Innovative Architectures Developed for the Power Supply Contol Units of the Ion Thrusters for Incoming Programs

IEPC-2007-294

Presented at the 30th International Electric Propulsion Conference, Florence, Italy
September 17-20, 2007

C. Tato * *and F. de la Cruz* †

* *Electronic Engineer, Madrid – Tres Cantos 28760 – Spain*

† *Electronic Engineer, Madrid – Tres Cantos 28760 – Spain*

J. Palencia ‡

‡ *Electronic Engineer, Madrid – Tres Cantos 28760 – Spain*

Abstract: In the frame of the activities carried out in the field of Electric Propulsions systems based on Kaufman Ion thrusters Astrium-Crisa has developed two Power supply units built to feed two well differentiated Ion thrusters: GOCE – IPCU for T5 Ion Thruster and HPEPS for T6 Ion Thruster (Alphabus parallel development), both thrusters developed by Qinetiq The two listed Power Supply Units show common elements as it is the basic concept of the Gridded Ion Engine to which it is devoted, the global unit architecture, the design architecture of the individual power supplies, the power distribution inside the unit, and the grounding concept. But these units show as well some differences being the fundamental one the power delivered depending on the size of the Ion Engine. Despite this difference and accounting on the common points of the unit common architectures that suits both Ion Engines can be built. The objective of this paper is to show the architecture evolution from the first unit developed to the subsequent ones. The different architectures shall be overviewed based on the improvements achieved as well as on the knowledge gained and heritage gained both on the thruster itself and on the electronics driving it.

I. Introduction

The main functionalities of a unit driving the Gridded Ion Thruster –Kauffman type- shall encompass:

- Power and control provision for the Thruster Assembly
- Powering and control over the XFCU (Xenon Flow Control Unit)
- Full commandability and monitoring provision

* EADS-Astrium-Crisa, Technical Manager, Design Department, ctato@crisa.es.
† EADS-Astrium-Crisa, Senior Project Manager, Project Department, fcruz@crisa.es
‡ EADS-Astrium-Crisa, Technical Manager, Design Department, jpalencia@crisa.es.

From the above functionalities the first one is the most contributing one in terms of volume, mass and cost. The two remaining ones XFCU powering and control and TM/TC provision are based on conventional and standard architectures and due to the low relative size does not allow any further and contributing optimisation in the overall unit.

The following figures show an schematic of the main functions required for a PSCU driving a Kauffman Gridded Ion Engine:

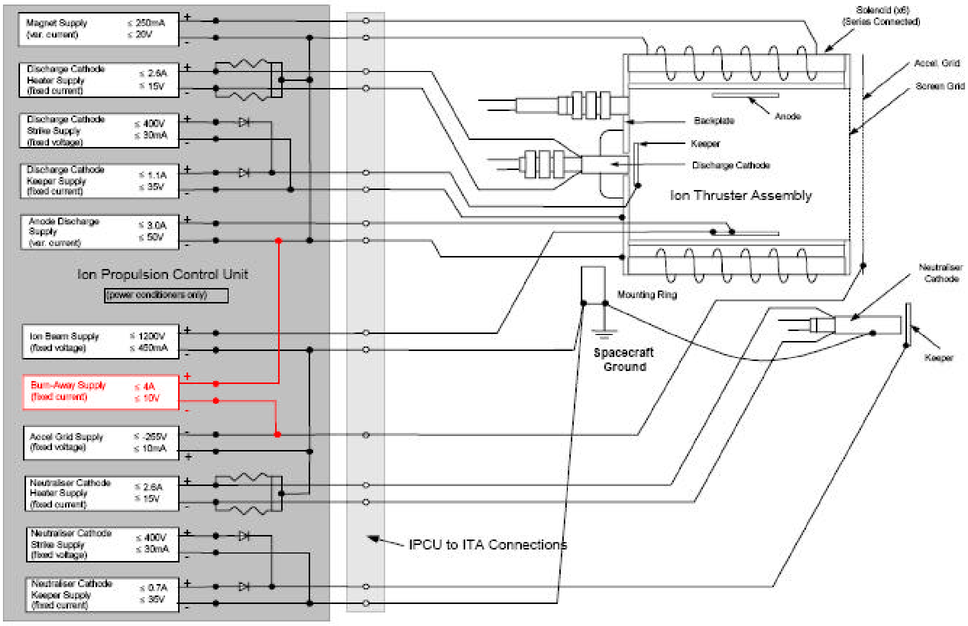

Figure 1: Power Supplies Functional Blocks Connection to ITA(GOCE-IPCU, Courtesy from Qinetiq)

