GSTP Element 1 “Develop” Compendium 2019: Generic Technologies
APPROVAL

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1 INTRODUCTION

The GSTP E1 “Develop” Compendium 2019: Generic Technologies is a list of candidate activities for the GSTP E1 “Develop” Work Plan, pre-selected following the ESA End to End process, including programmatic screening and consistency checking with technology strategy and with THAG Roadmaps. The aim of the GSTP E1 “Develop” Compendium; Generic Technologies is to provide to industry and Delegations a consolidated overview by Competence Domain of the priorities for ESA in the development of generic technologies within the GSTP.

This document follows the previous GSTP Element 1 Compendia of Potential Activities. In particular, the following documents:
- GSTP-6 Element 1 – Compendium of Potential Activities – (ref. TEC-T/2016-03/NP) issued in February 2016.
- GSTP-6 Element 1 – Compendium of Generic Technology Activities - (ref. TEC-T/2013-007/NP) issued in February 2013.

This document provides a list and descriptions of candidate activities for the Work Plan of the GSTP Element 1 (Chapter 2 and 3 of this document). The pre-selection of the activities corresponds to activities belonging to the GEN - Generic Technologies and Techniques Application Domain.

Furthermore, the activities are categorised according to the following Competence Domain structure:

- CD1 - EEE / Components / Photonics / MEMS
- CD2 - Structures, Mechanisms, Materials, Thermal
- CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C
- CD4 - Electric Architecture / Power and Energy / EMC (E2E)
- CD6 - Life / Physical Science Payloads / Life Support / Robotics and Automation
- CD7 - Propulsion, Space Transportation and Re-entry Vehicles
- CD8 - Ground Systems / Mission Operations
- CD9 - Digital Engineering for Space Missions
- CD10 - Astrodynamics / Space Debris / Space Environment

This compendium is issued to Delegations of GSTP Participating States and their industries for comments. Such comments will be considered in the following updates of the work plan for this GSTP Element 1 “Develop”.

The objective is to have a good indication of the developments the Participating States intend to support in order to present updates of the GSTP E1 “Develop” Work Plan with consolidated set of activities to the IPC for approval.
There were two main requirements driving the definition and selection of activities for this GSTP Generic Compendium 2019:

- The ESA Technology Strategy established in 2018 (document ESA/IPC(2018)93), and in particular to the strategic lines of action defined by Competence Domains.
- Technology developments corresponding to the GSTP objectives, notably in terms of Technology Readiness Levels (TRLs) and application domains.

In addition elements of critical importance were also taken into account: fostering state of art technology adoption, innovation, technology push, spin–in of commercial technologies, supporting industrial sustainability, capacity building, European competitiveness and risk obsolescence management of critical parts.

Further specific details on the selection rationales by Competence Domains are presented here after. The special area on Deep Space Optical Communication System is presented also here below in the section with the same name (activities are part of the CD8 objectives).

**CD1: EEE / Components / Photonics / MEMS**

Two major strategic goals were identified, common to the thematic covered by CD1: European non dependence and exploring recurrent usage of COTS (Components Of The Shelf) for enabling lower cost space projects.

In order to fit the specific CD01 strategy approach, the CD01 3-axis approach was used as selection criteria:

- **Explore** the major trends from state-of-the-art (e.g. 8-inch back-thinning line for detectors, hall sensor probes) through latest innovation (e.g. T2SL infrared detectors, VCSEL driver for high speed optical communications) till breakthrough (e.g. 3D stacked detectors) and spin-in technologies (e.g. optical fiber harnessing).
- **Enhance** higher performances and uptake by capitalizing on previous ESA R&D developments to push forward the technology (e.g. qualification of GaN microwave technology and processes, low noise RF PLL). Furthermore, enhance by improving and facilitating space usage of COTS in the wider sense, not only seen as electronic components, but also as complete elements and processes (e.g. assess the benefits of test methods used not in space up to now).
- **Exploit** previous R&D achievements by improving and facilitating space usage of ESA qualified processes (e.g. SerDes in DARE 65nm technology) and by ensuring the availability of better testing and characterization techniques (e.g. generic FPGA radiation test set-up).

**CD2: Structures / Mechanisms / Materials / Thermal**

The CD2 covers the following technical areas:

- **Structures**: Structural design and verification methods and tools; High stability and high precision spacecraft structures; Inflatable and deployable structures; Hot structures; Active/adaptive structures; Damage tolerance and health monitoring; Launchers, re-entry vehicles, planetary vehicles; Crew Habitation, Safe Haven and EVA suits; Meteoroid and Debris shield design and analysis; Advanced structural concepts and materials
- **Mechanisms**: Mechanism core technologies; Non explosive release technologies; Exploration tool technologies; Control electronics technologies; MEMS technologies; Tribology technologies; Mechanism engineering; Pyrotechnics technologies
- **Materials and Processes**: Novel Materials and Materials Technology; Materials Processes; Cleanliness and Sterilisation; Space Environmental Effects on Materials and Processes; Modelling of Materials Behaviour and Properties; Non-Destructive Investigation; Materials and Processes Obsolescence; Materials for Electronic Assembly
- **Thermal**: Heat Transport Technology; Cryogenics and Refrigeration; Thermal Protection; Heat Storage and Rejection; Thermal Analysis Tools

In addition, each selected activity had to correspond to several of the following high-level objectives:
- Capture and mature new ideas into products and/or improve performance of existing products,
- Support the reduction of cost of space products e.g. AIT/AIV cost reduction,
- Compress schedule,
- Alignment with corresponding roadmap.

Amongst CD2’s strategic lines of action defined in the ESA Technology Strategy, the selected activities belong to: composite materials, mechanisms building blocks, stable and lightweight structures, adhesives, cryogenics and focal plane cooling, two-phase heat transport systems, thermal control management, support to chemical propulsion, structures.


The strategic lines for CD1 are the following:
1. Processing solutions
2. COTS based solutions
3. Miniaturized / integrated solutions
4. Modular architecture
5. Interface solutions
6. On-board autonomy
7. On-board security
8. How to increase data throughput and improve performances for TT&C and payload data links
9. Increase AOCS/GNC Performance
10. Avionics development methods

In the selection of activities for this compendium emphasis has been given to CD3 strategic lines 1,2,3 and 9, based on the current demand from projects and due to the fact that there are already developments ongoing covering the other lines.

In particular, one objective of the compendium has been to support the emerging reconfigurable FPGA technology implemented in the BRAVE component to produce All Programmable System on Chip (APSoC), covering the CD3 strategic lines of processing solutions, of miniaturisation (also addressed by), and avionics development methods.

In addition, on the AOCS and GNC side, pushed by project trends, priority has been given to the control strategy and techniques to optimise the performance and extent of space instruments based on Active and Adaptive Optics design, as well as autonomous navigation using star trackers.

In terms of product, a 3-axes accelerometer development is proposed, in order to increase performance and robustness for thrust monitoring of spacecraft flight manoeuvres, together with an objective of non-dependence, as well as low cost GNSS receiver. Finally, the increase of TT&C data throughput is addressed as well as avionics bus communication.
CD4: Electric Architecture / Power & Energy / EMC

The activities were selected based on their adherence to CD4 strategy (as per the ESA Technology Strategy), and to the Harmonisation dossiers for Power Management and Distribution and Energy Storage (both first semester 2019) as well as the established one for Power Generation, Solar Generators and Solar cells (2015).

In particular, the activities were selected among the ones in high or medium urgency and criticality according to the harmonisation dossiers.

For EMC, the two activities proposed (Qualification of novel grounding for composite structural panels, and Immunity to In-Band Electromagnetic Interference for Radio-Frequency Receivers using Signal Modulation) are considered of high relevance and interest as EMC and system technology enhancing options.

CD5: End-to-end RF & Optical Systems / Products for Navigation, Comm. & Remote Sensing

As captured by ESA/IPC(2018)93, the developments in the radio frequency and optical systems domain are mainly driven by the need of the planned ESA scientific and exploratory missions and by the expected evolutions of the institutional and commercial applications market, covering Space Ground and User segments. In general the new systems will require more powerful single satellite architectures or conversely very large constellation composed of low cost ground and space components, including swarms of micro or mini-satellites, in order to satisfy the needs for an increased overall data throughput in the telecom area, an enhanced portfolio of services for what concerns navigation, and a more accurate and frequent observation capability of the earth or the in situ environment for what concerns earth observation or exploratory missions.

The supporting technologies therefore:

- will include microwave, digital and photonics technologies aiming at improving the efficiency of the payload, yet increasing its overall performance (e.g. frequency reuse, overall throughput, RF power, etc.);
- will rely on scalable architecture, reusable building blocks, larger deployable structure, more powerful active arrays;
- will exploit higher frequency for the user and feeder links, more efficient and powerful ground-to-space/space-to-ground communications plus networking architecture necessary to manage efficiently larger and more distributed ground segment architecture;
- will benefit from the development of advanced user terminals to explore to the maximum the synergies with terrestrial systems embracing the evolution of the consumer technology;
- will provide a continuous enhancement of the security of the services as delivered to the final users through, more resilient signal and context aware user equipment, robustness to interference etc...
- will leverage on the advances in Software Defined Radio (SDR) technology that allow to reduce cost, volume and power consumption;
- will pursue the enhancement of the instruments technology, e.g. radiometers, synthetic aperture radars, scatterometers, optical imaging, topographic measurements, thermal infrared sensing, landing and ground-penetrating radars, accompanied by the parallel introduction of terrestrial, potentially game changing technologies through dedicated spin-in efforts;
- will increase resilience to the challenging operational conditions of the planned new exploratory missions.
CD 6: Life / Physical Science Payloads / Life Support / Robotics and Automation

The Competence Domain 6 is engaged in the following strategic lines:
- Technologies for environmental control, life support
- Robotics building blocks
- Technologies for active space debris removal and for orbital support services
- In-orbit assembly and robotic modular space systems
- Instrumentation for health monitoring and countermeasures, telemedicine applications
- Autonomy in Exploration
- Technologies for in situ resource utilisation

CD6 covers a wide range of activities and offers an interdisciplinary approach, with a focus on exploration related activities, but as well with uses beyond Human Spaceflight and Exploration. In this respect the proposed activities are within the realm of the strategic lines, as they address aspects of orbital robotics, instrumentation and as well exploration and sustainability but serve as well potential applications beyond the field of CD6.

The know-how built up in the area of exploration related instrumentation, planetary protection and AIT in contamination-controlled environment is being pursued with the development of an operational mobile cleanliness and contamination facility. Structural health monitoring of space structures subject to creep makes use of machine learning to reliably detect and characterise changes in material morphology over time.

The grasping and refuelling system development targets to make satellite platforms more sustainable developing a standard interface for refuelling of platforms. Sustainable biopolymers in space is targeted at testing the suitability of biopolymers for space applications. This may open up a new area of spacecraft materials, as well in relation to life support systems and sustainability efforts for the future. Last not least the dynamics of water recycling technology targets common interests in flow dynamics, for life support systems and as well for propulsion aspects.

CD 7: Propulsion, Space Transportation and Re-entry Vehicles

The CD7 technology developments selected are corresponding to the GSTP objectives, notably in terms of Technology Readiness Levels (TRLs) and application domains for propulsion, space transportation systems, and (re-)entry. Supporting new services for return from space, non-destructive Earth and planetary (re-)entry, the developments include a compound of new technologies ranging from propulsion to aerodynamics, from materials to GNC, from thermal to structures.

There were three main propulsion requirements driving the definition and selection of activities for this GSTP Generic Compendium 2019 laid on the ESA Technology Strategy established in 2018 (document ESA/IPC(2018)93), and in particular to the strategic lines of action defined by CD07:
- Develop European propulsion components and propulsion equipment, considered strategic on a global non-dependence scenario;
- Drive the development of propulsion technologies, components and systems. This will represent the creation of new markets in propulsion technology to stimulate economic expansion across Member States;
- Improve the development, manufacturing, and qualification of European reliable and competitive technologies, products, and processes for propulsion systems.

In addition to the two overarching requirements (compliance with GSTP and ESA technology Strategy), the selection of activities also examined the issues of having generic activities and whether the timeframe would be commensurate for 2020 – 2021.
Once the requirements were met and the issues positively answered, the proposals were selected based on the importance with respect to the strategy of CD7 in the lines of:

- Reducing the development cost of propulsion and fluid dynamics;
- Technology push in aerothermodynamics and structures;
- Enhancement of existing and new tools and systems;
- Enabling re-usability for future advanced launchers.

### CD 8: Ground Systems / Mission Operations

The major drivers for technology developments are:

- Space Debris Detection: Space debris detection is performed with ground sensors using radar, passive and active optical tracking (laser ranging techniques). The technology development focus is on the cost efficiency of transmission, reception and synchronisation techniques of large-scale radars.
- Radio Science: Radio science covers multi-frequency up- and downlinks for the elimination of frequency-dependent phenomena with associated radiometric calibrations of solar plasma, Earth atmosphere including wet and dry troposphere, and antenna mechanical performance.
- Frequency and Timing: Frequency and Timing systems provide the stable underlying backbone in the deep space stations for Time Synchronization and Radiometric services (Ranging, Doppler, Delta-DOR) and for the provision of Universal Time Coordinated (UTC) in ESA as a basis for precise orbit determination.
- Ground Data systems: Efficient ground data systems aim at re-usable ground system software building blocks that cover the full mission lifecycle from concept to assembly, integration, test to operations. The main challenges to be addressed relate to keeping pace with the fast changing technology in the IT/software domain, to identify and benefit from spin-in opportunities from other areas, to respond to increasing mission requirements, including cybersecurity, to harmonise similar functionalities across domain, and to overcome missions’ reluctance to adopt new solutions that are not mission enablers. In order to support the EGS-CC adoption for new types of missions and application domains, priority is given to enhancements for multi-mission applications. The ground data systems include mission control systems (e.g. European Ground Segment Common Core software, EGS-CC), mission planning systems, operational simulators, large data archives, data analysis/distribution/preservation systems, as well as other innovative data systems.

### CD9: Digital Engineering for Space Missions

The objective of CD9, Digital Engineering, is to implement an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support the end-to-end engineering process along the space mission lifecycle, from concept to disposal and including data exploitation.

The final goal is to help achieving technology development targets by reducing spacecraft development time and improving cost efficiency via the adoption of innovative processes and technologies.

A significant part of the activities is related to spin-in and adaptation of technologies that are booming outside the space sector (Artificial Intelligence, Augmented/Virtual Reality) with potential to become game changers. Other activities target the continued effort towards application of model-based systems engineering and related challenges with regards to information exchange.
The proposed CD9 activities within this compendium cover the lines of action provided here below:

- Apply model-based system engineering to ESA projects
- Improve exchange of data and information between different stakeholders by addressing interoperability between the different data, models and tools
- Support collaborative design, verification and operations preparation by defining reference architectures and reference facilities for E2E testing and demonstration of new concepts
- Ensure dependable development, operation and exploitation of space missions by providing tools able to support the exploitation of quality-related data.
- Spin-in AI technologies for failures analysis and prediction (AI for automated failure investigation, prediction and prevention, AI for OBSW diagnostic and prognostic of degradations/failures, AI for advanced data visualisation)
- Spin-in VR/AR technologies for advanced visualisation of Space data

**CD 10: Astrodynamics / Space Debris / Space Environment**

CD10 strategic lines are:

- Space debris: Includes closing the 1mm gap through space based optical observations. Possibility to remove smaller debris by laser-based momentum transfer. In the medium term, automated collision avoidance including autonomous decision and execution of collision avoidance manoeuvres is necessary.
- Space Environments and Effects: Requires understanding and modelling of environments of concern to space system development and operation, and the establishment of capabilities for quantitative assessments of their effects. Development and flight of instruments for environment data capture and would benefit from adding low-resource space environment monitoring instruments on many platforms.
- Astrodynamics – Space Flight Dynamics and GNSS: Astrodynamics covers the areas of precise orbit determination (POD) for Earth oriented satellites in low and medium Earth orbits, as well as satellites in high eccentric orbits, based on GNSS observations as prime source complemented by other types of observations like satellite laser ranging, very large baseline interferometry etc. The R&D strategy focusses on the development of new satellite POD concepts for single satellites, satellite formation flying, and satellite constellations with a focus to exploit the full potential of the European GNSS elements.

