Activities of the H2020 Strategic Research Cluster on Space Electric Propulsion (2015-2019)

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Abstract: The Strategic Research Cluster (SRC) on Space Electric Propulsion (EP) is the new European Commission (EC) instrument into the European Union's Horizon 2020 research and innovation programme (H2020) to target mid-term and long-term objectives in the space electric propulsion field, considered strategic for Europe. The SRC is implemented through a Programme Support Activity (PSA) coordinating individual and specific research and development Operational Grants that aim at producing a significant demonstration and achievements of a specific technology in line with a defined roadmap. The Electric Propulsion SRC implementation and its roadmap are presented and the PSA and Operational Grants activities are described. Finally SRC next steps are detailed and future challenges are outlined.

Nomenclature

EP	=	*Electric Propulsion*
GEO	=	*Greostationary Earth Orbit*
GTO	=	*Greostationary Transfer Orbit*
Isp	=	*Specific Impulse [s]*
LEO	=	*Low Earth Orbit*
MEO	=	*Medium Earth Orbit*
P	=	*Power [W]*
P/T	=	*Power/Thrust ratio [W/mN]*
T	=	*Thrust [N]*
TRL	=	*Technology Readiness Level*

I. Introduction

WITH the Strategic Research Clusters (SRC) the European Commission (EC) introduced a new instrument into the European Union's Horizon 2020 research and innovation programme (H2020)[1]. The idea of the SRCs is to enable the EC to target mid-term to long-term objectives in their research programmes. This will not be done by creating large projects with great funding and long runtimes but by combining the results of different smaller

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projects, called "operational grants" to achieve a common goal. The coordination and interaction of these operational grants will be ensured by means of a Programme Support Activity (PSA) and a dedicated Collaboration Agreement. The Strategic Research Clusters is a coordinated effort of individual research and development grants that aim at producing a significant demonstration of a specific technology.

II. Electrical Propulsion Strategic Research Cluster (SRC)

The SRC on "In-space Electrical Propulsion and station keeping" is part of the Horizon 2020 Space theme. As a first step to build up the Electric Propulsion SRC, a call for proposals for the Programme Support Activity was issued in December 2013 as part of the first Space Work Programme in Horizon 2020[2]. In summer 2014 the proposal was selected and since 1st October of the same year the PSA "EPIC" is operating. EPIC stands for Electric Propulsion Innovation & Competitiveness. The next step for the SRC was the publishing of the call for proposals for the first Operational Grants on the Space Work Programme 2016-2017[3] under topic COMPET-3-2016 and the selection of its proposals. This article takes a closer look into the logic of the SRC on "In-space Electric Propulsion" calls, the EPIC PSA activities and the objectives and technical details of the on-going Operational Grants. The following step for the SRC is the preparation and publishing of the call for proposals for the second phase of Operational Grants on the Space Work Programme 2018-2020 under topics SPACE-13-TEC-2019 and SPACE-28-TEC-2020 and the subsequent future selection and implementation of its proposals. The first topic has already happened.

A. Electric propulsion, a strategic interest for Europe

Electric propulsion makes use of electrical power to accelerate a propellant by different possible electrical and/or magnetic means. Compared to chemical thrusters, electric propulsion requires considerably less mass to accelerate a spacecraft. The propellant is ejected up to twenty times faster than from a conventional chemical thruster and thus delivers an up to twenty times higher impulse per unit of propellant mass. Therefore, the overall system can be much more mass efficient, and satellites equipped with EP Systems may either carry more payload or be launched with a less powerful and less expensive launcher. The use of EP Systems for station keeping of geostationary communication satellites is well established and the use of EP Systems may enable new space applications and missions.

The different applications which currently make use of electric propulsion or may make use of it in the future, are: LEO (for example, earth observation, earth science, constellations), MEO (navigation), GEO (telecommunications and earth observation), space transportation (launcher kick stages, space tugs), space science, interplanetary missions and space exploration. For these different types of missions and requirements, the technology is faced with operational challenges in order to be able to cope with different type of maneuvers, such as: continuous LEO operations (air-drag compensation), electric transfer from GTO to GEO, Station Keeping (SK), Electric Orbit Raising (EOR), interplanetary cruise, extreme fine and agile attitude control, long-endurance missions, etc.

Major mass savings can be achieved, if EP Systems are used for orbit raising. Due to their lower thrust, the transfer time is longer compared to chemical propulsion (several months instead of some weeks). These applications span a very wide range of requirements. No single EP System may be optimum for all of these applications. The "All-electric" satellites, which use electric propulsion for both orbit raising and station keeping, are not a new vision anymore and in the coming decades they may take an increasing share of the commercial communication satellite market. All-electric European satellites under construction are Electra (by OHB Systems) and Neosat (by Airbus DS and THAS), and also there are other new hybrid satellites under development preparing Europe satellite manufacturers and satellite operators to play in the new Satellite electric propulsion arena.