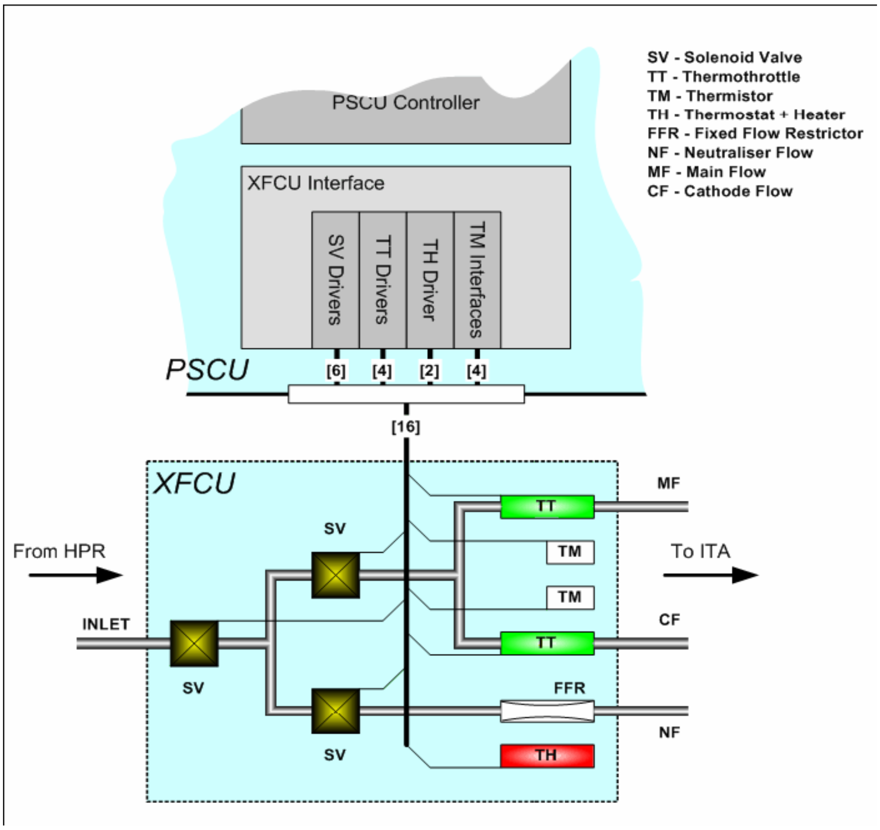

Figure 2: PSCU Functional Blocks Connection to XFCU (Courtesy from Qinetiq)

As seen above the PSCU is in charge of two main functions:

i. Supplying and Control the ITA (Ion Thruster Assembly) elements
ii. Supplying and control the XFCU (Xenon Flow Control Unit) elements

The former function shall supply and control the following elements:

- Neutraliser Cathode Heater, referred to S/C structure
- Neutraliser Cathode Keeper, referred to S/C structure, both including an Strike functionality to start the discharge and a Keeper functionality to sustain discharge
- Accel Grid, referred to S/C structure
- Beam Supply, referred to S/C structure
- Discharge Cathode Keeper, referred to the High Voltage provided by the Beam Supply
- Discharge Cathode Heater, referred to the High Voltage provided by the Beam Supply
- Anode Supply, referred to the High Voltage provided by the Beam Supply
- Magnet Supply, referred to the High Voltage provided by the Beam Supply

The latter shall supply and control the valves providing the xenon flows: cathode flow, main flow and neutraliser flow.

In order to allow a better understanding of the PSCUs supplying this sort of Gridded Ion Engines it is important to highlight that some of the Thruster elements are referenced to the high voltage supplied from the Beam Supply. This condition involves two main constraints far apart from conventional electronic units:

i. Provision of the high voltage power supply feeding the Beam and, as important as this,

ii. The remaining power supplies must be able to withstand this high voltage reference, while the complete unit assembly is referenced to S/C structure.

This IPA (Ion Propulsion Assembly) architecture has been the base for the design of the two current models developed by CRS. However, this power supplies architecture can be optimised to reduce the electronics needed to feed all Thruster elements, while providing the same functionality not only in terms of powering capabilities but as well on monitoring and commanding provisions.

