Electric Propulsion Electronics Activities in Astrium Germany

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Electronic equipments for electric propulsion systems have been built by Astrium over many years. Main contributions have been made to the programs EURECA, GOCE, and AlphaBus. This has formed the basis for the development of "Generic High Voltage Power Supply – Next Generation" (HVPS-NG) providing a "tool box" of functional blocks and modules – with a very efficient high voltage converter as core element. By selecting from the choice of functional blocks, the specific requirements of a thruster type can be easily accommodated. An overall efficiency of 97% at 1,000 V operating voltage and 1,400 W power has been demonstrated for a Generic HVPS together with a HEMP3050 plasma thruster in a common vacuum test. The qualification of complete propulsion electronics is going to be performed by a flight opportunity in a German On-Orbit Demonstration Program on-board the innovative German telecom platform SGEO. This platform will give the prospect to provide tailored versions of the HVPS to other electric propulsion systems onboard. A derived development – a high voltage power supply for a µN-RIT – is currently being designed and is considered to have an on-orbit verification opportunity by the ESA mission PROBA-3.

I. INTRODUCTION

For European space missions the importance of electric propulsion is increasing strongly. The initial drivers for this growth are the ambitious space programs of the European Space Agency and the national European space agencies – explicitly by the German Space Agency (DLR). In addition, Electric Propulsion is getting more and more accepted by European commercial satellite manufacturers. Germany's space industry, especially Astrium, being part of the EADS company, is playing a major role in development and provision of Electric Propulsion Technology (Astrium ST: RIT & FEEP) and dedicated Electronics for Electric Propulsion by the business unit Satellites of Astrium GmbH, Friedrichshafen.

In Europe several space missions have been flown with Electric Propulsion, for example the

- EURECA Platform
  European **RE**trievalbe **CA**rrier, transferred to space in 1992 by the Space Shuttle STS-46 and captured in 1993 by STS-57, carrying a RIT electric propulsion system.
- ARTEMIS Satellite
  Advanced **R**elay **Te**chnology **Mis**sion, a telecom satellite, was launched 2001 on an Ariane 5, carrying two supplementary electric propulsion system: a RIT and a T5 Kaufman Ion Thruster (UK).

- SMART-1 Mission
  Europe's flight to the moon with a "small probe" (2003-2006) moved by electric propulsion only, Hall Effect Thruster.

The following missions are in preparation:

- GOCE Mission
  the **G**ravity Field and Steady-State **O**cean **C**irculation **E**xplorer mission, with an ion thruster as main engine, to be launched in 2008.
- LISA Pathfinder Mission
  a technology demonstrator for the LISA mission, using a FEEP for high dynamic, low thrust
- AlphaBus/AlphaSat Mission
  a telecom technology demonstrator with electric propulsion (plasma thruster and/or ion engines)
- BepiColombo Mission
  Flight-to-Mercury mission with electric propulsion (RIT or Kaufman ion engine)

In the future, various mission are considering electric propulsion or have decided for it: LISA (FEEP), PROBA3 (µN-propulsion), MTG (MeteoSat Third Generation) and XEUS (Space Telescope).

In addition, a new innovative telecom platform "SGEO" is planned to be equipped with EP for direct injection into geostationary orbit. An option without chemical propulsion, featuring an EP apogee engine is under consideration.

European electric propulsion engines are developed for example by the companies ASTRIUM (RIT, µN-RIT, FEEP), SNECMA (Hall Effect Thruster), QinetiQ (Ion) and Thales (HEMP). About Astrium´s contribution of electric propulsion electronics is reported in the following.