High-thrust power units that could accomplish the orbit transfer electrically are in great demand. At the same time, also simple, reliable and cost-efficient EP Systems for application in satellite constellations could suit the future market. The repartition of the worldwide EP-market will be determined in the coming years. European players are working on promising technologies, which could be transformed into marketable EP Systems to achieve commercial success.

In Europe, developments have been carried out in all the different areas of electric propulsion over the last four decades. At the moment the most promising technologies for Europe, from the mature type of thrusters, are based on the Hall Effect Thruster (HET), the Gridded Ion Engine (GIE) and the Highly Efficient Multistage Plasma Thruster (HEMPT). The European Commission acknowledged the relevance of EP technology and has an objective: "To contribute to guarantee the leadership of European capabilities in electric propulsion at world level within the 2020-2030 timeframe". The Strategic Research Cluster offers an unique opportunity to carry out coordinated research and development activities of high impact and consistency paving the way for this objective.

The SRC will be implemented through a system of grants that consists of a Programme Support Activity (PSA), and of the Operational Grants (OGs). The objective of this system of grants is that the expected results of each individual grant can be combined to achieve the overall objective of the SRC. At the moment it is foreseen that there will be two phases of Operational Grants in H2020.

B. EPIC Programme Support Activity

Electric Propulsion Innovation and Competitiveness (EPIC) is the Program Support Activity (PSA) of the EP Strategic Research Cluster (SRC) H2020[4]. The project is a grant (nº 640199) funded by the H2020 2014 Space Work Programme. The European Space Agency (ESA) is the project coordinator of the EPIC PSA, and the other partners in the consortium are: several European National Agencies (ASI (Agenzia Spaziale Italiana), BELSPO (Belgian Science Policy Office), CDTI (Centro para el Desarrollo Tecnológico Industrial), CNES (Centre National D'Etudes Spatiales), DLR (Deutsches Zentrum für Luft- und Raumfahrt), UKSA (United Kingdom Space Agency)); and two space industrial associations (EUROSPACE and SME4SPACE). The main role of the PSA is to elaborate a roadmap and an implementation plan for the whole SRC, to provide advice to the European Commission for the description of the operational grants, as well as to assess the results of the OGs with respect to the SRC EPIC roadmap, in order to check if they are compatible and expected to achieve the SRC objectives. The roadmap describes a plan for implementation in H2020 to increase European competitiveness in electric propulsion. The Operational Grants shall address different technological challenges identified in the roadmap.

The EPIC PSA main tasks are the following: evaluation on the state of the art and needs, definition of SRC roadmap and master plan, definition of the SRC Call topics and related documents, SRC risk management, definition of the collaboration aspects (CoA), assessment of the progress and results of the Operational Grants, dissemination and education activities. The EPIC PSA webpage is: http://epic-src.eu/.

III. SRC EPIC roadmap

The SRC EPIC roadmap work logic is explained in the following paragraphs. First, the state of art in electric propulsion and related EP technologies were analyzed by the EPIC PSA. At the same time, requirements and needs from all stakeholders were identified. This was performed in the first EPIC Workshop in Brussels in November 2014.

The second step was the prioritization of the EP technologies. This exercise was again performed in contact with the interested stakeholders, in the frame of the second EPIC Workshop in Stockholm in February 2015. This work logic produced the integrated roadmap that describes the technology to be developed through the H2020 SRC. The technology mapping of electric propulsion in Europe has been performed by the EPIC PSA and presented in the first EPIC Workshop.

Many EP technologies are available in Europe and some are in advanced development stages or have already flight heritage but others very promising ones are in early stages of its development. On the thruster side, three technologies targeting the commercial market are available with TRL ranging from 7 to 9. Thruster technologies with lower and medium TRL or others targeting less developed applications or less market-oriented, such as space science, constellations, exploration and others, are being developed in Europe as well, many of them by universities or research institutes.

The EPIC PSA has taken a technology versus application based approach in order to arrive at a prioritization of the thruster technologies to be further developed through the SRC. The most mature technologies targeting the commercial market, HET, GIE, and HEMPT, are found to have individual profiles and offer slightly different responses to the different application requirements. For station keeping the HET currently seem to be a bit at the low end of required specific impulse, nevertheless they are currently the most used EP Systems for this purpose. In the orbit raising case GIE thrusters are at the moment slightly below the range of desired thrust-to-power ratio, but the full EP satellites now operational are using GIE for orbit transfer. HEMP thrusters are deemed to perform between HET and GIE, but have no flight heritage yet. So, all three mature technologies have the potential to serve the commercial market, but need to develop individually in one or other direction for future success. For the SRC and the PSA, these three technologies are what we call the "Incremental Technologies".