**Deep Space Optical Communication System**

This special area is part of CD8 objectives.

Optical communication from deep-space has the potential to substantially increase the returned science data volume at the same onboard burden (mass, power) compared to radio frequency communication, or to reduce the onboard terminal mass and power at similar data rates.

For payload data transmission systems in optical frequencies, the technology R&D focus is on direct-to-Earth communication for increased data return or substantially smaller on-board systems compared to RF. The corresponding ground terminals fall into small (60-100cm) optical antennas for LEO up to Lunar distance communication with data rates of 1-10Gbps, and large ground terminals (4-12m) for deep space communication with normalised data rates of 100Mbps from 1AU distance or miniaturised onboard terminals at shorter distances.

Essential technologies are therefore large optical antennas for day and night operations with segmented optical mirrors made of aluminium for cost efficiency, photon counting detectors, high photon efficiency modulation and coding, and high-power laser uplinks with associated safety systems.
2 LIST OF ACTIVITIES

GEN - Generic Technologies

CD1 - EEE / Components / Photonics / MEMS

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
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<tbody>
<tr>
<td>GT17-300ED</td>
<td>Reconfigurable SerDes IP Core development for mixed-signal ASIC platform DARE65</td>
<td>1,600</td>
</tr>
<tr>
<td>GT17-301ED</td>
<td>Optical fibre cable for space applications</td>
<td>500</td>
</tr>
<tr>
<td>GT17-302ED</td>
<td>Space validated improved low noise RF frequency synthesizer on BiCMOS</td>
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</tr>
<tr>
<td>GT17-303QE</td>
<td>SRAM based FPGA radiation test set-up</td>
<td>400</td>
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<tr>
<td>GT17-304ED</td>
<td>Alternative test methods for COTS</td>
<td>1,200</td>
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<tr>
<td>GT17-305MM</td>
<td>3D stacked hybrid visible image sensor</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-306MM</td>
<td>High performance Type-2 Super Lattice (T2SL) Infra-Red detectors</td>
<td>1,000</td>
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<tr>
<td>GT17-307ED</td>
<td>Radiation hard VCSEL (Vertical-Cavity Surface-Emitting Laser) driver and receiver chain for high speed digital optical transceivers</td>
<td>600</td>
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<tr>
<td>GT17-308ED</td>
<td>Magnetic probe development for position and speed feedback</td>
<td>700</td>
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<tr>
<td>GT17-309ED</td>
<td>Space application of a mm-wave GaN MMIC process</td>
<td>500</td>
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<tr>
<td>GT17-310ED</td>
<td>Space validation of a 8 inches back-thinning manufacturing line</td>
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<td><strong>Total CD1</strong></td>
<td><strong>9,500</strong></td>
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CD2 - Structures, Mechanisms, Materials, Thermal

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<tr>
<td>GT17-311MS</td>
<td>Advanced aluminium-lithium alloys for space applications</td>
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<tr>
<td>GT17-312MS</td>
<td>Smart NDT system for complex shape polymer matrix composite space structures and assemblies</td>
<td>900</td>
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<tr>
<td>GT17-313MT</td>
<td>Development of a very high efficiency and compact heat exchanger for Reverse Turbo Brayton</td>
<td>800</td>
</tr>
<tr>
<td>GT17-314MS</td>
<td>Enhancement of brushless motors technology for space applications</td>
<td>600</td>
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<tr>
<td>GT17-315MS</td>
<td>Pointing mechanism for electric thruster propulsion for nanosats</td>
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<tr>
<td>GT17-316MS</td>
<td>Low shock release actuators</td>
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<tr>
<td>GT17-317MS</td>
<td>Noise free long life potentiometer</td>
<td>450</td>
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<tr>
<td>GT17-318QE</td>
<td>&quot;Green&quot; surface treatments for adhesive bonding of glasses/ceramics on metal surfaces</td>
<td>500</td>
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<tr>
<td>GT17-319MS</td>
<td>Adhesive connections to ceramic structures</td>
<td>600</td>
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<tr>
<td>GT17-320MS</td>
<td>Improvement of NDI-methods for ceramic structures</td>
<td>800</td>
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<tr>
<td>GT17-321MS</td>
<td>CFRP sandwich inserts design, test and verification methods</td>
<td>500</td>
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<tr>
<td>GT17-322MS</td>
<td>New generation ceramic optical bench</td>
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<tr>
<td>GT17-323MT</td>
<td>Towards a thermal digital twin</td>
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<td>GT17-324MT</td>
<td>Flexible joint for axial grooved heat pipe</td>
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<td>GT17-325MT</td>
<td>Development of generic MLI flap for spacecraft interface ring</td>
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**CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C**

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<tr>
<td>GT17-326SA</td>
<td>Active optics control in the presence of mid to high frequency perturbations</td>
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<tr>
<td>GT17-327ED</td>
<td>Strategies for reliable on-board reconfiguration of FPGAs</td>
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<tr>
<td>GT17-328ED</td>
<td>Dependable avionic system based on BRAVE ULTRA SoC</td>
<td>1,200</td>
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<tr>
<td>GT17-329ES</td>
<td>Low cost GNSS spaceborne receiver for guaranteed positioning and autonomous orbit manoeuvres in LEO - EQM</td>
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<tr>
<td>GT17-330SA</td>
<td>High accuracy 3-axis accelerometer unit EM</td>
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<tr>
<td>GT17-331ES</td>
<td>Very high data rate K/K-band (22 Rx/26 Tx) transponder for near-earth missions</td>
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<tr>
<td>GT17-332ES</td>
<td>Miniaturisation of the deep space transponder</td>
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<td>GT17-333SW</td>
<td>Heterogeneous modelling, design and analysis of complex space systems</td>
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<tr>
<td>GT17-334SW</td>
<td>Payload data processing SW architectures definition and modelling</td>
<td>800</td>
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<tr>
<td>GT17-335SA</td>
<td>Autonomous relative navigation using star-tracker images</td>
<td>600</td>
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<td>GT17-336SW</td>
<td>Guidelines, methods, processes and tools for development of reliable SoC systems</td>
<td>800</td>
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<td>GT17-337ED</td>
<td>Physical layer testing of SpaceFibre link</td>
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<td>GT17-338ED</td>
<td>System analysis, benchmarking and improvement of CFDP IP core</td>
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### CD4 - Electric Architecture / Power and Energy / EMC

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<td>GT17-339EP</td>
<td>Behaviour of 4G32 solar cells under particle irradiation</td>
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<tr>
<td>GT17-340EP</td>
<td>Advanced multi-junction solar cells focusing to cost reduction</td>
<td>700</td>
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<tr>
<td>GT17-341EP</td>
<td>Power unit for high power radars and altimeters, improving the dynamic performance under pulsed operation</td>
<td>800</td>
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<td>GT17-342EP</td>
<td>N channel latching current limiter</td>
<td>500</td>
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<td>GT17-343EP</td>
<td>New packaging techniques to increase power density of power control and distribution units</td>
<td>800</td>
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<tr>
<td>GT17-344EP</td>
<td>Isolated magnetic feedback generator</td>
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<td>GT17-345EP</td>
<td>Immunity to in-band electromagnetic interference for radio-frequency receivers using signal modulation</td>
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<td>GT17-346EP</td>
<td>Qualification of novel grounding for composite structural panels</td>
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<td>GT17-347EP</td>
<td>End of life battery management system</td>
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<td>GT17-348EP</td>
<td>Cell and battery validation approach</td>
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<tr>
<td>GT17-349EP</td>
<td>Technology improvement for lift-off and transfer processes to obtain light and flexible solar cells</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td><strong>Total CD4</strong></td>
<td><strong>8,300</strong></td>
</tr>
</tbody>
</table>

### CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-350EF</td>
<td>Broadband RF absorber coating for space applications</td>
<td>850</td>
</tr>
<tr>
<td>GT17-351EF</td>
<td>Validation of the mitigation of plasma effects on RF communications during re-entry</td>
<td>600</td>
</tr>
<tr>
<td>GT17-352EF</td>
<td>Micro reference oscillator</td>
<td>800</td>
</tr>
<tr>
<td>GT17-353EF</td>
<td>Next Generation of spaceborne phased arrays</td>
<td>1,200</td>
</tr>
<tr>
<td>GT17-354ES</td>
<td>Low-cost dongle for enabling satellite radio links on handheld devices</td>
<td>480</td>
</tr>
<tr>
<td>GT17-355ES</td>
<td>Generic in-orbit interference monitoring unit</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-356ES</td>
<td>Advanced Remote Radio Head (RRH) module for scalable satellite radio communications stations in L/S/C/X bands</td>
<td>800</td>
</tr>
<tr>
<td>GT17-357EF</td>
<td>Advanced technologies based on groove gap waveguide designs</td>
<td>500</td>
</tr>
</tbody>
</table>
### CD5 - Development

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-358EF</td>
<td>Two-Way Time Transfer and Ranging: in-orbit performance demonstrator</td>
<td>600</td>
</tr>
<tr>
<td>GT17-359ES</td>
<td>Adaptive interference monitoring technology for ground infrastructure using Software-Defined Radio and Artificial Intelligence</td>
<td>600</td>
</tr>
</tbody>
</table>

**Total CD5** 7,430

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### CD6 - Life / Physical Science Payloads / Life Support / Robotics and Automation

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-360MM</td>
<td>Mobile cleanliness and contamination verification facility</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-361MS</td>
<td>Structural health monitoring of space structures subject to creep</td>
<td>450</td>
</tr>
<tr>
<td>GT17-362MM</td>
<td>Grasping and refuelling system development (TANKERS)</td>
<td>5,200</td>
</tr>
<tr>
<td>GT17-363MM</td>
<td>Sustainable biopolymers for space applications</td>
<td>600</td>
</tr>
<tr>
<td>GT17-364MM</td>
<td>Dynamics of contamination on nozzle surrounding surfaces as well as water recycling technology</td>
<td>850</td>
</tr>
</tbody>
</table>

**Total CD6** 8,100

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### CD7 - Propulsion, Space Transportation and Re-entry Vehicles

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-365MP</td>
<td>Development of standard test equipment for dynamic thrust measurements</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-366MP</td>
<td>Novel AIT techniques to lower the price of electric propulsion equipment</td>
<td>500</td>
</tr>
<tr>
<td>GT17-367MP</td>
<td>Material point method for sloshing and multiphase flows</td>
<td>300</td>
</tr>
<tr>
<td>GT17-368MP</td>
<td>Computational fluid dynamics acceleration through hardware</td>
<td>500</td>
</tr>
<tr>
<td>GT17-369MP</td>
<td>Disruptive conceptual sizing and cost optimization methodology of reusable flight vehicles</td>
<td>800</td>
</tr>
<tr>
<td>GT17-370MS</td>
<td>Morphing of aero-thermally loaded structures</td>
<td>1,000</td>
</tr>
</tbody>
</table>

**Total CD7** 4,100
## CD8 - Ground Systems / Mission Operations

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-371GD</td>
<td>Operational migration to multi-mission control system</td>
<td>500</td>
</tr>
<tr>
<td>GT17-372GS</td>
<td>10Gbit/s protocol ground implementations</td>
<td>400</td>
</tr>
<tr>
<td>GT17-373GS</td>
<td>Correlator for array of deep space large aperture antennas</td>
<td>650</td>
</tr>
<tr>
<td>GT17-374GS</td>
<td>Prototype of deionised cooling system for 80kw high power amplifier (HPA)</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-375GD</td>
<td>Reconfigurable wideband ground station transceiver</td>
<td>600</td>
</tr>
<tr>
<td>GT17-376GD</td>
<td>Generic flight operations segment for HAPS</td>
<td>1,200</td>
</tr>
<tr>
<td></td>
<td><strong>Total CD8</strong></td>
<td><strong>4,350</strong></td>
</tr>
</tbody>
</table>

## CD9 - Digital Engineering for Space Missions

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-377QQ</td>
<td>RAMS in-orbit data exploitation (RIDE) operational tool</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-378QQ</td>
<td>Nanosat on-orbit prognostic and health management SW</td>
<td>600</td>
</tr>
<tr>
<td>GT17-379GD</td>
<td>Augmented, mixed and virtual reality for space safety use cases</td>
<td>500</td>
</tr>
<tr>
<td>GT17-380GD</td>
<td>Ontology for ground segment and operations</td>
<td>300</td>
</tr>
<tr>
<td>GT17-381SY</td>
<td>MBSE applied to complex nanosat projects</td>
<td>400</td>
</tr>
<tr>
<td>GT17-382EO</td>
<td>3D visualization of fluid surfaces (3DFLUS)</td>
<td>300</td>
</tr>
<tr>
<td>GT17-383G</td>
<td>Space mission digital twin</td>
<td>500</td>
</tr>
<tr>
<td>GT17-384SY</td>
<td>Instrument design models development</td>
<td>500</td>
</tr>
<tr>
<td>GT17-385SY</td>
<td>Model-based system engineering for AIV (MBSE 4 AIV)</td>
<td>400</td>
</tr>
<tr>
<td>GT17-386G</td>
<td>Failure root cause analysis automation</td>
<td>500</td>
</tr>
<tr>
<td>GT17-387G</td>
<td>Big data challenge in space mission design</td>
<td>300</td>
</tr>
<tr>
<td>GT17-388G</td>
<td>System engineering model-based information exchange</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td><strong>Total CD9</strong></td>
<td><strong>5,700</strong></td>
</tr>
</tbody>
</table>
### CD10 - Astrodynamics / Space Debris / Space Environment

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT17-389EP</td>
<td>Shape effects in hypervelocity impacts</td>
<td>550</td>
</tr>
<tr>
<td>GT17-390EP</td>
<td>Nanosat rated booms and deployment systems for space environment electro-magnetic fields sensors accommodation</td>
<td>800</td>
</tr>
<tr>
<td>GT17-391EP</td>
<td>Global radiation belt model improvement by radiation monitor data</td>
<td>700</td>
</tr>
<tr>
<td>GT17-392GF</td>
<td>Atmospheric models applied to operations</td>
<td>500</td>
</tr>
<tr>
<td>GT17-393SD</td>
<td>Characterising the radar cross section (RCS) of space debris</td>
<td>500</td>
</tr>
<tr>
<td>GT17-394EP</td>
<td>Plasma analyser for spacecraft charging characterisation</td>
<td>500</td>
</tr>
<tr>
<td>GT17-395SD</td>
<td>Thermomechanical fragmentation model for re-entry break-up simulation tool</td>
<td>500</td>
</tr>
<tr>
<td>GT17-396SW</td>
<td>Low cost radiation monitor for large cooperative satellite missions</td>
<td>1,000</td>
</tr>
<tr>
<td>GT17-397SW</td>
<td>Enhancement of physical and assimilation modelling of radiation belts</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total CD10</strong></td>
<td></td>
<td><strong>5,350</strong></td>
</tr>
</tbody>
</table>

### Deep-Space Optical Communication System (CD8 - Ground Data Systems / Mission Operations)

<table>
<thead>
<tr>
<th>Programme Reference</th>
<th>Activity Title</th>
<th>Budget (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT1D-301GS</td>
<td>2m-class segmented optical antenna prototype</td>
<td>5,000</td>
</tr>
<tr>
<td>GT1D-302GS</td>
<td>Autonomous deployable high-power uplink beacon system for deep space optical communication</td>
<td>3,000</td>
</tr>
<tr>
<td><strong>Total DOCS</strong></td>
<td></td>
<td><strong>8,000</strong></td>
</tr>
</tbody>
</table>
3 DESCRIPTION OF ACTIVITIES

3.1 GEN - Generic Technologies

3.1.1 CD1 - EEE / Components / Photonics / MEMS

<table>
<thead>
<tr>
<th>Domain</th>
<th>Generic Technologies - CD1 - EEE / Components / Photonics / MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref. Number:</td>
<td>GT17-300ED</td>
</tr>
<tr>
<td>Budget (k€):</td>
<td>1,600</td>
</tr>
<tr>
<td>Title:</td>
<td>Reconfigurable SerDes IP Core development for mixed-signal ASIC platform DARE65</td>
</tr>
<tr>
<td>Objectives:</td>
<td>The objective of this activity is to develop a SerDes (at least 6.25 Gbps/lane) IP block for mixed-signal ASIC platform DARE65, which can be used for modern high-speed serial link protocols such as SpaceFibre, SRIO, JESD204B.</td>
</tr>
<tr>
<td>Description:</td>
<td>Serialiser/Deserialiser (SerDes) are important building blocks for modern ASICs that need to interface external devices via serial high-speed link protocols such as SpaceFibre, JESD204B, ESIfstream, Ethernet or Serial RapidIO. Currently, a new rad-hard by design mixed-signal ASIC platform for TSMC’s 65 nm process is under development in order to support future on-board network components, instrument front-end ASICs etc. Thus, this activity aims at developing a complementary radiation hardened and fully configurable SerDes IP block for this technology up to a test vehicle, to be then tested and characterized in terms of its functionality and radiation performance. The planned ASIC could make use of DARE65 plus the newly developed SerDes, providing improved feature set compared to existing solutions and potentially cost reduction for future ASIC developments.</td>
</tr>
</tbody>
</table>
| Main tasks to be done include: | • Critical requirements review  
• Design of a new or the porting of an existing SerDes to the target ASIC technology (including all required steps to harden the IP)  
• Development and tape-out of a test vehicle  
• Functional validation of the chip and the characterization of its radiation performance in an irradiation test campaign. |
| Deliverables: | Breadboard, Prototype, Report |
| Current TRL: | 3 |
| Target TRL: | 5 |
| Duration (months): | 24 |
| Target Application/Timeframe: | Application Specific Integrated Circuits/ TRL5 by 2023 |
Title: Optical fibre cable for space applications

Objectives: The objectives of this activity are to develop, test and perform a space assessment on an optical fibre cable suitable for space applications.