II. GOCE IPCU Overview

As part of the DFAC system on GOCE platform CRS has developed the IPCU (Ion Propulsion Control Unit) dedicated to supply the T5 Ion Engine developed by Qinetiq.

The basic architecture of the PSCU section (excluding the XFCU and TM/TC functions) is defined in the picture below:

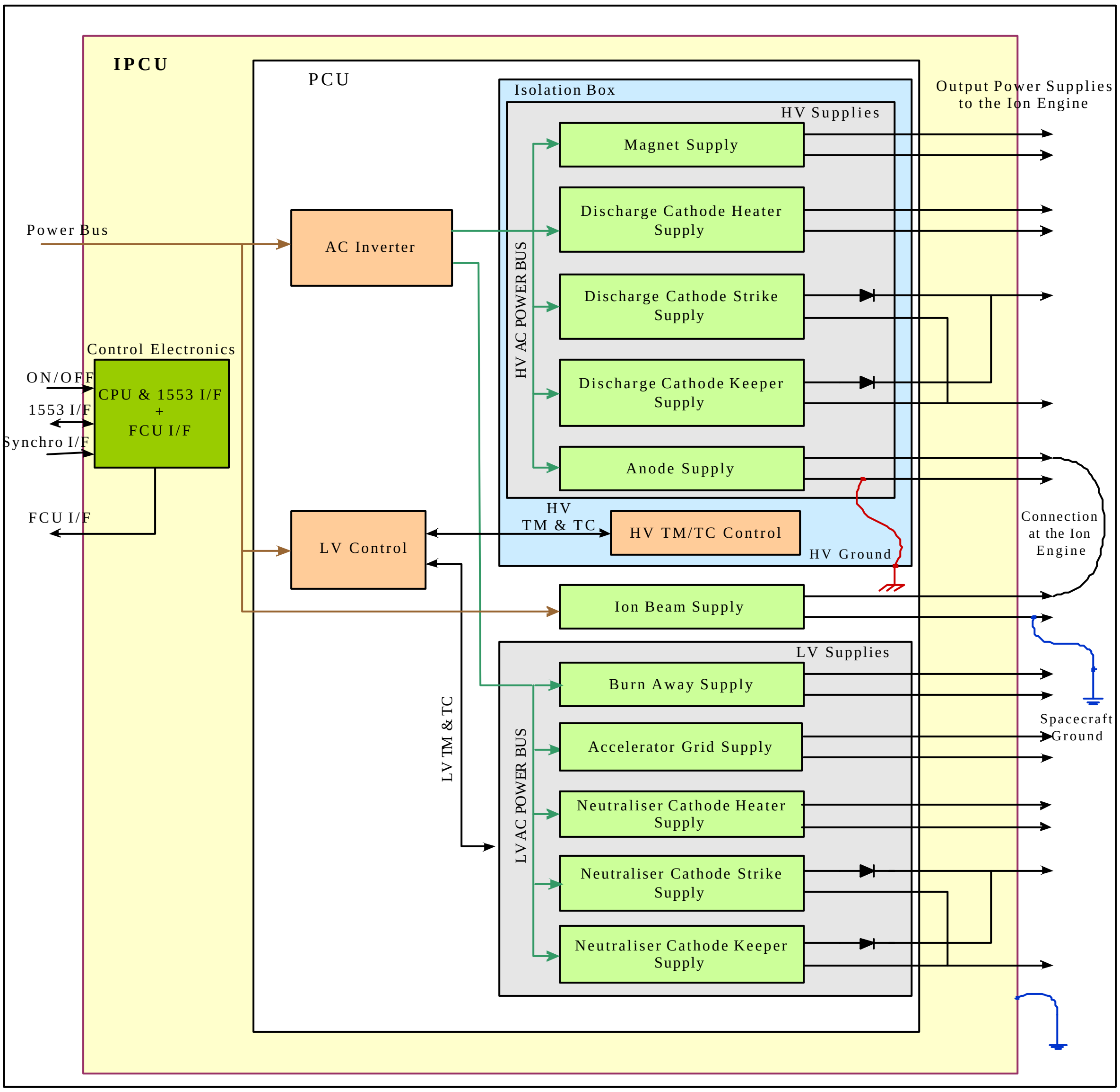

Figure 3: GOCE-PSCU (ITA supplies) architecture

As seen above the GOCE PSCU consists of the following functions:

- AC Inverter providing an AC Power Bus for the thruster power supplies and as well providing the internal supplies needs for the High Voltage referred side
- LV Control providing the internal powering for the Low Voltage referred side
- Powering the Thrust elements:
    - Ion Beam (developed by ASG, Friedrichshafen site)
    - DC and NC Heaters
    - DC and NC Keepers (both including two well differentiated operational modes)
    - Accel Grid
    - Anode (programmable current source allowing an accurate thrust control)
    - Magnet (programmable current source allowing an accurate thrust control)
    - An additional power supply, Burn Away, intended to remove sort-circuits between grids is provided

As depicted in the picture above the supply elements for GOCE have required eleven separated power supplies:

IBCV
Accel Grid
NC Heater
NC Keeper
NC Strike
Burn Away
} *All these power supplies referenced to S/C structure (0 V)*

Anode
Magnet
NC Heater
NC Keeper
NC Strike
} *All these power supplies referenced to High Voltage*

From the power supplies listed above the second group are referenced to the high voltage provided by the Ion Beam Supply (ASG development). This voltage, 1200 V for the GOCE PCU, does require these supplies to be able to withstand and operate in non-conventional way: they have to operate at high voltage while having the unit structure referenced to 0V. For this reason a dedicated enclosure, the Isolation Box, is built to house the electronics.

This Isolation Box will act as a Faraday Cage for this electronics. This electronics will see a physical enclosure set at its reference voltage, so they can be designed as "conventional" electronic. The drawback of this solution is that the new enclosure must be able to provide good high voltage isolation while providing good thermal conductivity. This last aspect is relevant since a thermal path needs to be provided to allow the dissipated power to be drained to the S/C structure.

This power supplying concept provides a dedicated power supply for each one of the thrusters elements. In addition the NC and DC Keeper requires two dedicated power supplies each one since the Keeper has two well differentiated operational modes, as a voltage source and as a current source.

In addition each one of the eleven power supplies will have dedicated monitoring both in current and in voltage and as well a complete dedicated control circuitry. This is highly relevant when taking into account that this extremely accurate control on two of the power supplies, Anode and Magnet, as well as in the Flow Control Valve driver is providing the capability of this unit to achieve a fine and accurate control over the applied thrust level.

The GOCE-IPCU design is sized as follows:

- Dedicated unit for a single Thruster
- Input Power Bus: 22 V to 34 V
- HV provided to the thrusters: 1176 V

- Total Mass: 17.3 Kg
- Dimensions (in mm): 380x300x205 (LxWxH)
- Maximum delivered Power: 650 W (for thruster operation @ max. thrust, 20 mN)
- Maximum Power dissipation: 118 W (at maximum power delivered)

It is important as well to highlight the feature required and achieved in GOCE-IPCU which allows the extremely accurate control of the Thruster (commandabe in steps of 12 uN).

One EQM and two FMs GOCE-IPCU models have been fully tested, including complete Propulsion System tests (carried out by ASG), and already delivered to ASG.

III. HPEPS (parallel AlphaBus development) Overview

As part of the HPEPS (High Power Electric Propulsion System) on Alphabus parallel development funded by ESA for telecommunications satellites, Astrium Crisa has developed the PSCU (Power Supply Control Unit) in charge to control and power the QinetiQ T6 Kauffman Ion Engine.

The design, architecture and development of the PSCU was in turn based on the practical experienced gain in the design, development, qualification and manufacture of the Ion Propulsion Power Unit (IPCU) for the ESA GOCE Program.

The proposed PSCU for Alphabus is composed of two well-differentiated parts:

- The Beam Supply (BS), developed by Astrium (Friedrichshafen site) and,
- The Discharge-Accelerator-Neutralizer Supply (DANS), developed by Astrium Crisa

