed in a geostationary orbit, where it will supply Spain, Portugal, the Canary Islands and South America with multimedia services. The paper presents an overview of the satellite modular design and main features together with a brief description of the new payload technologies that will fly onboard the mission. The operational concept behind the mission is described by going through the details of the ground segment design together with the operability requirements and solutions that fulfill those requirements, also the highlights of the different mission phase operations including preparation, LEOP, payload and platform IOT, and on-station. Two scenarios are discussed regarding the transfer strategy: a geo-stationary transfer approach and a super-synchronous transfer approach. And finally an overview of mission timeline is presented.

I. Introduction

THE The main objectives of the HISPASAT AG1 satellite mission to be embarked on board the SGEO platform are:

1) To provide continuity within the HISPASAT Satellite System by adding extra capacity in the Ku- and Ka-bands.
2) To provide back-up to HISPASAT Satellite System.
3) To provide advanced multimedia services based on the DVB-RCS/DVB-S2 standard.
4) To provide additional coverage flexibility for all type of services.

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This satellite is designed to operate at an orbital position defined by Hispasat. To achieve these objectives, the Hispasat mission for the ARTES 11 initiative consist of one base line mission that incorporate 2 payloads to be embarked on the satellite:

HISPASAT AG1 REDSAT Payload based on the initiative, started in the frame work of the Spanish Space National Programme. This payload includes a Receive Active Antenna, an On-Board Processor, and all the subsidiary RF units needed to provide the Service in the areas defined as coverages across the land masses of the orbital slot. The system provides 4 reconfigurable uplink beams in Ku-band and up to 4 regenerative channels of 36 MHz to provide broadband services in Ku- or Ka-band.

HISPASAT AG1 Transparent Payload in Ku- and Ka- bands, based on transparent Payload concepts, and making use on advanced technologies that will permit service provision of up to 24 transponders simultaneously.

The design of the SGEO satellite follows strictly a modular approach. The spacecraft is divided into the major modules

1) Core Platform Module
2) Propulsion Module

forming the Platform Module, and

1) Repeater Module
2) Antenna Module

forming the Payload Module.

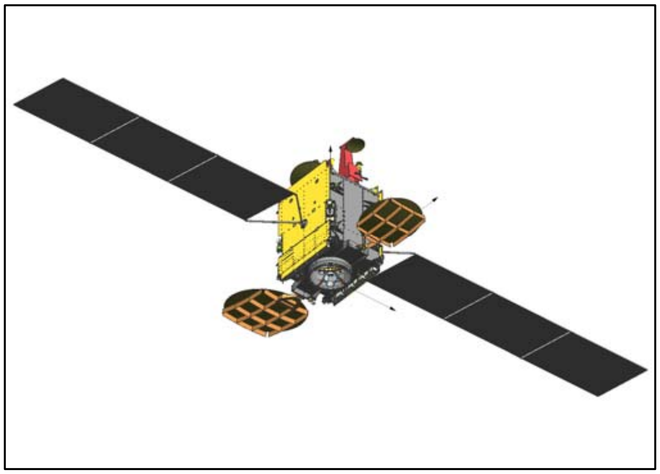

Figure 1. HAG1 In-Orbit configuration.

This modular approach enables a parallel AIV process supporting a fast recurring time.

The payload can operate simultaneously within different coverage zones. Looking from orbital location, these zones are:

1) Ku band America RX/TX coverage (AME), defined as a global coverage from North to South America covering the territory as seen from the orbital position
2) Ku band Europa coverage RX/TX (EUR), which includes the Iberian islands and the Balearic, Canary, Madeira and Azores islands, along with most part of Europe and North of Africa (including Tel Aviv).
3) Ku band RX spot beam coverages which include the areas generated through the active antenna on the visible earth from orbital location (S1, S2, S3 and S4).
4) Ka band RX/TX spot (IBERIA/CANARY) defined as one spot over Continental Spain, Balearic Islands, Portugal and Canary Islands

The SGEO satellite has the familiar geometry of most geostationary communication satellites. The payload antennas boresight are parallel to the positive Z axis (nadir), while the Y axis points south. The X axis is aligned with the orbital velocity vector in GEO. The apogee engine nozzle protrudes from the negative Z (zenith) side of the satellite. For On-Orbit station keeping and relocation manouevres, chemical propulsion is no longer used, necessary thrusts are provided by 4 redundant Electrical Propulsion thrusters. Communications for TT&R is provided in Ku Band. The satellite is PUS based offering a high degree of autonomy and a corresponding low commanding density for control. SGEO can accommodate a wide range of different communication payloads and is ideally suited for HISPASAT AG1.

