The Ariane Group Electric Propulsion Program 2019-2020

IEPC-2019-592

Presented at the 36th International Electric Propulsion Conference
University of Vienna • Vienna, Austria
September 15-20, 2019

Hans J. Leiter[1] and Dagmar Lauer[2]
Ariane Group GmbH, Lampoldshausen, 74239, Germany

Philipp Bauer[3]
Ariane Group GmbH, München, 28199, Germany

and

Marcel Berger[4] and Michael Rath[5]
Ariane Group GmbH, Bremen, 28199, Germany

Abstract: The Radio Frequency Ion Thruster (RIT) technology is widely scalable. Based on a common fundament ArianeGroup offers a thruster family covering a thrust range from few mN up to more than a quarter of a newton. This corresponds with a power range from some Watts up to more than 7,5 kW. From the application perspective the ArianeGroup thruster and system family covers the three fields science, commercial and new space. In the introduction the electric propulsion market, its needs and its constraints are discussed. After a general technical introduction to the RIT technology the thruster family members RIT-µX, RIT 10 LC and RIT 2X together with theirembedding programs are described.

I. Introduction

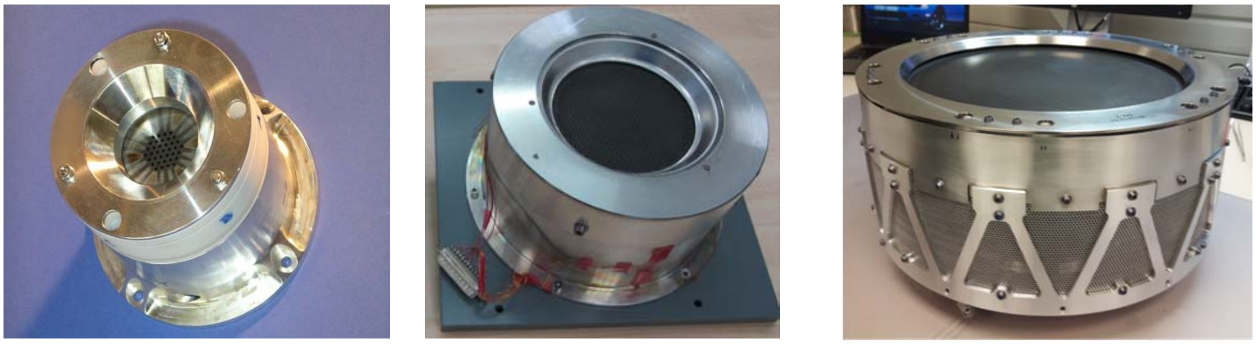
Ariane Group Ariane Group is the European leading company for orbital propulsion systems and products with a broad product portfolio. Chemical propulsion systems for nearly any applications are available. Presently, the Ariane Group portfolio is extended with contemporary electric propulsion thrusters and systems.

Fundament of the ArianeGroup electric propulsion portfolio is the radio-frequency ion thruster technology. In radio frequency ion thrusters "RIT" the propellant is ionized in alternating electromagnetic field and accelerated in electrostatic fields. Advantages of the RIT concept are the inherent high voltage insulation, perfect thrust control, very low thrust noise and last, but not least the excellent scalability. Especially the natural high voltage insulation simplifies both thruster and system design with obvious cost advantages for ArianeGroup's customer. The calability is key for a family of systems covering the thrust range from some few Micronewtons up to a quarter of a Newton.

During the last five years a bi-furcation of the market is observed. On the one hand the classic market for telecommunication satellites requests high performance systems. On the other hand, a new and rapidly growing market summarized also as "New Space", demands for innovative low cost solutions, especially for large constellations and fully new applications.

---

[1] Lead Engineer EP, Expert, hans.leiter@ariane.group.
[2] Development Engineer, dagmar.lauer@ariane.group
[3] Program Manager, philipp.bauer@ariane.group.
[4] Program Manager, marcel.berger@ariane.group.
[5] Program Manager, michael.rath@ariane.group



RIT-µX: Miniaturized RF Ion Engine for Science and Small Satellites

RIT-LC: Industrialized New Issue of the Space proven RIT-10

RIT 2X: High Power, High Performance Multi Mode Engine for Geo satellites and Probes

Figure 1 Ariane Group Radio-Frequency Ion Thruster Family

There is also request for electric thrusters propelling scientific missions. Even if in the perception the presence of science might seem to decrease, it still has a driving role as technology incubator for electric propulsion.