Description: Optical fibre cables suitable for space are not yet on the market. Space applications request a very large range of temperature, radiation robustness and the use of materials able to pass outgassing screening tests. Today the only solution currently qualified for space is a solution based on the use of a loose PEEK tube fitted over bare fibre protected by a simple buffer layer. This solution is considered by most users as inadequate as it suffers from several drawbacks such as the PEEK material tends to maintain its original coiled configuration and is difficult to straighten, and that the thin PEEK tubing can be prone to kinking.

The activity would be focused on the development of a new cable construction that could provide a generic solution covering a wide variety of space applications, test the solution and prepare a way to industrialize it. One key aspect of the cable design is that it should be suitable to up jacket a wide variety of optical fibres as specified by the end-user or final space customer. The variety of fibres which shall be considered include both single mode and multimode fibres as well as single fibre and multi-fibre solutions.

The main tasks necessary to executed in order to achieve the objectives include:

- Definition: specifications for space fibre networks, optical metrology, telecom applications.
- Design including testing definitions
- Manufacturing: Procurement of various fibre types, manufacturing of the cable, up jacketing of the fibres
- Testing: characterisation, environmental tests, radiation testing
- Industrialization

Deliverables: Engineering Model, Reports

Current TRL: 4  Target TRL: 6  Duration (months): 24

Target Application/Timeframe: Generic optical fibre cable design meeting the needs of wide variety of missions including: Space Fibre networks based on optical links, metrology using interferometers, and high data rate telecom applications.

Applicable THAG Roadmap: Photonics (2018)
Consistent with activity C01 “Space fibre optical harness”
Title: Space validated improved low noise RF frequency synthesizer on BiCMOS

Objectives:
The objectives of this activity are to design, manufacture and perform space validation testing on an improved low noise RF Phase Locked Loop (PLL) frequency synthesizer on BiCMOS process.

Description:
Satellite communication relies on RF PLL frequency synthesizers for the generation of a wide range of LO frequencies. The quality of the LO frequency signal in terms of phase noise and spectral purity are critical parameters for system performance. Most currently existing components are either for terrestrial market and not designed for radiation environment or lack in performance in terms of noise and spectral purity or frequency band.

The aim of this activity is to make available a space compatible RF PLL frequency synthesizer with improved noise and spectral purity for the European space industry since, currently, there is no such component available in Europe. This will be achieved by mapping the requirements for a future European space compatible RF PLL frequency synthesizer, followed by design, two manufacturing runs and space validation testing. Thus, this activity encompasses the following tasks:

- Literature survey and collection of the industry feedback for the requirements of a future European space compatible RF PLL frequency synthesizer,
- Generation of synthesizer specification and design of the synthesizer based on a European manufacturing process (BiCMOS or RFSOI), fully ensuring radiation hardness and reliability requirements for space application,
- 1st wafer manufacturing run,
- Testing and design optimization,
- 2nd wafer manufacturing run,
- Space validation testing including radiation and reliability testing,
- Results assessment.

Deliverables: Breadboard, Report

Current TRL: 3  \( \text{Target TRL: } 5 \)
\( \text{Duration (months): } 30 \)

Target Application/Timeframe:
RF components for satellite communication links for all missions

Applicable THAG Roadmap:
Critical Active RF Technologies (2013) Consistent with activity H09 “High Performance PLL”
Title: SRAM based FPGA radiation test set-up

Objectives: The objective of this activity is to develop a flexible test setup for Single Event Effect (SEE) test of advanced FPGAs and SoC, compatible with all European radiation facilities, allowing the implementation of different SEE mitigation techniques and fault injection with real error signatures.

Description: FPGAs/APSoc (All Programmable System on Chip) components are highly complex and very sensitive to single Event Effect (SEE), especially the configuration memory. Different techniques can be used to mitigate SEE in configuration memory such as internal scrubbing, readback and external scrubbing or blind reconfiguration. Nevertheless, the heavy ion or proton testing of these techniques is very difficult because of specific characteristics of the different particle accelerators (accelerated flux, pulsed beam, scanned beam...). It is, therefore, very challenging to analyse and understand the test results. In addition, very often assessment of SEE sensitivity is based on results available in literature, or based on tests with a specific test setup (i.e. vendor demonstration board) where the test conditions are often unknown or not directly comparable to the intended application.

A flexible test set up will allow to mimic the SEE mitigation scheme intended in an application and synchronise the data acquisition with the irradiation. Then, an accurate assessment of the mitigation implemented is possible. This test setup will allow independent testing reproducing exactly SEE mitigation scheme intended on a given application and will be particularly useful for homogenizing radiation testing of state of the art COTS SoC, often used for Artificial Intelligence applications. The same setup will also allow performance of fault injection with realistic error signatures (as observed during irradiation tests) allowing for verification of mitigation strategies before the actual beam testing.

This activity will then encompasses the following tasks:
- Initial trade-off of possible FPGA based test setup solutions in order to optimize the flexibility and adaptability of the test setup,
- An FPGA based test setup will be designed and built to test devices like Brave FPGA, Xilinx Kintex7 FPGAs and Zynq SoC,
- Proton and heavy ion testing,
- Fault injection testing,
- Validation of the test setup through the assessment of the results of the testing tasks.

Deliverables: FPGA/SoC test set-up and user manual

Current TRL: 4  Target TRL: 5  Duration (months): 24

Target Application/Timeframe: Data processing applications. SRAM based FPGAs flying in space is increasing in payloads and in platforms.

Applicable THAG Roadmap: Relevant to the Roadmap Radiation Environments & Effects
Alternative test methods for COTS

The objectives of this activity are to gain further insight into the actual performance and reliability of commercial parts with special emphasis on automotive and to investigate the effectiveness for EEE compared to board/unit level testing and also address new highly accelerated test methods (HASS, HALT).

Industry is at very fast pace increasing the number of commercial components (COTS), mainly for cost reasons but also for performance, mass/volume etc. More and more often board or unit level testing is suggested instead of classical component level set-up. While this may be very useful the space community does not yet have access to information about the effectiveness of the new test regime, neither to any vast information on commercial components reliability when used in space application.

Thus, the aim is to investigate the effectiveness of board/unit level testing compared to traditional EEE level where a test vehicle should be extensively tested for reliability, infant mortality and radiation and the results compared to corresponding tests performed at EEE level, along with along with the preparation of recommendations for board/unit level testing and to collect large amount of test data on commercial components. For this, several tasks need to be achieved:

- Procure a number of commercial component batches from different families (may be standard and RF microcircuits and discrete, photonics and passives), preferably of automotive grade, and assess the degree of information and traceability available. An existing product is preferred and the feasibility of the test vehicle shall be presented together with supporting documentation (declared component and material lists, design description, part stress analysis as a minimum).
- Perform tests on component as well as board/unit level and compare the results, which shall cover both reliability and radiation.
- Assess the benefits of test methods previously not used for space like HASS and HALT, where comparison between the two test methodologies shall be done and the results used to propose guidelines for unit level testing as alternative to component testing for screening, lot acceptance and total dose radiation.

Deliverables: Report

Current TRL: 3  Target TRL: 5  Duration (months): 24

Target Application/Timeframe: Commercial components/COTS / TRL5 by 2023

Applicable THAG Roadmap: Relevant to the Roadmap On-Board Payload Data Processing
Title: 3D stacked hybrid visible image sensor

Objectives: The objectives of this activity are to evaluate the performance of hybrid visible image sensors that are manufactured using a novel hybridization approach based on e.g. direct bonding techniques and avoiding the use of bump bonding, shrinking the pitch and improving the robustness of the interconnects.

Description: CMOS image sensors offer new possibilities for imaging and spectral applications with fast, flexible readout and they are typically available in two formats - monolithic and hybrid. While monolithic are the most common, due to ease of manufacture, hybrid image sensor technology offers the ability to independently customize the performance of both the readout circuit (ROIC) and the detection layer, including the wavelength from UV to IR. In commercial applications, the 3D stacking technology is used for the fabrication of hybrid image sensors, bringing many advantages in cost and performance, which has never been applied in detectors for space.

Hybrid, flip-chip bump-bonded detector arrays are already used successfully in space applications but present difficulties with smaller pixels and/or larger arrays, affecting both cost and yield. The aim of the proposed activity is to evaluate alternative hybridisation technologies through the design, fabrication and characterization of a breadboard visible hybrid sensor using 3D stacking technology e.g. through-Silicon vias (TSVs), direct bonding etc., and the comparison of the achieved results with standard bump-bonding.

The added value of this innovative technology can be used by all ESA optical missions targeting the use of CMOS image sensors. The benefit will be cost reduction, yield improvement and performance improvement (e.g. easier handling of thin backside illuminated detection layers, wafer level process, smaller pixels = better resolution, increased pixel-level electronic functionalities).

Finally, in order to achieve the objectives, this activity will encompass the following tasks:

- Review of the requirements and design of the building blocks of a 3D stacked visible hybrid sensor
- Manufacturing of the sensor
- Characterization of the electro-optical performance and basic space qualification
- Suggestion for technology industrialization

Deliverables: Breadboard, Reports

Current TRL: 2  
Target TRL: 5  
Duration (months): 24


Consistent with activity B02 "Back-illuminated thinned CMOS imager – Hybrid"
Domain | Generic Technologies - CD1 - EEE / Components / Photonics / MEMS
--- | ---
Ref. Number: | GT17-306MM | Budget (k€): 1,000

Title: High performance Type-2 Super Lattice (T2SL) Infra Red detectors

Objectives: The objective of this activity is to develop a high performance Type-2 Super Lattice infrared detector array for future space and ground-based applications.

Description: Mercury Cadmium Telluride (MCT) is currently one of the leading materials used in Infra Red detector arrays due to its flexibility and the high reliability of the hybridization process. Alternatives technologies are being investigated in order to facilitate lower-resource detector operation at longer wavelengths and higher temperatures. T2SL is recognized as the most promising alternative to MCT for 2D Long Wave infrared (LWIR) and Very Long Wave infrared (VLWIR) arrays. This material structure offers great flexibility on tailoring the bandgap (cut-off wavelength) to any desired detection wavelength in the infrared wavelength region. By individually varying the thickness and composition of the alternating layers in the lattice structure, detectors covering from short wave infrared (SWIR, 0.9 - 1.7µm) to very long wavelength infrared (VLWIR, 10.5-16 µm), can be manufactured. In the context of an ESA TDE activity on the development of Low Dark Current VLWIR T2SL Infra Red detectors, proofs of low dark current and high quantum efficiency are demonstrated. This activity focus on the optimization of the photodetector material and makes use of an off-the-shelf Read-Out Integrated Circuit (ROIC).

In the proposed activity, improved performance, lower cost along with better uniformity and operability are few of the potential advantages of T2SL that are going to be investigated further. More specifically, the aim is to manufacture and characterize a medium format infrared detector array based upon a custom Read-Out Integrated Circuit (ROIC) that will be designed specifically for a high performance T2SL detection layer. The target at the end of the activity is to provide to the space community a European T2SL Infrared Detector of high TRL and competitive to the currently available non-European products, in which the following tasks are necessary in order to reach the end goal:

- Requirements review,
- Design of the ROIC and identification of the T2SL detection layer structure,
- Manufacturing of the ROIC and the T2SL layer and hybridization,
- Characterization of the detector,
- Recommendations on the industrialization roadmap.

Deliverables: Breadboard, Engineering Model, Reports

Current TRL: 4 | Target TRL: 6 | Duration (months): 24

Target Application/Timeframe: Space and ground-based application infrared detectors / TRL6 by 2022

Applicable THAG Roadmap: Optical Detectors, IR Range (2017)
Consistent with activity B07 “ROIC for VLWIR detector for multispectral application up to 13 µm validation (HOT Technology)”
Domain: Generic Technologies - CD1 - EEE / Components / Photonics / MEMS

Ref. Number: GT17-307ED  Budget (k€): 600

Title: Radiation hard VCSEL (Vertical-Cavity Surface-Emitting Laser) driver and receiver chain for high speed digital optical transceivers

Objectives: The objectives of this activity are to develop and validate an engineering model of a VCSEL (Vertical-Cavity Surface-Emitting Laser) laser driver and receiver chipset operating 28Gbps.

Description: Today optical interconnects have been baseline for next generation of telecom processors, however there is a lack of a European radiation hardened optical transceivers. The main limitation identified has been the lack of a commercial radiation hard ASIC solutions for the VCSEL drivers and receivers amplifier chain. Steps were taken towards realising a radiation hard micro-electronics solution for these high speed optical transceivers. They have been demonstrated to be functional at 25Gbps on ground conditions, but radiation tests performed have shown sensitivity to heavy ion radiation, which results in numerous single event transients.

The purpose of this activity is to develop and validate a VCSEL driver and receiver that is compatible with one of the European suppliers of VCSELs and diodes in cooperation with the final customers. This would entail the following:

- Create the specification of the VCSEL driver and receiver chain and derive the specification for the VCSEL driver and receiver ASICs,
- Design the VCSEL driver and receiver ASICs circuit and layout for the chosen manufacturing technology,
- Manufacture the VCSEL driver and receiver ASICs,
- Demonstrate electrical and radiation performance of the VCSEL driver and receiver ASICs,
- Build an optical transceiver prototype of with the VCSEL laser driver and receiver chipset operating 25Gbps,
- Validating the electrical, optical and radiation performance of the prototype.

Deliverables: Engineering Model, Report

Current TRL: 3  Target TRL: 5  Duration (months): 18

Target Application/Timeframe: Receiver chipsets suitable for multichannel 28Gbps optical transceivers / TRL5 by 2023

Title: Magnetic probe development for position and speed feedback

Objectives: The objectives of this activity are to develop and test a magnetic probe for position and speed feedback targeting at space mechanism applications.

