Development, Qualification and Delivery Status of the HEMPT based Ion Propulsion System for SmallGEO

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Thales Electron Devices GmbH TEDG has developed and is currently qualifying a novel type of ion propulsion system based on High Efficiency Multistage Plasma Thrusters HEMPTs. This so-called HEMPT Assembly will be integrated on OHB-System AG's SmallGEO geo-stationary telecommunication platform to perform attitude and orbit control maneuvers for the Hispasat AG1 mission. The HEMPT Assembly consists of four HEMPT Modules and one Power Supply and Control Unit PSCU which supplies the HEMPT Modules with electric power and controls their operation. The so-called HEMPTIS program (HEMP Thruster In orbit verification on SmallGEO) initiated by German Space Agency DLR includes all associated component development, system engineering, testing and qualification activities, and the delivery of the respective flight units. Currently, the HEMPT Assembly is undergoing the Critical Design Review CDR. All relevant activities to demonstrate the compliance of the HEMPT Assembly with the satellite requirements have been mostly accomplished and production of qualification and flight hardware has been started.

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Nomenclature

ASM	=	Anode Supply Module
CDR	=	Critical Design Review
EMI	=	Electromagnetic Interference
FCU	=	Xenon propellant Flow Control Unit
GIT	=	Grid Ion Thruster
HCN	=	Hollow Cathode Neutralizer
HEMPT	=	High Efficiency Multistage Plasma Thruster
HEMPTIS	=	HEMP Thruster In-orbit-verification on SmallGEO
HET	=	Hall Effect Thruster
MMS	=	Mechanical Mounting Structure
NHKS	=	Neutralizer Heater Keeper Supply
PSCU	=	Power Supply and Control Unit
TEDG	=	Thales Electron Devices GmbH

I. Introduction

THALES Electron Devices GmbH TEDG has started the development of a new ion thruster concept, the so-called High Efficiency Multistage Plasma Thruster HEMPT since about a decade ago. After successful demonstration of the concept feasibility phase[1], breadboard model HEMPTs have been developed for the 1.5kW and the 7.5kW power range referred to HEMPT 3050 and HEMPT 30250, respectively[2]. Also the possibility to cluster HEMPTs supplied all by a single anode line from the power supply has been verified[3]. In addition, TEDG has started the development of a hollow cathode neutralizer based on space flight proven cathode technology derived from travelling tubes resulting in the HCN 5000 capable to deliver an electron current up to 5A[4]. The obtained operational and performance characteristics of both thruster and neutralizer and their compatibility with existing space power supply technology have shown the possibility to set up an ion propulsion system based on HEMPT 3050 and HCN 5000 which exhibits a high level of reliability and unique cost-efficiency[5]. In consequence, TEDG has initiated the development of a complete ion propulsion subsystem, the so-called HEMPT Assembly, targeted to the needs of commercial communication satellites but also offering a qualified and flight-proven off-the-shelf product for scientific missions. HEMPT Assembly development activities have started in 2007, and in 2008 German Space Agency DLR has kicked-off the so-called HEMPTIS (HEMPT In-orbit-verification on SmallGEO) project which includes development, qualification and flight hardware delivery for the SmallGEO platform of OHB Systems. SmallGEO is developed in the frame of European Space Agency ESA's Artes-11 Program, and its first launch will be through the commercial Hispasat AG1 mission.

Despite being a small to middle-sized telecommunication satellite with an in-orbit mass of 1900kg and a payload mass and power of 400kg and 3.5kW, respectively, the use of the HEMPT Assembly allows mass savings of as much as 220kg compared to conventional chemical propulsion. In combination with TEDG's highly cost-effective system approach it has become that ion propulsion represents an attractive commercial solution for space craft position control also for smaller satellites.

This paper presents the basic architecture and features of the HEMPT Assembly. It reviews the main operational performance characteristics of the HEMPT Module with the thruster and neutralizer as main parts, as well as the general set-up of the Power Supply and Control Unit PSCU. In addition the verification status achieved within the HEMPTIS Program is given.

II. HEMPT Assembly Positioning, Architecture and General Features

Position control on SmallGEO is achieved by means of 4 + 4 ion thruster modules which are mounted onto the satellite as indicated in Figure 1; whilst the thrusters are positioned at outer space craft surface, the respective power supply and control electronics are mounted inside.