II. Space Segment

The satellite key features for the HAG1 mission are summarized in the table below:

General	
Launcher Compatibility	For GTO injection: Ariane 5, Proton, Land Launch, Sea Launch, Falcon 9.
Satellite Lifetime	15-year design after IOT, >15-year manoeuvre life.
Satellite Mass (incl. Margins)	Wet ≤ 3200 kg Dry ≤ 1700 kg.
Power Consumption	< 5000 W (BOL) and 4500 W (EOL) without EPPS operation in GEO; < 6620 W (BOL) and 6120 W (EOL) with EPPS operation in GEO.
Eclipse Capability	100 % payload operation; battery max. 75 % EOL DOD.
Satellite Central Body Dimensions	2.26 m x 1.9 m x 2.53 m
Payload	
Repeater Subsystem	Transparent Ku-band Repeater with 24 (BOL) / 20 (EOL) simultaneously operating Transponders at saturation. Transparent Ka-band Repeater with 5 / 3 simultaneously operating Transponders at saturation. 4 DVB-RCS/DVB-S2 On-Board Processors (OBPs), using up to 4 channels in Ku-band.
Antenna Subsystem	2 Ku-band receive/transmit reflector antennas. 1 Ka-band receive/transmit reflector antenna. 4 Ku-band beams using a receive-only direct radiating phased array antenna (DRA).
Continuous, effective P/L Power	< 3500 W (EOL)
Total Payload Mass	400 kg
Telemetry, Telecommand & Ranging (TT&R)	
Frequency (receive/transmit)	Ku -Band
TT&R Antennas	LEOP, Contingency: near-omni directional antennas. Operational: global horn antenna.
Secure Communication	Authentication for TC, no encryption in TM or TC.
Propulsion Subsystem	
On-Station	Electrical Propulsion and Cold Gas.
GTO Transfer	Chemical bipropellant MMH/ MON
Electrical Power Subsystem	
Bus Voltage	Regulated 50 V_{dc} ± 0.5 %.
Energy Storage	Li-Ion Technology.
Solar Array (two wings)	Triple-junction GaAs solar cells.
Attitude Control Subsystem	
Stabilization	3-axis stabilized.
Station Keeping Accuracy	Better than ± 0.05° North-South/East-West.
Antenna Pointing Accuracy	< 0.1° (3 σ) half cone.
Command & Data Handling	
Data Bus	MIL Standard 1553B.
Flight Processor	LEON II – FT.

Table 1. Hispasat HAG1 Satellite key features

III. Ground Segment

The requirements for the ground segment are specified by OHB, and are split into three parts according to the mission phases:

1) Launch and Early Orbit Phase (LEOP) Ground Segment: The Ground Station Network that is baseline for the LEOP of HAG1 is at this time not yet defined.

2) In-Orbit Commissioning (IOT) Ground Segment: For IOT the following ground stations in Figure 2 are proposed. As the active IOT is performed in, or close to, the on station slot 24/7 coverage is assured.
   The following facilities are involved with the performance of the IOT:
   For Platform IOT: ground station of IOT service provider
   For Payload Ka-Band IOT: ground station, potentially supported by other ground stations network
   For Payload Ku-Band IOT: HISPASAT ground stations network

3) Routine Phase: On-Station mission operations will be conducted by HISPASAT. Nominal control is performed from the Arganda station with backup in the Canary Islands.

