Airbus Defence and Space Power Processing Units: New HET and GIT PPU developments Qualification Status

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I. ABSTRACT

Three major technologies are available on the market: HET, GIT and HEMP. Airbus Defence and Space – Space Equipment has developed PPUs for these three major technologies in order to answer all potential customer needs: Thrust to power ratio versus ISP driven. This paper presents the Power Processing Units in Airbus DS Space Equipment, describing the different products available with special focus on the new developments. Several new designs covering all technologies are being carried out internally in Airbus DS Space Equipment. This paper presents the development status of the new designs, presenting the different architectures, product features, and qualification status, making emphasis on the main performances achieved and demonstrated by test during the qualification test campaign. Three major designs are being carried:

- **PPU for HET (Elektro).** PPU developed to support 5 kW HET thrusters. The development has been concluded. Major product features and qualification test results are presented in this paper
- **PPU for 5kW T6 GIT**: Industrialised PPU for 5 kW T6 thrusters. Major features and development status are presented.
- **PPU for 5kW RIT-2X GIT**: New development for 5 kW RIT 2X thrusters. Major features and development status are presented
- **High Voltage Power supply (HVPS)**: This is the common building block for high voltage thruster technologies in particular used for RIT 2X and T6 PPUs new developments. Development status will be presented.

II. Motivation

Several EP technologies are competing against each other, in particular Hall Effect Thruster (HET), Gridded Ion Thruster (GIT) technology and High Efficiency Multistage Plasma (HEMP).The main two parameters used to trade-off the main EP technologies are Power/Thrust ratio and Specific Impulse (ISP).

The electric propulsion business case is driven by current technologies, operator's mindset, and future trends. Airbus DS Space Equipment has developed PPUs for all major technologies, to answer to these major parameters. Hence, Airbus DS Space Equipment is evolving their current PPU products covering all the different technologies in the market to answer to the short, mid and long term market needs: PPU for HET (Elektro), PPU HV for high voltage

technologies developing and a common building block for High Voltage Power Supply.Figure 1 illustrates the PPU mapping with respect the main EP technologies in the market:

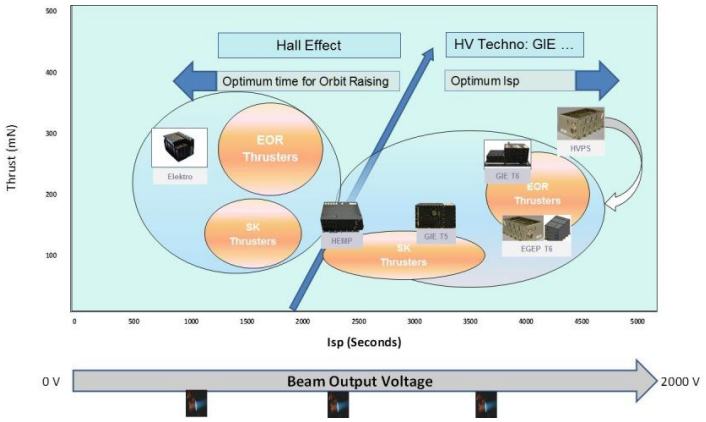

Figure 1 Airbus DS PPU activities to answer to the different Electric Propulsion Technologies

III. PPU Heritage

A. PPU for T5

The PPU for the QinetiQ T5 thruster, the so called IPCU has been developed by Airbus DS and successfully flown in the ESA GOCE mission. This unit was meant to be used for low power missions, operating in very low Earth Orbit (LEO), mainly for earth observation purposes. Refer to Figure 2

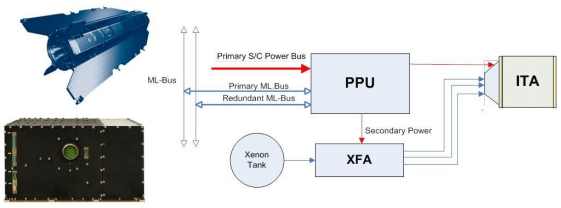

Figure 2 Airbus DS PFM IPCU for T5

B. PPU for T6

The PPU for T6 has been developed by Airbus DS in the frame of an ESA programme. This unit is the first 5 kW PPU ever developed in Europe, able to answer to the new full electric satellites needs for the Telecom market and the most demanding deep space missions. The first flight mission for the so-called PSCU will be ESA BepiColombo mission to Mercury.

