Airbus DS PPU Qualification status for HET, GIT and New Space Technologies

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Fernando Pintó[1] and Raul Velasco[2]
Airbus Defence and Space (Airbus DS Crisa), Torres Quevedo 9, 28760 Tres Cantos, Spain

Eric Guidoux [3]
Airbus Defence and Space (Airbus DS SAS),Rocade Jean Moulin ,Elancourt France

Abstract: This paper presents the Power Processing Units in Airbus DS Space Electronics, describing the existing products and mainly focusing in new developments for HET and GIT with special mention on the latest PPU development for New Space. Four new PPU designs have been developed, two per technology: HET and GIT Thrusters. This paper presents the development status, including product architectures and features, and qualification status, making emphasis on the main performances achieved and demonstrated by test

Nomenclature

DANS = Accelerator-Neutralizer Supplies
BS = Beam Supply
EP = Electric propulsion
FTSU = Filter thruster selection unit
GIT = Gridded Ion Thruster
HET = Hall Effect Thruster
HKI = Heater, keeper, ignitor module
PPU = Power Processing Unit
ISP = Specific Impulse

I. Introduction

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 mind-set, and future trends. Airbus DS Space Electronics has developed PPUs for all major technologies, to answer to these major parameters

1 HO Test and Validation, raul.velasco-valencia@airbus.com
2 HO Test and Validation, raul.velasco-valencia@airbus.com
3 Project Manager PPU HET,eric.guidoux@airbus.com

Airbus Defence and Space – Space Electronics has developed PPUs for the main technologies in the market in order to answer all potential customer needs: Thrust to power ratio versus ISP driven to answer to the short, mid and long term market needs: PPU for 5 Kw HET thrusters (Elektro), PPU for LEO HET below 1 kW and new generation PPUs for Gridded Ion Thrusters. Figure 1 illustrates the Airbus PPU portfolio mapping with respect the main EP technologies in the market.

The main highlights for the new generation existing products are as follows:

PPU for HET, ELEKTRO: Elektro PPU motivation is to respond to Satcom market towards full Electrical Propulsion solutions. It is a new innovative concept of PPU, able to drive up to six different thrusters with one single PPU. ELEKTRO is compatible to the main HET thrusters in the market. The product has been fully qualified in July 2017. Product qualification will be presented, including test results to demonstrate the good behavior of the product.

PPU for LEO applications (< 1 kW): Development status and main highlight for this innovative design will be presented. The PPU so called TOPAZ has been designed to answer to New Space market. It is a full COTS design but keeping quality standards. The main driver is the cost to have a competitive design and being able to answer to the new market trends. TOPAZ has been baselined already for mega-constellations. Latest development status will be presented, qualification and flight model production.

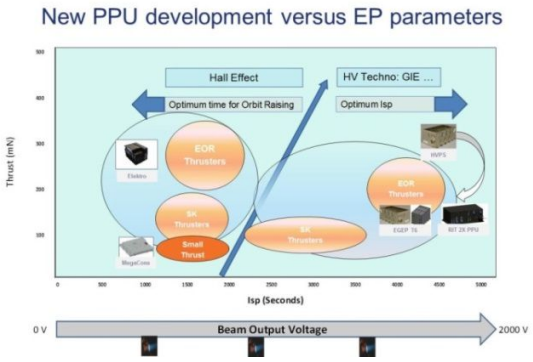


Figure 1. Airbus DS PPU portfolio versus EP Technologies.

PPU for GIT new development covering 5 kW gridded ion thrusters: RIT 2X.and T6/T7. The 5kW PPU designs aims at full electric geostationary satellites. In both cases, PPUs are new generation concepts able to answer to the commercial market trends, in particular: dual mode in voltage to get the optimum performances between thrust to power ratio versus ISP. Product architecture and features will be presented including EQM performance and coupling test results performed with the RIT2X thruster

II. PPU Heritage

A. PPU for T5

The PPU for QinetiQ T5 thruster, the so called IPCU has been developed by Airbus DS Crisa (Spain) and Airbus DS Germany for the beam output supplies. The IPCU has successfully flown in the ESA GOCE mission. This unit is meant to be used for low power missions, mainly for earth observation purposes. The main asset of this unit is the high level of controllability from 0.6 mN to 20 mN with a resolution of 12 μN, with a beam output voltage supply of 1200V. Refer to Figure2

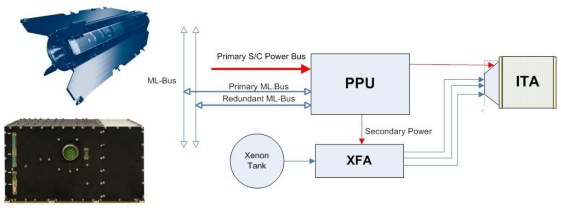


Figure 2 Airbus DS PFM IPCU for T5

B. PPU for T6

The Power Supply and Conditioning Unit, PSCU, has been developed as a parallel contract to AlphaBus (ESA under ARTES Program). The PSCU has been developed by Airbus DS Crisa and Airbus DS Germany for 1850 Vdc Beam Supply Modules 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 PSCU will be ESA BepiColombo mission to Mercury.