Description: Hall sensor probes are used in space mechanisms for electric motors speed telemetry as end-stop switch sensors or used as the building blocks for medium and low resolution position sensors based on hall effect technology. In addition, Hall sensor probes are used for brushless electric motors commutation, and although current state of the art techniques can allow to control the motor without a sensor, these techniques might be complex to implement for some space applications.

Currently, there are no qualified European sources of this kind of probes. Despite this, there are some not fully qualified hall probes that are already being used in ExoMars 2020. Furthermore, probes from non-EU countries are usually procured due to the lack of components availability in Europe, thus making a European source that could target a wide variety of applications necessary.

The activity aims at developing, manufacturing and testing switch probes to achieve successful component evaluation and qualification at subsystem level. The tasks necessary to execute in order to achieve this are the following:

- Market survey and elaboration of a set of requirements, targeting at different applications (e.g. End-stop switch sensors, medium and low resolution angular position sensors, Brushless motors commutation, etc.),
- Development of at least 2 hall effect probes (sensing hall effect element plus pre-conditioning electronic) targeting at i.e. low and high sensing range,
- Manufacture 2 batches (low and high sensing range) of hall sensor probes suitable for component evaluation and qualification at subsystem level (e.g. mechanisms),
- Perform component evaluation,
- Achieve qualification of the hall probe component for a specific mechanism application (e.g. electric motor, position sensor, etc.),
- Analysis of results.

Deliverables: Qualification Model, Report

Current TRL: 4 Target TRL: 7 Duration (months): 24

Target Application/Timeframe: Space mechanism for electric motors / TRL 5 by 2023

Applicable THAG Roadmap: Consistent with activity A03 “European magnetic switch probe development”
Title: Space application of a mm-wave GaN MMIC process

Objectives: The objective of this activity is to perform the development of a packaged test vehicles for assessing process reliability for space application in order to perform ESCC space evaluation of an existing European GaN (Gallium-Nitride) MMIC (Monolithic Microwave Integrated Circuit) process covering power and low-noise applications in the mm-wave frequency range.

Description: GaN HEMTs are an enabling technology for a wide range of applications in Telecommunication, Earth observation, Navigation and Science requiring high power and/or low noise amplification. There is a strong need to extend the frequency capability of GaN technology up to mm-wave frequency range as lower frequency communication channels become congested and more bandwidth is required by emerging high-throughput applications.

Previously, European 0.5 µm discrete GaN HEMT and 0.25 µm GaN MMIC processes have been space evaluated and can cover applications up to Ku-band. However, there is a variety of applications in areas like telecommunication, Earth observation, navigation and science requiring solid state high power and/or low noise amplification at Ka-band and above which can only be realised with a GaN MMIC process with a gate length of 0.15µm or shorter. Further, this lower gate length process can provide performance improvements at lower frequencies due to higher gain and therefore, improved efficiency. Industrial GaN MMIC manufacturing processes with a gate length of 0.15 µm or shorter already exist in Europe and this space evaluation activity is crucial for making such a process available for European space customers.

The main tasks to be undertaken to achieve the objective of this activity are:

- Definition of capability domain for space evaluation and review of existing data.
- Design of evaluation test vehicles (Technology Characterization Vehicle, Dynamic Evaluation Circuit, Representative Integrated Circuit). Representative Integrated Circuit (RIC) shall be a multi-stage MMIC power amplifier operating at Ka-band or above.
- Wafer manufacturing and test vehicle packaging. Test devices shall come from two different manufacturing lots.
- Process space evaluation testing with ESCC 2269010 as baseline.
- Review of evaluation test data and preparation of dossier for process listing in EPPL (European Preferred Parts List).

Deliverables: Test vehicle, Report

Current TRL: 4  Target TRL: 6  Duration (months): 24

Target Application/Timeframe: EO navigation, science applications and telecom / TRL 6 by 2022 (for 0.1-0.15 um process).

Applicable THAG Roadmap: Consistent with activity A17 “Space evaluation of a European mm-wave GaN HEMT MMIC process”
Domain: Generic Technologies - CD1 - EEE / Components / Photonics / MEMS

Ref. Number: GT17-310ED

Budget (k€): 500

Title: Space validation of a 8 inches back-thinning manufacturing line

Objectives: The objectives of this activity are to perform a space validation on an 8-inches back-thinning line for CMOS image sensors and to assess the long-term reliability and suitability of the back-thinning processes applied to image sensors.

Description: Back-thinning of image sensors is a key-element to enhance their performance. Various processes are used today to back-thin the CMOS images sensors, some ways going through wafer size reduction first to cope with 6 inches manufacturing lines, other having developed proprietary steps not always aiming to provide the capability to use the aluminium wire bonding for instance.

The activity focuses on the technology development of the elementary brick of the back-thinning in 8 inches line and its suitability for space use. The starting point is to use an existing design for space application available as back thinned version with a 6 inches line. The series of testing shall address the space critical area, like extended thermal range, exposure to vacuum, exposure to humidity and also demonstrate that current post-processes (as developed for 6 inches) are feasible and provide similar reliability, as a minimum.

One key aspect of this process is to have it available as a service for any CMOS image sensors foundries. In that view, one part of the activity would be dedicated on defining all the details to be included in the layouts by the potential designers of the front-face CMOS image sensors. In order to achieve all this, this activity encompasses the following tasks:

- Process definition: to define the processes and show how mature they are, to proceed to an Equipment Qualification Status Review (EQSR) vs. already qualified line for space e.g. for 6” CMOS image sensors,
- Test plan definition and preparation, process preparation,
- Procurement of 8” wafers,
- Manufacturing and characterisation,
- Space environment tests,
- Conclusion and recommendations.

Deliverables: Qualification Model, Report

Current TRL: 4  
Target TRL: 7  
Duration (months): 18

Target Application/Timeframe: Generic 8 inches back-thinning technology meeting the needs for Earth observation in the future, e.g. Next MSI (multi spectral imager) generation.

Applicable THAG Roadmap: Relevant to the Roadmap Optical Detectors, Visible Range
3.1.2 CD2 - Structures, Mechanisms, Materials, Thermal

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<th>Domain</th>
<th>Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal</th>
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<tr>
<td>Ref. Number</td>
<td>GT17-311MS</td>
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<td>Budget (k€)</td>
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Title: Advanced aluminium-lithium alloys for space applications

Objectives: The objective of this activity is to evaluate the corrosion and stress corrosion performance of advanced Al-Li alloys, a new class of alloys developed for aerospace applications, so that they can be adopted by the European space community.

Description: For today's aircraft manufacturers, the emphasis is on the affordability of airframe structures, both commercial and military, and the challenge is to provide integrated materials technology solutions which can enable airframe structures with lower cost. This has been partially achieved through the development of new aerospace alloys with improved mechanical properties and the use of advanced manufacturing methods. For aluminium alloys used in current space applications (launchers and spacecraft), the situation could not be more different. The alloys of choice for the space industry is still limited to a small number of alloys (AA7075, AA2024, AA6061, AA6082) which were predominately developed in the 1930's-1950's.

A new class of aerospace alloys contain additions of Lithium (Li) which simultaneously increases the elastic modulus and decreases the density. The current 4th generation of Al-Li alloys were developed at the beginning of the 21st century and include AA2198 for fuselage sheet panels which require high strength and high damage tolerance, AA2050 plate for medium to heavy gauge parts such as lower wing skins, frames, beams, spars and ribs, and AA2196 for small sections such as Seat tracks, floor-beams, and fuselage stiffeners.

Until recently, Al-Li alloys have only been used for launch vehicles, for example, AA2195 super lightweight external tanks of the space shuttle, and AA2198 for the Space X Falcon 9 launcher. For the first time, an Al-Li alloy (AA2050) has been selected for a spacecraft application. For the Orion Crew Module, the legacy AA2219 alloy has now been replaced with AA2050 Al-Li alloy for the forward and after bulkhead and cone. Although many of the new alloys have established design allowable, there are still some issues (mainly related to corrosion and stress corrosion cracking) which are preventing the alloys for being widely adopted by the European Space Industry. There is also a lack of data relating to the solid state welding of this type of alloy.

This activity will investigate the performance in the un-welded and welded configuration consisting of:

- Identify a number of potential applications (e.g. cryogenic tanks, propellant tank, bulkhead structures) and determine what properties need to be evaluated to enable such alloys to be successfully adopted by the European space industry.
- Perform stress corrosion (SCC) testing according to ECSS-Q-ST-70-36C, and measure the threshold stress values for different alloys.
- Perform additional testing in an appropriate environment, including long term exposure testing, and in the presence of a suitable coating (Surtec650).
- Perform a test programme to measure the required properties in the welded condition (solid state)
- Manufacture and test a suitable small scale demonstrator.
**Deliverables:** Breadboard, Report

**Current TRL:** 4  
**Target TRL:** 6  
**Duration (months):** 36

**Target Application/Timeframe:** Space structures

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
**Domain** | **Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal**
---|---
**Ref. Number:** | GT17-312MS
**Budget (k€):** | 900

**Title:** Smart NDT system for complex shape polymer matrix composite space structures and assemblies

**Objectives:** The objective of this activity is to develop a fully automated and fast non-destructive technology (NDT) system for assessing manufacturing defects and damages in complex shape polymer matrix composite structures and assemblies.

**Description:** More and more polymer matrix composites are employed in primary and secondary spacecraft structural components. These components vary from simple flat-plate shapes to complex assemblies of double-curved elements. No matter the complexity of the final product, it needs to be assessed during the qualification phase to exclude any presence of defects and damages that can compromise the structural integrity of the spacecraft.

Nevertheless, NDT methods that are currently employed in qualifying space composites are slow and manually operated. The quality of the inspection strongly depends on the experience and knowledge of the operator that is performing it and interpreting the results. It may be challenging to apply these NDTs in assessing complex shape structures and assemblies as usually they require physical coupling with the component being inspected.

Advancements in the fields of camera visualization, robotics and NDT (laser ultrasonic, NDT methodologies based on full Lamb-wave field imaging, non-linear acoustics, ultrasonic) can be directed towards the development of a fully automated and fast Non-Destructive Technology (NDT) for complex shape polymer matrix composite space structures and assemblies. The advantage of such technology for the space industry mostly resides in a considerable reduction of the risks related to the human factors that have been previously mentioned. Such risk reduction will automatically trigger a reduction of costs and delays in space programs.

Additionally, if fast and automated, the number and accuracy of inspections can be increased, extended to less critical items and to phases of the space program other than the qualification phase of the development project. The NDT system to be developed within this activity will comply with the following fundamental requirements:

- The system is fully automated.
- The target structure is a double-curved CFRP/honeycomb-core sandwich structure.
- The geometry of the structure is not given as an input: the NDT system is able to measure the surface geometry of the structure to be inspected.
- The NDT system is able to detect a delamination of at least 10x10mm within the face sheets and a debond of at least 25x25mm between the face sheet and the core.
- The minimum inspection speed is 5m^2/h, including data processing.
- Contactless technologies are preferred over contact technologies.
- Solutions optimized in terms of mass and volume are preferred.

**Deliverables:** Prototype, Report

**Current TRL:** 3 | **Target TRL:** 5 | **Duration (months):** 30
<table>
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<th>Target Application/Timeframe:</th>
<th>MAIT of any spacecraft (satellite structure, launcher structure, MGSE) containing composite parts.</th>
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<td>Consistent with activity E09 “Smart NDT system for complex shape polymer matrix composite space structures and assemblies”</td>
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</table>
Domain: Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal

Ref. Number: GT17-313MT

Budget (k€): 800

Title: Development of a very high efficiency and compact heat exchanger for Reverse Turbo Brayton

Objectives: The objective of this activity is to develop, build and test an engineering model of a High efficiency recuperator that can suit the needs of medium class Reverse Turbo Brayton coolers, where the design shall be scalable to be used for higher power needs like Reduced Boil-off or In-Situ Resource Utilization reverse turbo-Brayton coolers.

Description: Previous activities (ESA's TDE "Development of a 40-80K Vibration Free Cooler" and "Zero Boil Off Propulsion System Feasibility Demonstrator") demonstrate the potential break-through that Space Reverse Turbo-Brayton coolers could mean for Space Cryogenics. In addition, some key sub-elements of this type of coolers (centrifugal compressors and expanders) are under development in ESA activities while the recuperator is until now still procured outside Europe. Thus, the purpose of this activity will be to develop a European High Efficiency Recuperator (counter-flow heat exchanger) with the following key requirements:

- Medium Class: eff>99%, Neon@1.25 mg/s, P between 1 bar and 1.8 bar
- Large Class: eff>99%, Neon@20g/s, P between 1 bar and 1.5 bar

Where the medium class type of application shall also be complimented by a scalability study for high power type of applications. It should be added that this technology enables efficient European Reverse Turbo Brayton coolers. This type of cooler could potentially be the next Space Cryogenic revolution, as it permits to perform efficient vibration free remote cooling on the whole temperature range (from 4K to 150K) for medium power (e.g. Earth Observation) to High Power (e.g. for ISRU RBO) applications.

In a first phase, a comprehensive state of the art of high efficiency recuperator designs for space borne and earth borne applications (e.g. parallel plates, microtubes, sandwich structures) shall be performed. A review of the potential advanced manufacturing technics (e.g. composite material additive manufacturing) shall also be done. This will be followed by the proposing of multiple designs that can answer the need described above. The detail design phase shall close the trade-offs thanks to analysis and breadboarding in key performance area (e.g. thermodynamics). Ideally, one scalable design for the 2 types of applications is preferred. Finally, an Engineering Model of the recuperator shall be manufactured with PA/QA standards suitable for this kind of development. This unit shall undergo a full comprehensive characterization and test program so as to demonstrate the full performance at a level of TRL 6.

Deliverables: Engineering Model, Reports

Current TRL: 3  
Target Application/Timeframe: Earth observation, in applications where Reverse Turbo Brayton coolers are suitable (for example Copernicus new generation).

Target TRL: 6  
Duration (months): 36  
Applicable THAG Roadmap: Consistent with activity D02 “Development of a very high efficiency and compact heat exchanger for Reverse Turbo Brayton”
### Domain

**Domain**

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<th>Domain</th>
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| Ref. Number: | GT17-314MS | Budget (k€): | 600 |

| Title: | Enhancement of brushless motors technology for space applications |

| Objectives: | The objective of this activity is to enhance brushless motors technology for space application with improved sensing and commanding strategies. |

| Description: | European space industry competitiveness in cost and performances needs to be fostered with the development of off-the-shelf space rated products as building blocks for mechanisms. In this context, this activity is intended to cover the lack of European brushless motors readily available for space applications, where specific attention shall be put into the closed loop commutation strategy and into the commanding strategy, which currently remain the limiting factors of brushless selection for common applications. Open loop drive and self-piloting solutions shall also be addressed. |

Stepper motors usage in terrestrial application is becoming more and more seldom, whilst in space brushless motors are still discarded due to the demanding electronics and high reliability position sensors they require. Enabling self-standing solutions of motors, featuring an integrated closed loop capability, could definitively foster their usage in a wider number of applications with significant improvement compared to stepper motors (lower micro-vibration, more “agile” controllability, close-loop control, etc.). |

In the frame of this activity it is proposed to develop an EQM integrated brushless motor. Specific attention shall be put into the closed loop commutation strategy and into the commanding strategy, which currently remain the limiting factors of brushless selection for common applications. Open loop drive and self-piloting solutions shall also be addressed. The activity tasks shall include:

- Identification of already existing brushless motor designs suitable for being adapted for space applications
- Review of their design through a preliminary and a critical design phase, including definition of sensing and commanding strategies optimized with respect to the motor design,
- Validation for space usage of materials and sub-components embedded in the motor, including evaluation of high speed sensors typically used for commutation in closed loop
- Manufacturing of EQM motor and its assembly including EGSE and MGSE,
- Testing of the hardware with an extensive campaign to demonstrate robustness of the design towards space environment. Various commanding strategies shall be validated and traded off for different operating duty cycles.
- Establishment of a development plan to cover for the specialisation of the needed drive electronic, suitable for an in situ implementation of the most promising commanding approach.

| Deliverables: | Engineering/Qualification Model |

| Current TRL: | 3 | Target TRL: | 7 | Duration (months): | 24 |
Target
Application/ Timeframe: Brushless motors for space applications

Electrical Motors and Rotary Actuators (2015)

Applicable THAG Roadmap: Consistent with activity A09 “Development of an integrated self-piloting brushless DC motor solution with enhanced electronic”
Domain | Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal
---|---
Ref. Number: | GT17-315MS | Budget (k€): | 300
Title: | Pointing mechanism for electric thruster propulsion for nanosats
Objectives: | The objectives of this activity encompass the development and testing of a miniaturised pointing mechanism for electric thruster propulsion suitable for utilisation on nanosat platforms in order to enable thrust vector control for deep space missions, inter-planetary exploration or rendezvous with a Near Earth Objects.
Description: | In order to enable deep space missions, inter-planetary exploration or rendezvous with a Near Earth Objects using the nanosatellites, electric propulsion thrusters need to be employed. Due to the limited resources of this platforms in terms of power, mass and volume, thrust vector control needs to be implemented to enable efficient use of all on-board resources, including the propellant. A miniaturized 2-axis pointing mechanism provides the required thrust vector control in all operational modes.