II. ELECTRONICS OVERVIEW

Program/ Project	Max. Voltage	Power	Thruster Type & Manufacturer	Year of Delivery	Customer
RITA	1000 V	500 W	RIT Ion Thruster of Astrium Space	1998	ASTRIUM
GOCE MPE	13 kV	10 W	FEEP of ARCS Seibersdorf	2003	Austrian Aerospace
GOCE IBCV	1200 V	520 W	Ion Thruster T5 by QinetiQ	2003 .. 2005	ASTRIUM-CRISA
Advanced FEEP	13 kV	10-100W	FEEP of ARCS Seibersdorf	2003 .. 2005	Astrium internal
AlphaBus Eng. Model	2000 V	4800 W	Ion Thruster T6 by QinetiQ	2004	ASTRIUM-CRISA
HEMP HVPS Demonstrator	1200 V	1300 W	HEMP Thruster by Thales	2005	Thales (Germany)
GENERIC HVPS NG	1000 V... 15 kV	10 W- 5 kW	Thruster independent development GENERIC HVPS Next Generation	2007	German Space Agency (DLR)
German On-Orbit Verification for HEMP EPS on SGEO	1000 V	5 kW	HEMP Thruster by Thales	2008/09	German Space Agency (DLR) and ESA
„µN-RIT" HVPS Elegant Breadboard	1000 V ... 2000 V	100W	"µN-RIT"/ "RIT-µx of University of Giessen/ Astrium ST	2007-2008	German Space Agency (DLR) and Univ. of Giessen and ESA

Table I-1- Key Data of for Electric Propulsion Power Electronics Developments at Astrium
(yellow shaded: current developments)

The Table 1 gives an overview of Space Missions, where Astrium has made contributions to Electric Propulsion Electronics in the fields of power processing including control, power conversion and high voltage power supplies. Some key data of such equipments are listed in the Table II-1.

RITA:

Early developments have been completed for RITA, a power system for the RIT thruster, flown with the EURECA platform.

GOCE:

A first big step in EP electronics has been made in the frame of the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) mission, which is dedicated to measuring the Earth's gravity field and modeling the geoid with extremely high accuracy and spatial resolution. The advanced drag compensation and attitude-control systems is a key feature required to keep the sensor heads in near 'freefall motion' and to maintain the average orbital altitude at about 250 km. The system is based on ion-propulsion technology. The mission is planned to be launched into orbit in mid 2008.

Two EP electronics developments have been made for GOCE: A high voltage power conditioning module for a FEEP subsystem (Field Emission Electric Propulsion) providing 13 kV for a total of 96 micro-Newton thrusters.[1] A demonstrator was built, but the later selection was favoring a conventional cold gas thrusters instead FEEP – see Fig. II-1.

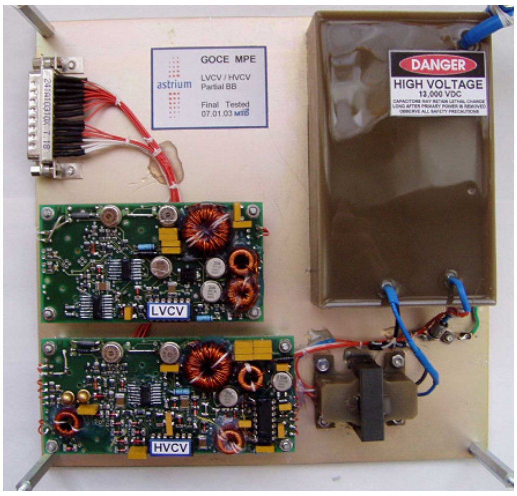

Fig. II-1: Breadboard of a 13 kV High Voltage Module

The other – today ready for flight - Ion Propulsion Assembly (IPA) provides variable thrust in the range of 1.0 to 20 mN for compensation of the atmospheric drag force in the satellite flight direction during measurement phases. In addition, the IPA supports the gradiometer calibration and satellite maintenance phases by providing sufficient thrust for orbit raise maneuvers and atmospheric drag compensation. The thruster is the T5 Ion Engine manufactured by QinetiQ (UK). Astrium has provided the Ion Beam Converter (IBCV), supplying the main power of the thruster.[2]