The SRC EPIC roadmap developed by the EPIC PSA builds on the prioritization results and is structured along two lines (Incremental Technologies and Disruptive Technologies) comprising two successive phases. The SRC EPIC roadmap is structured along two lines of developments: Incremental and Disruptive Technologies. The roadmaps are developed taking into account two phases, a first one starting with the 2016 Call, and a second one with 2019 Call for Disruptive Technologies, and with 2020 Call for Incremental Technologies.

The principal target of the SRC EPIC roadmap is to increase the competitiveness of the EP Systems developed in Europe. The expected competitive position in the European and non-European markets takes into consideration: future missions, valorization of competencies/technologies already developed at European level in other national, European and/or international projects, performances gain achieved through disruptive technology advancement, potential spin-off initiatives for cross-related fields, integration capability within launch systems worldwide, etc.

C. Incremental Technologies line

The Incremental Technologies are the most mature technologies, i.e. the ones with high TRL and possibly with flight heritage, with the physical principal well understood, and with established performances in all of the relevant parameters: thrust (T), specific impulse (Isp), power/thrust ratio (P/T), total impulse, and lifetime. They are the Hall Effect Thruster (HET), the Gridded Ion Engines (GIE), and the High Efficiency Multistage Plasma Thrusters (HEMPT).

In the SRC, the Incremental Technologies EP Systems aiming at enabling capabilities like operating at dual mode, higher/lower power, Electric Orbit Raising/Station Keeping, required by a number of applications and markets; and improve the current performances and reduce the cost of the EP Systems, in order to increase the competitiveness of the European systems. Their application domains targeted are: telecom/MEO (including navigation), space transportation, LEO (including constellations), exploration/Interplanetary/science.

D. Disruptive Technologies line

The Disruptive Technologies, are very promising EP thruster concepts or transversal EP technologies which could disrupt the propulsion sector by providing a radical improvement in performance and/or cost reduction, leading to become the preferred technology for certain applications/markets; or enable new markets or applications not possible with the existing (Incremental) technologies. Their application domains are also telecom, space transportation, LEO (including constellations), MEO, exploration, interplanetary and science, but not limited to new applications and markets.

Promising EP thrusters are for example: Helicon Plasma Thrusters (HPT), Electron Cyclotron Resonance Thrusters (ECRT), Magneto Plasma Dynamic Thrusters (MPDT), Pulsed Plasma Thrusters (PPT), Field Emission Electric Propulsion thrusters (FEEP), micro-propulsion EP thrusters, and any other innovative electric thruster concepts; but not the ones derived from HET, GIE or HEMPT.

Transversal EP technologies are for example radical innovations in Power Processing Units (PPU), magnetic nozzles, alternative propellants, testing techniques, new materials, modelling and simulations codes, new PPU and electrical system architecture for EP, hybrid solution to drive different types of EP thrusters, or any other promising and potentially transversal disruptive concept. In the field of disruptive technologies new ideas are encouraged, as long as the proposals can demonstrate a disruptive potential of the technology in question or/and enable new applications or current applications with better performance parameters. Deep space missions or new satellite applications or constellations are some examples of niches for disruptive technologies. Some number of thruster technologies of presently low and medium TRL may strive to develop into this regime, or likewise towards other niche applications or new markets.

E. SRC EPIC roadmap implementation

The Incremental Technologies line in its first phase, the EP Systems based on the three identified thruster technologies will have to be developed and advanced in TRL. On the other hand, the Disruptive Technology line in its first phase, foresees that only the thruster will be brought to higher TRLs. In both cases requirements shall be satisfied, which are derived from application scenarios. Additionally, in the Disruptive Technology line, the EP transversal technologies are also proposed.

Phase 2 guarantee the continuation of the two lines Incremental and Disruptive, as project continuation or establishment of new projects. Expected funding for the phase 2 is still under discussion and will remain open until the progress of the phase 1 operational grants has been assessed. The objective for this phase 2, is to support the more promising technologies developed in phase 1 towards higher TRLs, in order to live up to the SRC expectations and be ready to prepare the chosen EP System or Systems for a potential In-orbit demonstration (possible future phase 3).

Incremental Technologies are given different application scopes and associated requirements, such as TRL. As a consequence, the European Commission proposed to apply different funding ranges to the three Incremental Technologies, which take into account the assumed importance of the technology and the relative difficulty of the individual tasks.

The general SRC EPIC roadmap is characterized by a technology/application approach whose layout presents two domains: the thruster domain and the application domain. The technology line for the Incremental line is characterized by the electric propulsion system aspects. For the Incremental Technologies developments the complete EP System needs to be brought to the higher TRLs required for subsequent market introduction.