Ariane Group provides solutions for all three markets: The RIT 2X system is designed for the need of telecommunication satellites. Besides, it is also an attractive solution for scientific interplanetary probes. In contrast,

New flag ship of the ArianeGroup thrusters is the RIT 2X. RIT 2X is a multi-mode ion thruster in the 5kW power class serving orbit transfer (F~200mN; Is~2,500s), north-south station keeping (80-120mN; Is ~ 3,500s) and classic high thrust high specific impulse operation (F > 150mN; Is > 3,500s). The RIT 2X system qualification started in December 2017 and it is under completion. The comprehensive qualification program contains all standard elements and advanced tasks as endurance testing and proof of the electro-magnetic compatibility.

The RIT 2X development is clearly driven by the needs of commercial geo-satellites. Fast orbit rising, related with good power to thrust ratio is key here. However, RIT 2X has maintained the typical high specific impulse genes of gridded ion thrusters. This year, another important test campaign is under conductance, targeting the operational envelope of Mars Sample Return. For this application, the engine has already demonstrated capability to process more than 7,5kW electric input power.

The ArianeGroup's Arclight project marks the opposite to the high performance RIT 2X system development. The entire system is designed for the demands of new space market. The Arclight system is developed for a system power up to 450W. It will be operated at one level of thrust only, which can be adapted to specific mission needs in the range of 8-15 mN. In its power class, its specific impulse above 2400s is outstanding. The system's thruster control unit (TCU) provides autonomous system operation including the high pressure propellant management. The spacecraft's onboard computer (OBC) sends only high level commands to the TCU. No further control of the OBC for the Arclight system elements is needed.

RIT-µX is the smallest Ariane Group EP engine. Its development was motivated by the needs of the European Space Agency ESA's scientific missions (high precision formation flying or in-situ compensation of atmospheric drag or solar wind). At the thrust balance, a thrust resolution better than 0.1 µN is proven. In 2019 Ariane Group's work related to RIT-µX is focused on the proof of concept for a new one neutralization multiple thruster neutralization concept.

In the next chapter the basics of the RIT technology are explained and the generic system elements are described. Following the technology intro, the RIT thruster and systems are presented in order of the thruster size.

II. RIT Function Principle and RIT Systems Basics

A. Function Principle

Radio-frequency ion thrusters belong to the class of gridded ion engines. Gridded ion thrusters generate thrust in two steps. In the first step the propellant is ionized. In the second step the ionized fraction of the propellant is accelerated in an electrostatic field of an ion optics system ("grid system"). The ion acceleration in a grid system is the common feature of all gridded ion engines. However, different types of ionization are used. Radio frequency thrusters ionize the propellant in an oscillating electro-magnetic field. The propellant enters the ionizer via an integrated insulator and gas distributor. The ionizer vessel is made of an insulating material (quartz or alumina), and it is surrounded by the induction coil. The axial magnetic field of the rf-coil induces a circular electrical eddy field, which accelerates the discharge electrons and enables them to ionize the Xe-atoms by inelastic collisions.