Figure 4shows a block diagram of the PSCU of HPEPS

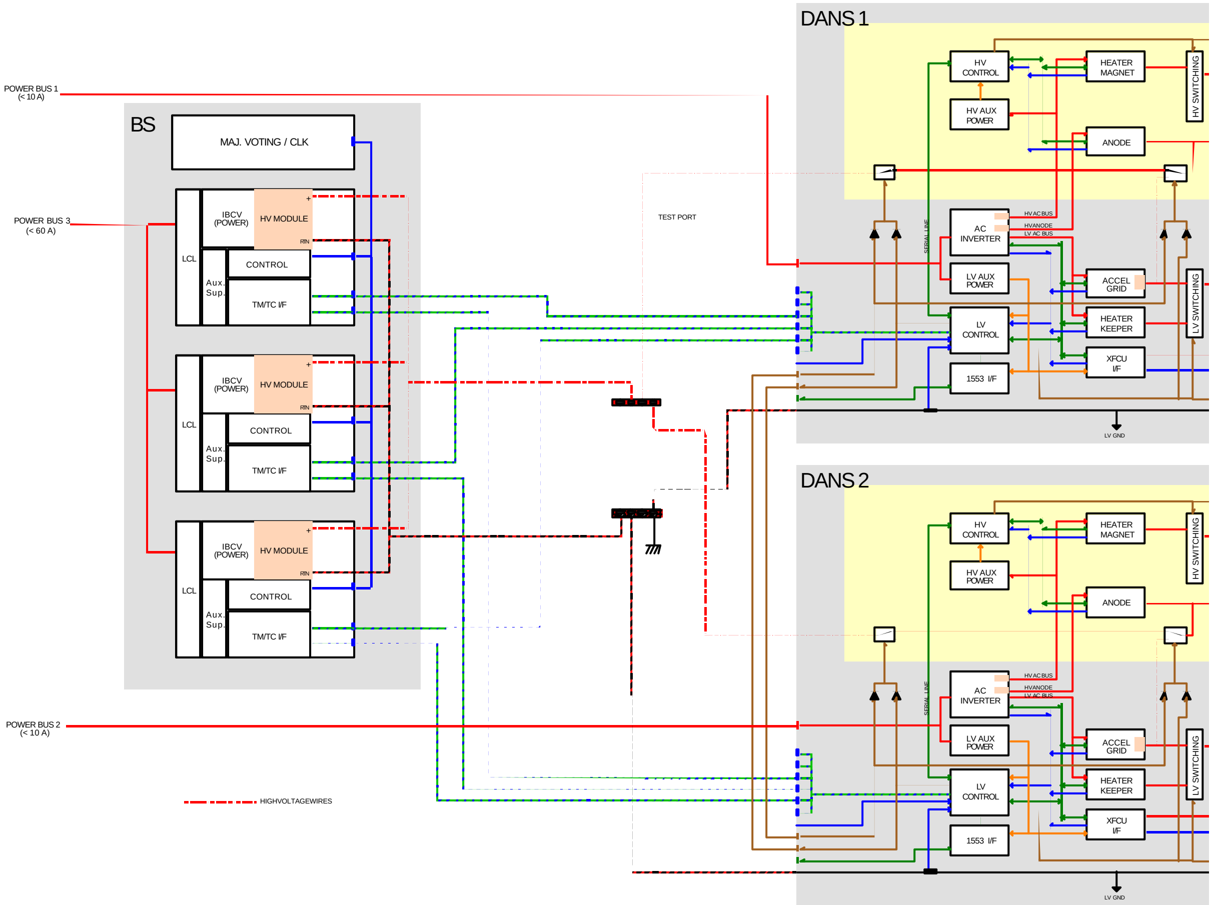

Figure 4: PSCU Block Diagram

The BS is in charge of providing the High Voltage reference for the discharge chamber of the thrusters. Due to the high power demanded by T6 Ion Engine, it is built of four identical paralleled modules which design allows, in case of failure of one of them to isolate the failed module and continue working without degradation of performances with the rest of modules providing the full power.

The DANS is carrying out the following functions:

- Providing power to the thrusters
- Providing as well power to the XFCU (Xenon Flow Control Unit)
- Controlling the BS
- Communications with the On-board computer via 1553 Bus
- Controlling the switching the power outputs between the thrusters and the XFCUs

The PSCU contains two of these DANS in order to allow in case of failure operation with the remaining one. Each DANS is able to switch between two thrusters, both may be connected to the BS output by means of High Voltage relays and both are able to command the BS and acquire its telemetries.

Both DANS may be operated simultaneously to allow Twin Thruster operation, although in this case the power delivered has to be shared by the thrusters.