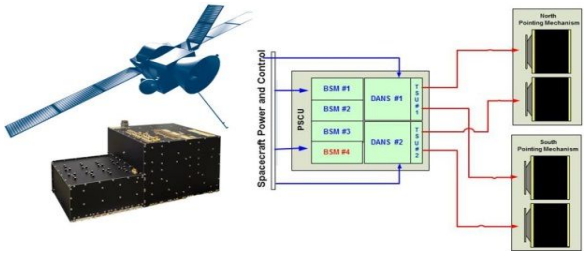

Figure 3. Airbus DS EQM PSCU for T6

C. HEMP PPU

Airbus DS has developed the PPU for HEMP thruster, the so-called PSCU. The hardware is fully qualified and is foreseen for a first flight within the German Heinrich-Hertz (H2) mission.

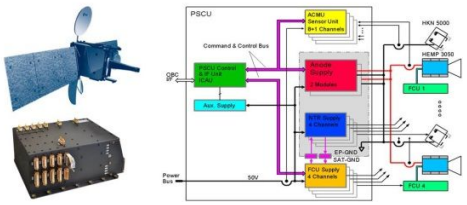

Figure 4 Airbus DS PFM PSCU for HEMP

IV. PPU New designs

A. PPU ELEKTRO for HET

1. ELEKTRO PPU Objectives

The PPU Elektro motivation is to respond to Satcom market towards full Electrical Propulsion solutions, capable to perform Station Keeping manoeuvres, Orbit Raising and transfer.

Airbus DS Space Equipment initiated the ELEKTRO PPU development with the following main objectives:

- ✓ Cost driven design but with the quality class required by the Satcom markets
- ✓ Flexible design able to drive one or several thrusters
- ✓ In-flight programmable operating points from 300V to 400V (in order to optimize ISP vs thrust)
- ✓ Compatible to all main HET thrusters: (PPS-5000, SPT140-D, XR5)
- ✓ Flexibility to change thruster parameters and operation in flight
- ✓ Excellent efficiency over the complete voltage range
- ✓ Power bus internally protected by active fuse, no need of external protections.

Figure 5 Airbus DS PPU Elektro for HET

2. ELEKTRO PPU Description

The Elektro PPU embeds all the supplies required to operate 5kW-class Hall Effect Thrusters. It can be operated through different modes of operations:

- ✓ Automatic mode. The sequencing of all supplies is managed automatically by the PPU, in particular for start-up and shut-down phases.
- ✓ Remote mode, which allows controlling all supplies independently.

It has been designed for 100V input power bus, but can be easily adapted to other voltages. It communicates with a platform through a 1553 bus. Elektro PPU is physically implemented in three main building blocks: Heater-Keeper-Ignitor module (HKI), anode module and Filter thruster switching unit (FTSU) as follows:

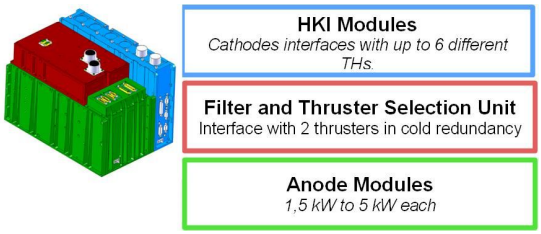

Figure 6 Airbus DS PPU "Elektro" Building Blocks (5 kW configuration)

Elektro implements an innovative architecture in order to get the most optimum figures for cost, mass and volume.

All functions which are not used permanently in the subsystem (Cathodes Power Supply: Heater, Keeper and Ignitor and sequencing of the overall PPU) are gathered in a module called HKISeq. This module is able to address up to 6 cathodes.
All other functions (Anode 5kW power supply, Magnet and Xenon Flow Control supplies) are gathered in the module called Anode module. The Filter/Thruster Switching Unit (FTSU) modules are used to filter and switch the Anode power supplies towards 2 thrusters.

The electrical architecture is presented in figure 7.

Elektro PPU architecture enables two different configurations of the PPU:

- Bi-thruster configuration: Able to interface with up to two thrusters
- Multi-thruster configuration: Up to six cathodes, offering redundancy at PPU level

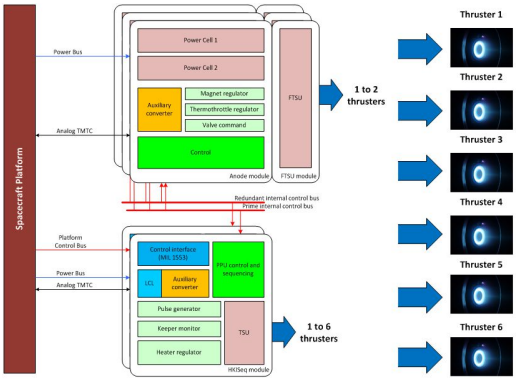

Figure 7 Airbus DS "Elektro Architecture

3. Elektro PPU development

The Elektro PPU development started with co-engineering phase, taking into consideration system needs and available HET thrusters in the market. The main goal was to select the best electrical, mechanical, architectures, packaging and technological solutions in order to propose the most competitive product.