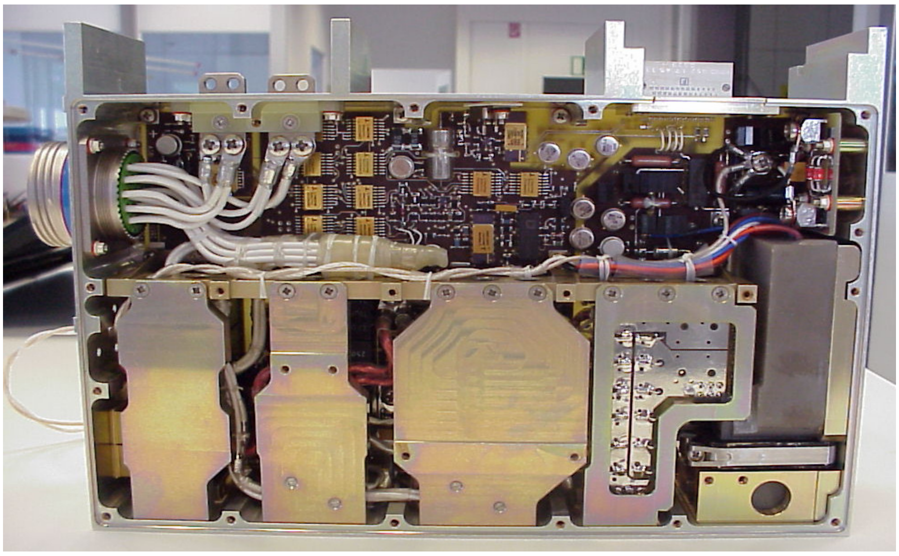

Fig. II-2: View of open box of an on Beam Converter Module, including Low and High Voltage sections - Mass: 3.4 kg

The module is shown in Fig. II-2. The IBCV receives low voltage (22-34 V) DC power from the unregulated primary power bus via an upstream LCL (Latching Current Limiter) and delivers isolated high voltage (nominally 1176 V) DC power to the anode of the Ion Thruster Assembly. The overall efficiency is between 90% and 94% for loads from 190 W to 420 W. The accuracy at end of life conditions (EOL) is better 0.2%.

LISA Pathfinder:

Astrium has outlined a subsystem design and a power processing unit in early project phases and is now responsible for the electrical design of the Indium FEEP thruster in the frame of the LISA Pathfinder Mission. [3]

AlphaBus:

AlphaBus is the new large communication satellite platform initiated by the European Space Agency (ESA). The platform is featured with high-power electric propulsion based on SNECMA's Hall Effect Thruster and QinetiQ's T6 Kaufman gridded ion engine (option). This high-power design offers efficient satellite station-keeping, orbit-topping as well as end-of-life de-orbiting.

In the frame of the AlphaBus development, Astrium was involved in power supply development since 2004. As a part of the propulsion assembly, Astrium contributes the ion beam converter unit (IBCV) required for supporting the electrical field for ion acceleration. The IBCV is part of the Power Supply and Control Unit (PSCU) supplied by Astrium CRISA.

The demonstrator delivered to the project provides up to 1850 V and 4625 W max from a regulated 100 V bus[4].

AlphaBus will be transferred into the AlphaSat as a flight program. Accompanying developments of a high voltage converter are performed in the frame of activities with “Generic High Voltage Power Supply – Next Generation (HVPS)” - an R&D program detailed below-

HEMP:

During AlphaBus development, EADS Astrium has derived a single-module to supply the grid-less HEMP thruster – a new thruster development by THALES in Ulm (Germany). While the module power was increased to 1200 W, the output voltage was changed to 1250 V. Besides that, a second output channel providing 700 V was added. This supply operates successfully with the HEMP 3050 thruster without need for an additional filter unit as some other thruster types may require.

For coming missions equipped with the HEMP thruster, power supply modules are derived from the Generic HVPS development – as detailed below /[4,5,6]/.

Generic High Voltage Power Supply – Next Generation

Generic High Voltage Power Supply (HVPS) – Next Generation – is a response to the growing number of applications for electric propulsion (EP). Major design goal for the “Generic HVPS – Next Generation” development is the improvement of power conversion concepts. The result is the introduction of a modular converter concept, which provides scaleable power and voltage. Instead of using converters of different topologies and heritage, in the future different power requirements are covered by assembling the appropriate number of functional blocks. This approach will lead to a reduction of the recurring costs by minimizing the need for different kinds of power components and mechanical parts. More details are outlined below.

uN-RIT:

Further upcoming mission are high precision thrusters for formation flying, like Proba-3 and XEUS. As a consequence, very fine adjustable thrusts at typically low levels in the micro-Newton range are needed. A promising approach for meeting such thrust requirements is the use of µ-Newton electric propulsion, based on Field Emission Electric Propulsion (FEEP) thrusters or µN-RIT (Radio Frequency Ion Thrusters).

