The RIT 2X propulsion system: current development status

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ArianeGroup is developing a modular electric propulsion system for the application in current and future telecommunication satellites. The system is based on the flight proven radio-frequency ion thruster (RIT) technology. The high performance, the extremely wide throttle range as well as the long lifetime capability of the thruster discriminates it from other EP systems. Depending on the available power level a nominal thrust range between 80mN and more than 200mN at specific impulse between 2500s and more than 4000s are achievable.

In this paper a brief technical description of the RIT 2X system will be given addressing the key functional elements and their impact on the system performance. An explanation of the radio-frequency thruster principle will be given and the engine design will be described. The performance envelop of the new generation of ArianeGroup RIT 2X thrusters will be presented. In this context the key performance parameters in terms of input power, thrust and ISP will be shown.

Nomenclature

AGG = ArianeGroup GmbH
EP = electric propulsion
FOA = flow orifice assembly
FSA = flow selector assembly
GIE = gridded ion engines
RIT = radio-frequency ion thruster
PPU = power processing unit
RIT = radio-frequency ion thruster
RFG = radio-frequency generator
TFC = thruster functional chain
XFC = xenon flow control

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I. Introduction RIT 2X System development program

Since 2014 ArianeGroup (formerly Astrium) is generically developing the RIT 2X thruster and adjacent elements targeting the technical requirements of geostationary satellites. The generic development activities resulted in the definition and build of a RIT 2X thruster which was operated in the typical high Isp operational regimes as well known from Gridded Ion Engines (GIE). With the market requesting high thrust engines for Electrical Orbit Raise (EOR), the thruster was further developed and verified to work in two modes: high-Isp/low-thrust and high-thrust/low-Isp. Since then the focus of the current ArianeGroup activities is laid on extending the performance envelop to provide a high thrust to power ratio for fast orbit raise and being capable to operate the thruster with highest possible ISP (e.g. for station keeping). All this while being compliant with a lifetime capability of typical geostationary satellites. The development program covers the development of an entire EP system that comprises the RIT 2X thruster, the radio-frequency generator (RFG), the state of the art power processing unit (PPU), and the xenon flow control (XFC).

II. Overview of the Electric Propulsion Subsystem

The electric propulsion system described here is accommodated around the RIT 2X thruster – a gridded ion thruster that is based on the Radio-frequency Ion Thruster (RIT) technology. A possible subsystem architecture with one thruster functional chain (TFC) is shown in Fig. 1. The RIT 2X TFC consists of all equipment and assemblies required to generate thrust over a wide throttling range – ranging from a lower power mode for efficient station keeping, where the system provides high Isp to a high power mode for good orbit raising performance focusing on a high thrust to power ratio to keep orbit raise durations as short as possible.

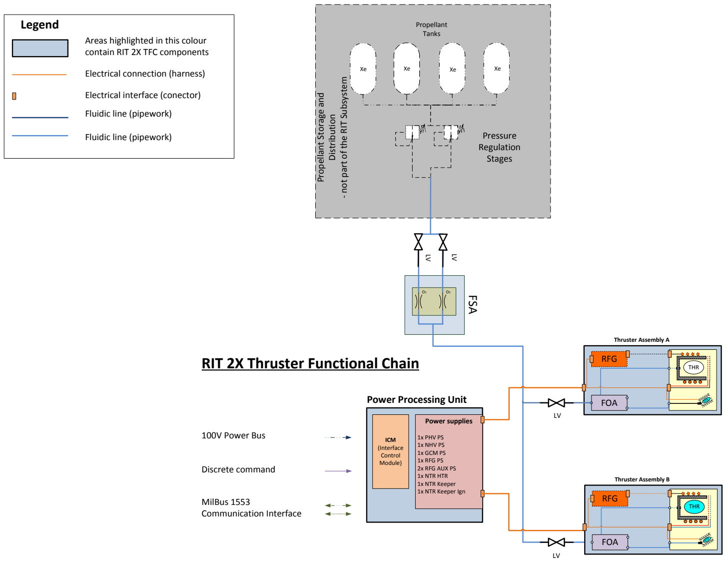

Figure 1. Fluidic and electrical architecture of a typical RIT 2X subsystem; the system can be adopted to mission needs by adding thruster functional chains

Each RIT 2X TFC consists of:

- **One** Power Processing Unit (PPU)
- **Two** Thruster Assemblies which again consist of
  - **One** RIT 2X Thruster (THR)
  - **One** Neutralizer (NTR)
  - **One** Radio Frequency Generator (RFG)
  - **One** Flow Orifice Assembly (FOA)
  - **One** FSA

In order to ensure this main function the functional chain has to:

- generate the xenon ions that can be accelerated to produce the thrust by plasma generation inside the RIT 2X thruster
- accelerate the ions using a DC extraction grid system
- generate and emit electrons to compensate the emitted ion current in the neutralizer (NTR activation and operation)
- deliver xenon gas to the thruster and the neutralizer in a controlled flow rate (XFC operation)
- allow to remove particles resulting in short circuits in the grid system (Grid Clearing)

Propellant flow control

The operation of the RIT 2X thruster does not require the implementation of active propellant flow control. Stable operation is achievable with passive flow elements. Nevertheless active propellant flow can be implemented and can be used to optimize performance mainly with respect to Isp, e.g. for long mission durations or high thruster efficiencies.

A. Thruster Assembly

The RIT 2X (Fig. 2) thruster is an enlarged version of the well tested RIT 22 and RIT 2X (24). It is dimensioned to cover the demand in high current outputs for maximum thrust generation. It is build up by a number of main functional assemblies: The two grid extraction grid assembly for ion extraction, the ionizer unit consisting of ionizer vessel with its isolating gas inlet and rf-coil, the housing for structural integrity as well as defining the mechanical, electrical and fluidic interfaces to the system.

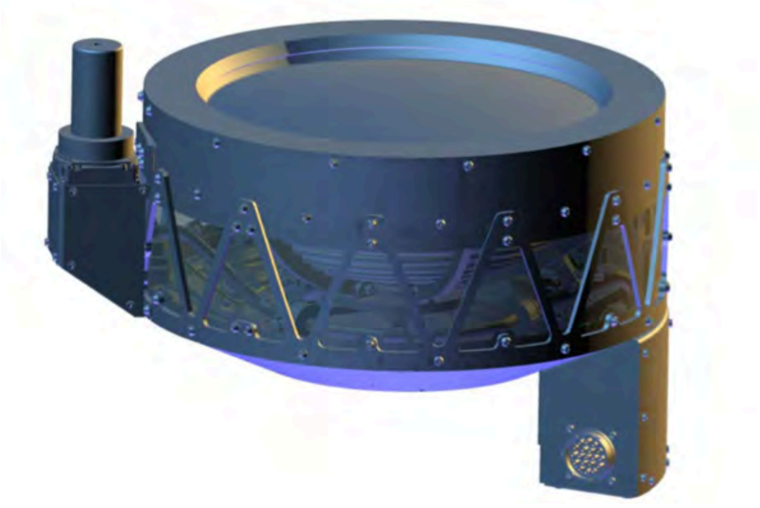

Figure 2. CAD depiction of RIT 2X Engineering Model

In contrast to other ion engines developed, the RIT has a unique feature: the propellant is ionized without using a cathode inside the thruster's discharge chamber. Instead, the plasma is generated by coupling rf-power from a coil shaped antenna into the plasma. The required rf-power is provided by the Radio Frequency Generator (RFG). This, ionization method ensures highest reliability, i.e. no life limitation is set by a discharge cathode. Furthermore, the thrust regulation strategy by regulating the rf-power provides excellent thrust control, low thrust noise and a high throttle range. The presence of an inherent insulation inside the thruster reduces electrical complexity of the RIT 2X subsystem. Only two elements of the Power Processing Unit (PPU), the supplies for the screen grid and the accelerator grid will have to operate on high electrical potential which simplifies the wiring, the grounding network and the overall PPU layout.

The neutralizer cathode is mounted directly on the thruster housing and electrical and fluidic connections are routed through the thruster main housing to provide only *one* electrical and *one* fluidic interface to the thruster assembly. The propellant distribution within the thruster assembly is realized by passive elements within FOA splitting the total propellant mass flow provided to the thruster assembly. Fig. 3 shows an operating RIT 2X EM thruster.

