The RIT-µX Miniaturized Ion Engine System way to TRL 5 for an extended thrust range

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Abstract: Airbus DS started the development of a miniaturized radio frequency ion thruster called RIT-µX, under an ESA contract in the Year 2007 together with partners. Within the LISA Pathfinder project the thruster and the overall RIT-µX system was significant improved. Following on this project ESA started a new project called *miniaturized gridded ion engine system for future space missions* at which Airbus DS is the prime contractor. The major goal of this project is the achievement of TRL5 with the RIT-µX based system for an extended thrust range. This paper describes the project structure and goals. It gives an overview of the actual status of the activities within this project. Apart from this ESA project, the additional activities with the RIT-µX and the complete system are described in this paper. This includes results of the system demonstration at ESA ESTEC in 2013 and a direct thrust measurement at the novel Airbus DS micro newton thrust balance in Friedrichshafen.

Nomenclature

CFI	-	Customer furnished item
MGIESFSM	-	Miniaturized Gridded Ion Engine System for Future Space Missions
NTR	-	Neutralizer
PPU	-	Power Processing Unit
RFG	-	Radio Frequency Generator
RIT	-	Radio frequency Ion Thruster
RF	-	Radio Frequency
TRL	-	Technology Readiness Level
U_{Screen}	-	Applied voltage at the screen grid

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I. Introduction

Electric propulsion has become state of the art for commercial geostationary satellites. More and more operators realize the advantages of EP for North South Station keeping and also electric orbit transfer will be soon standard. Increasing electric power drives the development towards higher thrust and power. Also for scientific missions the high specific impulse capability of electric propulsion is still major key feature. However scientific missions have more advanced requirements. Perfect thrust control, in terms of resolution, response reproducibility and linearity together with very low noise are keys to new ambitious missions. Two examples for this new type of missions are the European Space Agency's missions EUCLID and Next Generation Gravity Mission NGGM.

In the framework of these missions, ESA invited to tender to the Miniaturized Gridded Ion Engine System for Future Space Missions (MGIESFSM) project in 2014. This project has the major objective to achieve TRL5 in an extended thrust range for the complete propulsion system with the exception of the pressure regulator and the propellant tank. All other components are included in the system which will demonstrate the technology readiness level 5.

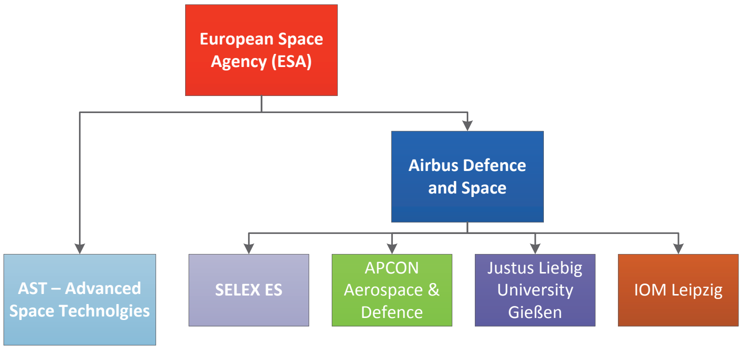

Figure 1. MGIESFSM Industrial structure

Airbus DS is the prime contractor of the MGIESFSM and is responsible for the complete system test and RIT-µX thruster. SELEX ES provides the PCU and the neutralizer. The micro flow control unit called µFCU from AST is a customer furnished item which will be provided by ESA. The schematic system architecture is shown in Figure 2.

II. System component description

A typical RIT-µX based electrical propulsion system consists of seven main components:

- RIT-µX thruster
- Power processing unit PPU
- Neutralizer
- Radio frequency generator RFG
- Flow control unit FCU

All these components are included in the MGIESFSM - system, which is shown in Figure 2. Additionally to this a Xenon tank and a pressure regulator are required, but these are mostly part of the space craft and not of the propulsion system itself.