Each DANS is internally organised in two well-differentiated parts:

- A High Voltage module that includes all Power Converters referenced to the high voltage (approx. voltage supplied from the Beam Supply) and,
- The remaining electronics referenced to the platform structure

The PSCU is supplied from a 100 V Power Bus that is distributed within the PSCU separately in two dedicated lines: one devoted to the BS modules and the other for the DANS modules.

The PSCU design will cope with the following objectives:

- Input Power Bus: 100V
- HV provided to the thrusters: 1850 V
- Total Mass: 38 Kg
- Maximum delivered Power: 5100 W (for thruster operation @ max. thrust, 141 mN)
- Maximum Power dissipation: 315 W (at maximum power delivered)

The improvement with respect previous topology used in the GOCE program is obvious when comparing the total mass. HPEPS-Alphabus unit, 38 Kg, although not providing a CPU board, is designed to power and control four thrusters, while a single GOCE-IPCU, 17 Kg, is for one thruster. This save in mass becomes more interesting when taking into account the power delivered by each unit (650 W for GOCE-IPCU vs. 5100 W in HPEPS case).

In terms of efficiency HPEPS-Alphabus unit is as well providing a better figure, 95% in comparison with 85% as worst case provided by the GOCE-IPCU.

Although there are some differences that makes the GOCE Unit to show worse figures than the ones showed by HPEPS-Alphabus unit –additional CPU board in GOCE Unit or increased voltage on input power bus- there is an interesting improvement on this last unit in terms of efficiency, mass and volume. It has been the obtained experience, both in the knowledge of the Thruster and its needs, and as well on the testing of the units that has allowed the improvement. This improvement is basically due to the following factors:

- Improved design of the Beam Supply module (ASG development)
- Use of Multi-Function supplies such as Magnet/DC_Heater supplies, NC Heater/Keeper Supplies and Anode re-routed to burn-away supply when needed.
- Combined Power supplies such as Anode-DC Keeper

However, as stated above the GOCE IPCU unit is required to allow a very accurate control over the thrust commanded, which makes the unit attractive but for sure having a cost in mass.

This concept of shared and multi-function power supplies has been extended to an additional topology able to supply the T5 Ion Engine and more competitive in terms of efficiency and mass than the first GOCE-IPCU Unit.

Two new architectures for the PSCU-T5 unit are hereafter presented as innovative developments for the low thrust T5 Ion Engine. Both Architectures presented shows a PSCU Unit able to power and control two Thruster assemblies, as it is done for HPEPS-Alphabus concept. This is carried out by means of a switching stage that will be able to select between the two thruster available, provided that it is not required both thrusters operating simultaneously.

IV. Improved PSCU-T5 architectures

A. Option 1

Next figure shows the concept of this new architecture (Option 1):