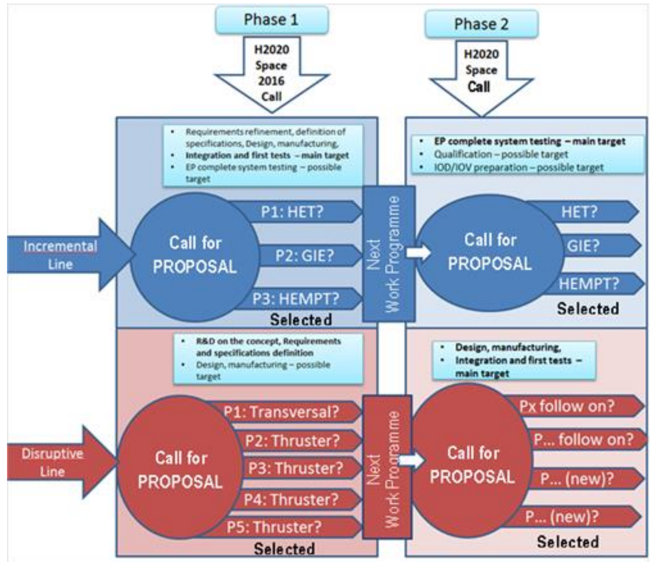

Figure: High-level SRC EPIC roadmap evolution.

Each EP System, for the purpose of the roadmap, shall include the development of the thruster with the following sub-elements: the thruster components, which includes the thruster itself (discharge chamber, anode, grids) and it(s) cathode(s) or neutraliser(s); the fluidic management system, including the valves, filters, pipes, pressure regulators, mass flow controllers; and last but not least the power components, which includes the PPU, thruster switching unit and other components such as electrical filters. For the SRC EPIC roadmap, the EP System does not include neither the thrust orientation mechanisms nor the propellant tanks.

Some common aspects to all thruster-based systems are the following: alternative/non-conventional propellants, high power testing facilities and diagnostics, EP Systems testing methods and standardization of EP testing. Requirements definition, mission and system impacts should be considered to better address the EP System developments for the targeted applications.

Disruptive Technologies, foresees funding of a certain maximum number of proposals for disruptive EP thrusters and some of them will be devoted to transversal technology (to the EP System), like a radically innovative PPU which would enable a much more cost-efficient EP Systems, or any other idea or technology which could change the whole picture. The thruster technologies mentioned in the roadmap, which are under development in Europe, are meant to be known examples of what could be considered Disruptive Technologies.

IV. Guidelines & Requirements

Specific guidelines and requirements were drafted by the EPIC PSA and published by the EC for the 2016 Call topic under topic COMPET-3-2016 as detail reference information in line with the SRC EPIC roadmap.

F. Incremental Technologies guidelines and requirements

For all Incremental Technologies (HET/GIE/HEMPT) activities, the main action needed is to improve the current state of the art performances specified and reduce the cost of the EP System, in order to satisfy the medium and future needs of different markets. The projects shall cover the development, validation (including testing) of the EP System following the relevant ECSS Standards, and testing shall be performed in a relevant environment.

The projects are meant to cover the following aspects of the EP Systems: thruster, cathode, PPU and fluidic management system.

Incremental Technologies requirements identify specific challenges for each application because each of the three EP System Incremental Technologies (HET/GIE/HEMPT) is based on different physics phenomena and different concept architecture. The performance requirements have been selected in order to request equivalent efforts beyond the actual state of the art for each technology. Therefore, all performance parameters targeted are technology specific and specifies for each application domain, including: target TRL, dual mode voltage, EP System power for EOR and SK mode, P/T power to thrust ratio for EOR and SK mode, specific impulse (Isp) for EOR and SK mode, thrust resolution, lifetime (total impulse), live time cycles, innovative and cheaper PPU specifications, recurring EP System cost reduction targets. Specific details can be found in the EPIC webpage in the guidelines document of the H2020 SRC 2016 Call COMPET-3-2016.

Proposals were presenting an adequate approach addressing the relevant applications to be covered in a balanced way including all aspects and equipment of the EP System (thruster, cathode, PPU and fluidic management system). Proposed developments also included modelling/simulation and testing of each equipment in the subsystem as well as of the EP System. Regarding the system impacts, thermal dissipation, plasma effects, electromagnetic interaction or any other effects were taken into account including considerations on integration of the EP System into the spacecraft. In order to reduce the cost of the full EP System for increasing competitiveness in the markets, proposals had to clarify the expected cost (indicative) reduction for the whole EP System and the specific subsystems together with a clear methodology.

G. Disruptive Technologies guidelines and requirements

Also for the Disruptive Technologies, specific guidelines and requirements has been drafted by the EPIC PSA and published by the EC for the 2016 Call topic under topic COMPET-3-2016-b as detail reference information in line with the SRC EPIC roadmap, but this time without specify the required market/application.