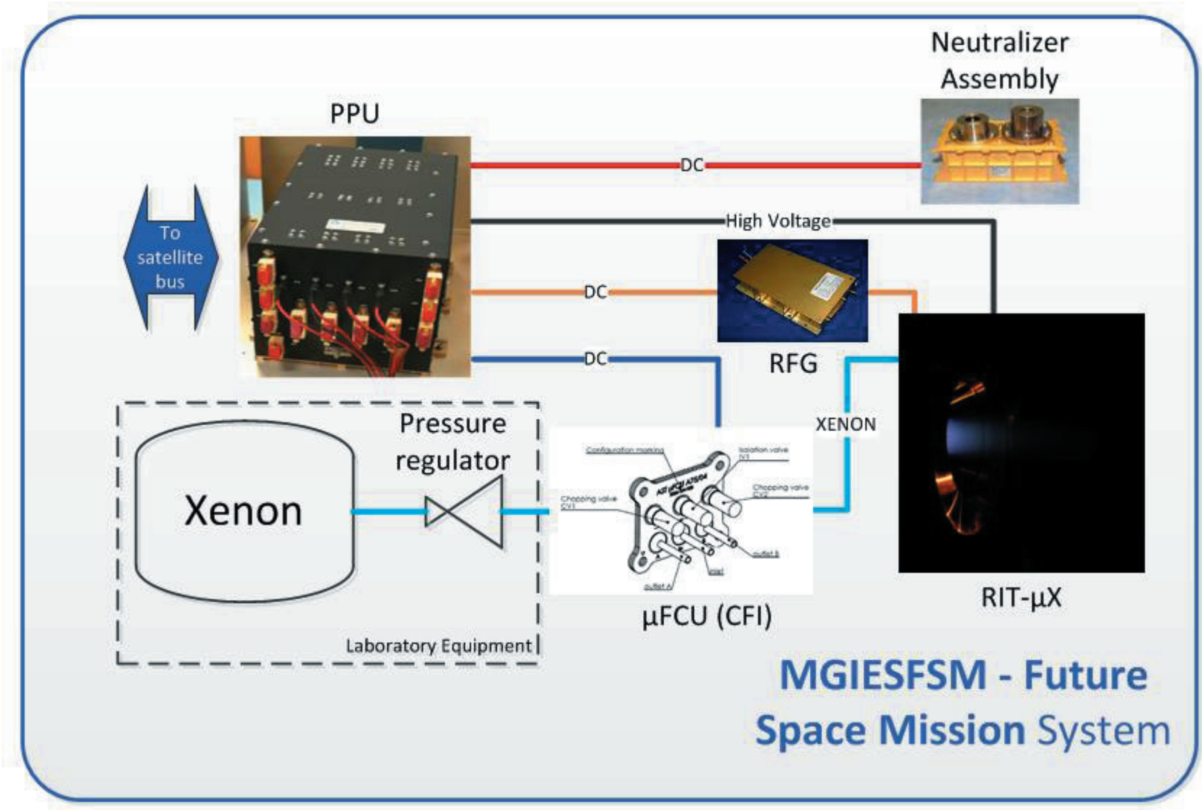

Figure 2. MGIESFSM System

The MGIESFSM system consists of the five main components mentioned above in the following these components will be described.

PPU: The power processing unit is the central component of a RIT-system. It receives the commands from the satellite bus, or EGSE and converts them into the system actions. The PPU converts and conditions the electrical power which gets provided by the bus. This includes the conversion of the bus voltage up to the high voltage required at the grids of the thruster. The same time it provides the power for the RFG the neutralizer and controls the FCU and all control valves.

RIT-µX Thruster: The RIT-µX thruster is a so called electrostatic ion thruster. It accelerates ions in an electrostatic field of a grid system. The neutral xenon is ionized within an alternating electromagnetic field. It is induced by a coil which surrounds the ionizer. The RFG is connected to this coil and provides the alternating current at radio frequency, to induce the electromagnetic field. The first grid is on positive potential between +400V and +2500V and the second grid, called accelerator grid is on a negative potential (typically between -100V and -300V). In contrast to the alternating current for the RF-Coil, the high voltage direct currents are provided direct from the PPU.

NTR: The neutralizer provides the same electron current as it is extracted by the thruster. This controls the potential of the space craft and neutralizes the ion beam of the thruster. Within MGIESFSM two neutralizers, developed for the Microscope and LISA Pathfinder missions will be used in parallel to provide a total electron current of up to 36mA. This is the required current for a thrust of 2.5mN.

