# GSTP T5 HVPS De-Risk
# GSTP T5 HVPS De-Risk Executive Report

QINETIQ/EMEA/AS/TR191388
Issue: Released
Date: 01/11/2019

Requests for wider use or release must be sought from:

Commercial Manager
Space Department
QinetiQ Limited
Cody Technology Park
Farnborough
Hampshire
GU14 0LX
United Kingdom



© QinetiQ Ltd 2019

# Administration page

| **Customer Information** | |
|---|---|
| Project title | GSTP T5 HVPS De-Risk |
| Document title | GSTP T5 HVPS De-Risk Executive Report |
| Customer organisation | European Space Agency |
| Customer contact | Andreas Franke |
| Contract number | |

| **Author(s)** |
|---|
| Kevin Hall |
| **Technically Approved By** |
| Jaime Perez Luna |
| **Approved By** |
| John Laycock |

**Record of changes**

| Issue | Date | Detail of Changes |
|---|---|---|
| 01-00 | 11/11/2019 | Released |


© QinetiQ Ltd 2019

# List of contents



# List of Figures



# List of Tables




© QinetiQ Ltd 2019

# 1 Introduction

The de-risk activity completed here involved the production of a high voltage power supply that would form part of the QinetiQ T5 gridded ion electric propulsion system in collaboration with Advanced Space Power Equipment GmbH (ASP), Germany.

The QinetiQ 'T5' – a low power (<1kW), high efficiency Gridded Ion Engine (GIE) EP system – flew successfully on the ESA GOCE mission in 2009, operating for 36,000 hours with an average thrust of 4mN from the primary thruster without problem. Despite its success, the market demand since GOCE for an engine of the class of the T5 has not been strong until recently when the emergence of a growing EP market in constellations and in-orbit servicing has generated significant interest in a low power, high efficiency EP solution.

The T5 power supply is currently obsolete and the development proposed by Advanced Space Power Equipment GmbH (ASP) will have distinct advantages to QinetiQ in that it will: provide a basis for a new T5 power supply; and also, importantly, take the system forward to a low cost and low mass solution that is designed for volume production.

The T5 system provides an EP capability that could be suitable for a number of opportunities that include: constellations - where the EP system is required for constellation dispersal and deorbit; institutional near-earth and deep space missions with limited available power; and the emerging market for in-orbit servicing of GEO telecoms satellites.

There are a number of potential competitors to the T5 in the EP market but as yet there are limited flight ready solutions that are comparable to the T5. Not only has the T5 got the 'time-to-market' advantage (given its previous flight heritage) but it also offers cost advantages to missions. For example, the majority of T5 opportunities are missions that have mass restrictions where the GIE solution has a clear advantage over competitors (i.e. Hall Effect Thrusters); the latter requiring approximately twice as much fuel than GIE to achieve the mission. In the case of the constellations (e.g. 100 plus spacecraft), the potential savings just in Xenon costs are significant. Add to this the cost and mass saving arising from the introduction of a novel power unit and the T5 has significant mission cost advantages over competing systems.


© QinetiQ Ltd 2019

# 2 Definitions and Abbreviations

| **Abbreviation** | **Description** |
|---|---|
| ASP | Advanced Space Power Equipment GmbH |
| COTS | Commercial off-the-shelf |
| EBB | Elegant Bread Board |
| EM | Engineering Model |
| EMC | Electromagnetic Compatibility |
| EP | Electric Propulsion |
| EQM | Engineering Qualification Model |
| ESA | European Space Agency |
| FCU | Flow Control Unit |
| FET | Field Effect Transistor |
| FM | Flight Module |
| FMECA | Failure mode effects and criticality analysis |
| FPGA | Field Programmable Gate Array |
| GaN | Gallium Nitride |
| GIE | Gridded Ion Engine |
| GSTP | General Support Technology Programme |
| HET | Hall Effect Thrusters |
| HVPS | High Voltage Power Supply |
| LEO | Low Earth Orbit |
| PCA | Printed Circuit Assembly |
| PCB | Printed Circuit Board |
| PPU | Power Processing Unit |
| PSA | Parts Stress Analysis |
| PWM | Pulse Width Modulation |
| SEE | Single Event Effects |
| SMT | Surface Mount Technology |
| SW | Software |
| TID | Total Ionising Dose |
| TRL | Technology Readiness Level |
| WCA | Worst Case Analysis |
| ZVS | Zero Voltage Switching |

*Table 2-1 - Abbreviations*


© QinetiQ Ltd 2019

# 3 Short Description of HVPS

The ultimate objective is the production of a T5 power supply capable of operating with QinetiQ's low power / high efficiency T5 gridded ion engine. The HVPS is a key part of the full PPU and is highlighted by a red circle in Figure 3-1 that provides context of where the HVPS would fit within a complete T5 EP system.

