

Radio Frequency Ion Thruster – Radio Frequency Generator, Power Supply, and High Voltage Converter

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Summary

APCON has developed and manufactured Radio Frequency Generators (RFG), since 2001 for Astrium Space Transportation and in cooperation with research projects with University of Giessen. The design is based on Design Reference Project of Satellite Artemis (RITA-10). The space qualified RITA-10 Radio frequency ion propulsion system has an operating life in excess of 20,000 hours and a nominal specific impulse of 3058 s. Until then APCON realized the following types of RFG's: RFG-900W for RIT-22/ ASTRIUM (thrust is 250 mN) (The thruster has achieved a nominal specific impulse of 6,400 seconds and has been operated in ground testing facilities for more than 10,000 hours); RFG-600W for RIT-15 (thrust is less than 180 mN); RFG-200W for RIT-10 (thrust is less than 80 mN); RFG-40W for RIT-3.5 (thrust is from μN to 4.0 mN). These thrusters were not built for aerospace application. The experiences with this unit have encouraged further and comprehensive design refinements which were applied in the following development of the ion thrusters next generation.

Keywords

Radio Frequency Ion Thruster (RIT); Electric Propulsion Power Systems; Radio Frequency Generator (RFG); RFG-Power Supply Control Unit (RFG-PSCU); Beam Current Control Unit (BCCU); Positive High Voltage Converter (PHVC), Negative High Voltage Converter (NHVC); Power System; Serial Command Interface (SPI); Analog/Digital Converter (A/D 12 Bit); Digital Analog Converter (DAC 12 Bit)

1. RFG Features

The units built to this date, RFG was in Cooperation with ASTRIUM and a lot of research projects with the University of Giessen and for commercial customer, e.g. for the application of surface treatment (high-performance mirror).

Based of Design is the Reference Project: Arthemis / RIT-10.

Same principles will be applied at our RFGs, but are now further developed.

The deliverable output power is defined for a range of 15 W to 900 W (e.g. RIT-22) sinusoidal RF-Power, measured on the series resonance resistance (R) in the RIT-XT resonance network R/L/C (resistor/inductor/capacitor).

The impedance range for the resistances is about 0.5 to 6 Ohm and includes all variations of the plasma as a function of ionization status, discharge pressure and operating frequencies.

The RFG-Input current is limited by the RFG-PSCU (RFG Power Supply Control Unit) to a maximum level of max 6 A which effects to a maximum output current of the RFG to 18.8 A.

The input voltage is limited by the RFG Power Supply to a maximum level of 160 V (e.g. at RIT-22) or 50 V (e.g. RFG_40 at RIT-3.5).

Characteristic for all power classes is: a Matching Network is not necessary!

The RFG power output stage is direct connected via the R/L/C-network and does not requires any impedance matching or adjustment.

Figure 1 represents different RFG Types for different RIT-Systems.

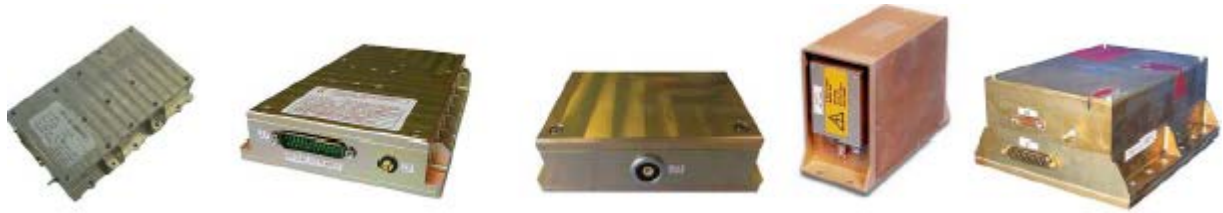


Figure 1 – RFG Types

2. Study Assembly RFG, RFG-PSCU, and PHV-PSU/ NHV-PSU

In the last sheet we have assembled a design study for the arrangement of RFG, RFG-PSCU and High Voltage Power Supply for the P-HV and N-HV Power Supply Unit.