The PDR was held in September 2014. To reach this development gate, a complete breadboard has been built to demonstrate the main principles of the Elektro PPU. It has been coupled with the SPT140D Fakel facilities (Kaliningrad - Russia) in Q1 2014 and then with the PPS5000 in Safran facilities (Vernon - France) in Q2 2014.

After the PDR, an Engineering Model, fully representative (fit, form, function) to the future flight models has been designed. EM has been designed for the various configurations described in the previous paragraph. A delta validation of the multi-thruster version is scheduled following the qualification of the bi-thruster version in 2018.
The EM models have demonstrated the functionality and performances as expected. Test results obtained demonstrate an excellent efficiency under the complete output voltage range (> 95% @ 300V)

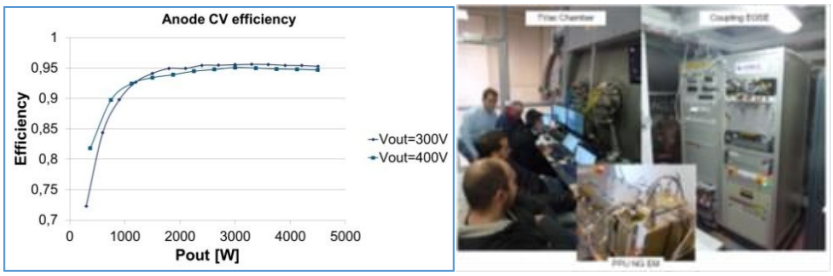

Figure 8 - Airbus DS PPU Efficiency figures & coupling tests

This EM has been successfully coupled with a SPT140D in Aerospazio facilities in January 2016. The CDR was held successfully in September 2016.

Following this phase, the manufacturing of the EQM has been released and the qualification held from May to August 2017. The following paragraph presents the qualification in details.

4. Elektro PPU QUALIFICATION

The Elektro PPU EQM is fully representative to the Flight model. The EQM has been instrumented internally and externally with a significant number of sensors in order to monitor: temperatures, vibration levels and pressure inside the modules. This has allowed to successfully correlating all PPU analysis.

It has been successfully submitted to a full qualification campaign including the following tests:

- Preliminary electrical tests (including bonding, isolation, electrical and functional tests)
- Mechanical environment : Sine and random vibrations and shocks along the 3 axes
- Thermal Vacuum tests: 1 OFF and 9 ON cycles with cold starts and full electrical performance tests at hot and cold temperatures. Moreover, some delta tests in temperature have been performed in order to tune the thermal model.

Figure 9 - Elektro PPU EQM with its instrumentation

This thermal vacuum test allowed also demonstrating the capability of the PPU Elektro to operate at partial pressure without electrical discharges which may occur with high voltage units. Indeed, 2 corona tests have been performed at 2 Pa with EOR and Station Keeping operating points.

The PPU internal pressure was measured during the depressurization of the thermal chamber and during the first switch ON. Internal outgassing of the PPU is very quick, allowing switching ON the HV of the PPU in less than 1h30 including margins.

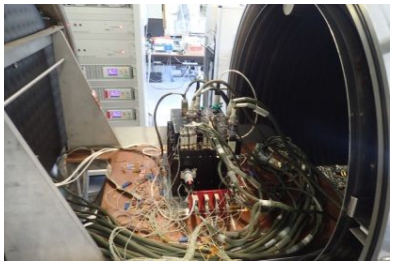

Figure 10 - Elektro PPU EQM in the thermal chamber

- Full EMC campaign including conducted emission and susceptibility, radiated emission and susceptibility and ESD tests. In particular, the good behaviour of the PPU has been checked with injections simulating the worst case behaviour of the thruster.
- Final electrical tests