A solution, the called RIT-µX is developed by Astrium ST and is based the well known “large” RIT technology of University of Giessen and Astrium ST.

A development of an electronics providing negative and positive high voltages up to 1.2 kV and a few ten watts of power is currently funded by the German Space Agency an will lead to a demonstrator ready in mid 2007. [7]

A candidate for flight of µN-RIT is the PROBA3 mission of the European Space Agency, a technology platform for a LEO earth observation mission.

Future Programs:

Several actual and future satellite projects of the European Space Agency (ESA) have established challenging requirements for high accuracy in positioning (LISA mission), in pointing (DARWIN mission) or long duration flights (BepiColombo mission to Mercury). Flexible “building blocks” for electronics forming power processing units, power control & supply units, or single high voltage converters and controller are well established technologies available in Astrium in Germany.[8]

III. THE GENERIC APPROACH

Generic High Voltage Power Supply (HVPS) – Next Generation – is an R&D program funded by the German Space Agency (DLR). Major design goals of the activities are:

- the improvement of power conversion concepts
  in order to achieve power conversion efficiency, to reduce complexity, mass and costs.
- implementation of a modular approach with dedicated control strategies, enabling combination of modules to fit to various power demands
- common functional blocks
  in order to allow variants without missing the advantage of the generic approach.

The program has resulted into the introduction of a modular converter concept, which provides scaleable power and voltage. Due to the actual needs of various EP subsystems the development program has been focused on two application scenarios:

- Generic HVPS NG “OPTIMUM” providing highest efficiency at fixed input and output voltages
- Generic HVPS NG “MULTI-RANGE” covering high efficiency at various output voltages and/or variable input voltage

Both applications are leading to slightly different generic HVPS modules with a high degree of common functional blocks.

In addition, the Generic HVPS is supplemented by building blocks of:

- TM/TC interfaces acc. to MIL-STD 1553 or UART
- Control of the thruster operation on command from the on-board computer
- Acquisition of analog and digital status signals from the modules
- Provision of the telemetry data as a serial data stream on command from the on-board computer
- Generation of auxiliary supply voltages for the data interface modules and all electronics requiring secondary power in the PCDU
- On/off control of the auxiliary converter on discrete commands from the on-board computer

The “OPTIMUM” Concept

Major design goal for the Generic HVPS – Next Generation “Optimum” was the development of a power conversion concept with highest efficiency at fixed input and output voltage. The single stage topology was chosen as baseline to minimize conversion losses and to reduce number of components.