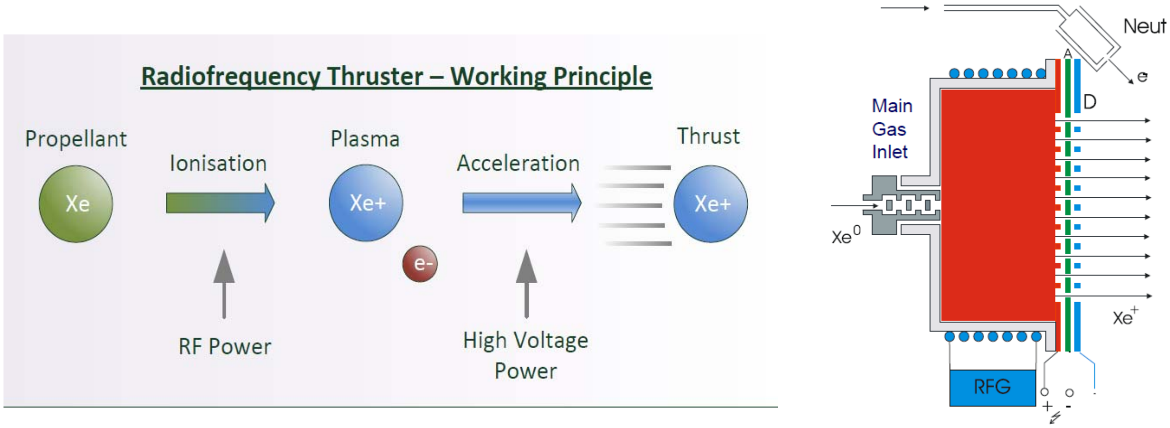


Figure 1 RIT Thruster Function Principle: 2 Steps of thrust generation (left) and thruster scheme (right)

Thus, an electrodeless, self-sustaining rf-gas discharge (plasma) is generated. By thermal movement ions from the bulk plasma find the way towards the grid system.

Eventually, the ions are accelerated in a system build of two or three grids. Concentric holes in these grids form a large number of single extraction channels. Every of these channels represent a single ion optical system. The ion optical system's properties are determined by the diameters of the holes, the grid spacing and the applied voltages.

Ionization and acceleration are clear spatially and functionally separated processes. This allows tuning and adaptation of an existing thruster to changing performance requirements.

Today, xenon is de-facto standard for all electrostatic thrusters (RIT, Kaufman, HEMP, HET) thus the RIT engines are optimized for the noble gas. However, the cathodless ionization allows operation with a manifold of propellants. Besides noble gases also inert and reactive gases can be ionized. For best performance ionizer and grid system have to be optimized accordingly.

The RIT technology is a flight proven. The first Western European operation of a gridded ion thruster on board the retrievable carrier EURECA [1] and the rescue of ESA's technology satellite ARTEMIS, which was the first orbit topping of a geostationary satellite [2] are still milestones in the history of electric propulsion.

B. RIT System Basics

The thrusters are embedded in a system. In the following the components for a RIT based EP System are summarized:

<u>Neutralizer</u>

A gridded ion thruster expels only positively charged ions. Necessarily the thruster's ion current has to be compensated with an equivalent electron current. Usually, hollow cathode type neutralizers are user for this purpose. Depending on the thrust range, for small thrusters, like RIT-µX, the propellant consumption of these devices is too high. Instead, gasless, low perveance e-gun type neutralizers are preferred for the lowest RIT-µX thrust range (10-100 µN). For the 'high' thrust level RIT-µX ArianeGroup is working on an rf-neutralizer which is in fact a RIT-µX in reversed mode.

<u>Radiofrequency Generator (RFG)</u>

The RFG converts DC current into the required AC current for the rf-coil inside the thruster. The ArianeGroup patented PLL technology ensures exact matching to the thruster's complex plasma impedance under all operational conditions.

<u>Management of the propellant flow</u>

It is common practice to separate the propellant flow management into two steps: Pressure regulation and flow control. The pressure regulator reduces the high pressure inside the xenon storage, which might consist of multiple tanks, down to pressure of typically 2 bars. The constant pressure is fed to the flow control units ("FCU") for the individual thrusters. The FCU devices regulate the mass flow to each thruster.

<u>Power Processing Unit</u>

Besides xenon, the thruster needs one positive and one negative high voltage for the grid system and an alternating current for the thrusters ionization coil. The AC current through the coil is driven by a radio frequency generator ("RFG"). The RFG is con-trolled via a power processing unit (PPU). The PPU provides also the two high voltages for the thruster and the drivers for the FCU. In fact, the PPU has to provide all voltages required by the electric propulsion sub-system. The PPU interfaces with the power bus and the spacecraft's data bus. It receives high level commands and translates them into operation sequences. Also autonomous exception handling is implemented.