The PSCU (see Figure 3) is composed of two Accelerator-Neutralizer Supplies (DANS), housed in a single box together with the Beam Supply (BS)

The PSCU T6 design has been upgraded for BepiColombo in order to provide full redundancy and flexibility at PPU level.

PSCU T6 enables the system to interface with up to four thrusters; operating one at a time with a total power of 5Kw. PSCU T6 is able to offer full redundancy for each of the power supplies

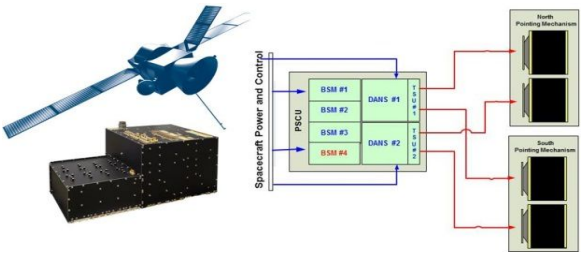


Figure 3. Airbus DS EQM PSCU for T6

The BEPI PPU EQM was successfully coupled with the thruster and fully qualified. Two flight models have been delivered and currently flying to Mercury.

The next steps for the PPU T6 product are the product industrialization. In the frame of the European GNSS Evolution Program (EGEP), Airbus DS has carried out the industrialization of the BEPI PPU Unit that will be briefly presented in this paper.

III. PPU ELEKTRO for HET 5 KW applications

A. ELEKTRO PPU objectives

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

Airbus DS Space Electronics 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 4.. Airbus DS PPU Elektro 5 kW.

B. 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:

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

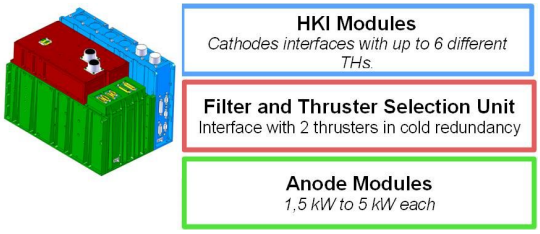


Figure 5.. Airbus DS PPU Elektro Building Blocks

The electrical 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

C. 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 several times with the SPT140D Fakel facilities (Kaliningrad - Russia) and with the PPS5000 in Safran facilities (Vernon - France).

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.

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)

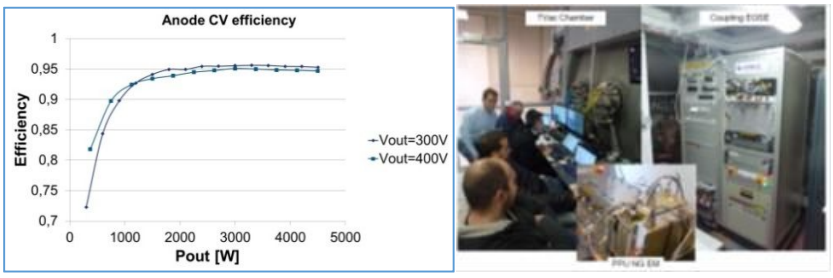


Figure 6 - Airbus DS PPU Efficiency figures & coupling tests

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

D. PPU Qualification results

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 7 - 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

- 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

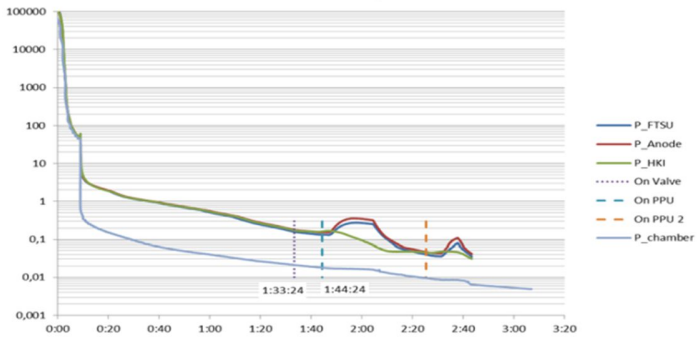


Figure 8 - Elektro PPU EQM first depressurization

All these tests were passed successfully from May to August 2017. New coupling tests have taken place with the Elektro PPU EQM with SPT140D and with PPS5000.