All modules are in the same performance class and can be designed - at least mechanically – with identical mechanical layout.

Because of the diversity of combinatorial possibilities of different ion thruster's power classes and DC/DC-Converter-topologies and the different S/C-Busbar Voltages, there is no standard available, e.g. COTS (Components Of The Shelf).

All modules must be designed in accordance with individual coaching in any case; application will be designed and manufactured.

Figure 2 shows a design concept of an assembly for the power system modules, in a row arrangement, for RFG, RFG-PSCU, PHV-PSU/ NHV-PSU.

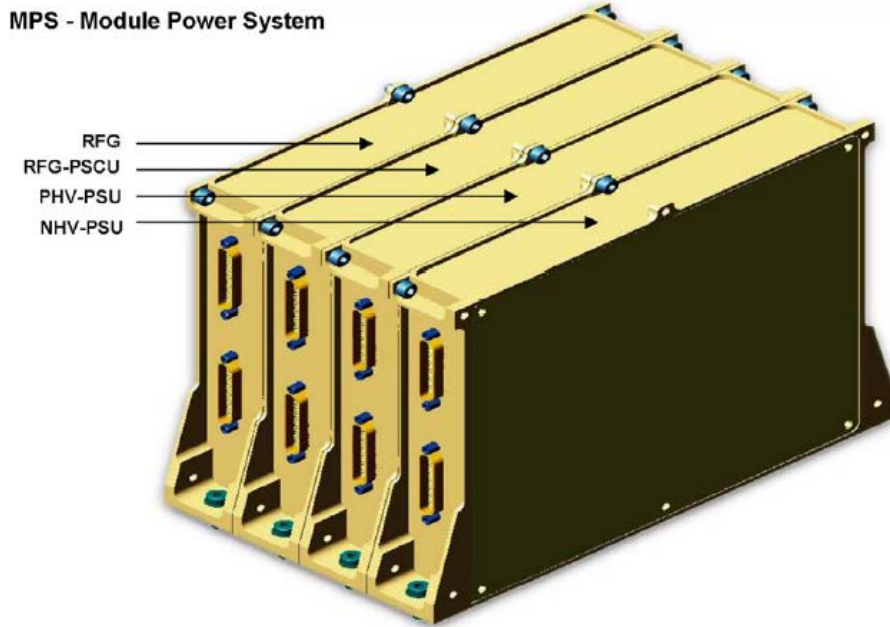


Figure 2 – MPS – Module Power System of RFG, RFG-PSCU, PHV-PSU/ NHV-PSU

3. RIT – Operational Principle

All Components with the green background show the Competences of APCON.

All the components are designed in the same technology.

Depending on performance and S/C-busbar voltage, the Power Converter topologies can differ from each other.

The Beam Current Controller compares Beam Current Reference Voltage with the actual measured Beam Current (I_{BEAM}) at the Engine, which corresponds direct to the thrust.

The beam current is the difference of the output current of the Positive High Voltage Converter (PHVC) and the Negative High Voltage Converter (NHVC) Power Supply.

The Beam Current Control Unit (BCCU) commands the value of Voltage and Current for the Radio Frequency Generator (RFG) to the RFG-Power Supply Control Unit (RFG-PSCU).

The Amount of RF-Energy is defined by the Radio Frequency Generator (RFG) input current and input voltage, and they are limited by the RFG-Power Supply Control Unit (RFG-PSCU).

Figure 3 represents the RIT Operational Principle.