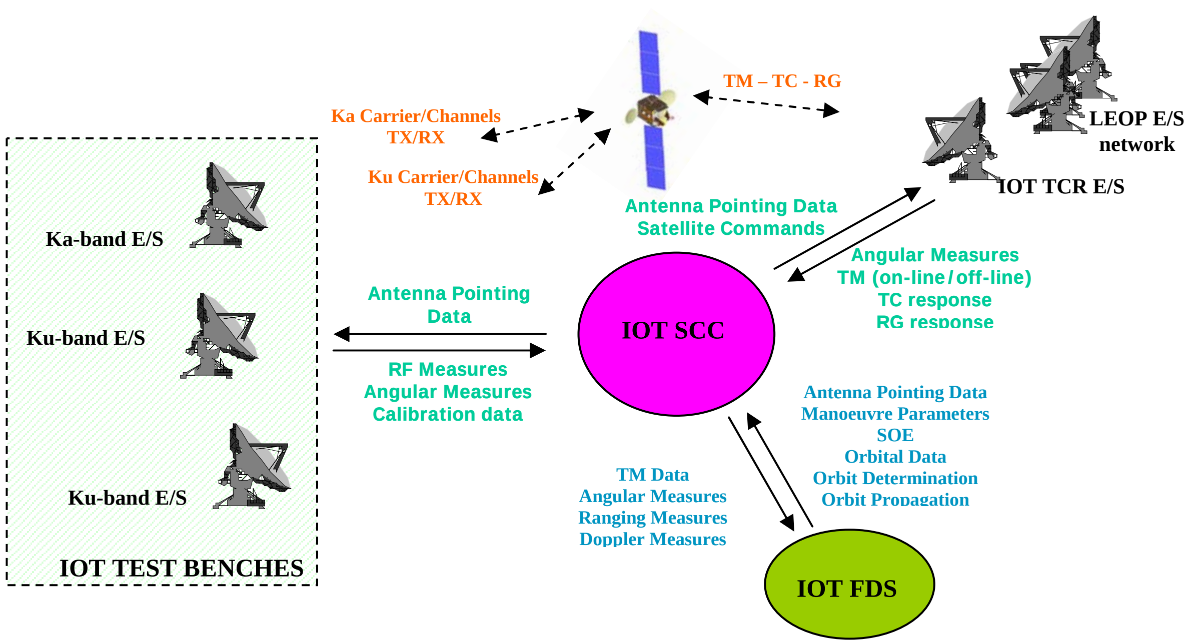

Figure 2. IOT station schematic.

IV. Mission Phases

A. Launch and Early Orbit Phase (LEOP)

The phase starts with launch and ends with the beginning of IOT at the designated GEO slot. A typical duration for this phase is approximately 2 weeks.

The launch scenario involves a launch into GTO, whereby the satellite will be transferred to GEO by means of chemical propulsion. This scenario requires additional ground station support in order to obtain constant RF contact. The additional ground station support is provided by a ground station network.

The LEOP activities include the launch phase from lift-off until separation of the satellite from the launcher, along with deployment of appendages, attitude stabilisation and initial satellite check out. The satellite remains under OHB responsibility, with the provision of flight control and ground stations under a service contract for both LEOP and IOT.

B. In Orbit Commissioning

Upon arrival in GEO, the satellite will undergo final commissioning and IOT to confirm its proper functioning. The phase ends with an In-Orbit Acceptance Review (IOAR) where the spacecraft is accepted and formally handed over to the customer. The duration of this phase is typically one month.

The IOT includes activities like turning on the payload, and functional checkout is performed for both prime and redundant chains to verify correct performance. The activities are separated to a dedicated platform IOT and payload IOT.

The purpose of the satellite platform IOT is mainly:

1) To assess the performance of each subsystem, including redundancies
2) To verify that no changes in performance have occurred since testing on-ground
3) To verify that the in-orbit performance is within the mission requirements
4) To calibrate actuators and sensors if not already performed during GTO

The purpose of the satellite payload IOT is mainly:

1) To verify the expected performance of the payload subsystem
2) To verify that no payload equipment have been damaged during launch

C. Nominal Operations

The on-station phase commences after completion of successful review and hand-over of responsibilities to the customer. The phase ends with either a re-positioning or disposal manoeuvre, which results in termination of the current mission.

It includes all the nominal and contingency on-station operations to maintain both the platform and the payload in their proper configurations in sunlight as well as in eclipse. It includes, daily, station keeping using electrical propulsion system for E/W, N/S, eccentricity control, and momentum management. The required thruster firing profiles for this control are calculated on-ground and uplinked weekly as timetags in an on-board schedule.

Predefined and validated Flight Control Procedures, which are part of the Flight Operations Plan, will be used covering both nominal and contingency cases.

The Customer Flight Control Team (FCT) is responsible for the operational phase and will undergo a training program before handover, to permit safe handover of the responsibility for the satellite.

An industry SGEO Engineering Support Team (EST) will continue to support the Customer FCT after handover and throughout the mission lifetime through the on-site and in-plant operational support which includes 24/7 on-call and analysis services.

D. Spacecraft Disposal

The end of life operations consists of raising the orbit above the GEO, typically about 300 km, by using the satellite's on-station EP thrusters. The minimum perigee height will be determined by the spacecraft mass and surface area, and will adhere to the European Code of Conduct for Space Debris Mitigation.