For all Disruptive Technologies activities, the main action needed is to focus on promoting the Research, Technology and Development (RTD) of very promising and potentially disruptive concepts in the field of electric propulsion, in order to increase the currently low or medium TRL of potentially breakthrough concepts which in the long term could change the electric propulsion landscape.

Electric propulsion thrusters currently at low and medium TRL and not part of the Incremental Technologies, is the main focus of this line. Proposals are expected for concepts such as: Helicon Plasma Thrusters (HPT), Electron Cyclotron Resonance Thrusters (ECRT), Magneto Plasma Dynamic Thrusters (MPDT), Pulsed Plasma Thrusters (PPT), Field Emission Electric Propulsion thrusters (FEEP), micro-propulsion EP thrusters, and any other innovative electric thruster concepts; but not the ones derived from HET, GIE or HEMPT.

The activities proposed shall include modelling, development and testing beyond the current state of the art in order to: understand fundamental physical processes and their impact on performance; improve current thruster performances (thrust, specific impulse, power/thrust ratio, magnetic thrust vectoring, throttability, efficiency, lifetime, noise, etc.); progress the development of associated cathodes/neutralisers, if applicable to a thruster; investigate alternative propellants to Xenon and/or non-conventional propellants; understood as gases constituting the atmosphere of a planet, such as oxygen, nitrogen and combinations in the case of the Earth, with consideration to potential applications; further analyse the impact of the thruster on the whole EP System.

It is important to acknowledge that there might be other elements in the EP System, aside from the thruster, with the ability to provoke a radical disruption. For example, new Power Processing Unit (PPU) concepts or architectures could substantially decrease the overall cost of the system. It is therefore also important and expected that proposals explore the potential for breakthrough innovation of Transversal Disruptive EP Technologies, such as: radical innovations in PPU; magnetic nozzles; alternative propellants; testing techniques; new materials; modelling and simulations codes; new PPU and electrical system architecture for EP; hybrid solution to drive different types of EP thrusters; or any other promising and potentially Transversal Disruptive Technology enable new performances, cost reduction and/or access to new applications or current applications with better performance parameters.

Proposals shall go beyond the present state of the art, preferably the expected state of the art at the time of completion if alternative technologies are being developed outside Europe. Persistent monitoring of the state of art within the electric propulsion sector throughout the project will be important. Proposals shall also explain and be ready to demonstrate how the proposed concept meets the Disruptive definition proposed in this call topic and what is it the expected impact of the development in the electric propulsion landscape, including the timeframe. In addition, proposals shall include a validation and verification plan, including milestones and one or more validation and verification methods to apply through the course of the project, which would allow verifying how the development targets are being met and how the landscape disruption shall take place in the future.

V. Electric Propulsion SRC 2016 Call evaluation results

The evaluation process of the H2020 EP Strategic Research Cluster (SRC) 2016 Call finalized by end of June 2016. The selected proposals finalized the Grant Agreement Preparation (GAP) period, and they have signed their Grant Agreements from November 2016 to January 2017 and all of them kicked off their Operational Grants and have started their developments and activities.

The proposals selected under COMPET-3-2016-a (Incremental Technologies) are the 3 proposals presented: CHEOPS, on HET; GIESEPP on GIE; and HEMPT-NG on HEMPT technologies. The proposals selected under COMPET-3-2016-b (Disruptive Technologies) have been 3 proposals from the 18 presented. They are: GaNOMIC on PPU innovative Disruptive Transversal Technologies; HiperLoc-EP, on Electrospray Colloid Electric Propulsion System (ECEP Systems) thrusters; and MINOTOR on Electron Cyclotron Resonance Accelerator (ECRA) thrusters; all three promising Disruptive Technologies.

A brief explanation and presentation of these ongoing SRC Operational Grants and their projects, objectives, ongoing activities and expected results are presented in line with the provisions of the SRC Collaboration Agreement and its confidentiality provisions.

H. CHEOPS

CHEOPS stands for: Consortium for Hall Effect in Orbit Propulsion System. CHEOPS proposes to develop three different Hall Effect Thruster electric propulsion systems: a dual mode EP Systems for GEO applications; a low power for LEO application; and a >20 kW high thrust EP Systems for exploration applications.

Each of these will be developed according to market needs and drivers applying incremental technology changes to existing EP Systems products. The development approach will follow the ESA ECSS approach and the dual mode and low power are targeting a System PDR review with 42 months from the project start. Development will cover the following elements: thruster, cathode, PPU and FMS.