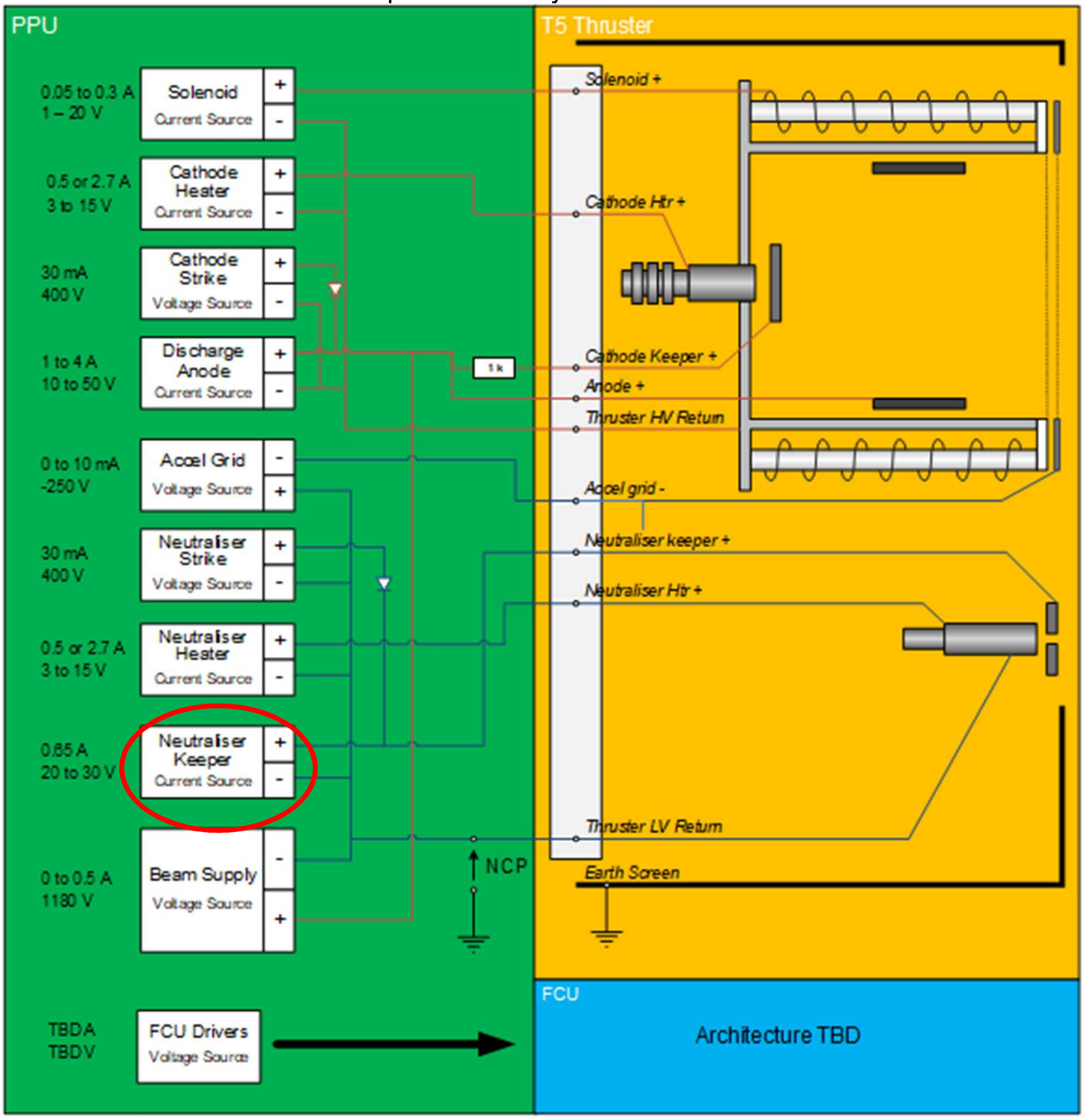


*Figure 3-1: T5 thruster system power supply function*

It's worth noting that the FCU element of the thruster system is the subject of an ongoing FCU trade off, that is outside the scope of this derisk activity, and therefore the architecture plus associated FCU driver hardware is TBD. A typical FCU interface has been considered based on QinetiQ's knowledge of FCU suppliers and the associated cost and mass of any solutions have minimal impact on the PPU design.