RFG: The radio frequency generator converts a direct current to the required alternating current. The used RFG within is developed from APCON Aerospace & Defence. It was developed within the LISA Pathfinder project.

µFCU: The µFCU from AST (Advanced Space Technologies) is a new developed miniaturized flow control unit. It bases on two chopping valves and one isolation valve. The isolation valve closes or opens the flow control unit complete. The additional chopping valves are used for the control of the mass flow on two separated flow paths. This allows providing a wide range of mass flow.

III. System operation

As described above, the PPU receives the commands from the satellite. The first action of the propulsions system after the launch is the neutralizer activation. This activation procedure needs several hours, but it has to be done only once in at the beginning of the mission. In the later mission the neutralizer is functional within a few minutes when the temperature for electron emission is reached (typically after seven minutes). After the ignition of the neutralizer the thruster ignition is the second step. The RIT-µX thruster ignition needs a combination of a pressure and power peak. The PPU synchronizes the flow control unit, the RFG and the grid voltages. After the successful ignition the thruster operates in the stand-by mode. In this mode the ionization is working, but the grid voltages are off. In this mode, the thruster produces no thrust. From the stand-by mode the transition to the thrust mode can be commanded. With applying of the high voltages to the gird, the thruster transits from stand-by to thrust mode. In thrust mode for each thrust level dedicated voltages are applied to the grids. The resulting thrust of the RIT-µX can be calculated. In the thrust mode, the PPU provides dedicated grid voltages for each thrust step. These thrust steps are stored in dedicated look up tables with It measures the beam current and adapts the RFG power to achieve the required thrust. The mass flow gets adapted to the thrust, but does not influence the produced thrust. The mass flow adaptation is only required to optimize the thruster operation point and to enable the outstanding throttle range of RIT-µX systems.

IV. MGIESFSM project status

The miniaturized gridded ion engine system for future space missions project is running since mid of 2014. The project is divided into three parts. The first one is the system definition phase, in which the system requirements were defined. Following on this phase the component tests phase verifies the functional performance of each component with respect to the requirements. The phase shall mitigate the risk of a failure during third phase, the system test phase. This phase includes a coupled

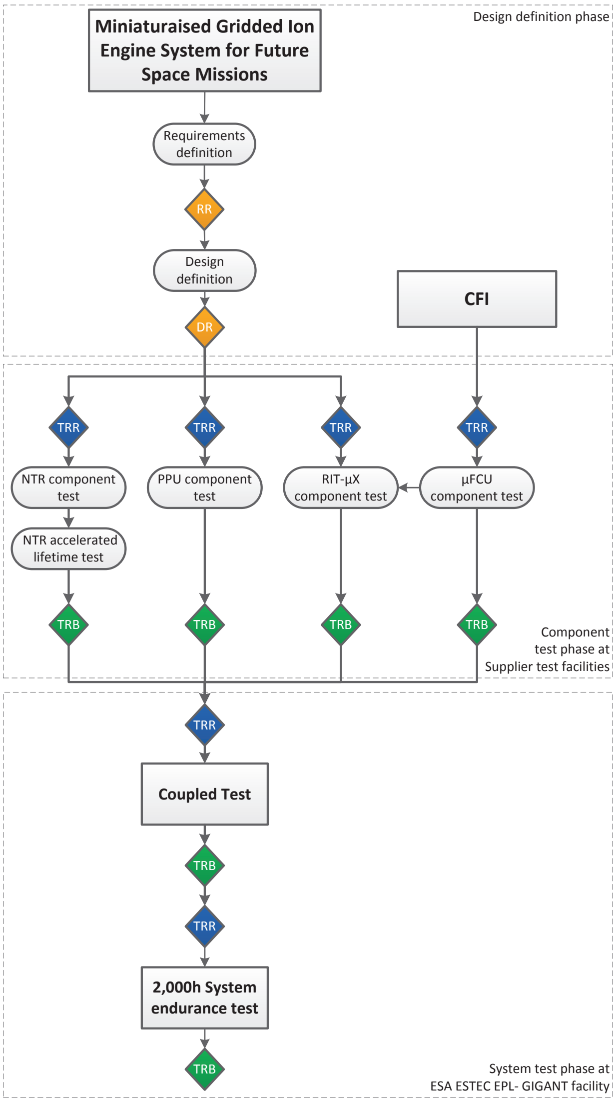

Figure 3. MGIESFSM project structure

and an endurance test to verify the complete system performance.