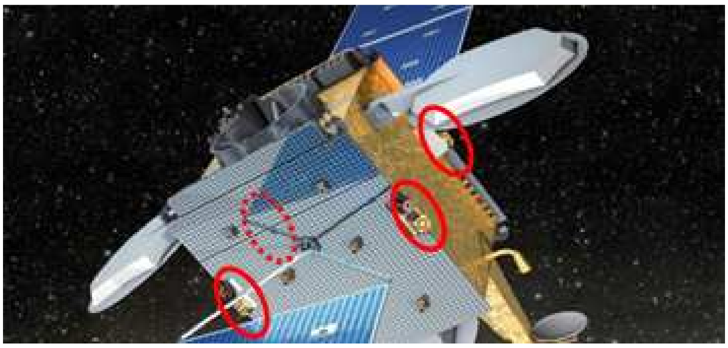


Figure 1: 3D view of the SmallGEO space craft.
The position of the HEMPT Modules is indicated by red circles; the PSCU is mounted inside the space craft.

The thrust direction is oriented in the North-South plane with a cant angle of about 45°. It is slightly displaced from the satellite's center of gravity. In such way consecutive firing of the thruster modules allows for North-South and of East-West Station Keeping, NSSK and EWSK, and for momentum wheel off-loading, respectively. For its first flight in course of the Hispasat AG1 mission the SmallGEO platform employs a mixed ion propulsion system which consists of one HEMPT and one HET Assembly with 4 thruster modules each. The HET Assembly is integrated by Snecma; it is based on SPT-100 thrusters from Fakel and a Power Processing Unit PPU from Thales Alenia Space ETCA, which both have demonstrated successful operation in orbit on several commercial space crafts[6].

A. The HEMPT Assembly

The HEMPT Assembly for SmallGEO consists of a Power Supply and Control Unit PSCU and of 4 HEMPT Modules which provide the effective thrust for satellite maneuvering. The PSCU manages the complete control of the HEMPT Modules and converts the power from the space craft's solar electric system based 50V bus to supply the required power levels.

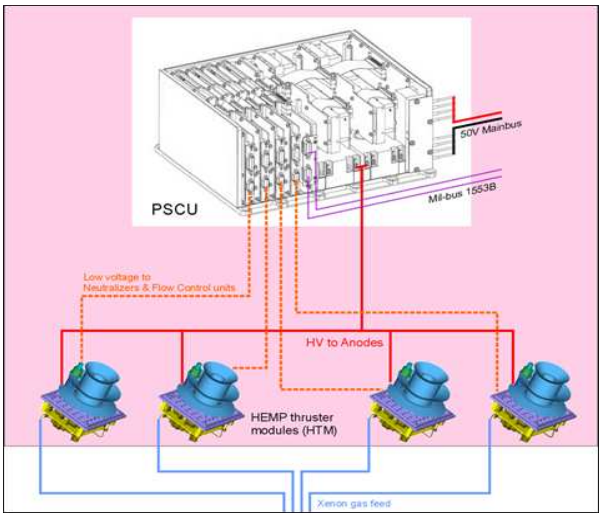


Figure 2: Schematic view of the HEMPT Assembly for SmallGEO.
The HEMPT Modules and the PSCU are shown as 3D drawings, the electrical and propellant harness are indicated schematically as orange/red and blue lines, respectively.

A schematic picture of the HEMPT Assembly is given in Figure 2. It is important to note, that the individual anode lines from the thrusters are all supplied in parallel without any switching unit. This is due to the fact that current is drawn from the thruster anode only if also Xenon is supplied. Therefore HEMPTs can be considered as variable parallel impedances the resistivity of which is only regulated by the propellant flow. This feature allows for thrust vectoring without the use of a thruster orientation mechanism since each HEMPT can be operated with an individual thrust level based on its respective ion current that results from the propellant input. In case of SmallGEO, this possibility is not used: the thrusters are operated with a fixed thrust level and are fired consecutively to obtain a defined impulse bit.

A detailed review on the architecture and performance features of the HEMPT Assembly is given in[7].

B. HEMPT Modules

The HEMPT Modules for SmallGEO consist of a thruster of type HEMPT 3050, a neutralizer of type HCN 5000 and a Xenon propellant Flow Control Unit FCU. All module components are integrated on a mechanical Mounting Structure which also represents the thermal and mechanical interface to the space craft. This compact modular design allows for a low handling complexity during test and verification and for easy integration into the satellite.

A 3D drawing of the HEMPT Module is given in Figure 3. The HEMPT 3050 is mounted on a dedicated thruster mounting flange which exhibits minimum thermal conductance and maximum stiffness. In combination with the radiation cooling concept of the thruster this reduces the thermal backflow to the satellite to less than 1% of the input power. The neutralizer is mounted such as to optimize ion beam neutralization. Similar to the thruster, a dedicated neutralizer mounting tube minimizes the thermal backflow to a negligible level. On the rear side of the HEMPT Module the FCU and the Electrical Interface Box are mounted. This provides defined thermal conditions for heat sensitive components such as valve seals and coils and cable insulations. Since the module's rear side is placed direction inside the space craft, also the radiation levels are on a non-critical level.