The planning of the transfer to disposal orbit can be done with the system and procedures used for the on-station phase. It is also foreseen that no additional ground segment equipment will be necessary for operations support.

The necessary propellant will be reserved in the propellant budget, and the manoeuvres will be done by means of electric propulsion. A Space Debris Mitigation Plan has been established which purpose is to minimize the risk of causing space debris during the whole mission. After reaching the final disposition position the spacecraft will be terminated following a passivation procedure based on the Space Debris Mitigation Plan.

V. Transfer and GEO Description

The Geo Transfer Orbit (GTO) perigee altitude is increased in discrete steps, taking advantage of the restart capability of the LAE. This strategy allows accurate orbit and attitude determination to take place after each step as input to the planning of the following step. The result is more accurate GEO insertion using the LAE itself, without the need for lengthy corrections using the station keeping thrusters.

The short duration of An LAE burn allows most of the thrust to be concentrated around the apogee, thereby minimizing thrust dispersion through "cosine losses" (also known as "gravity losses"), i.e. the generation of undesirable and wasteful thrust components away from the orbit tangent.

Several operational constraints help define the number and geometry of intermediate GTOs:

1) The perigee should be raised quickly to take the satellite above the Van Allen radiation belts, i.e. the inner belt which is in the range of 100 km to 10000 km and the outer, in the range of 15000 km to 30000 km.
2) The number of GTOs between LAE firings should be at least 2 to allow adequate time for attitude and orbit determination.
3) There should be adequate TT&R ground station coverage for timely attitude and orbit determination, and also for safe LAE monitoring during each burn. For the burns and the initial acquisition in LEOP coverage from two ground stations is required.
4) The orbital periods of the intermediate GTOs should be selected to allow GEO insertion as closely as possible to the designated IOT station longitude.

The precise definition of the intermediate GTOs is launcher and mission dependent. Communication satellites equipped with LAE require approximately 4 transfer orbits to meet the above constraints.

A staggered apogee engine firing sequence allows accurate orbit determination to be conducted in between firings, thereby enabling errors to be removed. If the apogee is raised in an asymptotic manner, the GEO injection accuracy will improve compared to a single, protracted burn. The staggered approach also facilitates orbital phasing, such that ground contact is optimized and the satellite arrives in GEO with the desired orbital elements. A sequence of four LAE burns is base lined for HAG1.

Two GTO scenarios are considered for manoeuvre planning, the nominal scenario and the backup scenario, which is an emergency case.

Nominal scenario characterized by all manoeuvres in daylight: launch window defined to have suitable eclipse profile and sun aspect angle during burns and critical GTO mission phases. LAE will be used to accomplish the orbital corrections and RCT for attitude control.

Manoeuvre baseline selected for nominal scenarios analysis is based on 4 burns; this manoeuvre plan will inject the satellite on a suitable drifting orbit from where the final GEO insertion phase will start by correcting the residual semi-major axis and eccentricity error and zeroing the residual inclination. The baseline manoeuvre strategy has been selected to optimize the precision of positioning (GEO slot) maintaining the propellant consumption within the available limits and to avoid long time exposition to protons radiation within the Van Allen belts, along with technical concerns such as commissioning and equipment calibration. The GTO strategy also guarantees adequate ground station coverage specifically during burns.

Emergency scenario, that considers transfer manoeuvre using RCT and EP systems in case of LAE failure. In the simulation the same initial conditions used in the nominal scenario are considered. Due to lower specific impulse, with RCT only it is not possible to bring the satellite to the desired GEO slot, which will be achieved with support of the Electrical Propulsion System (EPPS), at the cost of a longer duration to reach the GEO slot. The implementation of this scenario also takes into account every operational and safety constraint. Analyses performed consider the following:

1) Orbit topping analysis to compare a fully chemical transfer against a mixed, electrical and chemical propulsion solution.
2) Chemical transfer phase analysis of performances for the two proposed options
3) Electrical propulsion phase assessment of performances.
4) Assessment summary of the impact of the emergency scenario on mission requirements
5) Emergency scenario feasibility assessment versus operational and safety constraints
6) Propellant budgets for each considered option.

It is possible to inject the satellite into a Super-Synchronous Transfer Orbit (SSTO) with the following launchers: Falcon 9, Proton, Land Launch and Sea Launch. As the SGEO platform is a mixed CP+EP propulsion subsystem using exclusively the EP subsystem for GEO station keeping and relocation, the usual fuel advantage of a SSTO for CP only satellites is not given. Moreover the CP propulsion of the HAG1 satellite has to be reduced to a minimum at begin of GEO lifetime to minimize the Xenon propulsion consumption during lifetime (i.e. comply with nominal EP propellant budget).