© QinetiQ Ltd 2019

# 4 Technical objectives and requirements

The primary objective has been to develop a cost effective High Voltage module to be used in power equipment for the new market demands based on Planar Transformer technology.

Having such Planar Transformer design for High Voltage applications in place will reduce the development time for customised High Voltage power supplies. Additionally this technology provides a high reproducibility which will be also a key cost factor in order to address the evolving constellation market.

The main goals are:

- Design to cost; optimized for low recurring cost for FMs (Flight Module)
- Low volume / low mass; ideally SMT (Surface Mount Technology) parts only
- Optimized thermal behaviour

## 4.1 Key requirements for the de-risk activity

The key requirements for the high voltage module are as follows

Input:

- 26V to 38V

Output:

- Output voltage: 1000 to 1260V
- Output power: 600W
- Efficiency: ≥ 94%
- Transfer failure range: +/- 5% + ripple
- Output voltage to be adjusted by telecommand

Mass of less than 2kg for the HVPS (giving a potential T5 power supply total mass of 5kg)

Cost reduction: One main cost driving components element are the switching devices, therefore replacing the qualified silicon based Mosfet (costing around €1000 each) by qualified GaN transistor which cost around €350 each or even less results in cost reduction of at least €6500 when considering 10 devices in total. For a full-fledged PPU the use of GaN transistors results in a cost reduction of the EEE-parts in the range of 15%.


© QinetiQ Ltd 2019

# 5 De-risk activity overview

The de-risk activity has the following steps

- Generation of detailed requirements for the HVPS
- Generation of verification control document and statements of compliance against each requirement
- 1st iteration of the HVPS design focused on the following points
    - Comparison of three different Planar Transformer shapes
    - Validation of the selected Half-Bridge Resonant Topology (LLC) using frequency control (final target: 2x 300W in parallel = 600W)
- 2nd iteration of the HVPS design (Baseline) focused on the following points
    - Full-Bridge Resonant Topology (LLC) with a fixed frequency combined with a pre-regulator (one single 600W converter)
    - Flexible output concept; configurable output voltage ranges to address the different requirements for the main operational point of a T5 thruster
    - Analysis of the baseline design including FMECA, reliability and PSA
- Test of the Baseline design
    - Full functional testing in ambient conditions
    - Reduced function thermal testing in ambient pressure (-20°C to +50ºC)
- Critical assessment of the test results and success of the de-risk activity
- Production of a DDV for a follow development for a full PPU

.


© QinetiQ Ltd 2019

# 6 Baseline Design of HVPS

In order to further reduce the part count and increase the power capability of the HVPS a new architecture was selected. Thanks to the new concept the HVPS is able to deliver up to 600W by means of a single converter (parallel converters are not needed anymore to increase the power). In this case mass, cost and size are improved.

In order to optimize the transformer (reducing the size and improving the efficiency), the Full-Bridge converter is supplied by a Pre-Regulator (see Figure 6-1). This architecture allows the Full-Bridge to work at fixed frequency. The output voltage is adjusted by the Pre-regulator voltage adjustment. Thanks to the fixed switching frequency the following optimizations are feasible:

- reduction of the current flowing in the primary of the transformer as much is possible
- reduction of power dissipation for the main switches (delay time between high and low side switches does not need to be oversized)