The pointing mechanism enables 2-axis pointing lateral to the flight direction and is operable in all the environmental and operational conditions, including launch loads, without additional launch locks or power consumption in hold mode. The main challenge of the development is to find a concept able to provide a suitable pointing range, integrate thruster feed lines, provide mechanical and electrical interfaces to both the structure and the thrusters, and the miniaturization of all components in terms of mass, dimensions and power consumption.

In order to achieve this goal, the activity will encompasses the following tasks:
- Requirements definition
- Design trade-offs
- Optimization of the selected design in terms of mass, volume and power consumption
- Mechanical and electrical system design for 12U CubeSat configuration-Manufacturing and assembling of an EM
- Functional tests at unit level, life tests, and environmental tests (mechanical/thermal)

Deliverables: | Engineering/Qualification Model, Reports
Current TRL: | 3 | Target TRL: | 6 | Duration (months): | 18
Target Application/Timeframe: | Small missions, first application can be the M-ARGO mission, but the concept must be compatible with future nanosats application or be easily adopted if need be.
Applicable THAG Roadmap: | Not relevant to any Harmonisation topic
## Domain

**Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal**

### Ref. Number: GT17-316MS

| Budget (k€): | 500 |

### Title: Low shock release actuators

### Objectives:
The objectives of this activity are to develop, manufacture, integration and test of an extremely low shock release actuators (including preload monitoring).

### Description:
Historically Hold Down and Release Mechanisms were equipped with pyrotechnics device, before moving to Low Shock Release Actuators also called Non Explosive Actuator. The reason of this evolution was linked to the demand to reduce exported shock for all missions: less shock reduce the risk of damaging sensitive electronic or optical elements. Low Shock Release Actuators are now flying for more than a decade and today the needs in exported shock of Hold Down and Release Mechanisms are becoming more and more severe, both to simplify overall satellite accommodation and also increase satellite performances.

The use of few HDRM with high load capacity versus the use of many HDRM devices with lower load capacity is often an advantage since it improves the overall reliability of the whole system (less parts), and improves the structural behaviour (e.g. easier alignment, realisation of isostatic mounting). In addition, the increase of the size of stowed structures (heavy payloads held during launch), leads also to increase significantly the need of tightening tension capabilities of Low Shock Release Actuators (typically from 15 kN to 35 kN, or 100 kN) which comes in contradiction with the exported shock reduction goal.

In addition to that, the check of correct preload application as well as preload loss over time is a key need, in particular with on ground storage duration. As there are no “integrated monitoring” of the preload evolution, a standard best practices is to realize a regular maintenance per un-preload and re-preload sequence (typically every 6 months). Increasing the on ground storage duration can lead to high satellite constraints.

To sum up, the space community is facing the following main concerns with release actuator including an increase of tightening tension capabilities combined with exported shock reduction need as well as long duration storage and maintenance. Thus, the proposed activities aims to find a solution to the concerns described above by developing an add-on that will provide an extremely low shock release of the HDRM, and a standardised preload monitoring subsystem that could also be used on existing HDRA. If considered relevant these functions could also be combined or integrated in the release actuator.

This activity encompasses the following tasks:

- Survey of the available separation actuator technologies already developed in Europe for 35kN to 100kN loads application, particular attention shall be placed to the emitted shock.
- Design review of proposed solution and associated breadboarding when judged necessary.
- Extensive test campaign on an Engineering Model (EM), involving worst-case mission scenarios (environments, external load ranges, Hot and Cold temperatures, Life Cycle, disassembly and inspection etc...). To obtain a sufficient confidence on the reliability performance, several EM test items shall be built and tested to produce a statistically meaningful assessment.
**Deliverables:** Engineering Model, Report

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**Target Application/Timeframe:** All missions with appendages, needing low shock release of medium to high load HDRM.

**Domain:** Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal

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<th>Ref. Number:</th>
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<th>Budget (k€): 450</th>
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**Title:** Noise free long life potentiometer

**Objectives:** The objectives of this activity are to develop and test a potentiometer with improved contact technology to increase life and increase reliability reducing or eliminating the noise in the output signal seen in current potentiometers.

**Description:** Potentiometers are sensors that consist on a sliding contact (wiper) sliding along a resistive element (track) providing position feedback, which make them sensitive to the quality of the tribological contact between the wiper and the track. Therefore, their performance can change with time and operation under vacuum environment, making potentiometers subject to wear, contamination and having frequently issues with noise in the output signal and a limited life.

However, due to their simplicity and low cost this type of sensors are extensively used in many different applications targeting medium and low accuracy. Until there is a reliable contactless alternative technology capable to compete in price with potentiometers, and until that alternative is well established in the space market, there will be still very high interest from potentiometer users to improve the current technology, reducing the noise and enhancing the life capability.

This activity will then aim at designing, manufacturing and testing an EQM model of a potentiometer with improved contact technology, having as main core tasks the following:

- Elaboration of a set of requirements
- Trade-off elaboration of potentiometer contact technology looking at all the aspects of the sliding interfaces (e.g. materials, preload, lubrication, shape of wiper, surface roughness of tracks, etc.) and looking into other contact technologies used in industrial applications.
- Preliminary concept design based on trade-off result
- Breadboard manufacturing, testing and analysis of results.
- Consolidate design based on breadboard results
- Manufacture 2 EQM sensor assemblies
- Test EQMs at relevant environment at sensor assembly level
- Inspections and analysis of results

**Deliverables:** Breadboard, Engineering/Qualification Model, Report

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<th>Current TRL: 3</th>
<th>Target TRL: 6</th>
<th>Duration (months): 24</th>
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**Target Application/Timeframe:** Generic technology for all type of missions / TRL 6 by 2023

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
"Green" surface treatments for adhesive bonding of glasses/ceramics on metal surfaces

Objectives: The objective of this activity is to develop a REACH-compatible, environmentally friendly surface treatment process to enhance the performance and endurance of space-qualified adhesive bonding technology.

Description: The surface treatment of the adherends is one of the most important factors in assuring high initial strength and extended durability of adhesive joints. It is important for structural bonding to create a high surface free energy and introduce specific functional groups, in order to maximise the intimate molecular contact between adhesive or primer and the adherend, during the curing process. Processes, such as laser ablation and silane treatments, impart all the fundamental physicochemical properties required for initial adhesion strength and durability, including wettability, mechanical stability, micro- and nano-texturing.

The first part of the activity is a state of the art study in promising surface treatment technology for glasses, ceramics and metals as well as the market research of other, well-established adhesive applications within the automotive, railway and aircraft industries. The second part of the activity is to evaluate the adhesive systems as a whole (substrate/pre-treatment/adhesive/pre-treatment/substrate), particularly when bonding to glass, taking into account the coefficient of thermal expansion mismatch and the development of residual strains, the environmental effects on the adhesive system as well as the optical transparency of the glass. Ceramics have also been notoriously difficult to bond to, due to the surface graphitic layer which at first must be removed via a laser or plasma cleaning technique, followed by the application of a coupling agent for surface functionalisation.

The next part of the activity is to compare surface treatment techniques that are purported to be environmentally friendly, like chemical-based treatments (priming) and physical-based treatments (e.g. plasma treatment techniques, tuned laser-based treatments) which would be suitable for various substrates. Metal treatments such as etching, pickling and passivation are essential to enhance bonding performance of commonly used adhesive systems but due to many REACH restrictions, some of the products covering this technology area will soon disappear from the European market. To rely on the restricted and temporarily REACH-exempt materials is not a sustainable approach for future space projects. Therefore, to reduce the risk of obsolescence, this activity will also focus on "green" technologies, which are promising to be without any REACH restrictions in the future.

Life cycle assessment should be taken into account to assess the impact of specific techniques on the environment. Newly developed, commercially available surface treatment methodologies might be of interest, with the potential for further modifications to meet space application requirements. One of the key parameters for selection of the most prospective technologies will be the long term sustainability of the technology, availability in Europe and durability of treated surfaces in space environments. A well-established methodology for standard adhesive joint testing and for surface treatment durability testing are one of the prerequisites for this activity.
**Deliverables:**  Breadboard, Engineering Model, Report

| Current TRL: 2 | Target TRL: 6 | Duration (months): 24 |

**Target Application/Timeframe:**  Green technology for all type of missions, falling under “EcoDesign” umbrella of Clean Space initiative.

**Applicable THAG Roadmap:**  Not relevant to any Harmonisation topic
Domain | Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal
---|---
Ref. Number: | GT17-319MS
Budget (k€): | 600

Title:  
Adhesive connections to ceramic structures

Objectives:  
The objectives of this activity are to define design guidelines and manufacturing processes that ensure a reliable joint for a wide range of thermo-mechanical loads, while still preserving the strength of the ceramics/glass, while also identifying design and AIT guidelines that reduce the engineering and integration effort.

Description:  
Ceramic structures are typically affected by strength limitations at joints, e.g. when adhesive bonds are used. In fact, surface preparation often consists in increasing the roughness of ceramics for better adhesion, but this is in contrast with the target to avoid micro cracks that might decrease the ceramic (or glass) strength.

However, optical elements are commonly bonded to highly stable optical benches. Also, a considerable effort is usually spent during the integration of secondary or tertiary elements (e.g., MLI stand-offs, small brackets for harness support, purging lines or grounding rails) onto ceramic structures. In fact, the integration method, as well as the design of both the ceramic elements and the element to be connected, shall avoid the risk of local failures like chip-outs in case of large operational or non-operational temperature ranges.

In order to achieve the objectives, the activity will have as main tasks to be executed the following:

- Review the state of the art bonding materials and processes for ceramics, glass/ceramic and glass bonded connections. This shall include both, bonding with Silicon and Epoxy based adhesives for optical applications, and bindings for non-structural applications (heaters, thermocouples and tie bases) for hot, cryogenics and room temperature applications.
- Identify the limitations of the available methods in terms of performance, cost and integration methods.
- Propose innovate interface designs and bonding material and process aiming at reducing stress and stress at the interfaces and improving the integration process.
- Design and manufacture a set of representative breadboards to validate the proposed designs
- Test the BB in relevant environment including mechanical and thermal tests.
- Develop and issue a first guidelines handbook on bonded connections.

Deliverables: Breadboard, Report

Current TRL: 4  
Target TRL: 6  
Duration (months): 24

Target Application/Timeframe: Ceramic structures. All missions using optical payloads or optical instruments.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Domain | Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal
--- | ---
Ref. Number: | GT17-320MS | Budget (k€): | 800

**Title:** Improvement of NDI-methods for ceramic structures

**Objectives:** The objective of this activity is to identify and qualify an NDI technique able to detect cracks or defects that would lead to a failure below the proof test limit, which will allow reducing proof testing campaign on flight hardware which often leads to significant risk and cost during mission development.

**Description:** In the frame of the GSTP activity on Ceramic Sizing and Verification Method Improvements, X-ray tomography has been identified as a promising technique to detect volumetric flaws in ceramic components. These have been experimentally shown to drive the strength of the material.

The current state of art techniques, although limited in resolution, can replace or complement proof testing requirements on flight hardware.

The purpose of this activity is to qualify an inspection method, X-ray or other identified alternative that is able to verify the absence of critical defects in ceramic items, resulting either from incorrect manufacturing or over testing. The target is to demonstrate a sufficient detection threshold to allow replacing fully or partially the expensive and time-consuming proof testing required today. The identified inspection methods shall be compatible not only with applications at parts level, but also with later integration stages.

The activity will perform the following tasks:
- Review the results achieved in the frame of the GSTP on Ceramic Design and Verification methods improvement.
- Identify the most promising NDI method to fully or partially replace proof testing of large ceramic structures.
- Design and manufacture a set of samples with artificial embedded defects
- Qualify the NDI method to allow detecting the necessary defects according.

**Deliverables:** Breadboard, Engineering Model, Report

**Current TRL:** 4 | **Target TRL:** 6 | **Duration (months):** 24

**Target Application/Timeframe:** Ceramic structures

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic.
## Domain

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<th>GT17-321MS</th>
<th>Budget (k€):</th>
<th>500</th>
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### Title:
CFRP sandwich inserts design, test and verification methods

### Objectives:
The objectives of this activity are to derive updated design and analysis methods for CFRP skin sandwich inserts to reduce the test effort, while exploring automation methods for insert design and integration and captured improvements in state of the art EMC grounding performance.

### Description:
Insert design and verification guidelines as defined in ECSS-E-HB-32-22A still recommend to perform dedicated testing of each type of inserts when CFRP skins are considered. These conclusions are based on several studies performed in 1981 and 2003.

In the last decade, significant improvement in design and analysis methods for CFRP components and subassemblies have taken place. If these are sufficiently validated by test, it is possible to develop robust insert design and analysis methods without the need of exhaustive testing.

The objective of this activity is to review the state of the art in high fidelity analysis techniques, together with a review of the available experimental data, to propose an updated methodology based on analysis and supported by elementary test.

This updated methodology needs to be demonstrated with a set of representative breadboards. The activity shall address automated insert placement techniques in addition to those already described in ECSS-E-HB-32-22A.

The following tasks will be performed in the frame of the activity:
- Review of available representative breadboard tests
- Review the analysis techniques, analytical and numerical, to determine the strength of CFRP skin sandwich
- Identification of the test matrix to derive the elementary properties to retrieve the inserts strength capabilities.
- Design and manufacturing of representative breadboards of CFRP inserts
- Generation of updated guidelines for the design and dimensioning of CFRP skin sandwich inserts without the need of extensive BB qualification campaigns. This shall include automated insert placement techniques.

### Deliverables:
Representative Breadboard, Report

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<tr>
<th>Current TRL:</th>
<th>4</th>
<th>Target TRL:</th>
<th>6</th>
<th>Duration (months):</th>
<th>24</th>
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### Target Application/Timeframe:
All missions.

### Applicable THAG Roadmap:
Not relevant to any Harmonisation topic
**Domain**

| Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal |

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**Ref. Number:** GT17-322MS  
**Budget (k€):** 1,200

**Title:** New generation ceramic optical bench

**Objectives:** The objectives of this activity are to improve the design features of high stability ceramic optical benches and improve the stiffness to mass ratio.

**Description:** Current state of the art ceramic, glass-ceramics and ceramic matrix composites allow for a very high stiffness to mass ratio, as well as a very high strength and fracture toughness. However, the improvement of the design and verification methodologies and of the material processes is not always translating into lower mass structures. This is caused by the design and manufacturing constraints of each material (e.g. wall thickness, mechanical joints, local mechanical features, etc.). While some of these improvements can be made in the frame of development programmes, often they are not compatible with budgetary and schedule constraints, particularly at the early design phases.