III. RIT-µX Systems

A. Scope of the RIT-µX Development

RIT-µX is the smallest thruster in the RIT family. In fact, the high specific impulse in one advantage of RIT-µX based systems and this is clearly the fundamental advantage of electric propulsion. However, an appropriate EP technology offers features and advantages beyond simple mass saving.

Especially the RIT technology provides perfect thrust control, in terms of resolution, response, reproducibility and linearity together with very low thrust noise. This is the key for new types of scientific missions. It enables in-situ compensation of atmospheric or solar drag or high precision formation flying. All these concepts are related with smaller spacecraft (50-300 kg typ.)

A thruster for this type of applications is Ariane Group's RIT-µX. It can be adapted to different thrust ranges in the low Micro- and Millinewton thrust regime. Thrust resolution better than a tenth of a micro Newton has been demonstrated. Although the development of RIT-µX was clearly motivated by the needs of the European Space Agency ESA's ambiguous scientific missions, the field of applications is by far broader. RIT-µX systems can also power small commercial satellites. For earth observation and communication the satellites can be flown in substantially lower orbits; here, the EP system compensates the significant air drag in low altitude. This is the key to higher observation resolution or improved communication capabilities. Instead of circling around the Earth, also small lunar or planetary orbiters can be considered, too.

A third field of application is from different nature: Onboard telecom satellites, RIT-µX could be used as 'actuator', especially for roll-maneuvers. It can supplement or replace reaction wheels.

B. RIT-µX Thruster and RIT-µN neutralizer

From the very beginning RIT-µX has been designed in a modular way. The thruster housing is the primary structure. It carried the ionization unit, composed of ionizer vessel, rf-coil and combined gas inlet and insulator, the ion extraction and acceleration unit and the interface section.

For the extraction and acceleration unit three different ion optic systems are available optimized for the thrust ranges 10-100µN, 50-500µN and 80-2500µN. The three thrust ranges are derived from the needs of ESA's scientific missions[3,4]. The corresponding thruster configurations have been extensively tested in corresponding ESA programs.

As any gridded ion thruster, RIT-µX requires a neutralizer for compensation of the ion beam. For the two lower thrust ranges gasless thermionic devices are first choice because they do not diminish the system's specific impulse. In these thrust ranges the max. ion current is below 2 and 7mA and suitable and qualified electron sources are available..

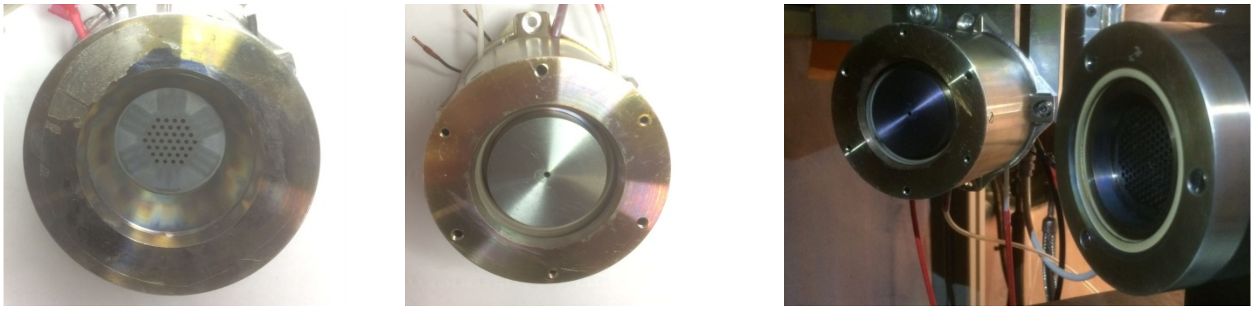


Figure 2 RIT-µX Thruster and RIT-µX Neutralizer

For the high thrust range the situation is different. The max. ion current reaches 30mA which represents the upper limit of the qualified device.