The baseline of the HAG1 satellite is to fill the CP tanks with an amount of 1287 kg propellant. This amount of propellant is derived from a 1500m/s delta-V for a GTO transfer orbit. Thus, in case of choice for a SSTO transfer, injection parameters shall be chosen in order to comply with the 1500m/s delta-V (take also into consideration that the decision is to do passivation at the end of the mission lifetime).

In the following table injection parameters for a SSTO are presented for the four launchers described above:

Launcher	Perigee height (km)	Apogee height (km)	Inclination (deg)	Nominal Delta-V (m/s)	Max. Payload Mass (kg)
Falcon9 (Cape Canaveral)	185	70000	21	1542	3365
Proton	4150	50000	26.4	1503	6130
Land Launch	200	70000	51.4	1934	4390
Sea Launch	2000	42000	0	1315	4533

Table 2. SSTO Injection Parameters

The four burn manoeuvre strategy will inject the satellite in a drift orbit, which should be as close as possible to the GEO arc but without interfering with existing GEO satellites. The drift orbit is required to have the following principal characteristics:

1) Drift rate shall be bigger than 1°/day
2) Minimum distance of the drifting satellite from the GEO arc, considering the longitude daily librations, shall not be less than 50 km.

Baseline scenario for the insertion of the HAG1 spacecraft into its IOT position is the use of Chemical Propulsion System (CPPS). Repositioning to the operational GEO position is based on the Electric Propulsion System (EPPS).

In order to minimize the manoeuvre duration, the spacecraft is reoriented to place the EP thrusters in either the orbit tangential direction, for orbit raise or lowering manoeuvres, or the orbit normal direction, for inclination manoeuvres. Inclination manoeuvres apart from station keeping are nominally not required, only in case of a CPPS failure during GTO.

The burn time during such manoeuvres is limited by the torque capabilities of the reaction wheels, as the thrust vectors exhibit an intended offset from the CoG. Therefore after a certain time the S/C is reoriented and another thruster is used in order to control the angular momentum.

For orbit raise or lowering manoeuvres the spacecraft is rotated by 90°around Nadir for each thruster burn in order to respect the limited torque capabilities of the reaction wheels. During the GEO slot acquisition the spacecraft will experience a total of four full rotations and 16 individual EP thruster firings per orbit.

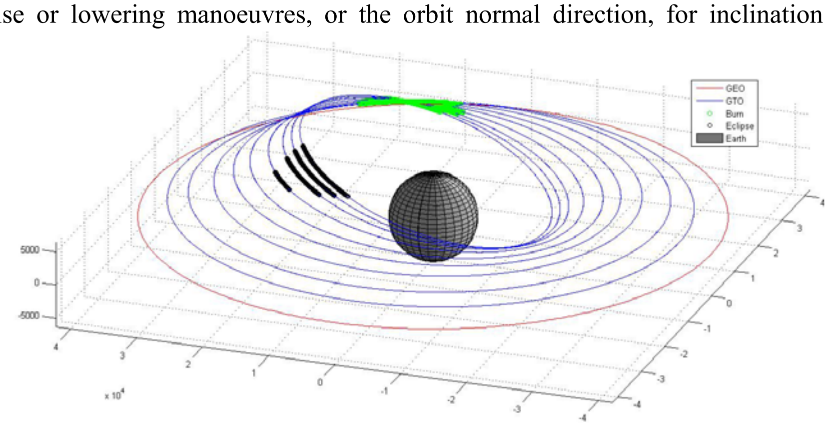

Figure 3. CP Transfer phase for a Falcon launch.

VI. Conclusion

The Hispasat HAG1 will be the first mission to test the small GEO platform developed by OHB Technology. It represents a small, cost-efficient and yet capable spacecraft platform. It is highly adaptable and although currently foreseen for telecommunication geostationary applications, it can be used for different types of missions.

What sets the SmallGEO platform apart is its modular structure. As a result, the satellite can be fitted individually in accordance with the customer's specific requirements without any major modifications to the satellite bus. The advantages are plain to see: Short integration times make it possible to react swiftly to new market needs and reduce costs. The relatively low complexity of the system ensures high reliability in tandem with reduced program risk.

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