In particular, CMC have been used in high temperature applications for several decades. On the other side, their usage in highly stable applications has only been recently investigated and showed that it is possible to develop an ultrastable C/C-SiC sandwich panel which contains exclusively carbon and SiC eliminating the use of outgassing elements and providing low thermo elastic distortions in all directions. In fact, while the weight of the structure is higher than equivalent CFRP sandwich, they are significantly lighter than equivalent monolithic SiC components. In addition, if used in combination with affordable low performance phenolic resins prepregs, the development of simple structures can allow significant cost reductions for extreme temperature applications.

Therefore, in order to improve the current performance of stable ceramic structures, it is necessary to perform a dedicated activity that will focus in investigating each of the local design features and will combine them to produce a lighter version of an existing ceramic optical bench design. In order to achieve this, the activity will include the following steps:

- Review of existing design features and manufacturing constrains for ceramic and CMC structures
- Improvement of local design features and development, manufacturing and testing of local breadboards.
- Based on the design of an optical bench meeting the specification of a flight application
- Detail design, manufacture and assemble the breadboard
- Perform mechanical, thermal vacuum and thermoelastic tests at room and cryogenic temperatures.

**Deliverables:** Qualification Model, Report

**Current TRL:** 4  
**Target TRL:** 7  
**Duration (months):** 36

**Target Application/Timeframe:** Earth ojoaquobservation and Science missions which require thermoelastically stable platforms.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Domain | Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal
---|---
Ref. Number: | GT17-323MT | Budget (k€): | 500
Title: | Towards a thermal digital twin
Objectives: | The objective of this activity is to develop technology and methods to enable the digital representation of spacecraft from the thermal perspective in order to better support the design, development, testing and operation of the spacecraft thermal control system.
Description: | The term Digital Twin is a hot topic in the simulation industry. Examples of digital twins in other comparable domains are for health monitoring of vehicles or gas turbines. The proposed activity aims to apply the ideas of digital twins, with a specific focus on spacecraft thermal control systems (TCS). A set of possible use cases is provided below with expected benefits:

- **Testing**: A real time digital representation of the article under test. Benefit: support monitoring and understanding of thermal test execution - data display, safety of test article, and near real time thermal model correlation. Improving the capture of the as-tested configuration.
- **Operations**: A real time thermal mathematical model of an operating S/C fed by telemetry and used for planning or what if studies. Benefit: allows informed decisions to be made by operators or optimisation of (for example) science operations.
- **Health Monitoring**: A health monitoring system for the TCS, possibly as part of a wider S/C level twin. Benefit: Early detection or prediction of anomalies, for example on constellations where human monitoring of telemetry is limited.
- **Data Fusion**: A repository of all the models and data pertinent to the TCS over the full lifecycle of the S/C. Benefit: more efficient access to data ensuring traceability.

Thus, in order to enable the digital twins it is necessary to develop a number of technologies; for example, the following topics may need to be addressed in the activity:

- Data modelling activities to make a formal link between S/C parameters (e.g. telemetry) and thermal engineering quantities (dissipations, current environment heat fluxes, etc.).
- Optimised thermal and radiative solvers for faster than real time simulations, enabling the operations use case above.
- Co-simulation with other disciplines (e.g. power) or an overall S/C simulator
- Use of “big data” to exploit large thermal data sets coming from analysis, test and operations.
- Modern 3D visualisation and linked data techniques, for example to overlay data from the digital twin onto S/C geometry (e.g. augmented reality).

It is important to note that these technologies need to be available to users at the time of generation of the data or models. An approach that relies on assembling a digital twin after the fact is unlikely to gain acceptance, the necessary links to the digital twin need to be embedded in the industrial processes.
Finally, the main tasks to be executed in this activity include:

- State of the art, requirements capture and selection of industrial validation cases
- Architectural design and identification of needed building blocks
- Developments
- Demonstration of developments on industrial validation cases

**Deliverables:** Report, Software

**Current TRL:** 3  
**Target TRL:** 5  
**Duration (months):** 18

**Target Application/Timeframe:** All missions. Enable the digital representation of spacecraft from the thermal perspective

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Title: Flexible joint for axial grooved heat pipe

Objectives: The objectives of this activity are to develop, build and test an Axial Grooved Heat Pipe (AGHP) that includes a flexible part to provide mechanical decoupling or flexibility without degrading thermal performances.

Description: AGHP are massively used as heat transport devices because of their low manufacturing cost (high production and mature manufacturing technique) and their high thermal performances. Even if this type of heat pipe can be bended in several directions, the accommodation flexibility is limited and the mechanical decoupling is null.

When accommodation / integration flexibility and high thermal performances are required, Loop Heat Pipes (LHP) can used but at higher cost, complexity (active control is needed for start-up and shut-down) and mass penalties. Flexible HP are a very promising generic technology for many applications providing a good compromise between AGHP and LHP to introduce flexibility in a low cost device. This kind of hardware has multiple applications and offers many advantages:

- Integration: use flexible part to move device in complex and low access cavity or enable movement during AIT once connected
- Accommodation: use flexible part to route HP in complex environment
- Deployable radiators: represents alternative to LHP to connect platform and radiators while enabling deployment (on ground and in flight)
- Linking heat pipe: use flexible AGHP as “friendly” linking HP
- Mechanical decoupling: ensure heat transport between 2 (or more) structure panels with different mechanical environments

The challenging aspect of such a development is to define a suitable material for the flexible part and connect it to condenser and evaporator parts. Physical properties shall be ensured such as flexibility, material compatibility with working fluid and with condenser and evaporator parts, robustness to multiple bending (no capillary function degradation) and capillary continuity to maintain thermal performances, whatever final position of the flexible link and exercised bonding’s (type and number). To address such aspects, the following tasks are expected to be performed:

- Review of requirements
- Concept Definition
- Trade-off studies with test coupons as required
- Design and analysis of the flexible AGHP
- Flexible AGHP manufacturing
- Thermal Performance Characterization Test
- Mechanical tests

Deliverables: Breadboard, Engineering Model, Report

Current TRL: 3  Target TRL: 5  Duration (months): 24
Target Application/
Timeframe: In the medium term, this technology can be used to increase flexibility of existing
low cost device, reduce costs, hence providing additional hardware solution to
answer future subsystem or system thermal design need.

Applicable THAG Roadmap:
Two-Phase Heat Transportation Equipment (2017)
Consistent with activity A04 “Flexible Joint for Axial Grooved Heat Pipe”
Domain: Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal

Ref. Number: GT17-325MT

Budget (k€): 750

Title: Development of generic MLI flap for spacecraft interface ring

Objectives: The objective of this activity is to develop a generic mechanism for MLI flaps to insulate spacecraft launch vehicle adapter ring once the satellite is separated from the launcher.

Description: This activity aims at developing a generic solution, adaptable to the various (but limited in number) types of interface rings, to insulate the exposed surface once the spacecraft has been separated from the launcher. It could consist in a series of MLI flaps with a passive mechanism keeping it away from the Launch Vehicle Adapter in "open position". The flap is automatically deployed in "closed position" to protect the interface ring from the external environment (cold Space, Sun flux, planet flux). Such a concept has already been used and flight proven on ATV. The activity may reuse such heritage and generalize it the different existing types of launch interface.

Spacecraft launch vehicle interface ring are often an unprotected part of the spacecraft, which cannot be insulated with MLI because of the interface with the Launch Vehicle Adapter (LVA). Due to the interface with the launcher, the possible solutions for coating are limited and constrained by several requirements (mechanical, electrical...). In addition, MLI insulation cannot interfere with the flight clamband attachment. Depending on the attitude of the spacecraft, the interface ring, once separated from the launcher vehicle becomes exposed to external environment, which may induce consequent heat leaks when in the shadow or heat input when it is Sun illuminated. Because of its strong mechanical and thermal coupling with the main structure of the spacecraft, the interface ring is a critical element for thermal control sizing, knowing that it has often a limited qualification temperature range (typically, -40degC, +70degC). This induces heavy constraints such as restriction of authorized attitude (e.g. no long sun illumination), heating power to compensate the radiated flux from its exposed surface, implementation of sunshield...etc.

List of foreseen tasks:
- User need and requirements (identification of need, Spacecraft Interface Requirements, MLI flap preliminary specification)
- Preliminary Design Phase (trade off, selection of technologies, materials, preliminary design)
- Detailed Design Phase (Detailed design, Test plan, design of test bench, possible demonstration mock-up, Model)
- Manufacturing and Assembly of STM
- Tests (deployment, thermal and mechanical tests)

Deliverables: Engineering Model, Report

Current TRL: 3
Target TRL: 6
Duration (months): 24

Target Application/Timeframe: All missions. The interface ring is part of a spacecraft/satellite.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
3.1.3 CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C

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<th>Domain</th>
<th>Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&amp;C</th>
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Ref. Number: GT17-326SA  
Budget (k€): 750

Title: Active optics control in the presence of mid to high frequency perturbations

Objectives: The objective of the activity is to design and test on breadboard a control system to mitigate the impact of microvibration on Active Optics image quality.

Description: Active Optics is used on-ground, and technology transfer for space applications has been analysed in the frame of different activities, in particular ESA TDE activity "Active Correction Chain for monolithic mirror". This activity studied the low frequency perturbation impact and mitigation but did not study the impact of medium to high frequency perturbations (from 1 Hz) on image quality performance for Active Optics system. The proposed activity shall address this point, by identifying an architecture to control the mid/high frequency perturbation impact on an Active Optics based system, and to assess its performance with breadboard tests.

The proposed activity consists in the following tasks:

- Characterisation of the degradation of image quality in the presence of different kind of mid/high level frequency perturbation sources (e.g. reaction wheels)
- Architecture trade-off for mid/high frequency perturbation control; trade-offs on actuators (e.g. deformable mirror vs independent tip-tilt mirror), on sensors (e.g. camera with image processing vs wave front error sensor), on control algorithms (e.g. ability to implement a high bandwidth controller to control deformable mirror using high frequency wave front sensor) and on the impact of control system on image quality performance to be performed.
- Architecture selection and specification of the constitutive parts of the control system to be implemented on the breadboard.
- Develop a test bench, preferably starting from an existing one developed in the frame of Active Optics activities, by adding elements of the selected control system architecture (sensor, control software and actuation) and prototyping of the mid/high frequency perturbations to be controlled (such as "vibrating" mirror and camera).
- Assess the performance of the control systems mitigating the mid/high frequency perturbations on the breadboard, considering several sources of perturbations representative of flight conditions.
- Conclusion and development plan for Active Optics control systems (actuators, sensors and control algorithms).

Deliverables: Breadboard, Prototype

Current TRL: 4  
Target TRL: 5  
Duration (months): 24

Target Application/Timeframe: Missions that required high quality and very high image resolution like Earth Observation, Science, Space weather.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Domain: Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C

Ref. Number: GT17-327ED

Title: Strategies for reliable on-board reconfiguration of FPGAs

Objectives: The objective of the activity is to identify FPGA re-configuration methods under space environment conditions (radiation, temperature), assess their strengths and weaknesses, reconfiguration times and behaviour.

Description: New FPGA devices suitable for on-board use offer the possibility of being many times reconfigurable, in particular flash or SRAM: Microsemi RTG4; Xilinx KU60; NanoXplore BRAVE FPGA, are selected for their high performance data processing capabilities. This allows to change its functionality, to save resources by dynamically reprogramming and running different applications or introduce algorithmic improvements after the instruments are flying.

FPGA on-board reconfiguration involves uploading a new bitstream and programming it onto the FPGA, following strategies that differ depending on the FPGA technology. Although guidelines and tools are provided by the vendors, the challenges of re-configuring on-board, in radiation environment with extreme temperatures is not always addressed. SEE and TID can affect the reconfiguration and might lead to unsuccessful configuration or even total destruction of the FPGA or other components on the same board.

The following main tasks are proposed for each of the target technologies (flash RTG4; SRAM Xilinx and NanoXplore):

- Identification of reconfiguration methods for the target technologies, and their characterization in terms of reconfiguration times, feasibility of partial reconfiguration, available protocols.
- Assessment of the probability of SEE (destructive and non-destructive) during re-configuration in radiation environment as well as aging effects due to TID; taking into account information provided by vendors and conducting independent radiation and temperature tests.
- Propose a strategy for safe FPGA onboard reconfiguration, addressing system level aspects of total or partial FPGA reconfiguration (considering also systems with one or multiple FPGAs or using FPGAs as co-processor accelerators), including:
  - time and bandwidth required to upload a full or partial bitstream, and compression schemes for missions with low upload data rates;
  - safe storage of bitstream in memory, including an analysis of optimal location and required mechanism to read or write it;
  - prevention and detection of corruption in the programmed file (built in self tests);
  - fault isolation schemes at unit level that prevent possible damages caused by a faulty bitstream being configured;
  - operational aspects related to the FPGA being unavailable during reconfiguration.
- The design of a boot loader that implements TM/TC functionality to execute the necessary steps from the upload of the bitstream to becoming operational with a new configuration, as detailed above. Investigation of the optimal computing platform within the spacecraft which should execute such boot loader.
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<th><strong>Deliverables:</strong></th>
<th>Breadboard, Prototype, Report</th>
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<td><strong>Current TRL:</strong></td>
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**Target Application/Timeframe:**
Future missions requiring high performance data processing on FPGA. Enabling in-flight reconfiguration of FPGAs for different applications. Missions leveraging COTS.

**Applicable THAG Roadmap:**
Not relevant to any Harmonisation topic
Dependable avionic system based on BRAVE ULTRA SoC

The aim of this activity is to develop a DAHLIA based Dependable Avionics System (DDAS) and to expedite its adoption on ESA mainstream mission without sacrificing the dependable operations.

The BRAVE Ultra is a very high performing SoC based on 4 ARM Cortex-R52 cores and an SRAM based FPGA. It will soon become available as a space-qualified device. Its performances, expected to be 20 to 40 times the performance of the GR740. DAHLIA is an instance of the BRAVE Ultra device. While enabling key applications to be executed by the same device, leading to significant mass and cost reduction, DAHLIA usage to develop a flawless Avionics System (AS) is more difficult and complex w.r.t to mono-core AS development if DAHLIA AS is not addressed properly from specification to verification & validation. Aiming the risk reduction associated to a new development inside a mission program, a generic reference design, at HW and at SW level, of a flight quality AS Demonstrator (DAS) shall be produced. The DAS shall be based on the BRAVE Ultra. The DAS shall inherit the SAVOIR and the ESA OIRD (Operational Interface Requirement Document) specifications to ensure a holistic AS functions coverage including the operations.

Moreover, the DAS shall consider dependable features (e.g. resilience to sporadic communication channels issues, resilience to receiving incorrect data from memories due to soft errors, resilience to the EFPGA soft-errors due to harsh environment, switching between main and redundant busses, units). The overall DAS specification, including the BRAVE configuration, shall complement the parent specifications. Selection of devices such as memories and companion ICs, Interfaces, FPGA, DAS board form factor, DAS backplane/box implementing the DAS shall be analysed and/or specified, as part of this activity, to develop the DAS. The DAS specification is the input to the DAS design, manufacturing and tests. The DAS SW is composed of two parts:

- Board SW Package (compliant to SAVOIR) includes the multi-core boot software, the eFPGA bootloader and the SW drivers.
- CSW (Central SW), based on a TSP (Time and Space Partitioning) solution, ensures the expected OIRD operations.

The SW shall follow a product assurance process. The documentation shall report on the real-time impact of the use of a multi-core computing HW & SW features.

The activity shall contain the following tasks:

- Analysis and DAS Specification
- DAS Design & manufacturing
- DAS testing
- DAS SW development & verification
- Product assurance.