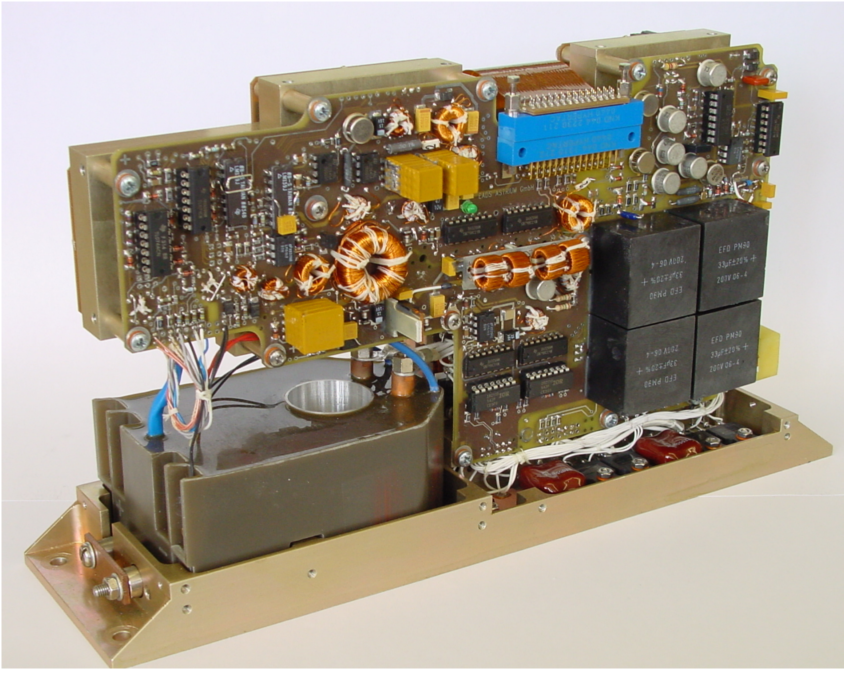

Fig. III-1 Mechanical Outline of a High Voltage Power Supply Module “Optimum”

An engineering model (EM) of the Generic HVPS NG “OPTIMUM” has been built and tested (see Fig. III-1). Since the generic concept is scalable, the output and input voltage for this EM are reflecting “typical” requirements of a high power thruster:

- Input Voltage: 100 V +/-2V (regulated power bus)
- Output Voltage: 1000 V
- Maximum Output Power: 1400 W
- The mass of the complete module including baseplate is 2900 g for the converter
- The dimensions are: Footprint 300 x 96 mm2 , Height 160 mm
- The resulting mass to power ratio is about 2 kg/kW
- An overall efficiency above 97% power levels from 700 W to maximum power (1400 W) was demonstrated

The EM was tested under ambient conditions and in thermal vacuum. A 48 h vacuum test was successfully performed together with a HEMP 3050 thruster of Thales verifying the generic approach and was allowing an electric and thermal characterization.

The Generic HVPS “OPTIMUM” provides a single stage, controllable concept with high efficiency due to rectangular currents and low switching frequency. The dynamic behavior of the converter was analyzed by a control system model and stable operation was proved for different load dynamics. Mass savings are achieved due to comparatively small filter capacitors and inductors.

The “MULTIRANGE” Concept

The single stage concept achieves highest efficiency at fixed (regulated) bus voltages and at constant output voltages. On the other hand, some thruster applications require operation at variable bus voltages or have to drive thrusters in different operating modes. As a consequence, the single stage concept needs to be extended by an additional stage, without changing the majority of the functional blocks from the “OPTIMUM” concept.

A promising topology offering a higher efficiency and a simple control loop design is the 'DC output series connected converter' as shown In Fig. III-2. It comprises two converters:

A main converter is delivering the major part (80%-90%) of the output voltage and a small, controllable converter is used to complete the required amount of output voltage.. While the small converter is also directly supplied from the power bus, at the output side, it is switched in series to the main converter. The overall efficiency is mainly determined by the single stage main converter. Only a small portion of the power needs to be converted by the Push-Pull regulator. Other alternatives are currently studied.