For larger ion thrusters neutralizers based on the hollow cathode principle are de-facto standard. For operation they need about 10% of the main engines mass flow which is acceptable and they are capable of delivering currents from Milliamps to Amps. However, for neutralization of the RIT-µX currents they have a severe disadvantage: It is not possible to reduce the xenon consumption linear with the electron current. There is a first threshold when the coupling plasma bridge breaks down and a second when also the main discharge stops. As result the neutralizer would consume more propellant than the thruster itself.

Interestingly, it is the rf-ionization principle that bridges the gap between thermionic emission and the hollow cathode principle. It is possible to extract electrons instead of ions from the plasma via a plasma bridge. Two elements are necessary: Inside the RF-neutralizer an "ion catcher" is require which collects an equivalent positive current for the expelled electron current. The details would exceed the scope of this overview. Secondly, an orifice is needed which forms a plasma bridge between the inner of the neutralizer and its environment.

The modular concept of RIT-µX allowed the adaptation of the thruster towards a neutralizer by changing a few parts only. As the ionization unit is not touched also the RF-generator for the thrusters are usable without any modification. More details on RIT-µN are provided in ref. 5.

C. The MRGAN project

The development of the RF neutralizer is embedded in an ESA GSTP (GSTP 617-145 MP) project. It is called 'Miniaturized Radiofrequency Generator and neutralizer for RIT-uX' or 'MRGAN# for short.

A further specific key element in any RIT based system is, besides the thruster, a suitable radio-frequency generator. In fact, thruster and rf-generator represent a functional unit. In this view, the rf-generator can be considered also as a part of the thruster itself.

Ariane Group labels the rf-generators according to their DC input power ('RFG-XX'). Starting with the so called RFG-40, succeeding models had continuously improved performance and functionality. With 'RFG-60 Advanced', which was developed in context of the LISA Pathfinder technology demonstration activity, both performance and function have reached their targets.

In the frame of the MRGAN project a further miniaturization of the device is ongoing. The development team targets are a mass reduction of 25% and a reduction of the RFG volume by a factor of two.

Past RIT-µX activities revealed that a load simulator for the rf-generators would be helpful. A standardized load simulating the thruster is very useful during the RFG development. Furthermore it is an essential tool to establish a standardized rf-generator acceptance procedure. The development of an adequate load simulator is the second element of the MRGAN activity.

C. **Endurance Testing**

The RIT-µX model for thrust range 80-2000µN has undergone two 500 h endurance test. The first 500h block was conducted in the frame of the ESA activity 'Miniaturized Gridded Ion Engines for Future Scientific Missions'. The test was performed in the ESA ESTEC electric propulsion laboratory. Here the Giant vacuum facility provided excellent test conditions. Later the test was extended in Gießen Universities 'Jumbo' for another 500 h. This test was funded by ArianeGroup RT.

Presently another 2,000h test with this thruster is in preparation in Gießen. Frame of the activity is another GSTP Project. Besides RIT-µX endurance testing, the project will investigate also effects of testing two ion thrusters in parallel.

IV. RIT 10 LC and Arclight

A . Scope of the Arclight Project

Through the rise of mega-constellations, the demands of the markets shifted dramatically: instead of tailor-made and highly customized systems, satellite prime look for simpler, standardized products, easily available in large volumes, all that at dramatically decreased unit costs.

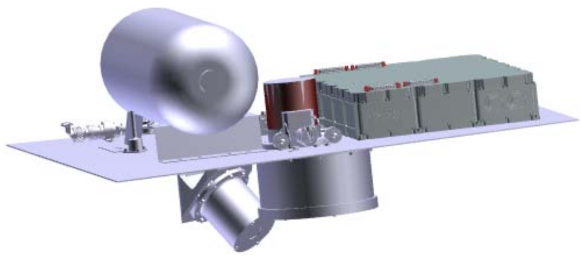
Answering this shift in the demand, ArianeGroup incepted the Arclight program: aimed at providing a simple, RIT-based built-in propulsion system available in large numbers, it led the ArianeGroup teams to completely rethink not only the propulsion system, but the commercial approach at large. Following a deep customer discovery process, the team settled on a first product, suitable for spacecraft in the 150kg range. For that application, the specifications were set up and all components were completely reengineered and re-tooled.