Currently, recurring Flight Models production is on-going. Elektro PPUs have already been ordered by primes in Europe and USA

IV. New Space PPU for Low Power HET thrusters

PPU HET low power (LP) is the new Airbus DS PPU for 300W class HET thrusters that have been developed for constellation applications. Specifically tailored to New Space types of applications, it features a lifetime of 10 years in LEO, with latch-up-free parts and error protection. PPU HET LP is well suited to support all kind of maneuvers for LEO applications: orbit raising, station keeping and deorbiting maneuvers

The LP Power Processing Unit (PPU) offers the best of essential functionalities in a compact and lightweight design. It provides Power conditioning and control for low power Hall Effect Thrusters and the Xenon Feed System. It is a flexible and disruptive design based on automotive grade parts to answer the latest space market trends for new space applications. All components of PPU HET LP have been intensively radiation tested to ensure flawless in-orbit operations.

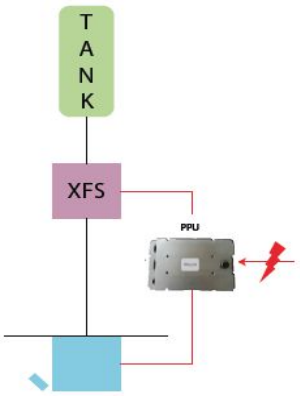


Figure 9 - PPU EP subsystem interfaces

The main features are as follows:

- Delivered Power Capability: 300 W
- Generate and monitor the voltages and currents to the Electric Propulsion System; to perform start up, nominal operation and shut down sequences and to respond to thrust commands
- Power converters are galvanically isolated from primary power bus : 27-38V (battery follower)
- TM/TC interface: CANBUS (N&R) or MILBUS 1553
- Mass optimized
- Disruptive design based on automotive grade parts (intensively radiation-tested to ensure flawless in-orbit operations)
- Breakthrough price-performance ratio
- PPU for Low power Hall Effect Thrusters 300W class
- Bi-compatibility to the latest generation plasma thrusters
- High reliability with unprecedented flight heritage

- **Figure 10 - PPU EP subsystem interfaces**

Airbus DS PPU for 300W class HET thruster's development is finished:

- EM coupled with a HET thruster in March 2017
- Characterization is done, including thermal vacuum
- EQM manufacturing and qualification is completed
- First 10FMs batch completed, delivered and flying
- FM production on going

V. Industrialised PPU for T6 thruster

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:

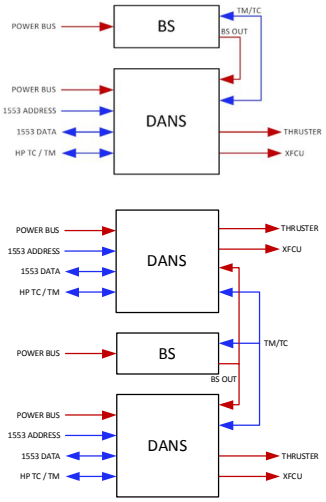
- Strong reduction of recurring cost, this is the major goal
- Keep the Technology Readiness Level (TRL)

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. 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 11 - EGEP PPU System Configurations**

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 design goals expected with respect to former design are significant improvements in Mass, Volume, number of EEE parts and related cost and Power Dissipation. The mass of the complete PPU including one DANS, one BS and the interconnection harness between them is 22 kg and the efficiency 95%.

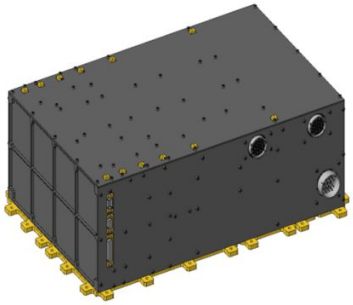
The design phase is finished and EM have been manufactured and tested

VI. PPU GIT-RIT 2X thruster for 5 kW applications

A. PPU objectives

Strongly based on the existing design heritage, Airbus DS has developed 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 PPU for RIT 2X thruster is a new generation concept able to answer to the commercial market trends, in particular:



- **Figure 12 – RIT PPU**

- PPU dual mode capability in voltage that will allow operating the thruster in the optimum configuration during Orbit raising (thrust mode) and SK (ISP mode).
- Interfaces two thrusters in cold redundancy. 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
- Full autonomy to maximize thrust availability and minimize Xe consumption.
    - Recovery from arcs
    - Recovery from cathode mishaps.
- Power bus internally protected, no need of external protections