The project is perfectly aligned to the SRC guidelines published with the SRC 2016 Call. Through a detailed development plan the project will demonstrate their ability to achieve by the end of CHEOPS Phase II (2023) the following: a) TRL7-8 for dual mode and low power; b) high power HET EP Systems TRL6. Common transverse activities will include advanced numerical design tools for electric propulsion which will further the understanding of the observable behavior and interactions with the satellite platform and predict performances of a given design. This includes alternative propellants and the ability to estimate the system lifetime. Finally significant progress will be made in establishing a HET performances measurement standard and developing advanced non-intrusive tests for measuring thruster erosion.

The CHEOPS consortium is led by: Safran Aircraft Engines and is comprised of representatives of the biggest European Prime satellite makers (Airbus Defense and Space, OHB System, Thales Alenia Space), the full EP Systems supply chain (Advanced Space Technologies, Bradford Engineering, Deutsches Zentrum fuer Luft – und Raumfahrt (DLR), SITAEL) and supported by academia and research centres (Centre National de la Recherche Scientifique, Chalmers Technology University, SME4SPACE, Universidad Carlos III de Madrid).

CHEOPS project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N. 730135. For further information visit the CHEOPS website (www.cheops-h2020.eu/)..

I. GIESEPP

GIESEPP stands for Gridded Ion Engine Standardised Electric Propulsion Platforms. GIESEP proposes an innovative activity to develop, build and test to TRL5 the first European Plug and Play Gridded Ion Engine Standardised Electric Propulsion Platform (GIESEPP) to operate Airbus Safran Launchers and QinetiQ Space ion engines. These are the only European ion engines in the 200-700W (LEO) and 5kW (GEO) domains that are space-proven, and the consortium’s intention will be to improve European competitiveness and to maintain and secure the European non-dependence in this field.

The project will design and develop a standardised electric propulsion platform for 200-700W and 5kW applications, which has the capability to run either Airbus Safran Launchers or QinetiQ thrusters. In addition, the 5kW electric propulsion system will be designed to allow clustering for 20kW EP Systems for space transportation, exploration and interplanetary missions. In order to cope with challenging mission scenarios, Dual Mode functionality of the thrusters will be realised. This ensures that the beneficial high Isp characteristics of Gridded Ion Engines are maintained, whilst also offering a competitive higher thrust mode. The GIESEPP systems will not be limited to xenon as an operating medium; assessments will be performed to ensure functionality with alternative propellants.

The approach to system standardisation and the resulting solutions will provide highly cost competitive and innovative EP Systems for current and future satellite markets, whilst meeting the cost efficiency requirements.

The activity will also provide the roadmap to higher TRL by 2023-2024, providing a cost competitive EP Systems. For further information visit the GIESEPP web (www.giesepp.com/).

J. HEMPT-NG

HEMPT-NG stands for High Efficiency Multistage Plasma Thruster – Next Generation. HEMPT-NG addresses the topic COMPET-3-2016-a on Incremental Technologies part of the SRC electrical propulsion in line with the SRC EPIC roadmap "to increase the competitiveness of EP Systems developed in Europe" by developing an integrated solution based on HEMPT (Highly Efficient Multistage Plasma Thruster) , the fluidic management system, and the power processing unit.

The proposed development will raise the performance of all components beyond current state-of-the-art. The results will offer an ideal EP System for LEO application up to 700 W and for Telecom/Navigation application up 5 kW. The HEMPT technology offers unique innovative features compared to other EP technologies and makes HEMP a key candidate to overcome all the currently identified deficiencies: No discharge channel erosion leading to higher lifetimes of the thruster; Acceleration voltages enabling a high specific Impulse (Isp) leading to a drastic reduction of propellant consumption; Unique large range of thrust offer enormous flexibility; Minimal complexity of concept providing an excellent basis for economic competitiveness.

The HEMPT-NG consortium is led by TES (Thales Electronic Systems GmbH), subsidiary of the Thales Group, worldwide leader in the development and production of space products, responsible for thruster equipment and integrated EP Systems. European industrial partners are: Thales Alenia Space (FR, BE, DE), OHB System, Airbus Defence and Space and Aerospazio Tecnologie, who bring their expertise in spacecraft mission studies, equipment development and testing capacities. The University of Greifswald will provide plasma simulation to support the thrusters developed. These partners in five European member-states (Germany, France, UK, Belgium, Italy) will develop an economical and well-performing HEMPT LEO and GEO EP Systems to guarantee European leadership and competitiveness, as well as the non-dependence of European capabilities in electric propulsion.

K. GaNOMIC

GaNOMIC stands for GaN in One Module Integrated Converter for EP Systems.

Satellite contractors are permanently looking for cost and performance improvements. This cascades to the PPU, a subsystem having a very high impact on the cost and performance of EP Systems. GaNOMIC proposes to focus on the PPU "heart" studying a disruptive power converter, with major innovations complementary to the incremental improvements, beyond the state of the art. GaNOMIC will demonstrate and combine in a synergistic way innovative technologies (such as GaN, digital control, adaptive filtering and embedded packaging), thus resulting in a radical breakthrough applicable to advanced EP System architectures based on such PPU designs.