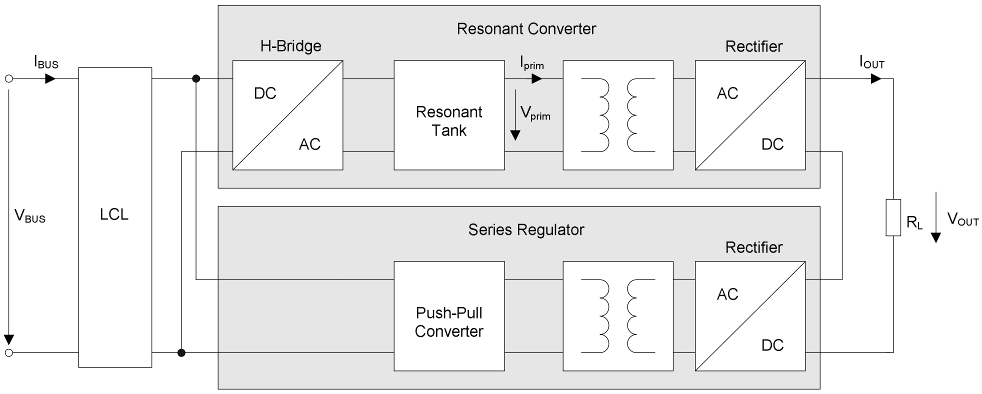

Fig. III-2 Block Diagram DC-Output Series Connected Converter

IV. ON-ORBIT DEMONSTRATION

SGEO is a European platform for small geostationary satellites, which is going to be developed by OHB-System AG (Bremen, Germany) for the European Space Agency (ESA) within the funding program ARTES-11. SGEO has been designed as an optimum platform for communications payloads, providing up to 3 kW payload power. The first satellites are to be placed in orbit in 2010.

Within this new satellite program, it is planned to integrate two or more electric propulsion systems on the spacecraft, as main engines and as supplementary engines to provide an On-Orbit Demonstration opportunity. The selection of engine types has not been completed, but as main candidates the Snecma PPS1350 (Plasma Thruster, Snecma, France), the RIT10 (Astrium ST, Germany) and the QinetiQ T5 (Ion Thruster, QinetiQ, UK) are considered.

In addition, it is intended to fly the HEMP3050 (Plasmathruster, Thales, Germany) in frame of an On-Orbit Demonstration program directly funded by the German Space Agency DLR and placed on SGEO. As outlined in Fig. III-3 the power supply and control unit is proposed to consist of

- 3 Generic HVPS-NG Modules supplying the anode voltage
- 4 Neutralizer Keeper Supplies
- 4 Flow Control Units (FCU)
- 2 Command Interfaces and Control Units
- 8 Current Sensors

in order to control 4 HEMP Thrusters.

The Generic HVPS-NG topology is the single stage converter ('OPTIMUM') with 97% efficiency at fixed output voltage 1000 V and a maximum power of 1400 W.

Furthermore, since the HEMP On-Orbit Demonstration system is supplementary to the above mentioned other electric propulsion systems, the Generic HVPS-NG module can be provided as building blocks to the power processing units of the main EP-systems. This is enabled by the generic approach of the power supply developments.