Incorporating supply chain considerations from the cradle on, it led to a new class of systems: enormous simplified, delivering robust performances at drastically reduced unit prices.

For this initial product, AG was already able to attract first clients for customization, currently under study.

B. **Main components & status**

The following illustration presents the Arclight system in a typical small-satellite arrangement, as it would be proposed for constellations in the 150kg-space.



Requirement	Value
Total impulse	210+ kNs
Thrust	12 – 13 mN
System ISP	>2600s
Electric Power	< 400W
Life-time (on orbit)	5.5 years
Dry Mass	10 - 12 kg
Propellant	Xe

Figure 3 - Arclight / Core system (left) and main specification parameters (right)

The Arclight propulsion system is a single-string all-in-one propulsion system, and encompasses:

- *A Xenon Propellant Tank (XeT),* storing the Xenon under high pressure,
- *A Shape-Memory Alloy Valve (SMA)***,** which acts as a priming device, and ensures safe handling on the ground. This device acts similarly to a pyro-valve, excepted that it does not bear all the classical limitation of pyro-technical equipment,
- *A Pressure Storage and Conditioning Assembly (PSCA)***,** which regulates xenon flow required by the thruster and the neutralizer. Built on a bang-bang pressure regulator, it is further equipped with pressure gauges and thermal control loops.
- *A Radiofrequency Ion Thruster (RIT 10 LC),* which converts the Xenon into ions, thereby generating thrust,
- *A Neutralizer (NTR),* which converts Xenon into an electron beam, in order to neutralize the ion flow.
-
- *All these units are controlled by a Thruster Control Unit (TCU):* which controls the propulsion system over all function modes, from priming over normal use to recovery. Acting as abstraction layer, the incorporated chip contains the flight software, and interfaces directly with the power and data busses of the spacecraft.

This architecture warrants that the function modes of the propulsion system are appropriately and robustly implemented, and that the integration into the flight software is effortlessly done.

C. Status

Being developed through the means of SCRUM on hardware techniques, and leveraging extensively fast prototyping and test-driven development, the system has reached an overall maturity of TRL 6. Further activities are under way in order to keep the development in sync with the market needs

V. RIT 2X

RIT 2X is Ariane Group's 'flagship' RIT engine designed for the needs of contemporary and future telecommunication satellites. These satellites demand for dual or even multi-mode operation.

For geostationary satellites the pioneer years of electric propulsion are gone. Electric propulsion (EP) is widely used for North-South-Station keeping (NSSK) and operators ask for adequate EP solutions for orbit transfer, too.

Performing both, NSSK and OR with one and the same engine means a challenge for the thruster design because the requirements for NSSK and Orbit Raising (OR) contrary.

A. Concept

During NSSK operation high specific impulse for maximum mass saving is highly desirable whereas OR requires higher thrust at cost of reduced specific impulse. It is the unavoidable trade in the triangle of power, specific impulse and thrust which results in a desirable specific impulse around 2,500s for the OR maneuver.

Comparing the two major thruster technologies, Hall Effect Thrusters (HET) and Gridded Ion Engines (GIE) shows that the natural best specific impulse of the technologies is typically ~800 s above the target for HET and starts ~800s below for GIE. A bit simplified, it is the erosion which increases with the ISP for HET and is the space charge limitation for GIE which makes the reduction of ISP together with increasing thrust so difficult.

Ariane Group faced this challenge and the result is the new RIT 2X thruster with its new and unique 2,500s high efficiency mode for high thrust maneuvers. This mode takes benefit of the special behavior of RIT engines, when operated with high RF-power and increased propellant mass flow.