GaNOMIC consortium plans to demonstrate the selected technologies by means of a 7.5 kW power converter to be tested in electrical propulsion existing test facilities, thus providing measurable validation, and specification definition, within the Phase 1 time frame.

This will lead to dramatic improvements in cost, mass and volume targeting part list reduction (by 3), converter efficiency (98%) and optimized thermal characteristics (200°C), translating into system optimization and increased power requirements.

Being at the forefront of technological developments, the consortium members are able to anticipate emerging technologies and medium to long term performance requirements consistent with existing and planned space programs at national, commercial and ESA levels. GaNOMIC will constitute a solid technical basis for future Direct Drive configurations, and further down the line, to "distributed" configurations where the PPU can be eliminated altogether.

In addition to promoting and accelerating the development of breakthrough EP-related concepts, the consortium members have identified other markets, e.g. aeronautics and automotive, which could benefit from these innovating high performance power converter and related technologies under consideration. For further information visit the GaNOMIC project web: (www.ganomic.eu/).

L. HiperLoc-EP

HiperLoc-EP stands for High Performance Low Cost Electric Propulsion for small satellites.

Even though the current state-of-art electric propulsion EP Systems provide impressive performance, these technologies have not been possible to scale down in size, whilst retaining system performance. As a result, such technologies are not available for nano- and micro satellites. The HiperLoc-EP project aim to use a novel approach to develop an Electrospray Colloid Electric Propulsion System (ECEP System). The project seeks to develop a disruptive electric propulsion technology that provides a high performance EP System cost that is at least one order of magnitude lower than today. A High Performance Low Cost Electric Propulsion system would enhance the functionality, performance and the value of many micro/nanosatellite missions in the future. The objectives include identifying the performance requirements, enhancing the TRL for an ECEP System, and understanding key processes in order to determine the optimal way to operate an ECEP System. Also included in this project is the design, manufacture and test of an ECEP System breadboard. The duration of the project is 24 months starting in January 2017.

The 4 consortium participants all have specific expertise in miniaturized and/or electric propulsion technologies for spacecraft:

- QMUL (United Kingdom) provides the leading understanding and expertise in Europe of electrospray processes and systems, having pioneered this research for the past 16 years.
- SystematIC (Netherlands) is a IC design house with focus on analog and mixed signal integrated circuit. Has delivered power supply and control circuitry to the Delphi C3 nanosatellite.
- The team also includes Airbus DS (United Kingdom) – one of Europe's leading satellite prime contractors and a recognized expert within the field of electric propulsion and as a user of such systems.
- NanoSpace AB (Sweden), has expertise in miniaturized propulsion systems and was among the first to fly a propulsion system onboard a CubeSat in 2015.

The HiperLoc-EP System is anticipated to operate at an efficiency of 50% at an Isp of 2500s. The cost target for HiperLoc-EP is to be feasible also for CubeSats and nanosatellites. Thus, HiperLoc-EP will provide Europe with an internationally commercially competitive, highly performing EP thruster in the timescale for 2020 and beyond.

M. MINOTOR

MINOTOR stands for MagnetIc NOzzle thruster with elecTron cyclOtron Resonance.

Electric propulsion has been identified by European actors as a strategic technology for improving the European competitiveness in different space areas such as in-space operations and transportation. In recent years, ONERA has built up an expertise on the ECRA (Electron Cyclotron Resonance Accelerator) disruptive technology for electric propulsion, and the need for further maturation along with Europe's search for new technologies lead to the MINOTOR project (MagnetIc NOzzle thruster with elecTron cyclOtron Resonance).

MINOTOR's strategic objective is to demonstrate the feasibility of the ECRA technology as a disruptive game-changer in electric propulsion, and to prepare roadmaps paving the way for the 2nd EP SRC call of 2020, in alignment with the overall SRC EPIC roadmap.

Based on electron cyclotron resonance as the sole ionization and acceleration process, ECRA is a cathodeless thruster with magnetic nozzle, allowing thrust vectoring. It has a significant advantage in terms of global system cost and reliability compared to mature technologies. It is also scalable and can potentially be considered for all electric propulsion applications, from microsatellites to space tugs.

Although the first results obtained with ECRA have been encouraging, the complexity of the physics at play has been an obstacle for the understanding and development of the technology. Thus in-depth numerical and experimental investigations will take place in MINOTOR.