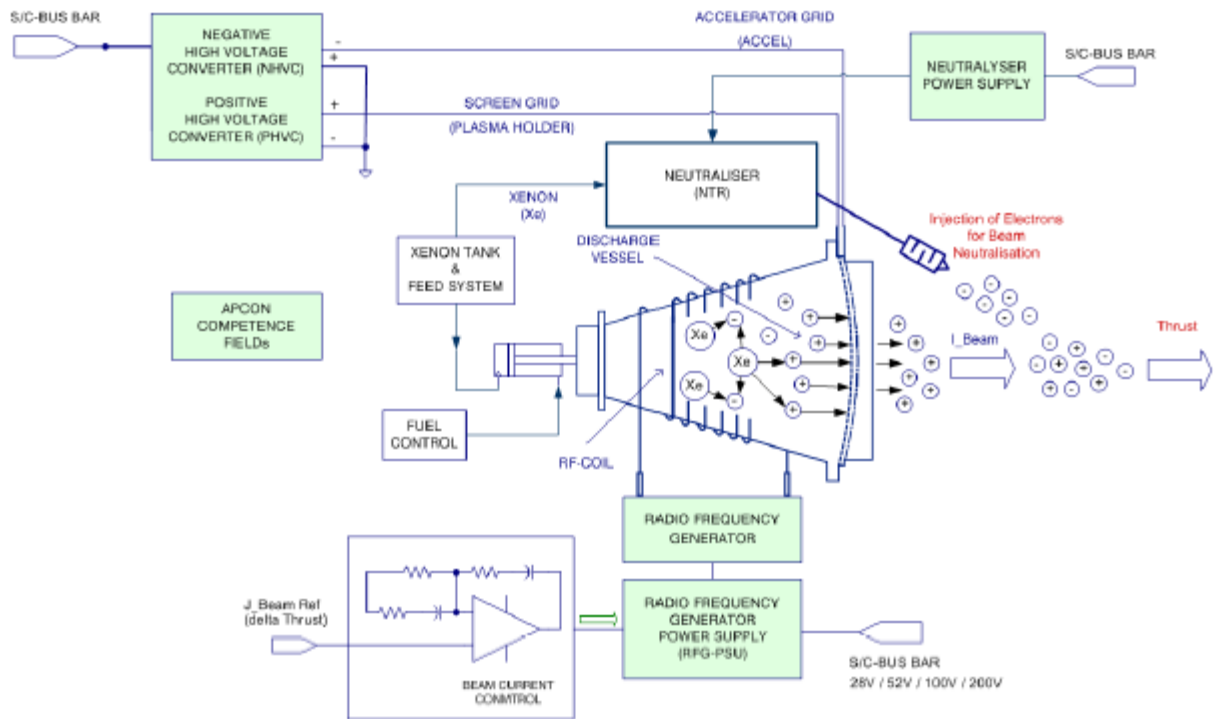


Figure 3 – RIT Operational Principle

4. RIT - Operational Principle between RFG, RFG-PSCU, PHV-PSU/ NHV-PSU

Radio Frequency Generator (RFG) is based on the phase controlled signal processing principle.

This is a closed loop frequency control system, detecting a phase difference between an input and an output signal of a controlled oscillator.

Alternating current (AC) output power is transferred from Radio Frequency Generator (RFG) via the RF-Coil into the plasma.

Figure 4 gives an overview of the operational interaction principle between the key components of RFG, RFG-PSCU, BCCU, PHVC, NHVC .