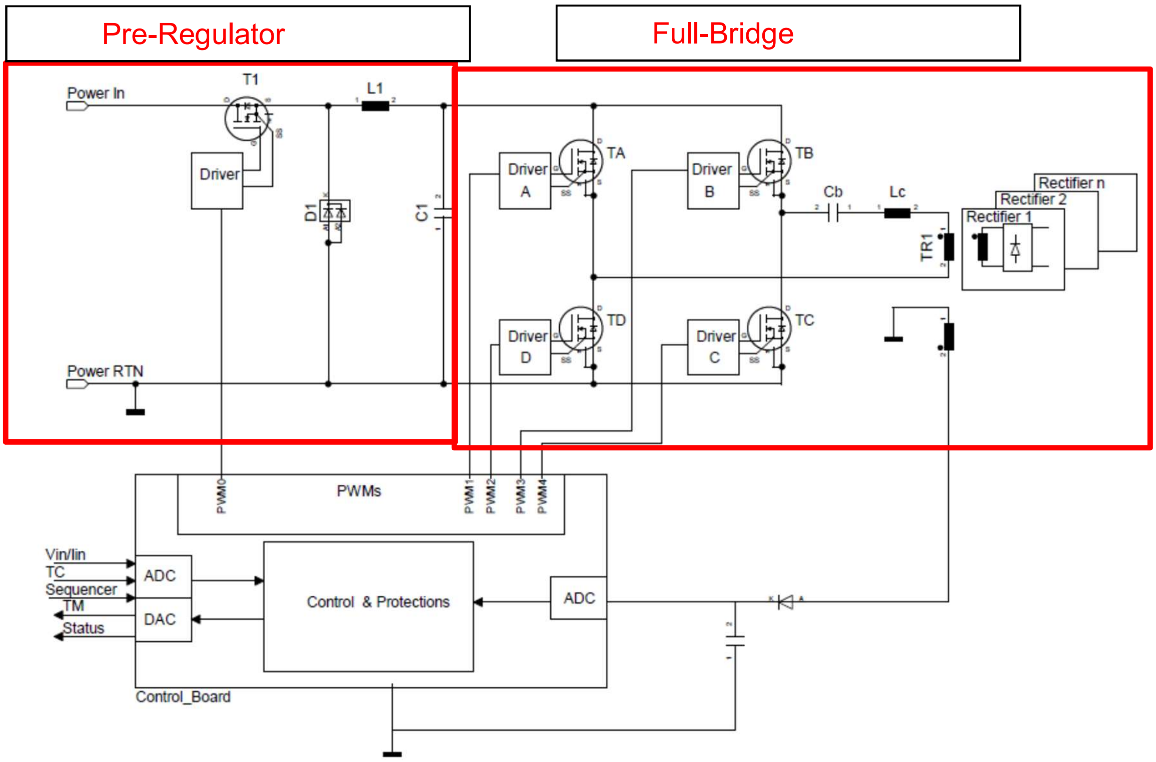


*Figure 6-1: Beam Power Supply – Top schematic*

The high frequency and planar transformer design allows the mass and volume to be significantly reduced (see Figure 6-2).


© QinetiQ Ltd 2019

*Figure 6-2: Beam supply voltage supply – Demo board baseline design 100x150mm*


© QinetiQ Ltd 2019

# 7 Conclusion

The HVPS de-risk activity has been shown to meet the main objectives that demonstrated the capability to produce a low cost and lightweight high voltage supply.

The main drivers on an EP system are cost, mass and finally performance for majority of the commercial applications that would suit a T5 sized thruster. Ultimately each of these three parameters are related to the overall mission cost of the T5 EP system solution both in terms of the direct cost of the hardware and propellant but also in the indirect costs of the launch due to reductions in the wet mass. When operated at high thrust operating points the T5 thruster has significant advantages in terms of Isp that reduce not only the propellant that is required but also the tankage for propellant storage.

Based on the results of this de-risk activity the Mass/Volume Budgets:

For a complete T5 PPU 600W incl. Flow Control driver interfaces the following budgets are concluded, note these are un-margined design targets:

- Volume : 280 x 200 x 40mm$^3$
- Mass: ~2,3kg

Compared to the 5kg budgeted in advance to the de-risk activity the 2,3kg show a significant additional improvement. Thanks to the use of Planar Transformers and GaN Transistors in combination with Digital Control.

The technology maturity level to be reached within this de-risk project was initially targeted to TRL 5 = Breadboard critical function verification in relevant environment. Considering the High Voltage aspect, the Breadboard would need to be tested within Vacuum, which would not be representative with regard to the final targeted PCB design. Therefore the currently reached TRL needs to be rated at TRL 4.

Nevertheless the use of Planar Transformers in combination with GaN based high frequency switching, for such application has proven to meet the mass/volume targets as expected and the stacking approach for the secondary windings does fully support the broad voltage range needed for configuring the different operational points for the thruster. Additionally it has proven that the design can be fully based on SMT parts, which is the basis for cost effective high volume production.


© QinetiQ Ltd 2019

# Initial distribution list

**External**

Andreas Franke ESA
Martin Blaser ASP
Kai Schmid ASP

**QinetiQ**

Peter Jameson


© QinetiQ Ltd 2019