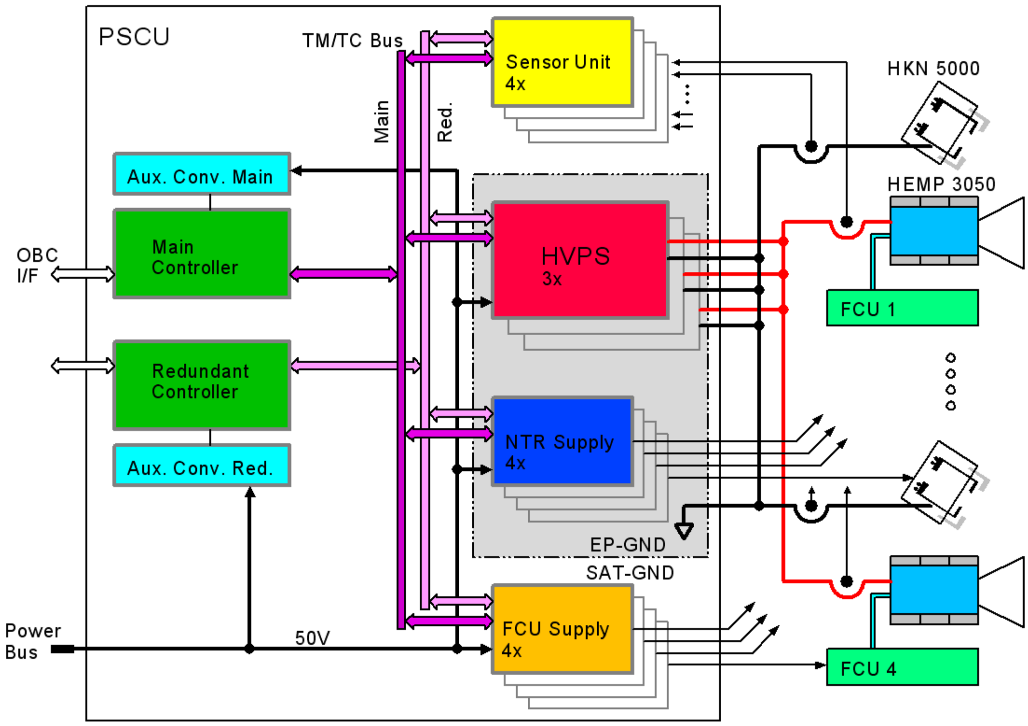

Fig. III-3 Block Diagram of a Power Supply and Control Unit for Servicing 4 HEMP 3050 Thrusters onboard a SGEO Satellite (Proposed Concept)

V. CONCLUSIONS

The heritage in building power electronics for electric propulsion systems for the space missions EURECA, GOCE, and AphaBus has formed the basis for the development of "Generic High Voltage Power Supply Module" and related functional blocks and module. By selecting from a choice of functional blocks, the specific requirements of a thruster type can be easily accommodated. For the core element of EP electronics, a new approach of converter design has been introduced. The so-called "OPTIMUM"-Converter allows high voltage generation in a single stage by using an innovative single stage converter principle in order to reduce the mass to power ratio, increases the power conversion efficiency and to ensure a robust voltage control loop. In combination with new Silicon Carbide Diode technology an overall efficiency 97% has been demonstrated in a thermal vacuum test together with a HEMP3050 thruster. The single stage concept achieves highest efficiency at fixed bus voltages and at fixed output voltages. Since some thruster applications require the operation at variable bus voltage or have to drive thrusters in different operating modes, the single stage concept is to be extended by an additional stage, without modifying the majority of the functional blocks from the "OPTIMUM" concept. Concept implementation is currently ongoing.

Next steps are the qualification of the Generic HVPS in connection with a flight opportunity in a European On-Orbit Demonstration program on-board the innovative telecom platform SGEO. This platform may also give the opportunity to provide tailored versions of the HVPS also to other electric propulsion systems onboard.

Other first flight opportunities might be given by the European space missions AlphaBus, BepiColombo, or commercial Telecom Missions. A derived development – a high voltage power supply for a µN-RIT – is currently designed and might have an on-orbit verification opportunity within the ESA mission PROBA-3.

VI. REFERENCES

1. M. Gollor, K. Breier, „Compact High Voltage Power Conditioners for Field Emission Electric Propulsion (FEEP)", Proceedings of'Seventh European Space Power Conference', Stresa, Italy, 9-13 May 2005 (ESA SP-589, May 2005)
2. M. Gollor, M. Boss, et. al. : "Generic High Voltage Power Supply with High Efficiency for Electric Propulsion" 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Sacramento, California, July 2006
3. M. Gollor, K. Breier "Compact High Voltage Power Processing For Field Emission Electric Propulsion (FEEP)", 29th International Electric Propulsion Conference, Princeton University,2005, IEPC-2005-276
4. M. Gollor, M. Boss, et. al. : "Generic High Voltage Power Supply – Next Generation" 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Cincinatti, Ohio, July 2006
5. N. Koch, H.-P Harmann and G. Kornfeld, "Development and Test of the THALES High Efficiency Multistage Plasma (HEMP) Thruster Family" Proceedings of the 29th International Electric Propulsion Conference, Princeton University, October 31 – November 4, 2005 - IEPC-2005-297
6. G. Kornfeld, N. Koch, H.-P. Harmann, P. Micheli, H. Meusemann, E. Gengembre: „High Power HEMP-Thruster Module, Status and Results of a DLR and ESA Development Program", 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Sacramento, California, July 2006, Paper AIAA 2006- 60150
7. M. Gollor, M. Boss „Micro-Newton Electric Propulsion Subsystems for Ultra-Stable Platforms" 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, July 2006, Sacramento, California, Paper AIAA 2006-4825
8. H. Meusemann, M. Winter et. al. „Electric Propulsion in Germany: Current Program and Prospectives" Proceedings of the 29th International Electric Propulsion Conference, Princeton University, October 31 – November 4, 2005, IEPC-2005-130

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