The DAS design, namely schematics, board design, bill of materials (components), test reports and the "basic software package" shall be clearly documented and freely available as open source (excluding the TSP Kernel) to all users in ESA member states.
Deliverables: Breadboard, Report, Software

Current TRL: 4  Target TRL: 5  Duration (months): 24

Target Application/Timeframe: This development is considered generic to Earth Observation (Copernicus 4.0), Science missions.

Applicable THAG Roadmap: Data Systems and On Board Computers (2016) Consistent with activity A14 “Multicore ARM Based computer”
Domain | Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C
---|---
Ref. Number: | GT17-329ES
Title: | Low cost GNSS spaceborne receiver for guaranteed positioning and autonomous orbit manoeuvres in LEO - EQM
Budget (k€): | 1,200
Objectives: | The objective of this activity is to design, develop and qualify (at EQM level) an integrated nanosat avionics that contains a GNSS receiver and its interfaces with AOCS in order to demonstrate guaranteed positioning and continuous autonomous manoeuvres on-board without ground intervention.
Description: | LEO constellations of satellites would be a reality soon, which increase substantially the risk of collision. To cope with this known issue, autonomous and guaranteed on-board orbit control are deemed necessary. The associated technology can spin-off in multiple areas, for instance new Earth observation missions (reduced operation workload for control of tandem satellites). The activity will develop and test the equipment and the guidance algorithms to demonstrate the capability to keep a satellite within the predefined orbit (also called “corridor” or “tunnel”) and support collision avoidance. The EQM will include multiple modules, namely: GNSS receiver (with Precise real-time On-board Orbit Determination) and nanosat platform avionics (modified version of an already existing nanosat, including the autonomous on-board guidance algorithms to command the Orbit Control Mode). A fast IOD in a nanosat mission is targeted, therefore the EQM should be in a nanosat form factor. Yet attention shall be given that experiment at nanosat form factor is valid and scalable for the missions targeted to make use of such development.

The main work of the activity will consist in the integration of existing modules and develop a guidance module using the GNSS receiver data to provide autonomous and safe guidance to the AOCS Orbit Control Mode so that the closed loop control system can act to keep the satellite safely and robustly within the pre-defined orbit corridor. The target corridor size is 10-20 meters in radius in order to demonstrate a decisively improvement for missions like Sentinel-1 and for formation flying capabilities. The activity tasks shall contain the following:

- State of the art review and identification of available building blocks.
- Design of the product (including definition of the concept of operation)
- Development of the product: hardware (EQM) and software (guidance and AOCS)
- Testing/qualification

Deliverables: | Engineering/Qualification Model, Report, Software
Current TRL: | 5
Target TRL: | 7
Duration (months): | 18
Target Application/Timeframe: | Constellation missions in order to simplify operations and reduce collision risk, EO and LEO constellation missions that require frequent station keeping and enabling automated re-entry.
Consistent with activity C03 “Low cost receiver implementing the guaranteed positioning and autonomous orbit manoeuvres – EQM”
Domain

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Ref. Number: GT17-330SA  
Budget (k€): 800

Title: High accuracy 3-axis accelerometer unit EM

Objectives: The objective of the activity is to design and test an engineering model of a 3-axis high accuracy accelerometer unit.

Description: All recent ESA interplanetary or L2 missions are making use of an accelerometer assembly to control orbital manoeuvres. Missions requiring to operate in vibrations environment (launchers, landers) need to have gyroscope and accelerometers co-packaged, and the range used for the accelerometer measurement is also very large, up to 20g. Delta V monitoring requires to measure very small accelerations, in the range of 10 mg only, and with stability requirement of a few micro-g. Therefore, the analogue electronics guaranteeing this performance stability over life, radiations and temperature shall be designed.

As of today, it is only possible to procure an accelerometer function as an option connected to a gyro. All missions do not require high performance gyros, and therefore there could be a significant advantage in terms of mass, price and power needs to have a dedicated 3-axis accelerometer assembly.

A previous ESA activity E905-021EC “Stand Alone 3 Axis European Accelerometer Unit” has developed a 3-axis accelerometer, but it was based on MEMS sensing elements and the performance is not sufficient to meet the needs required for delta V monitoring.

Until recently, there was no single axis accelerometer component in Europe with sufficient performance, and all implementations required to procure accelerometers in non-EU states. The introduction of a newly developed high accuracy European accelerometer paves the way to the development of a fully European 3-axis High Performance accelerometer Unit.

The activity can be articulated along the following tasks:
- Requirements definition (i.e. mechanical levels, data and power interfaces, performances) ending with a Unit Requirements Review (URR)
- Preliminary design and bread-boarding ending with a Preliminary Design Review

Deliverables: Engineering Model, Report,

Current TRL: 3  
Target TRL: 6  
Duration (months): 15

Target Application/Timeframe: Exploration and Scientific Missions for delta V monitoring and control.

Consistent with activity B02 “3 Axis Accelerometer unit EQM”
Very high data rate K/K-band (22 Rx/26 Tx) transponder for near-earth missions

The objective of the activity is to develop and test a K/K-band TT&C transponder EM with standard and high order modulation schemes, with data rates from few Mbps to 100 Mbps, Low Density Parity Check (LDPC) and Serial Concatenated Convolutional Codes (SCCC) coding/decoding, navigation techniques, and working at low Signal to Noise Ratio (SNR) values.

European missions to the cislunar region are currently under study and new developments are necessary to enable these missions. One of the key technologies identified is the communications equipment to support the high data rates expected between the different mission assets: Earth, Moon, lunar surface elements, orbiting elements, visiting vehicles, descent/ascent vehicles, and other elements in cislunar orbit. Frequencies for links in the lunar region correspond to those in the Space Research (SR) service; these K-Band frequencies (22GHz/26GHz) are applicable to all missions in the “near-earth” range up to 2Mkm that includes Lunar orbits but also Lagrange/Libration Points for example.

The unit shall implement the full receiver and transmitter frequencies, allowing this equipment to be embarked in an orbiter and in a landed element. Consequently it is mandatory that the equipment is compact and has a low mass. The transponder shall include standard and high order modulation schemes for the receiver/transmitter, with data rates from few Mbps to 100 Mbps, and Forward Error Correction coding schemes including Low Density Parity Check and Serial Concatenated Convolutional Codes according to CCSDS standards, as well as navigation (Ranging/Doppler) techniques, and receiver working at low SNR values.

The activity shall encompass the following tasks:

- Review the technical requirements specification of the transponder, adding or proposing changes to the proposed requirements based on analysis/simulations.
- Provide a detailed design of the transponder that meets the technical requirements specification. The design proposed shall be justified by suitable trade-offs and simulations.
- Manufacture and test an Engineering Model to verify that the transponder meets the specifications and validate the design from an electrical & performance viewpoint.
- Provide a qualification and development plan for the evolution of the design towards the production of a Flight Model (FM)

During the development of the transponder Engineering Model, synergy with the following R&D activities shall be pursued:

- Very high data rate receiver for the Earth-Space link in the 22 GHz frequency for future moon exploration missions
- Breadboard for telemetry ranging (CCSDS 401, 2.4.24)
<table>
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<tr>
<th>Deliverables:</th>
<th>Engineering Model, Report</th>
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<tr>
<td>Duration (months):</td>
<td>24</td>
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<tr>
<td>Target Application/Timeframe:</td>
<td>Typical applications could be lunar missions (orbiters/landers etc.) and ascenders. TRL6 expected by end 2021</td>
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<tr>
<td>Applicable THAG Roadmap:</td>
<td>Not relevant to any Harmonisation topic</td>
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</table>
**Domain:** Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C

**Ref. Number:** GT17-332ES  
**Budget (k€):** 2,000

### Title:
Miniaturisation of the deep space transponder

### Objectives:
The main objective of the activity is to design, manufacture and test a miniaturized X/X Deep Space Transponder.

### Description:
Traditionally Science and Interplanetary missions are cornerstone missions in which mass, volume and power consumption are not necessarily constrained even though there are limitations due to the launcher performances and programmatic aspects (such as equipment availability and cost). Nowadays Space Agencies are looking into opportunity missions in which the overall size, mass and power are limited in order to optimise the resources.

The challenge of this activity will be to keep and improve the demanding performance of the Deep Space transponder and at the same time aiming at low recurring cost, mass, volume and power consumption and reducing the tuning effort during the manufacturing and integration phase by applying more novel techniques. It is recalled that this activity is for “class 1” qualification level thus does not overlap with lower class / qualification equipment developments typically needed for nanosats.

This activity shall consider the results of the on-going TDE activity “Miniaturisation of the Deep Space Transponder” for the proposed implementation. The activity shall encompass the following tasks:

- Review the technical requirements specification of the transponder, adding or proposing changes to the proposed requirements based on analysis/simulations.
- Provide a detailed design of the transponder that meets the technical requirements specification and takes into consideration of the outputs of the previous TDE activity. The design proposed shall be justified by suitable trade-offs and simulations.
- Manufacture and test an Engineering Model to verify that the transponder meets the specifications and validate the design from an electrical & performance viewpoint.
- Provide a qualification and development plan for the evolution of the design towards the production of a Flight Model (FM).

### Deliverables:
Engineering Model, Report

### Current TRL: 4  
**Target TRL:** 6  
**Duration (months):** 24

### Target Application/Timeframe:
This unit can be implemented in opportunity missions in Science and in the exploration domain. TRL6 expected by end 2023.

### Applicable THAG Roadmap:
Not relevant to any Harmonisation topic
Title: Heterogeneous modelling, design and analysis of complex space systems

Objectives: The objective of this activity is to integrate the state of the art analytic and simulation based design tools into model-based avionics, AOCS, GNC, system and software engineering models in order to handle complex distributed control problems.

Description: Early life-cycle system design and analysis is difficult to achieve because domain specific models are still used traditionally, which lack a common notation. Collecting, aggregating and exchanging information at system level is complex and error prone, which hampers the use in a multi-disciplinary concurrent design setting. This limits our ability to analyse system-level requirements such as performance and dependability in phase A/B1, causing postponement of design decisions to later phases, which lowers the opportunities to study alternative solutions and validation of fitness for purpose.

The main challenges of the activity are:

- To adopt multi-physics modelling techniques to alleviate the problem of a lacking common notation and integrate those into existing design tools and analysis techniques
- To deal with the need for heterogeneous levels of model fidelity, to integrate discipline specific viewpoints to capture system behaviour efficiently at the required level of detail at the right time
- To perform meaningful and timely analysis even before any physical system is available (digital twin concept), bridging the gap between the engineering disciplines
- To model faults explicitly, to enable investigation of (cross-domain) error propagation and their potential mitigation strategies (i.e. FDIR), already in phase A/B1
- To support multi-disciplinary design trade-off studies
- To provide the basis for digital continuity (reuse of models in later phases).

The proposed activity shall make use of multi-physics modelling tools to provide the means to create system dynamics models that can be integrated with the aforementioned tools to support multi-disciplinary design dialogue, in particular related to the avionics design.

The activity shall be performed in three phases:

- Definition (requirements by users) and implementation of the integrated tool infrastructure, with application on existing use cases to demonstrate the rapid prototyping capability (9 months, 400k)
- Continued evolution of the tool set, and development of a supporting methodology, driven by one or more realistic use cases at subsystem level, in a laboratory setting (9 months, 800k).
- Application of the tool set on a challenging new system design in a concurrent design setting (i.e. shadow engineering in CDF or project context) (6 months, 300k)
**Deliverables:** Prototype, Software, Report

**Current TRL:** 3  
**Target TRL:** 4  
**Duration (months):** 24

**Target Application/Timeframe:** Generic mission design in the early phases.

**Applicable THAG Roadmap:** Avionics Embedded Systems (2016)  
Consistent with activity C09 “Multidisciplinary Design Optimization (MDO) for Avionics Systems”
Ref. Number: GT17-334SW  
Budget (k€): 800

Title: Payload data processing SW architectures definition and modelling

Objectives: The objective of this activity is to adapt On-Board Reference Architecture (OSRA) and Model Based Avionics Design toolchains to Payload Data Processing Architectures and perform the implementation of a representative Use Case.

Description: Following the definition of the SW Payload architecture (OSRA-P) and its reference implementation (PEPS), the current activity focuses on the modelling aspects of Payload Data Processing Architectures. The modelling is supported by the OSRA toolchain and the Model Based Avionics Design toolchain developed in the frame of the CoRA-MBAD activity.

The activity shall include the following tasks:
- The analysis of Payload Data Processing Architectures and the outcomes of OSRA-P and PEPS activities.
- The analysis of the OSRA and CoRA-MBAD toolchains.
- The adaptation and link of the two toolchains in order to support the modelling of Payload Data Processing application using Space Component Model and supporting HW and SW generation from models.
- The definition of representative Use Case(s) that exercises the full set of features of the toolchains.
- The modelling of the Use Case(s) using the updated toolchains.
- The generation of different configuration of the Execution Platform at SW level as well as HW level (taking into consideration SMP and TSP solutions and a reconfigurable platform).
- The execution of the Uses Case(s) covering different configurations and their characterisation.

The updated toolchains will be made available to ESA projects to ease the development and integration of the payload applications.

Deliverables: Prototype, Report, Software

Current TRL: 4  
Target TRL: 5  
Duration (months): 18

Target Application/Timeframe: Applies to generic missions, the technology push for improving the development cycle of Payload applications and for improving their integration with the Platform.

Consistent with activity A02 “Payload Data Processing SW Architectures Definition and Modelling”
**Domain**
Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

**Ref. Number:** GT17-335SA  
**Budget (k€):** 600

**Title:** Autonomous relative navigation using star-tracker images

**Objectives:** The objective of this activity is to develop an autonomous navigation function that uses Star-Tracker images of extended or unresolved (point-like) objects to estimate the SC trajectory.

**Description:** ESA has developed vision-based navigation systems using dedicated visual cameras for autonomous relative navigation (e.g. ROSETTA asteroid fly-bys, JUICE Jovian moons fly-bys). Based on previous experience, this activity will develop an autonomous navigation system without dedicated HW developments. The main navigation sensor is a star-tracker (STR) that provide images to the OBC, which hosts the image processing and navigation filter for autonomous navigation. Note that STR images are slightly de-focused (optimized for star centralising) and, therefore, special measures might be needed for the image processing.

When the SC is near the celestial body, the STR images show extended objects (the object spreads over many pixels). The image processing algorithm shall derive useful measurements to the navigation filter (e.g. Line-Of-Sight towards to the geometrical centre of the object).

When the SC is far from the celestial body, the objects are unresolved (point-like) and the image processing algorithm shall be able to distinguish it from the stars. The navigation filter will estimate the SC trajectory.

Three scenarios shall be analysed:
- Relative navigation during approach or fly-by.
- Navigation in Earth-Sun L2 using Earth or Moon images
- Orbit around a celestial body

The navigation chain, including the image processing techniques, shall be assessed for each mission scenario. The autonomous navigation system design shall require only parameter modifications to be used in different missions.

Validation of the image processing algorithms shall be performed with simulations using representative images including defocusing of the STR images. Performance models of the STR and image processing shall be developed to perform Monte Carlo simulations of the navigation chain. Finally, the full navigation algorithms will be implemented in a representative flight processor and perform HW-in-the-Loop tests (STR EM, OBC, Functional model or representative emulator) in representative flight conditions.

**Deliverables:** Prototype, Report, Software

**Current TRL:** 3  
**Target TRL:** 5  
**Duration (months):** 18

**Target Application/Timeframe:** Technology push that has applications in Navigation, interplanetary flights and asteroid missions.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Guidelines, methods, processes and tools for development of reliable SoC systems

The objective of this activity is to define a complete framework for developing applications targeting System on Chip (SoC) components integrating generic purpose processor and re-programmable FPGAs

The number of SoC based on reprogrammable FPGAs that are proposed for space applications is growing. The ZynQ is already proposed for Cubesats platforms and instruments. The BRAVE Large should be available Q3 2019, the BRAVE Ultra in 2020 opening the way to DAHLIA systems. No complete framework for developing space applications exists considering the specific features of SoCs and in particular tightly coupled HW (FPGA) and SW (General Purpose Processor - GPP), possibility to reconfigure HW (FPGA) while ensuring the overall reliability of the system.