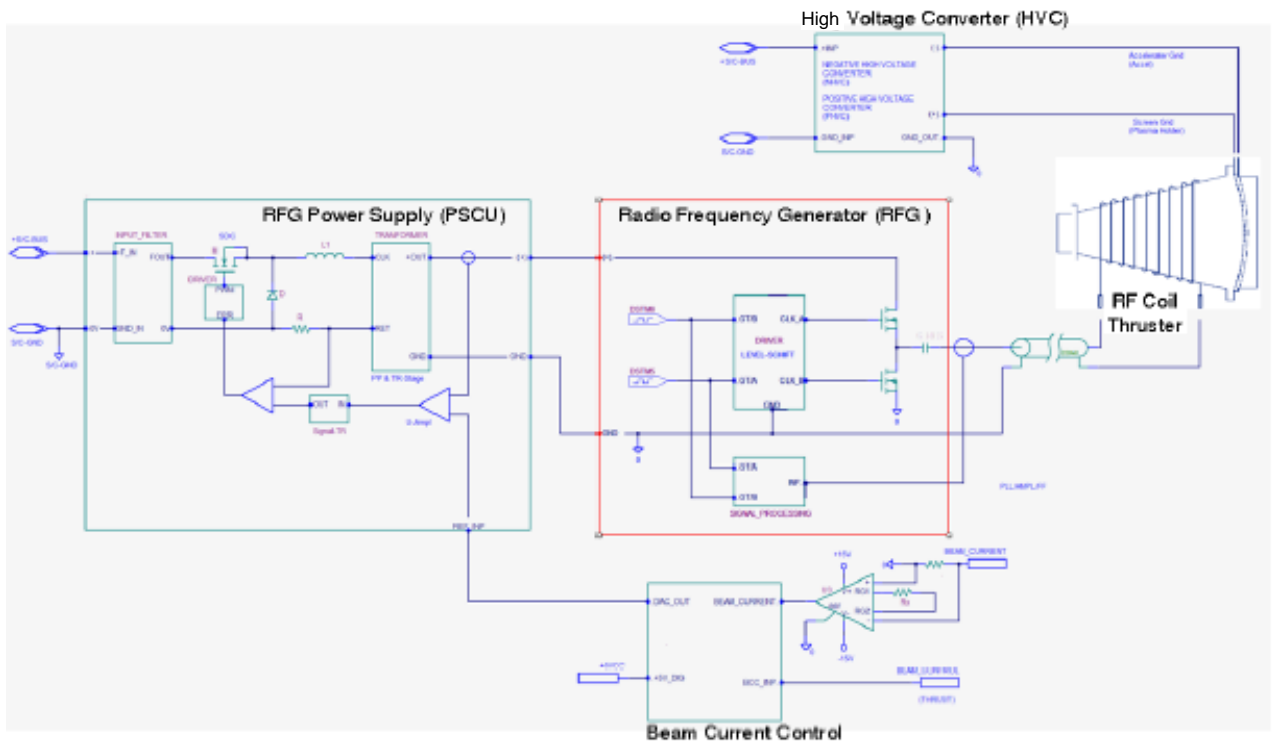


Figure 4 – RFG, RFG-PSCU, BCCU, PHVC, NHVC

5. Section Drawing of RIT

The RFG produces from the DC-Input a phase controlled RF-Power.

The RF-Energy is direct transmitted by inductive coupling via a RF-Coil, which is mounted on the outer diameter of the discharge vessel.

The RF-Energy is defined by the input current and input voltage and they are limited by the RFG Power Supply.

RFG is direct connected via an R/L/C series resonant network to the RF-Coil.

The RF produces an electromagnetic field Xenon plasma inside the discharge vessel of the RIT. Figure 5 represents the 3D-Assembly of RIT.

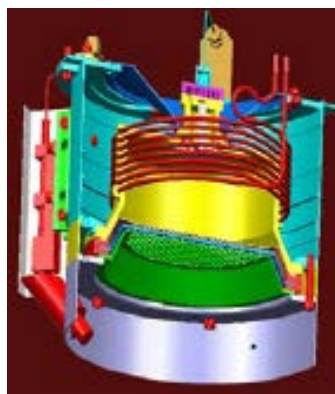


Figure 5 - 3D-Assembly of RIT (Picture/Source: by Astrium)

6. RFG Operating Frequency

The operating frequency of the RFG depends on the operating mode, the actual mass flow and the plasma impedance and beam current (Phase/Frequency Control of RFG).

The APCON preferred technology does not require matching networks.

The RFG automatically adjust the operating frequency to achieve optimum direct RF-power coupling over the operating frequency range.

Theoretical resonance frequency is:

$$f_{res} = \frac{1}{2\pi\sqrt{L_c C_{res}}}, \quad (1)$$

where

L_c - is RF-coil inductance;

C_{res} - is resonance capacitor.

7. RFG-PSCU Features

The main converter topology is a PR–PPC Converter (Pre Regulated–Push/Pull Converter).

Converter #1 is a PWM (Pulse-Wide Modulated) Step Down Converter.

Converter #2 is a Push/Pull power stage – which transfers the input power via RF–Transformer's to the secondary side.

The stabilization is assured by an Average Current Mode (ACM) regulation System.

A stable operation also possible under an unstabilised S/C–Bus Bar.