The radio-frequency generator is considered part of the thruster assembly. The RFG is a dc to ac converter and provides a rf-current/voltage to the coil of the thruster. The operating frequency of the RFG is within the range of 500-900 kHz. The key feature of the RFG is phase locked loop operating principle. By adjusting its operating frequency the RFG operates at the resonance frequency of the tank circuit defined by varying impedance of the thruster and its harness. A large effort has been made to develop a solution that allows a flexible placement of the RFG on the spacecraft. The RFG can be placed up to several meters away from the thruster unit.

Table 1 lists three possible operating points (OP) of the RIT 2X thruster assembly. Depending on choices made on system level regarding flow control strategy and input power typical thruster performance is tabulated.

Table 1. RIT 2X thruster asssmebly performance at different operating points.

OP	F	Isp	P
	[mN]	[s]	[W]
1	70–88	3400–3500	2000-2500
2	151–171	3300–3500	4000–4500
3	198–215	2450–2750	4800–5300

Figure 3. Photograph of RIT 2X operating in a vacuum test facility and part of the beam diagnostics setup.

B. Power Processing Unit for RIT 2X

The PPU for RIT 2X answers to satcom market needs towards full electrical propulsion solutions, capable to perform station keeping, orbit raising and transfer maneuvers. The PPU for RIT 2X embeds all the supplies required to operate a RIT thruster and its associated RFG unit. 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.
- Semi-manual mode, which allows controlling the different sequences independently.
- Protected full manual mode mainly for diagnostics and ground tests.

In the current layout the PPU has been designed for a100V input power bus. The architecture allows for adaptation to other bus voltages. Communication to the platform is established through a 1553 bus. In the baseline configuration one PPU interfaces with two RIT thrusters, with only one thruster operational

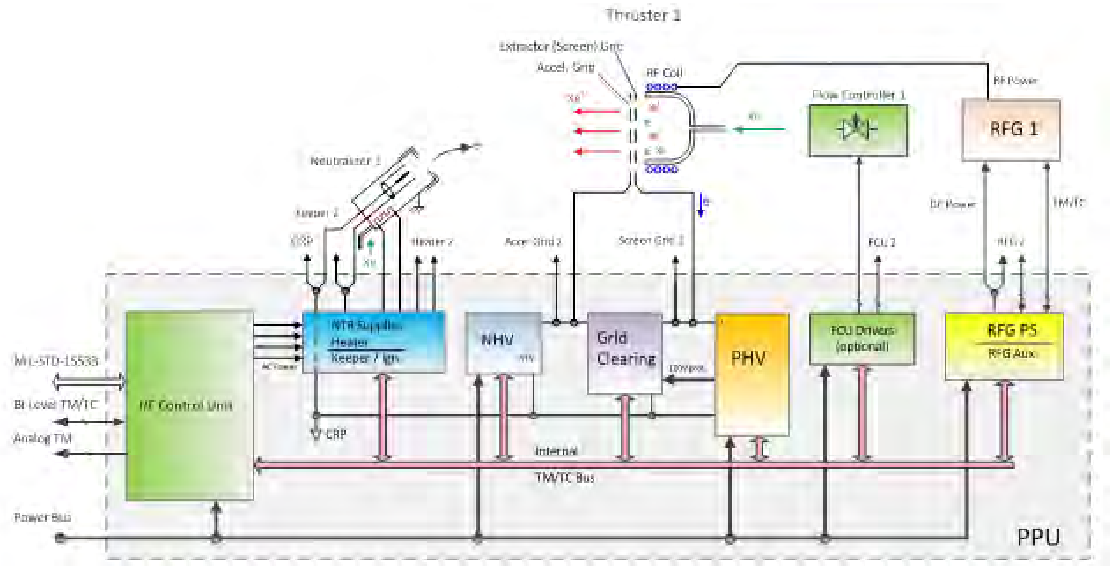

Figure 4. Block diagram of PPU for RIT

at a time. No internal or external switching units are part of the PPU design which leaves a level of simplicity without implementing complex cross-strapping. Redundancy at satellite level can be achieved by flying two independent PPUs on one satellite or introducing switching units. Depending on the system layout a single unit can be sufficient to support a mission. Thruster parameters and thruster operation sequences can be changed in flight, if needed and thus provides a large flexibility. The unit provides a wide set of adaptable protection functions and telemetries that allow a very easy adaptation to different satellite platform requirements. The unit has an implemented grid clearing functionality to enable removal of (semi)permanent shorts among the grids. Double isolation is implemented in the main bus interfaces with not need of additional external protections. The PPU has a robust high voltage design based on high thermal performance hard-potting, stringent high voltage isolation rules and soft switching power converters. The following building blocks that are also depicted in Fig. 4 are found in one PPU:

Interface and control module (ICM) It provides the brain of the PPU and interfaces with the platform. Communication is realized with a 1553 serial bus and ON/OFF signal. The ICM also includes two internal supplies from main bus, one for unit power functions and the other for unit control. The brain is the thruster controller, implemented in fused based FPGA and EEPROM with capability to reprogram thruster operation in flight through 1553 if needed. High-level functions provided are:

- Automatic ignition and ramp-ups
- Beam current control
- Autonomous arc management
- Protection and error handling
- Monitor and control of telemetry data

Neutralizer power supplies (NTR-PS) The NTR power supplies to operate the neutralizer feature the following functionalities:

- Low ripple, controlled current source for NTR Keeper minimizes cathode plasma instabilities. Current is settable by command with high accuracy for cathode optimization.
- Cathode ignition function guarantees reliable cathode ignition .
- Heater supply is a current or voltage controlled supply depending on selection of cathode. The same design can be configured for different current and voltage ranges (0 to 70 V, 0 to 18 A), with a maximum heating power capability of 400 W.

- Heater and keeper can operate at the same time in case required by the cathode or in case of cathode recovery.
- Ignition process is controlled by ICM with autonomous protection to avoid cathode overheating.

Negative High Voltage (NHV-PS) This module supplies the acceleration grid with negative voltage within a range from -200 V to -700 V. It also implements ignition function of the thruster discharge and a grid clearing functionality.

Positive High Voltage (PHV-PS) Provides controlled high voltage for the screen grid. In a baseline configuration the beam voltage is programmable in flight in a range from 815 V to 1250 V. It provides ramp rate control of the high voltage during ignition, start-up and arc recovery so the main bus conducted emissions are minimized while the thrust availability is maximized. The module includes fast arc detection enabling a fast reaction of the unit to control the arc recovery maximizing thrust availability.

Radio-Frequency Generator Power supply (RFG-PS) The RFG-PS is included to power two external RFG units, one per thruster, which can be specifically adapted to the thruster. RFG power supply is key in the beam current control since it enables the control of RF power by having the capability of regulating output voltage and current in a wide range. Ionization power can be up to 1 kW. It also enables fast and safe recovery after arc events in grids.

Flow Control Unit (FCU-PS) A power supply for Flow Control Units (FCU) inside ICM module can optionally be added on demand.

Following a successful coupling test between PPU and RIT 2X thruster in early 2017 the qualification of the PPU is currently under preparation.

III. Development and Qualification

The presented EP subsystem has undergone an extensive development program preparing the system for qualification. Several RIT 2X EM thruster test campaigns were performed in 2015, 2016 and 2017. In particular, different engineering models (EMs) of the RIT 2X thruster have been designed, manufactured and tested. The EM hot firing tests were performed in different European test facilities to characterize and optimize thruster performance. The tests included performance mappings of the RITs wide throttling range with respect to the key performance parameters and specifically focusing on performance enhancements. Different ion beam diagnostics [1] were performed during the test campaigns with the RIT 2X thruster (Fig.3:

Near-field measurements were performed using a rotary table with the single Faraday probe. The Faraday probe was moved across the grid diameter at a short distance of approximately 20 mm. The probe can be moved in an angular range of 12 deg with respect to the thruster central axis. The data acquired confirmed good uniformity of current densities across the grid diameter and a beam flatness in the range of 0.84 to 0.95 was determined.

Plume measurements were performed at several distances from the thruster before and after exposing the thruster to mechanical environment testing. The beam divergence was not significantly influenced after exposure to mechanical loads. For a typical definition where beam divergence is described by the half angle of cone containing 93% of the ions a beam divergence in the range of 16 deg to 23 deg depending on the thruster operation point and distance to the faraday probes.

ExB probe measurements were performed to determine the content of double- and single-charged ions in the beam. Across the full operational envelop of the thruster a ratio between double- and single-charged ions between 1 % 4 % were found.