B. PPU Description

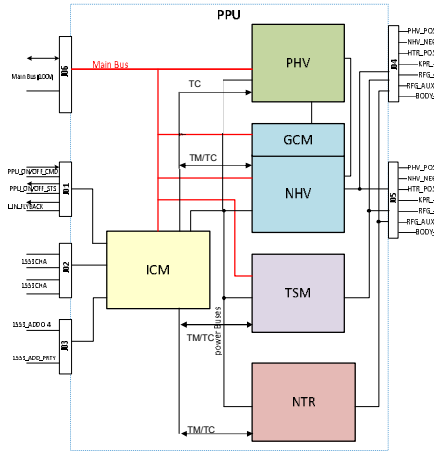
The design is specifically optimized for the latest RIT-2X thruster developed and built by Ariane Group. The PPU is required to interface two thrusters, only one operated at a time. The design maximum power delivered to the thruster can be up to 6.5 kW, 5 kW/1.5 kV in the grids, 1 kW for the plasma ionization through the RFG unit of the thruster and 500 W for the neutralizer. Although the PPU can deliver these figures in permanent conditions, this is the envelope to cover all operation phases of the thruster, being the steady state power consumption of the thruster lower. The main drivers of the design are summarized in the following list.

- Low cost, low mass, high power density and high efficiency to avoid burdening advantages of a high impulse Gridded Ion Propulsion System.
- Very high operating temperatures and large number of power cycles during the 15 years mission. Low thermal gradients are needed to avoid mechanical fatigue.
- Wide high voltage operating range in both grids, 1:1.6 in screen and 1:3 in acceleration and high commanding resolution and accuracy for trading impulse vs. thrust-power ratio in the thruster operation.
- Low energy stored in HV output filters leading to fast control bandwidth of power processing for proper thruster operation.
- No HV relays are allowed due to low maturity for Space and no high voltage can be exposed to vacuum.
- Large voltage regulation range 1:10 for RFG unit power supply.
- All thruster power lines isolated from spacecraft ground subjected to differential and common mode perturbations (current ripples, arcing, ignition, ...).

- Reliable ignition process at low mass flows.
- Grids clearing functionality.
- Autonomous operation and fast thrust recovery under abnormal neutralizer function or arcing between grids.
- In flight reconfiguration of PPU functionality if needed.
- High reliability in a worst case GEO radiation environment for a 15 years mission.

The following building blocks are gathered in one PPU:

- Interface Control Unit: Providing the brain and all internal secondary supplies and forms the communication center for all external (e.g. MIL-1553) and internal communication bus system. The brain is the thruster controller, with capability to reprogram thruster operation in flight through 1553 if needed
- Neutralizer-Supply(NTR): It provides all neutraliser supplies with very high configuration capability
- 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



- **Figure 13 – RIT PPU**

A successful coupling test between PPU EM and thruster took place in early 2017. Tests performed have successfully demonstrated a High Voltage Power Supply efficiency of 95% average for the complete voltage range.

The qualification of the unit is almost concluded and FM models manufacturing is ongoing. Next paragraph includes main highlights on coupling tests results

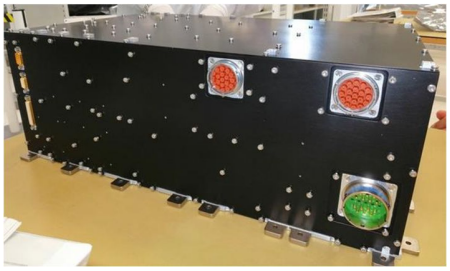
C. PPU Coupling test results

The next figure shows the EQM PPU. A different model, EM2 (fit, form and function), was used for coupling test in January 2019, showing perfect compatibility and expected performances in all different operating points. The capability to trade ISP vs. thrust-power ratio (dual mode) was fully demonstrated during the test campaign

The system was artificially stressed in abnormal conditions to check fault detection an autonomous recovery of the PPU. These aggressive tests were also successful.

Airbus Space Electronics has developed and is about to finish a successful qualification of the PPU for RIT 2X thruster, enabling advances in electrical satellite propulsion. First flight models are already being manufactured for delivery beginning of next year.

The PPU tests results confirm that main performances, mass, cost and efficiency are met and aligned with commercial RIT 2X EPS system needs. Tests with EQM thruster have shown electronics maturity, very good performances and operation autonomy of the PPU.



- **Figure 14 – RIT PPU EQM**

The PPU product has been designed to supply other gridded ion thrusters by adapting the TSM module to the particularities of the thruster.

VII. Conclusion

This paper introduces the heritage PPU and the main highlights for the new generation PPU developed by Airbus DS Space Electronics. In particular, it describes HET and GIT PPU developments status, including qualification test results.

Airbus DS Space Electronics PPU portfolio contains solutions for the main 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 for applications in satellites manufactured in Europe and the United States.

Currently more than 40 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 Electronics strategy to be able to answer to the short, mid and long term needs.

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