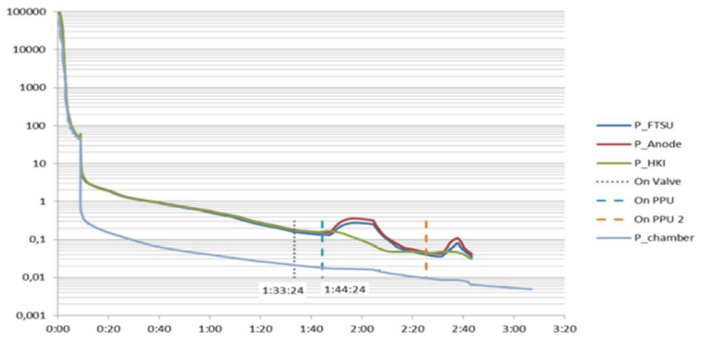

Figure 11 - Elektro PPU EQM first depressurization

All these tests were passed successfully from May to August 2017.

Two coupling tests are now scheduled with the Elektro PPU EQM:

- First with SPT140D in Aerospazio facilities in November 2017
- Second with PPS5000 in Q1 2018.

Currently, Flight Models manufacturing has been started. First FM will be delivered first half of 2018. Twelve Elektro PPUs have already been ordered by primes in Europe and USA.

B. PPU for GIT-T6 - New Generation PPU

Airbus DS currently performs an industrialization of the former design for the QinetiQ T6 thruster. Existing PPU has been successfully qualified and two flight models delivered to support BEPI EP system. The next development step has focused on the industrialization and optimization of the PPU in order to enable it to compete in the navigation and telecom markets.
This evolution is being performed in the frame of the European GNSS Evolution Program (EGEP) targeting Galileo Second Generation platform as the first customer to implement the evolved EP system based on T6.

The evolution of the PPU has taken into account the inputs coming from:
- ✓ the analysis of cost drivers of BEPI PPU development
- ✓ the lessons learnt along BEPI development
- ✓ the review of those requirements that were identified as critical for BEPI PPU development

The major objectives for the new EGEP PPU design are:
- ✓ Strong reduction of recurring cost, this is the major goal
- ✓ Keep the Technology Readiness Level (TRL)
- ✓ System flexibility: The new PPU design allows a greater system level flexibility, so that with minor (or none) unit adaptations it would be possible to configure different system architectures.

In order to get the flexibility goal pursued the PPU has been redesigned as two sub-units:
- ✓ The DANS built off four modules:
  - Power Conditioning Module
  - LV Control Module
  - LV Power Module
  - HV Electronics Module
- ✓ The Beam Supply (BS) based on the common building block concept, HVPS

The DANS together with the BS and the harness connecting both sub-units built off the complete PPU.

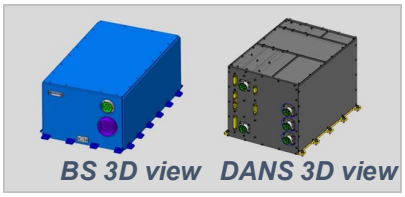

Figure 12 EGEP PPU

This configuration allows expanding the unit to connect two or three thrusters increasing the number of DANS but not BS modules as far as only one of the thrusters is powered at full power or two of them are powered simultaneously with at half power each, as shown in figure below.
Additionally this system allows distributing the power dissipated by the PPU in different platform allocations by separating the DANS and BS as the distance between them is not constrained by the design.

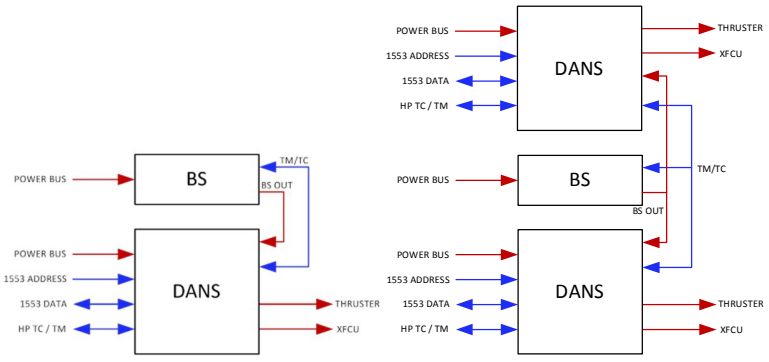

Figure 13 EGEP PPU System Configs

The EGEP PPU is capable of operating with a high degree of autonomy. In particular, it is capable of starting up the thruster (and XFCU) ramp up the thrust to the required level and then maintains it at that level. Furthermore, it is able to deal with beam events without requiring intervention from system level. Additionally, the implementation of control sequences allows for as much flexibility as is practical to ensure that the propulsion system can operate throughout life.