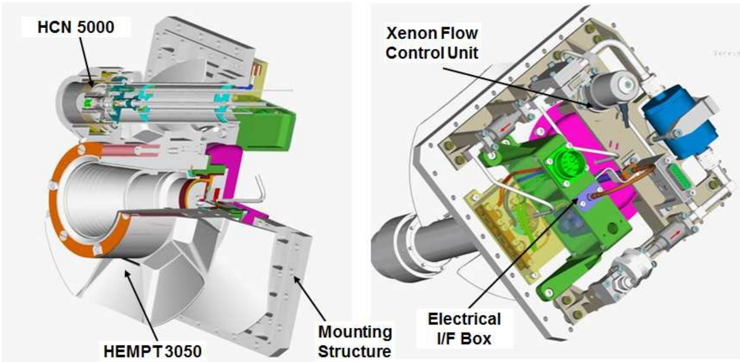


Figure 3: 3D-drawing of the HEMPT Module.
Left: front side; right; rear side.

The total input power from the PSCU to the HEMPT Module is about 1440W. This power is distributed mainly to the thruster, and it supplies further the neutralizer and the FCU.

B. 1) HEMPT 3050

The HEMPT 3050 has a nominal input power to the anode of 1500W at 1000V and provides a thrust of 50mN at a specific impulse of 3000s. For SmallGEO, the input power is limited to 1380W resulting in a thrust level of up to 45mN at an anode specific impulse in excess of 2800s. The high thermal efficiency of about 85% results in a dissipation load of about 210W. The radiation cooling concept of the thruster exhibits two large radiator cones with a directional emission characteristic. Such way and in combination with the low conductive thruster mounting flange and mechanical mounting structure less than 15W are conducted to the satellite structure, which represent less than 1% of the module input power.

Details on the HEMPT concept and on general operational and performance characteristics are reviewed, e.g., in[8], [9] or [10].

B. 2) HCN 5000

The HCN 5000 is capable to produce an electron current of up to 5A at cathode temperatures allowing for lifetimes in excess of 50,000h. In case of the HEMPT Modules for SmallGEO, the HCN 5000 is operated with a keeper current of 1.5A neutralizing an ion current of about 1.4A. The resulting keeper and coupling voltages are typically below 15V each. The observed cathode temperatures suggest neutralizer life-times in excess of 100,000h.

Details on the HCN concept and on general operational and performance characteristics can be found in [11], [12] or [13].

C. Power Supply and Control Unit PSCU

The PSCU of the HEMPT Assembly for SmallGEO is developed by and procured from EADS Astrium GmbH, Friedrichshafen, Germany. It consist of an Anode Supply Module ASM which supplies the thruster anode and of 4 Neutralizer Heater Keeper Supplies NHKS's. The high voltage ASM consists of two modules arranged in parallel configuration which are capable to provide 1.45kW of power at 1000V each in order to enhance internal cold redundancy and system reliability. The ASM supplies all 4 thrusters in parallel. As mentioned above, thruster load is exclusively controlled by the propellant input. The NHKS supplies both the neutralizer and the FCU. Each HEMPT Module is controlled by an individual NHKS. Thrust level control is performed via closed loop control of the anode current through the Xenon flow. The respective controller is embedded in the NHKS. Once the thruster discharge is ignited the anode current is measured and the FCU is controlled such that the input Xenon flow to the thruster yields the commanded thruster current. Since this is a direct measure for the thrust, thrust control is exclusively performed via propellant flow control.

Details on PSCU operation are given in [7].

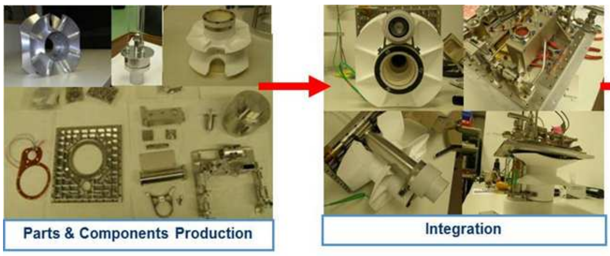
III. HEMPT Assembly Verification Status

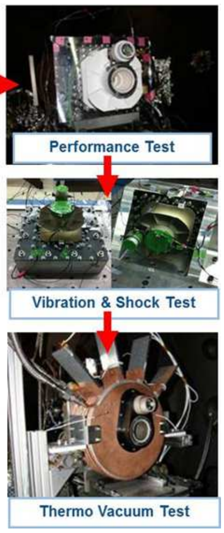
The HEMPT Assembly and its constituents have been extensively verified versus the SmallGEO requirements. Besides the operational and performance characteristics general compatibility aspects with the platform design have been addressed.