In preparation of thruster qualification, the thruster has also been exposed to mechanical environmental tests (Fig. 5). On system level, several coupling tests with EM power supplies were performed. Early 2017 a system coupling test on EM level was conducted including a RIT 2X EM, an RFG 1000 EM an a PPU EM.

The overall RIT 2X Subsystem qualification approach is driven by verification of performance, endurance and lifetime, efficiency and robustness against failure modes for a flight representative configuration. A

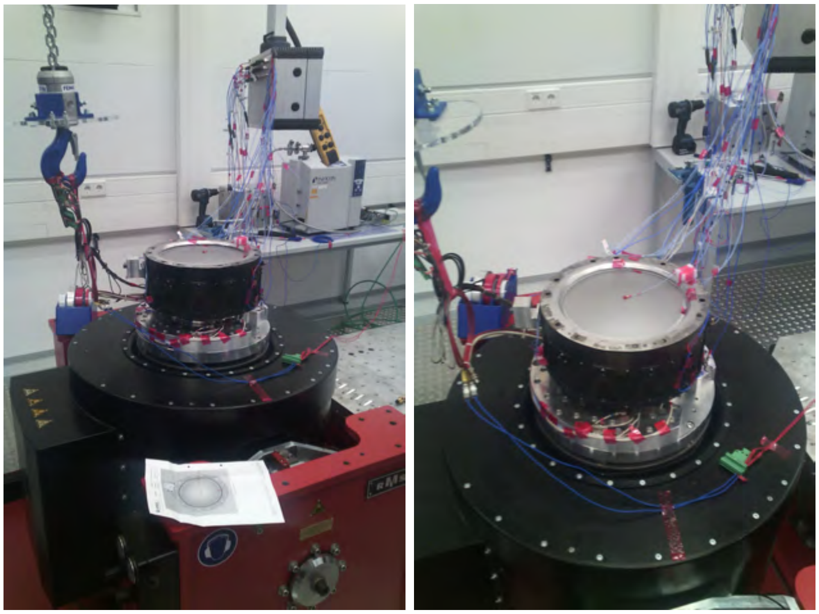

Figure 5. Photographs of RIT 2X EM thruster at Lampoldshausen vibration facility.

parallel qualification with two qualification models (QM) was defined. The test logic for the qualification phase has been derived from the thruster life sequence and is depicted in Fig. 6. The first line (using hardware QM1) starts with an acceptance test that induces the real environmental loads to the thruster assembly . After that the endurance test combined with lifetime simulations will be conducted to verify thruster assembly lifetime for the mission duration. Lifetime simulations (comparison to validated grid erosion model) shall support and shorten the lifetime qualification. During the life test flight representative operation cycles with respect to the mission profile will be performed. The second line (using hardware QM2) is used for the system qualification test which consists of the qualification environmental test and functional chain performance qualification including conducted EMC tests. After checkout this set undergoes radiative EMC tests. The qualification activities will commence in late 2017

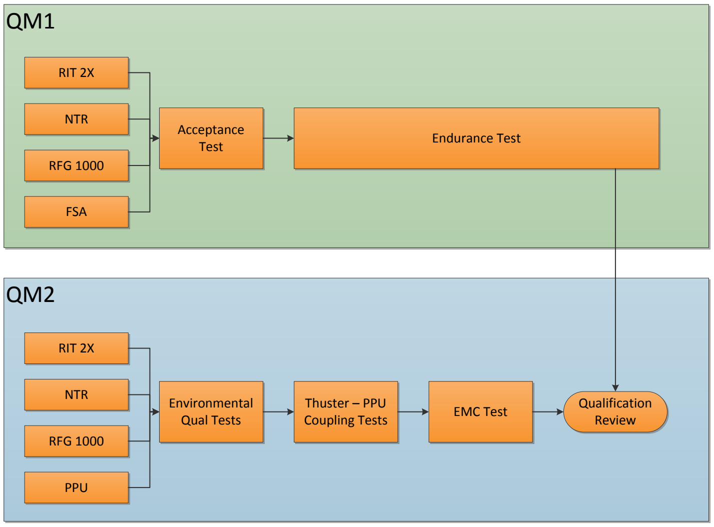

Figure 6. Fluidic and electrical architecture of the RIT 2X subsystem

Acknowledgments

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