For operation in dual thruster configuration it is also provided the means required to start-up both thrusters synchronized without the need of system intervention

The expected improvements/design goals expected with respect to former design are: Mass and volume reduction , EEE parts reduction and Power Dissipation reduction.The mass of the complete PPU including one DANS, one BS and the interconnection harness between them is 22 kg and the efficiency 95%.

The design phase is finished and EM under manufacturing. EM PPU delivery is expected in 2018

C. PPU for GIT-RIT 2X - New PPU

Strongly based on the existing design heritage, Airbus DS currently develops a new PPU design for high power RIT-2X applications. The 5kW PPU design aims at full electric geostationary satellites. It covers the complete performance range necessary for orbit raising and station keeping.
The design is specifically optimized for the latest RIT-2X thruster developed and built by Ariane Group. The major design objectives are:

- ✓ Strong reduction of recurring cost. This is the major goal in order to answer to commercial market needs.
- ✓ Full modularity and flexibility to allow easy tailoring to different satellite platforms

Figure 14 RIT PPU

The following building blocks forming one PPU:

- ✓ Interface Control Unit: Providing all internal secondary supplies and forms the communication center for all external (e.g. MIL-1553) and internal communication bus system
- ✓ Neutralizer-Supply (NTR)
- ✓ Negative High Voltage Supply: For Keeper-functionality / ignition, including a grid clearing function
- ✓ Positive High Voltage (PVH) Power Supply: Providing controlled high voltage for the screen grid
- ✓ Radio-Frequency Generator Power supply (RFG PS) is included to power an external RFG which can be specifically adapted to the thruster
- ✓ A Flow Control Unit (FCU) can optionally be added on demand

The PPU for RIT 2X thruster is a new generation concept able to answer to the commercial market trends, in particular:

- ✓ PPU dual mode capability
- ✓ Interfaces two thrusters in cold redundancy. Simplicity avoiding cross-strapping. In the baseline configuration one PPU is able to operate one out of two RIT thruster modules at the same time. Redundancy can be achieved by flying two independent PPUs on one satellite, while a single unit is sufficient to support the mission.
- ✓ Full flexibility to change thruster parameters and operation in flight, if needed. The unit provides a wide set of adaptable protection functions and telemetries that allow a very easy adaptation to each satellite's needs.
- ✓ Grid clearing functionality to remove permanent shorts in grids
- ✓ Power bus internally protected, no need of external protections

Following a successful coupling test between PPU and thruster in early 2017 the qualification of the unit is currently under preparation. Tests performed have successfully demonstrated a High Voltage Power Supply efficiency of 95% average for the complete voltage range.

D. HV Generic Building Blocks: HVPS

The new High Voltage PPU generation for high voltage technologies (GIT, HEMP) will be focused on two main axes:

- ✓ To develop new modular, flexible and cost effective solutions
- ✓ To maximize the communalization or building blocks between the different PPUs for the several technologies.

The development of a new generation of the generic High Voltage Power Supply has been started in order to meet the needs of Orbit Raising applications. The main technology developments and improvements are:

- ✓ Increase of power from 1,4 kW up to 5 kW
- ✓ Modular approach (1,4/2,5/5 kW)
- ✓ Configurable output voltage
- ✓ Design for manufacturing
- ✓ Introduction of new technologies

Generic HVPS development is expected to be concluded in 2018 and widely used for the new High Voltage generation PPUs. HVPS is todays baseline for the on-going developments for Gridded Ion Thrusters: T6 and RIT 2X. The common building block has been a key element in order to maximize the communalities between the different GIT PPUs developments

V. Conclusion

This paper introduces the existing PPU products and the latest status for the new PPU to come in Airbus DS Space Equipment. In particular, it describes HET PPU development, including qualification test results and the latest highlights on the PPU for High Voltage Technologies (Gridded Ion)

Airbus DS Space Equipment PPU portfolio contains solutions for all the Electric Propulsion HET and High Voltage technologies: We continue to innovate our PPU product line as thruster technology and space mission requirements advance. We are committed to support all major thruster technologies (HET, GIT, HEMP) for applications in satellites manufactured in Europe and the United States.

Currently more than 20 PPUs have been contracted by primes in Europe and USA. It includes PPU for the two major technologies, HET and GIT. This reinforces Airbus DS Space Equipment strategy to be able to answer to the short, mid and long term needs