A. Performance and Environmental Verification of the HEMPT Module

The performance requirements were verified on component level; after successful verification component integration into the HEMPT Module was performed followed by verification on Module level. As most recent step the HEMPT Module Engineering Qualification Model EQM has successfully undergone performance, mechanical and thermal vacuum testing. In parallel, a HEMPT Module Engineering Model EM has been subjected to a 4800h endurance test which represents the required mission life time. Qualification activities of the neutralizer cathode versus the fairing environment of the launcher are currently ongoing.

Photographs and figures of the assembly and the results of performance and environmental of the HEMPT Module EQM are given in Figure 4. The table indicates that all major performance characteristics are met. In addition the HEMPT Module has shown unchanged characteristics after both mechanical (i.e., vibration and shock) and thermal vacuum testing to qualification levels.





Quantity/Unit	Req.	Test Value	Compl.
Thrust	≥ 44 mN	44.9 mN	Y
Thruster power	≤ 1380 W	1370 W	Y
Neutraliser discharge power	≤ 42 W	16.3 W	Y
HTM specific impulse (=v/g)	≥ 2300 s	2474 s	Y
Mechanical Load Sine Vibration	20 g	20 g	Y
Mechanical Load Random	0.5 g^2/Hz	11.6 g rms	Y
Mechanical Load Shock	2000 g	max. 3500 g	Y

Figure 4: Photographs of the HEMPT Module EQM and performance verification table.

In order to identify possible life time limiting effects prior to start of life time qualification and flight hardware production, a 4800h endurance test called Endurance Test ET1 has been performed with a HEMPT Module EM[14]. The components of this module had the same design as those of the EQM, only the harness rooting was different and not EMI representative. ET1 has revealed excellent long-term behavior and unique reliability. As an example no single HEMPT Module induced firing interruption has been observed. Thruster performance degradation induced by a conductive graphite layer from chamber material re-deposition could be avoided by chamber wall material with a sufficiently high vapor pressure.

B. HEMPT Assembly Verification

After performing a series of so-called coupling tests with different development models of both the PSCU and the HEMPT Module, final verification has been performed with the PSCU Elegant Bread Board EBB Model and the HEMPT Module EQM. The PSCU EBB could be fully commanded with the underlying telemetry and telecommanding specification and the HEMPT Module has shown full functionality and performance.

C. Compatibility with the SmallGEO platform

Compatibility verification included analysis of the thruster ion beam impingement effects on the space craft's solar panels and electromagnetic compatibility. In addition possible effects on HET performance induced by the HEMPT magnetic stray field have been investigated.

In all cases, the HEMPT Module has shown full compatibility with SmallGEO:

- Ion beam impingement analysis has shown that less than 3% of the silver strings connecting the solar cells on the panel will have an erosion depth beyond the requirement.

- Electromagnetic compatibility has been verified in course of ESA's EPCOMSIM program performed at Alta Centrospazio, Pisa, Italy. Here the ion beam of a HEMPT Module EM has been fired cross to the antenna beam using the representative EM antennas and reflectors implemented in Alta's large vacuum testing facility. As a result neither attenuation nor phase shift of the antenna signal has been found.
  An additional EMI qualification campaign recently has been performed at Aerospace Corp., Los Angeles, U.S. Final data evaluation is still undergoing but first statements from OHB indicate that the radiated levels are compliant with SmallGEO's payload operation.
- In course of a dedicated test campaign at Aerospazio, Siena, Italy, operation and performance of the SPT-100 have been investigated in the magnetic stray field of the HEMPT 3050. No degradation or change of characteristics has been found.

In summary all relevant compatibility aspects of the HEMPT Assembly with the SmallGEO platform could be successfully verified.

IV. Conclusions

TEDG has further developed its HEMPT technology to set up a reliable and cost effect ion propulsion system. Supported by German Space Agency DLR through the HEMPTIS project, a HEMPT Assembly has been set up which shall have its first flight on OHB's SmallGEO platform.

So far essential operational, performance, environmental and life time requirements could be verified on EM and EQM level. Currently the HEMPT Assembly Critical Design Review CDR is in its close-out phase, the HEMPT Module Qualification Models are in their final production sequence and flight hardware production on piece part level has been initiated.

Next steps are the successful close out of the CDR, the start of the HEMPT Module life time qualification and finally the delivery of the HEMPT Assembly Flight Unit to OHB.

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