The main objective of the project is to bring the ECRA technology from TRL3 to TRL4/5, in order to demonstrate its potential in a large range of thrust levels. To reach this goal, the following achievements are planned:

- get a full understanding of the physics, by deep numerical modelling studies in parallel to an extensive experimental investigation, leading to optimised designs, performance maps and scaling laws for the thruster;
- demonstrate ECRA performances with tests at three thrust levels (30 W, 200 W and 1 kW) and with erosion tests;
- demonstrate features such as compatibility with alternative propellants and magnetic beam steering;
- demonstrate the feasibility of an efficient microwave generator, and tests it on the thruster;
- determine quantitatively the impact of the ECRA technology on the EP System, including the PPU (Power Processing Unit), and on the satellite platform, and establish the future industrial roadmaps for development. These roadmaps shall aim at realising a high TRL in the timeframe of 2023-2024.

The 36 months MINOTOR project (2017-2019) involves 7 partners from 4 countries. The consortium is composed of academic experts to perform the research activities on ECRA, along with experienced industrial partners to quantify its disruptive advantages on the propulsion subsystem and its market positioning.

- ONERA (France, Coordinator) will be in charge of most experimental investigations of the thruster configuration.
- University Carlos III de Madrid (Spain) will develop the codes and implement the numerical modeling of the thruster.
- Thales Microelectronics (France) will demonstrate a high efficiency microwave generator technology.
- Universitaet Giessen (Germany) will conduct the higher power tests (1 kW) and the erosion test on the 200 W prototype.
- Thales Alenia Space Belgium SA (Belgium) will investigate the impact of the ECRA technology on the PPU architecture and cost.
- Safran Aircraft Engines (France) will provide expertise in electric propulsion thruster production and performance.
- L-up (France) will help on the project management.

ECRA's advantages as an electric thruster technology can be a disruptive force in a mostly cost-driven satellite market. The MINOTOR project will result in a significant step in maturity, and will help assess its potential to improve European competitiveness, help develop low-cost satellite missions such as constellations, and provide end-of-life propulsion solution, while paving the way for other future emerging electric propulsion technologies. For further information visit the MINOTOR website (www.minotor-project.eu/).

VI. Electric Propulsion SRC Activity

The Research European Agency (REA) REA is responsible for the proposal evaluation using independent experts, and the management, monitoring and payment of the ongoing SRC Operational Grants, including the EPIC PSA. All ongoing SRC Operational Grants as developing its technology activities in line with their Grant Agreements monitored by REA and the results and achievements will be disseminate by them in due time by the selected channels, including the EPIC PSA.

The EPIC PSA current activities are focusing on the assessment of the progress and results of the ongoing Operational Grants steaming from the SRC 2016 Call, in the context of the SRC objectives, always in coordination with REA. The PSA is participating in most of the progress meetings and technical reviews with designated PSA teams.

The evaluation on the state of the art and the market needs is a continuous activity for the PSA in other to update if necessary the SRC EPIC roadmap and master plan.

In preparation of the second phase of the SRC EPIC roadmap, the EPIC PSA is already giving support to EC on the definition of the SRC Call texts, related documents and technical annexes for the next SRC 2019 Call topic (SPACE-13-TEC-2019) and the following SRC 2020 Call topic (SPACE-28-TEC-2020).

Regarding the next steps on the dissemination and educational activities, the EPIC PSA will contribute as required in all EC H2020 Info Days at national and international level to inform, promote and disseminate all the information regarding the EP SRC, the PSA activities, the SRC EPIC roadmap and the SRC Operational Grants activities.

The EPIC PSA is going to organize three additional dedicated EPIC Workshops, the first next one in Madrid (Spain) took place on 24-25 October 2017; the next one took place on 15-17 October 2018 in London (United Kingdom), and the last one will take place on 21-23 October 2019 in Noordwijk (Netherlands). The EPIC Workshop scope is to present the Horizon 2020 Electric Propulsion SRC activities to the electric propulsion community and stakeholders and to collect and assess the latest EP technology developments in Europe.

In concurrence with the next EPIC Workshops, the EPIC PSA is going to organize in collaboration with local universities and research organizations active in EP, three dedicated educational activities called: EPIC Lecture Series. The first next one in Madrid (Spain) on 26 October 2017; the next one on 18-19 October 2018 in London (United Kingdom), and the last one on 24-25 October 2019 in Noordwijk (Netherlands). The EPIC Lecture Series objective is to provide to science and engineering university students (bachelor, master, PhD) with a selection of lectures on space electric propulsion, from the basic technology and concepts to the latest developments. The EPIC Lecture Series will cover in its different occasions, different subjects such as: basic electric propulsion physics and technology, electric propulsion subsystem elements, relevant physical models, current developments and technological challenges, experimental and measurement techniques, and examples of past, ongoing and future missions using electric propulsion. Lectures will be imparted by invited prominent professors and researchers in the field of space electric propulsion from Europe. Further information and the programme can be found in (http://epic-src.eu/lectureseries2017/).

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