The project is at the end of the component test phase. The neutralizers are tested for function and performance, and are still in the accelerated lifetime test. This test consists of a neutralizer operation at higher operation temperatures than nominal.

The RFG was tested together with the RIT-µX thruster. During the thruster component tests the modular approach of the RIT-µX thruster was used to test two different grid configurations. The first one with 61 extraction channels focused on a thrust range between 50µN and 1300µN and the second one with 121 extraction channels provided a thrust range of 84µN to 2.5mN. The results are shown in Figure 4. Both thrust ranges were verified within this test. The thruster total input power strongly depends on the operation point. It is obviously affected by the thrust, but it also is influenced by the mass efficiency, which mainly affects the specific impulse and the thruster lifetime, especially at the highest thrusts. At higher mass efficiencies, the power consumption but also the thruster lifetime increase. Thus the choice of the best operation point is always a tradeoff between these factors.

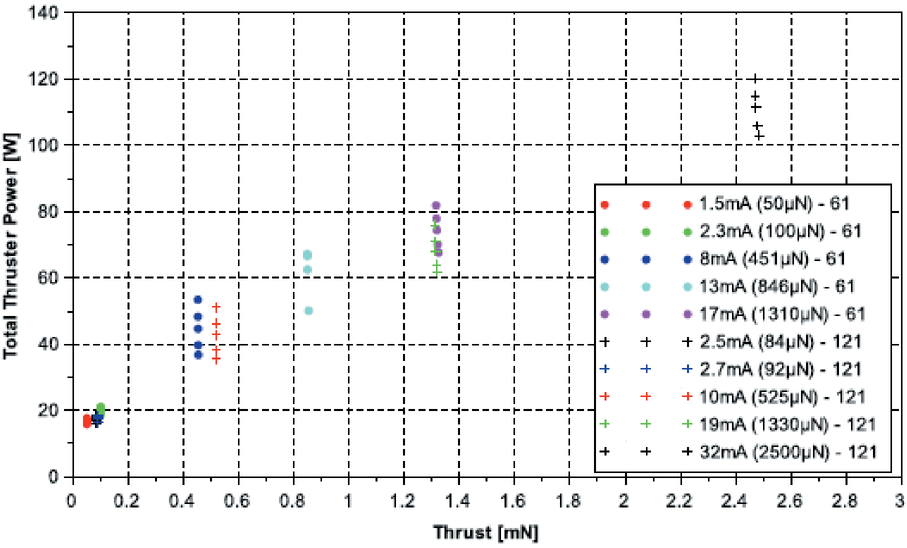

Figure 4 RIT-µX performance mapping

Also the PPU and the FCU are in the last phase of the component verification tests. After the completion of these tests, all components will be shipped to ESA ESTEC for the final system integration inside the GIGANT facility. After the finalization of the integration work, the coupled test shall verify the functional performance of the system.

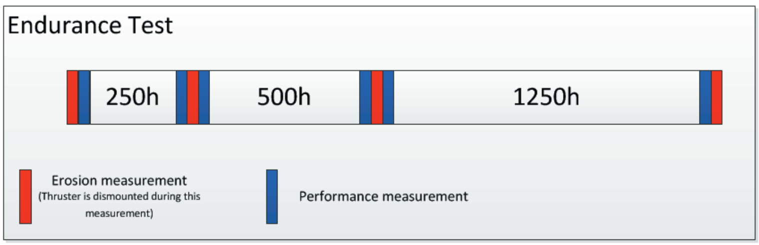

Figure 5. Endurance test inspection sequence

Subsequently the system endurance test follows beginning of August 2015. It covers a total firing time of 2,000 hours. The results of this test will be compared with grid erosion simulations. To provide a better data basis for this comparison intermediate erosion measurements are required. As this measurements demand the dismounting of the thruster and the grid system, a trade-off between the best number of erosion inspections and the risk to damage the hard ware lead to the inspection sequence shown in Figure 5. The erosion will be measured before the start of the endurance test, the second time after 250 hours, a third time after additional 500 hours and the last time after the complete 2,000 hours firing.