Figure 4 RIT 2X in operation

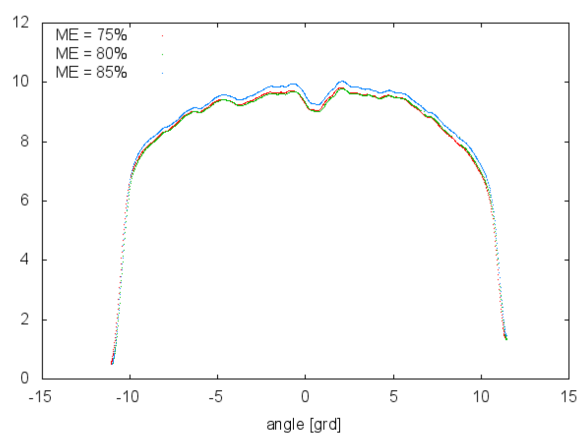


Figure 5 Nearfield measurement of beam current density, performed 20mm downstream the accelerator grid of a RIT 24 EM thruster

RIT 2X is the first gridded ion thruster worldwide, offering a dedicated high thrust OR mode with ISP 2,500s.

The challenge for gridded ion thrusters is the fact, that operating at lower Isp means operating at lower beam voltage. However, the required beam current for a given thrust increases which is opposite to the space charge limitation of any electrostatic ion thruster.

The implementation of the high thrust mode bases on four elements. First, there is the high beam flatness of RIT engines, which provides a homogenous load to the thruster's grid system. Beam profile measurements performed in the near field of the engines confirmed, that a high xenon throughput further increases the flatness. Fig.5 shows an example of a near field measurement. (The flatness factor was found to be 0.92)

Second, there is the composition of the grid system. From the very beginning, Ariane Group is using graphite for the acceleration grid instead of commonly used molybdenum. The sputter yield of graphite is typically 6 times lower than the one of molybdenum.

Third element is the plasma properties of rf-discharges. At any power level an increase of xenon throughput reduces the electron temperature. In fact, the RIT 2X electron temperature is lowest in the high thrust mode and screen grid erosion is nt an issue in the mode.

Forth, accomplishing the required beam current made a slight increase in size necessary. RIT 2X is larger than RIT-22. More information about RIT-22, its test heritage and its evolution is provided in ref. 6.

In the next years a further increase of electric power onboard geo-satellites can be expected. This will also shift the trade between Isp and thrust more towards specific impulse. Thus, RIT 2X contains also a third mode for high Isp and high thrust. This mode is already supported by the PPU which is ready to process up to 6.5kW input power.

B. Qualification Status

Since December 2017, the RIT 2X system qualification program is running[7]. To squeeze the qualification ArianeGroup works in parallel with two qualification models QM 1 and QM 2. QM1 undergoes the is lifetime qualification whereas QM 2 is used for advanced system tests as proof of the electro-magnetic compatibility and correct coupling with the power processing unit.

All environmental tests have been successfully passed: Vibration, shock and thermal vacuum cycling. To date, in the endurance test QM 1 has been successful accumulated more than 3,500 hours. The test started in the novel orbit raising mode. As predicted, the thruster has already demonstrated a typical orbit raise maneuver. Recently the operational mode was changed to NSSK. QM 2 is just in preparation for the EMC test campaign. In parallel to the thruster qualification the qualification of the rf-generator, the PPU and the neutralizer is performed. The important coupling test was also successful completed.

C. High Power Geo-Satellites and beyond

Inherently an increased thrust to power ratio means sacrificing specific impulse and electric efficiency. The definition of the operational points is a trade between available power on the one hand and thrust and propellant saving on the other hand. For today's telecom satellites RIT 2X is optimized w.r.t max. thrust at limited power. In case more power is available, both thruster and power processing unit are ready for operation at increased power, thrust and specific impulse. The max. power which the PPU can provide is 6kW in total.

However, 6kW are not the power limit of the thruster. Without any hardware modification the characteristics can be shifted further towards higher specific impulse. Presently, ArianeGroup conducts a Technology Demonstration Activity (TDA), initiated by ESA for the potential NASA/ESA mission "Mars Sample Return". In this context thruster operation with 7.5kW.has been demonstrated. For the MSR mission profile "classic" high specific imulse operation is sufficient. With an ion optics system designed for very high specific impulse the thruster can reach specific impulse 7-10,000s and it is capable processing 20-30kW input power.