The AVCM Topology has an excellent dynamic, a high loop stability margin and high audio susceptibility (CS) stability.

The commanding of RFG-Current is set by a first Digital Analog Converter (DAC 12 Bit), which includes a Serial command interface (SPI).

The commanding of RFG-Voltage is set by a second Digital Analog Converter (DAC 12 Bit), which includes also a Serial command interface (SPI).

Figure 6 represents the block diagram of the Regulation Loop between RFG and RFG-PSCU.

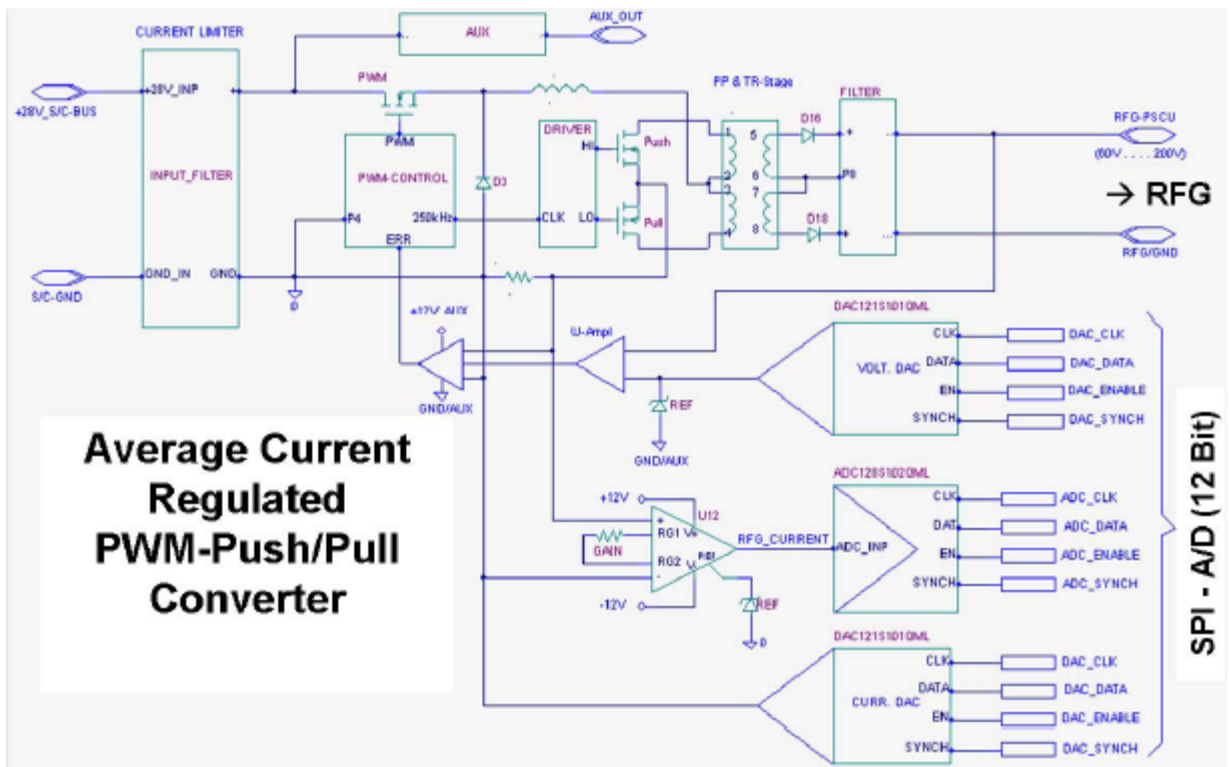


Figure 6 – Block Diagram of RFG-PSCU Regulation Loop

8. Positive High Voltage Converter (PHVC), Negative High Voltage Converter (NHVC)

Figure 7 represents the Average Current Regulated PWM-Push/Pull Converter principle for Positive High Voltage Converter (PHVC), also in principle for Negative High Voltage Converter (NHVC).