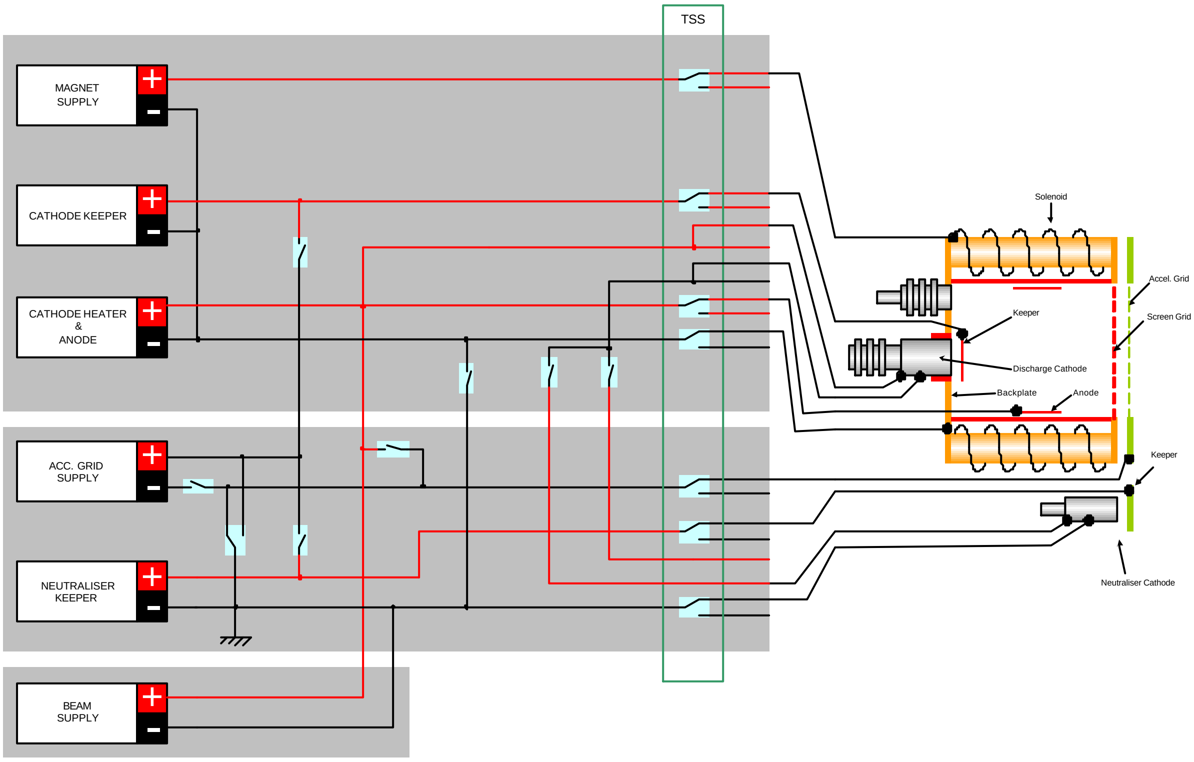

Figure 5: IPCU-Lite architecture - Option 1

Option 1 design hints allowing a reduction in mass and volume would be as listed below:

i. Magnet supply: This unit is dedicated to the solenoids and could be exactly the same as used on GOCE.
ii. Cathode Keeper supply. This unit is dedicated to the cathode keeper and could be exactly the same as used on GOCE.
iii. Cathode/Neutraliser Heater and Anode supply. The control, current and voltage capability of the existing anode supply make it possible to operate both heaters simultaneously in series.
iv. Accel Grid and Strike supply. The Accel grid supply would be switched to both the cathode and neutraliser keepers to act as a strike supply. Once both devices are struck it would revert back to the Accel grid. Otherwise the supply could be exactly the same as used on GOCE.
v. Neutraliser Keeper supply. This unit is dedicated to the neutraliser keeper and could be exactly the same as used on GOCE.
vi. Beam supply improved design.

In addition of the benefits exploded above, reduction of needed power supplies, additional optimizations can be achieved on the remaining unit consisting basically of an optimization on the Beam supply module as follows:

- Optimization of the topology to increase the efficiency, as done for T6 PSCU
- Adaptation to a regulated 50V power bus input
- Increase of output power to twice the IPCU IBCV value

In addition to the basic advantages the isolation box concept it provides an additional advantage by decoupling the design of the HV referenced power supplies form the selected beam voltage; i.e. the beam voltage can be increased without having to make any changes to the other supplies in the IPCU-Lite. This offers the flexibility in later applications to changes the system SI without having to re-design the IPCU-Lite.

In addition an optimisation on the mechanical and thermal design of the isolation box taking advantage of the developments performed for the Alphabus PSCU is as well to be considered.

B. Option 2

Next figure shows the concept of this new architecture (Option_2):