VI. Electric Propulsion - Production and Test at Ariane Group's Site Lampoldshausen

From the very beginning Lampoldshausen site has all facilities for hot firing of chemical thrusters and in fact, the need for testing chemical thrusters was the major origin for establishing Lampoldshausen operated by the German Space Agency DLR and Ariane Group.

For chemical propulsion test stands covering the needs from 1N chemical, hydrazine, up to the Ariane Vulcain engines (LOX, 1359kN thrust) are available. Since 2017 also a test facility for EP is available on site because only an acceptance test facility in close vicinity to manufacturing and integration sites ensures an effective work flow. In this context Ariane Group has taken the decision to build a dedicated vacuum test facility for electric propulsion in Lampoldshausen. In contrast to typical development- and endurance test facility the new Ariane Group facility is designed from the very beginning for the needs of serial acceptance testing [K].

Figure 6 Manufacturing Center Lampoldshausen

Figure 7 Sub-System Integration Center Lampoldshausen

Figure 8 On Spacecraft Integration Center **Figure 9 Electric Propulsion Test Facility Asterix**

In fact, testing was the first pillar on which the site was built. The second pillar of Lampoldshausen is production of orbital propulsion components. In the production center 'M69' all production steps for components are integrated. From stock, raw materials find their way through the workshops and integration facilities. Finally they reach the cold test section, which includes also a stand for vibration testing. A special designed elevator allows the transportation from floor to floor without leaving cleanroom conditions. All necessary instrumentation for optical and tactile parts and product inspection is available, too[8].

Third pillar of the site is the integration center for orbital subsystems In Lampoldshausen, ArianeGroup can offer their customers also the option of propulsion system integration directly to their spacecraft

VII. Conclusion

The market for electric propulsion changes both way: Evolutionary and disruptive. In fact, there is not one market, there are three different markets: The classic commercial market, the institutional market for scientific missions and new space, the world of mega-constellation. They are very different, however they interact and presence in all of them is essential.

For the classic market ArianeGroup qualifies its high performance, high power RIT 2X multimode system. RIT 2X is also the ideal propulsion solution for any scientific mission with demand for high total and specific impulse like NASA/ESA's Mars Sample Return mission.

The small RIT-µX system was originally developed for the needs of sophisticated formation flying, high precision positioning and role control of spacecraft. It is also a solution for new space propulsion needs which are not focused on high numbers of systems, but on thrust quality.

Finally, there is the disruptive market for large constellations and mega-constellations. ArianeGroup is prepared with its Arclight program.

VIII. Acknowledgements

Several projects reported herein are supported by the European and the German Space Agency

The support of the German Space Agency DLR is gratefully acknowledged

The support of the European Space Agency ESA is gratefully acknowledged

The authors like to express their gratefulness to all our partners who have supported our activities in manifold ways.

IX. References

[1] H. Bassner,H. P. Berg, R. Kukies, and H. Müller, Flight Test Results of the RITA Experiment on EURECA, IEPC-1993-102

[2] R. Killinger, H. Gray, R. Kukies, M. Surauer, G. Saccoccia, Angelo Tomasetto, Ray Dunster, *ARTEMIS Orbit Raising In-Flight Experience with Ion Propulsion*, IEPC 2003-0096

[3] D. Di Cara et al., Experimental Validation of RIT Micro-Propulsion Subsystem Performance at EPL ; IEPC-2013-90

[4] H. Leiter et al. RIT-µX Miniaturized Radio Frequency Ion Thruster Systems - Applications and recent Program Status, SPC-2018-00350

[5] H. Leiter et al A Nouvelle Neutralization Concept for RIT-µX Miniaturized Radio Frequency Ion Thruster Systems IEPC-2019-806

[6] H.Leiter et al. RIT-22 Ion Engine Development - Endurance Test and Life Prediction , 2006-4667 Sacramento (CA)

[7] J.-P. Porst et al Development and qualification status of the RIT 2X electric propulsion system
SPC-2018-00366, Seville

[8] H.Fulge et. al. Test Facility for Electric Propulsion Testing at ArianeGroup - Lampoldshausen, THE 2ND GROUND-BASED SPACE FACILITIES SYMPOSIUM
17-19 October 2017, Toulouse, France