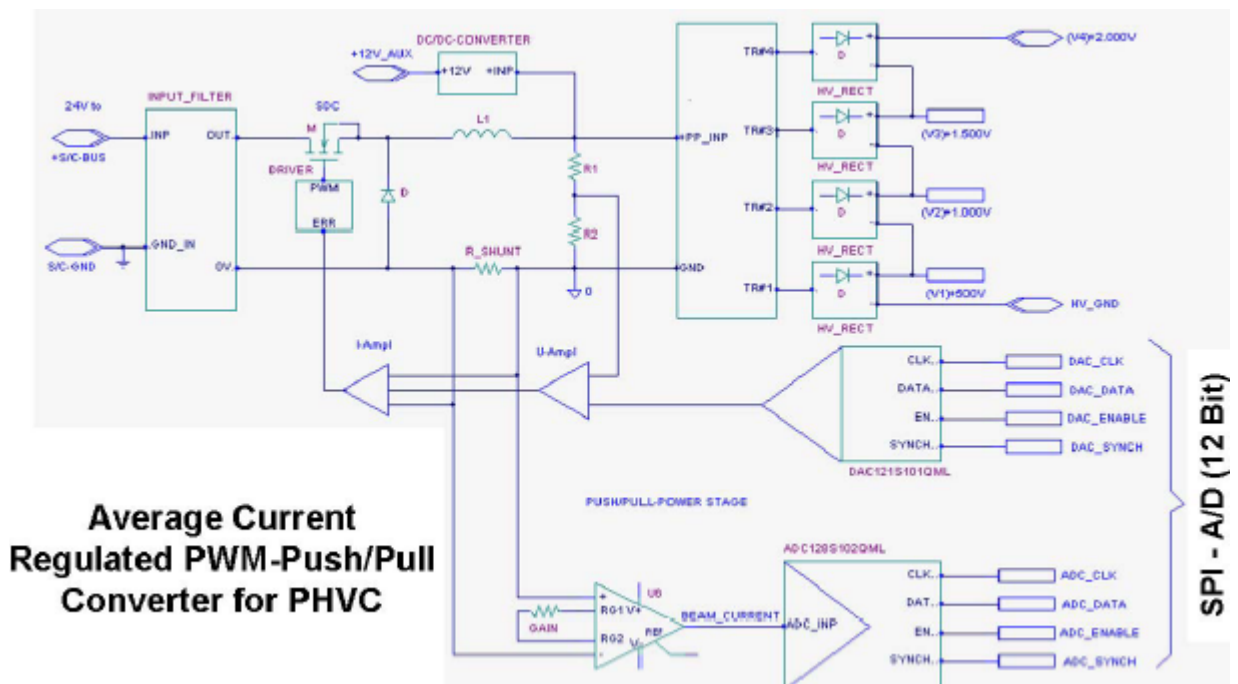


Figure 7 - Average Current Regulated PWM-Push/Pull Converter for PHVC/NHVC

9. APCON Ion Propulsion Activities 2012

New current Designs and Developments are:

- Nano Satellites: Design and Study Phase for Nano Thruster Engines. Thrust is less than 100 nN in cooperation with University of BW Neubiberg (see Figure 8).



Figure 8 – Pico-Satellit UWE-3

- ESA LISA Pathfinder Evaluation Program. μ N-Ion Thruster Engine – RFG_40 / RFG_60 Hardware Phase in preparation (see Figure 9).

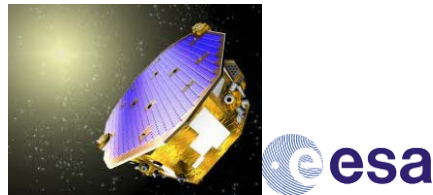


Figure 9 - ESA LISA Pathfinder

- RITSAT: Thrust is less than 1 mN-Ion Thruster Engine – Hardware Study Phase in preparation (see Figure 10).



Figure 10 – RIT-SAT

10. Conclusion

Special know how of Electric Propulsion Power Systems for RIT. Heritage in flight proven power systems over the last 25 Years. Power technology for RIT is based on APCON state of the art power designs, realized in all APCON hardware components for space, defense, military-airborne and –missile, applications.

References

- [1] <http://www.apcon.aero>

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