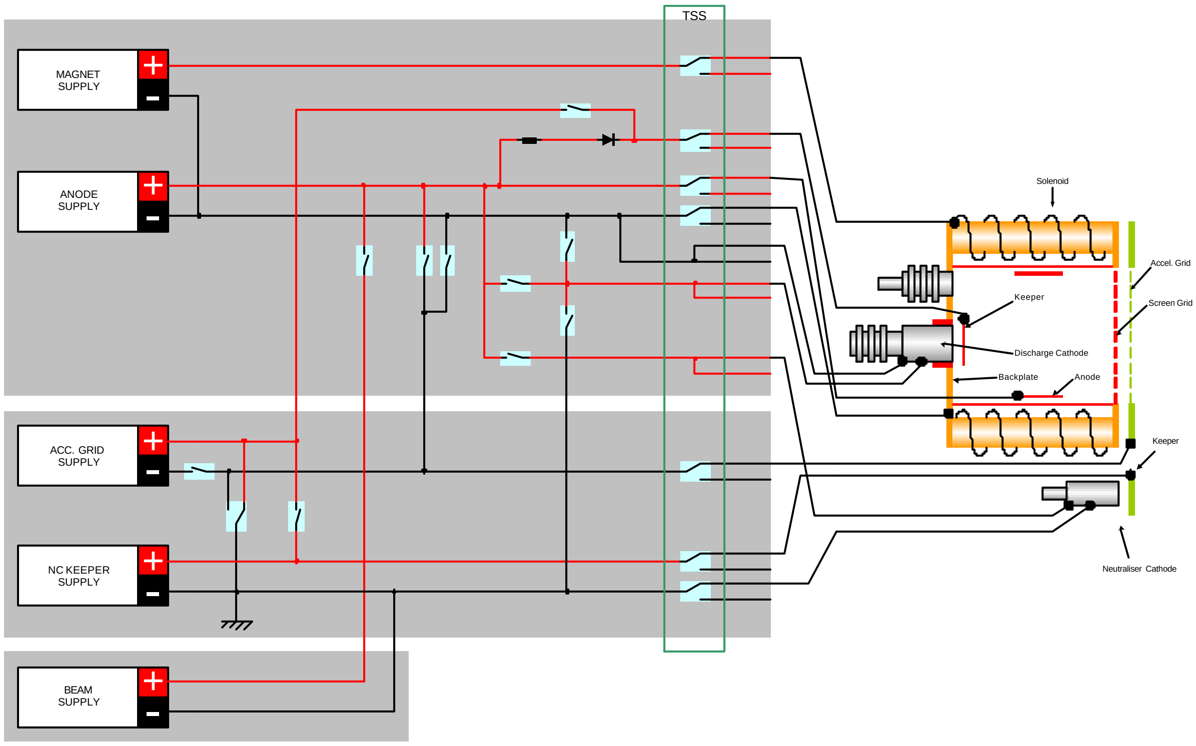

Figure 6: Schematic IPCU-Lite architecture - Option 2

Option 2 eliminates the discharge cathode keeper supply by connecting the keeper and anode via a resistor. This approach is also used on T6 and is considered to be feasible on T5. The justification for this conclusion is that T5 has been operated with the keeper supply switched off at high anode currents, the operational principle is therefore possible. Main hints of this concept:

i. Magnet supply: This unit is dedicated to the solenoids and could be exactly the same as used on GOCE.
ii. Cathode/Neutraliser Heater and Anode supply. The control, current and voltage capability of the existing anode supply make it possible to operate both heaters simultaneously in series. This supply could be exactly the same as used on GOCE.
iii. Accel Grid and Strike supply. The Accel grid supply would be switched to both the cathode and neutraliser keepers to act as a strike supply. Once both devices are struck it would revert back to the Accel grid. The current capacity and voltage of the supply is sufficient for the strike function and therefore it could be exactly the same as used on GOCE. The trip status of the supply would indicate whether or not the discharges have struck.
iv. Neutraliser Keeper supply. This unit is dedicated to the Neutraliser Keeper and could be exactly the same as used on GOCE.
v. Beam supply improved design.

As explained above this unit concept will as well incorporate the additional benefits gained on the Beam supply module as well on the Isolation Box concept.

A preliminary mass and dimensions budget have been calculated for this option. The described new IPCU -Lite architecture will have a total mass of 17 Kg approx. Similar mass than the old architecture but a considerably reduction at system level, since this unit is able to drive two T5 complete assemblies, while the old unit was needing two units, giving a reduction on mass at system level of approximately 50 %.

As well overall dimensions are reduced being the estimated size of this IPCU unit in mm 350x270x205 (LxWxH). These figures are slighter lower than the old IPCU with the clear advantage of the two thrusters driving capability on a single unit on the IPCU-Lite concept.

V. Conclusions

Based on the knowledge gained over these last years on the frame of the development of PSCUs (Power Supply Control Units) for Gridded Ion Engines Astrium-Crisa is now in the position to update and improve the designs carried out on the past in order to offer more competitive PSCUs. The goal of these new PSCUs is still the same, to be able to feed and control the Ion Engines, by achieving a reduction on mass and volume and increase of efficiency with respect to previous topologies. This update, as presented, has been addressed for two differently sized Ion Engines.

As it has been explained this goal can be achieved not only with the heritage gained in the previous units but as well on the experience obtained from the extensive characterisation and performance of these units when supplying the above referred thrusters. This comprehensive knowledge both on the electronics itself and the load to be supplied has been the key to allow the stepped evolution of the electronic unit as described, both for the models already built and as well for the new and innovative ones.