V. Other RIT-µX system development activities

Beside the MGIESFSM project other develop activities basing the RIT-µX were performed, on which these project now bases. The first step was done with the ESA GSTP project called "Mini-Ion propulsion system development". During this project the RIT-µX was developed from the breadboard to the engineering model which nowadays has reached TRL 5. Especially within the LISA Pathfinder program a complete system demonstration based on the RIT-µX thruster was performed. The project consisted of six separated test campaigns. During the first five test campaigns, the thruster was characterized the first time and all components were stepwise tested in standalone configurations and also together with the thruster. These tests could be seen as preparation for the final system demonstration which was performed at ESA ESTEC [1]. With the finalization of this program, the RIT-µX System reached TRL 5 for the thrust range of 10µN to 120µN, which was the required range of LPF.

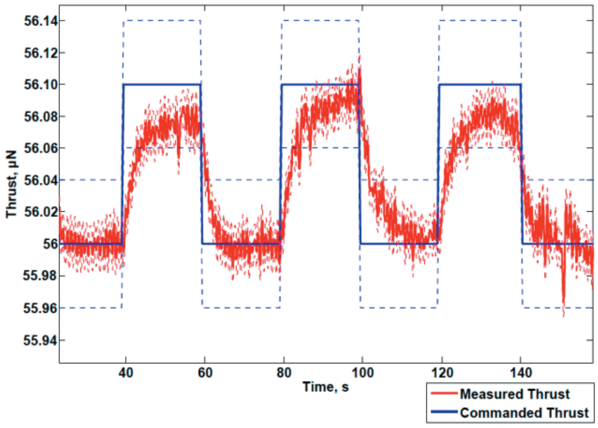

Figure 6. 0.1µN thrust stepping [2]

During this demonstration the complete system performance was demonstrated, starting with performance test, which characterized the system power consumption and dynamic behavior. Within the system dynamic tests, the thrust was calculated from the electrical measured thruster parameters. It could be verified that a step size of 0.1µN is possible with the RIT technology. Never the less this was just a thrust calculation. In 2015 Airbus DS repeated a thrust stepping on the novel Airbus DS micro newton test facility at Friedrichshafen. Within these tests, it could be clearly verify the validity of the thrust calculations and that 0.1µN resolution is possible (Figure 6). Also a thrust noise measurement was performed in this framework, which demonstrated the outstanding performance of the thrust balance and the RIT-µX thruster [2]. This test campaign gave the confidence that a thrust calculation by using the electrical data is sufficient for performance demonstrations on the one hand and demonstrated the possibility of direct thrust noise characterization on the other hand.

Additionally to the thruster performance also a verification of the neutralization concept was performed within the LISA Pathfinder project. These concept has a shared neutralizer foreseen, which means, that it is not located directly to the thruster and shall be used for several thrusters. The major outcome of these was the verification of the new concept. The neutralizer provided self-adjusting the current which was extracted by the thruster.

VI. Outlook

The ongoing works in the MGIESFSM project will lead to the 2,000 hour system endurance test at ESA ESTEC the start of these test is scheduled for the end of July. In advance to this test, the coupled test will prove the full functional performance of the system also at the ESTEC GIGANT facility.

Basing on the promising experiences with the new micro newton thrust balance, the next logical step would be a complete system thrust noise test. Only this test can verify the full system compliance wrt the actual scientific missions. Additionally to the thrust noise measurement, further investigations of the influence of neutral xenon gas flow on the total thrust shall be performed in the next steps. The first major steps towards this system test are done and the test demonstrated that the facility and the thruster are ready for it.

VII. Acknowledgments

We would like to thank Niccola Kutufa, Alexandra Bulit, Davina Di Cara and Clive Edwards from ESA ESTEC who enabled the RIT-µX development from the past to the present.

We also like to thank Franz Georg Hey from Airbus DS in Friedrichshafen. He development the excellent novel micro newton thrust balance and build up the complete test facility in the LET.

VIII. References

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[2] F. G. Hey et al., "Development of a Highly Sensitive Micro-Newton Thrust Balance: current status and latest results"; IEPC-2015-260