The activity is aiming at defining a complete framework for the development of reliable applications on SoC-based systems. This framework includes the definition of guidelines, methods, processes and tools.

In particular, the activity shall address:

- Hardware/Software co-engineering covering the full process from requirements to verification and validation supported by methods and tools (e.g. based on results of CoRA-MBAD activity).
- Optimisation of FPGA and processing cores resources and communication between the two.
- Reconfiguration of the FPGA covering both complete and partial reconfiguration capabilities.
- Optimisation of the use of external interfaces.
- Reliability of SoC based systems during nominal operations, i.e. covering the specific failure modes and effects and the implementation of mitigation techniques if required.
- Reliability of SoC based systems related to the reconfiguration of the FPGA, i.e. covering upload of data (full or patches), safe storage of different versions on-board, reconfiguration process, verification of the updated FPGA and operational aspects related to the unavailability of the complete part of the FPGA during reconfiguration.

The activity shall consider ZynQ and BRAVE Large or Ultra SoC components.

Deliverables: Prototype, Report, Software

Target TRL: 5
Duration (months): 24

Target Application/Timeframe: BRAVE components start to be available and proposed for future ESA missions including on Copernicus. Such framework would greatly improve the development of applications on these SoCs, i.e. reduce development time and increase performance.

**Domain:** Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C

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<th>Ref. Number:</th>
<th>GT17-337SW</th>
<th>Budget (k€): 800</th>
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**Title:** Physical layer testing of SpaceFibre link

**Objectives:**
The objective of this activity is to develop a test jig and a test procedures handbook for transmitter and receiver at-connector testing of copper/optical links and SpaceVPX backplanes.

**Description:**
SpaceFibre is a point-to-point high-speed serial link protocol based on SerDes technology. The ECSS standard was published in 2019 and first FPGA and ASIC designs become available. In contrast to similar commercial protocols such as USB3, the standard does not include a test specification yet. Particularly in the space domain where electronic units are often unique designs that are provided by different entities it is important that compliance and interoperability is closely monitored throughout the development cycle.

Aside from a test specification, a test jig is needed to perform the required TX and RX measurements on the Device Under Test (DUT). In case of a stand-alone unit, the jig must work at connector level (copper) whereas a test motherboard is required for modular boards with backplane connectors.

This activity comprises the following tasks:
- The development of a handbook that comprises test procedures for transmitter and receiver at-connector testing of copper/optical links and SpaceVPX backplanes.
- The development of a test jig for the copper tests and a test motherboard for SpaceVPX modules.
- The exact characterization of the test jig and the test motherboard (S-parameters etc.) and all additional steps required to compensate their effects on the measurement results.
- Validation of the test specification and test hardware on a real system.

The proposed activity would lead to a big improvement of the current state of the art since no test procedures exist right now that could be made applicable for upcoming ESA mission. While, in some cases, the lack of a test specification might be acceptable for medium speed links such as SpaceWire, it certainly will lead to serious integration issues in case of high-speed links.

**Deliverables:** Breadboard, Report

**Current TRL:** 2  
**Target TRL:** 4  
**Duration (months):** 24

**Target Application/Timeframe:** All missions.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Title: System analysis, benchmarking and improvement of CFDP IP core

Objectives:
The objective of this activity is the validation of the CFDP IP Core and upgrade it to the latest version of the CCSDS standard CCSDS 727.0-B-5.

Description:
The CFDP has been implemented as reusable Intellectual Property (IP) Core and it will be soon offered to the space community as part of the ESA IP Core portfolio. It will constitute the reference building block both for on Board Computers and Payload applications. Its architecture exploits a tailor able hardware/software approach. In particular, its hardware is a VHDL model, to be implemented in FPGA; the software, written in C, is made to be ported in RTEMS and was designed to run on LEON2 or LEON3FT processors.

The activity aims:
- To analyse different future application scenarios making use of CFDP for file based data communication.
- To derive specific requirements and constraints for the next generation CFDP implementation.
- To assess the adequacy of the current CFDP implementation w.r.t. the new needs identified before and to carry out an optimization of the current CFDP Core to meet the new requirements.
- To define an optimal partition between functions to be implemented in HW and in SW.
- To perform an independent evaluation of the ESA CFDP IP Core; adapt the IP core to the latest version of the CCSDS standard (CCSDS 727.0-B-5); validate the CFDP against mission-specific tailored implementations.
- To analyse the co-existence of CFDP with other TC/TM processing functions (eg. authentication, DTN, compression, Variable Bit Encoding).

The activity comprises the following tasks:
- Analysis of the strengths of the current CFDP implementation offered in the ESA IP Core's portfolio.
- Revision and benchmarking of the partition between hardware and software in the current CFDP IP Core both for OBC/Platform applications and for Payload applications.
- Modifications necessary to adapt to the latest version of the standard.
- Modifications to the interfaces as needed after HW/SW partition revision. Interfaces shall meet demands of different service classes.
- Verification of the IP Core against a golden reference model.
- Validate the IP Core in a demonstrator, representative of several space missions in which different CFDP classes are utilized, allowing for full demonstration of the concept.
- Provide technology mapping results for the updated CFDP IP Core in relevant FPGA technologies (Xilinx KU60, Microsemi RTAX, Microsemi RTG4, BRAVE).
- Verification of IP core portability on different target platforms (LEON/ARm SoCs, FPGAs)
- End to end performance verification (especially for Class 1+2 Gbps payload TM applications) with reference designs.
This activity aims to enhance existing CFDP implementation portability (To LEON4 and ARM platforms, as well as other FPGAs eg.) and to measure the differences in terms of throughput performances. The activity will also enhance the CFDP performances for Payload TM class 1 applications to a target download data rate in the order of 10 Gbps.

System analysis is needed to understand how higher performances impact CFDP implementation both on Board and on Ground. Once it is decided what it can be achievable at system level, the analysis shall go at box level to understand how the tasks should be partitioned between SW and HW.

**Deliverables:** IP core Breadboard, Report

**Current TRL:** 4  **Target TRL:** 6  **Duration (months):** 15

**Target Application/Timeframe:** Earth Observation, Science and Exploration missions. CFDP functionality is requested by the common platform study performed for the Copernicus 4.0 including 6 candidate missions: CHIME, CO2M, LSTM, ROSE-L, CIMR, PICE/CRISTAL

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
3.1.4 CD4 - Electric Architecture / Power and Energy / EMC

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<tr>
<th>Domain</th>
<th>Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC</th>
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<tr>
<td>Ref. Number: GT17-339EP</td>
<td>Budget (k€): 500</td>
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<tr>
<td>Title: Behaviour of 4G32 solar cells under particle irradiation</td>
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<td>Objectives: The aim of the activity is to perform an irradiation campaign for 4G32-Advanced solar cells and the corresponding isotype cells followed by a performance characterization and the establish of a degradation model based on the DDD (Displacement Damage Dose) and EQFLUX (equivalent fluence) approaches.</td>
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<tr>
<td>Description: As successor of the 3G30 solar cell, the next generation of space solar cell product 4G32-Advanced is introduced which is a 4-junction device with metamorphic layers on Ge substrate. This cell is currently under ECSS qualification. 4G32-Advanced cell exhibits an EOL efficiency of 28.5% after 1e15 cm-2 1MeV equivalent electron irradiation (corresponds to 15 years in GEO orbit) which is 2% abs more than the EOL performance of the 3G30 solar cell. In terms of radiation hardness, the 4G32 solar cell is currently the best-in-class space solar cell worldwide. Despite the successful development and running qualification programme, there is still a significant demand for a detailed understanding of its degradation behaviour after electron and proton irradiation within a range of energies relevant for different space environments. Moreover, the 4G32-Advanced solar cell consists of new semiconductor materials such as quaternary III/V compounds and materials with high phosphorus content. Sufficient data on their degradation and possible recovery effects due to thermal and photon annealing are still missing. In the proposed activity, an extensive irradiation campaign is planned for 4G32-Advanced solar cells and corresponding isotype cells followed by performance characterization. Based on those results degradation models in line with the so-called DDD and EQFLUX approaches will be derived. These models will then be made available within ESA's SPENVIS tool, which satellite primes and manufacturers of solar generators need for making a reliable power analysis prediction. Moreover, the gained knowledge on the degradation behaviour of new solar materials will also be used for further improvement of 4G32 upright metamorphic solar cell class as well as for development on novel cell architectures employing these materials. This activity encompasses the following tasks: manufacturing of 4G32-Advanced solar cells and corresponding isotype cells (these are single junction cells with identical electrical and optical properties as the corresponding subcell in the 4-junction stack) Beginning of life characterisation of solar cells Irradiation campaign and end of life characterisation of solar cells Analysis of data and establishment of characteristic degradation curves in line with the DDD and EQFLUX methods Implementation of degradation models in SPENVIS</td>
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<tr>
<td>Deliverables: Degradation Models, Report</td>
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<td>Current TRL: 3</td>
<td>Target TRL: 5</td>
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Target Application/ Timeframe:

All type of missions. Expected TRL 5 by 2024

Applicable THAG Roadmap:

Solar Generators and Solar Cells (2015)
Consistent with activity D05 “Radiation testing for new solar cell generations”
Domain | Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC
--- | ---
Ref. Number: | GT17-340EP
Budget (k€): | 700

Title: Advanced multi-junction solar cells focusing to cost reduction

Objectives: The objective of the activity is to reduce the cost of advance multi-junction solar cells by reviewing an adapting respective process steps at Ge wafer level, solar cell epitaxy and solar cell processing.

Description: Solar cell development for space up to now is mainly driven by increasing the power/mass and power/area ratio. Therefore, the main objective in solar cell development is to increase the efficiency of the cell. For those type of products, customers are prepared to accept also higher costs as long as the €/Watt measure do not increase.

However, especially with the emergence of mega constellation programs, the cost of the cell becomes a relevant parameter. The whole satellite and therefore also the solar generator shall be made as cheap as possible (of course, by meeting some minimum performance figures). In this quite aggressive market, it is important that European space solar cell manufacturers can offer a product which answers to those new demands. Therefore, one of the initial tasks of this activity is to identify all areas with cost reduction potential and develop (in case needed) an adapted process that allows for meeting the requested €/Watt figures.

Potential areas of cost reduction are found in the complete production chain, starting from the substrates (Germanium wafers), over the epitaxial growth process and finally the solar cell processing. On Ge wafer level, the idea could be, to omit some expensive process steps which then would result in a rougher wafer surface. A dedicated nucleation process would have to be developed in order to limit any detrimental effects on the final product. Furthermore, on epitaxy level one would have to look into higher growth rates in order to increase production throughput. Also during solar cell processing different options shall be investigated in order to safe costs.

This activity encompasses the following tasks:
- Review of all process steps in the whole production chain identifying cost reduction potentials
- Defining new process route and modification needs for affected production steps
- Development/Adaptation of processes complying with changes in preceding process steps
- Implementation of adapted solar cell manufacturing process and manufacturing of first low cost prototypes
- Engineering tests

Deliverables: Engineering Model, Report

Current TRL: 3 | Target TRL: 5 | Duration (months): 24

Target Application/ Timeframe: All types of missions, technology push, expected TRL 5 in 2023

Applicable THAG Roadmap: Consistent with activity C08 “Cost reduction and yield increase of solar cells from 6” wafers (140um)”
Domain: Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

Ref. Number: GT17-341EP  Budget (k€): 800

Title: Power unit for high power radars and altimeters, improving the dynamic performance under pulsed operation

Objectives: The objective of the activity is to develop an Elegant Breadboard of a power unit for high power radars and altimeters that demonstrates significant performance improvement by identifying the best system configuration for high power pulsed payloads, the best topology for the payload power system and the best converter topology for the active filter and the DC/DC conversion.

Description: Pulsed loads like radars, altimeters and scatterometers usually have very demanding power requirements. The power is delivered in short pulses which require precision, synchronisation, and the ability to deliver high power in very short time. In general, the platform is highly affected by these pulses and it is key to minimise the noise injection at platform level. Future mission will have to double the pulse repetition frequency, reduce the duty cycle and increase the power. Missions with pulsed payloads usually show problems related to the interaction of the power pulses with the rest of the platform. Thus, an improvement of the performance and reliability of those units is highly needed. Missions with RADARs, altimeters and scatterometers will all benefit from this development.

The improvement of the performance of pulsed payloads has to be tackled from multiple sides. The system level concept is important in order to channel the high power pulses through paths that have the least disturbance effect. Thus, a power system trade-off is necessary to understand the best possible system configuration.

In terms of reducing the electrical noise, the development of active filtering techniques is key. Given the frequency of the pulses, passive filtering is cumbersome and active filtering seems the best alternative.

The DC/DC converter topology is also a key point due to the high current capability needed. Concepts with current doublers or multi-phase converters will be needed to comply with the requirements. Since the conversion stage is located as close as possible to the antenna, mass and volume is a key aspect. In that sense, the trade-off related to the number of converters needed in parallel or in a matrix configuration will define many aspects of the topology. The matrix concept using a high number of converters (>200) looks like a very promising option.

Operation at high switching frequency will be needed to reduce mass and volume. Thus, the exploration of GaN switches operating in the MHz range is a viable option. Encapsulation of these Building Block converters could be an option that enables very high integration levels. This high switching frequency can enable the elimination of tantalum capacitors, which is a source of problems in this high current applications.

In order to handle the high power pulses with multi-converter solutions, digital control can enable complex connection/disconnection patterns of the matrix configuration that can enable a higher performance of the system.

This activity encompasses the following tasks:
- Power System analysis to trade off different concepts at platform level
- Payload power subsystem trade off to identify the main building blocks and redundancy concept
- Identification of critical EEE components
- Design of the filtering system
- Design of the conversion stage
- Manufacturing of an EBB to demonstrate the concept
- Testing of the EBB in relevant load conditions.

**Deliverables:** Elegant Breadboard, Report

| Current TRL: | 3 | Target TRL: | 4 | Duration (months): | 36 |

**Target Application/Timeframe:** Future missions with high power pulsed payloads like RADARs, altimeters or scatterometers with demanding power requirements for the payload.

**Applicable THAG Roadmap:** Power Management and Distribution (2019) Consistent with activity E52 “Development of new techniques to power pulsed payloads”
Title: N channel Latching Current Limiter

Objectives: The aim of the activity is to design a Latching Current Limiter with an N channel MOSFET, to build an EM and test it.

Description: The overall conversion path in a power unit comprises not only conversion stages but also many protection devices. In the base of Battery Charge Regulators (BCR) and Battery Discharge Regulators (BDR), a protection is typically needed at the input and at the output. Thus, two additional devices will be added to the path and, as a consequence, it will have a significant impact on the efficiency. It has to be noted that, for simplicity, those protections are implemented with P channel MOSFETs. The downside of this choice is the largest Rs on and the higher losses. In many cases, the protection devices is where the highest dissipation is concentrated.

Power units have by nature a very high dissipation level. Reducing the losses is a key aspect to simplify the thermal design. The input and output protection of BCR and BDR modules has been identified as a key point to reduce the dissipation. This development will reduce the module dissipation by close to 50%.

The activity will focus on the development of an N channel LCL for BCR/BDR protection. An N-channel LCL will have the difficulty of needing a supply voltage on top of the voltage rail (Battery / Main Bus) to bias the MOSFET gate source. The implementation of this auxiliary voltage is a key part of this development since its simplicity is a key aspect. Moreover, the MOSFET source will be connected to the output of the LCL meaning that all sense and control circuit will see that large common mode voltage range when the LCL turns on/off. The LCL on/off control inputs have to be level shifted to refer to power ground. Since the driving scheme is different and the MOSFET has different characteristics, the dynamic performance of the circuit will have to be carefully analysed, as well as its stability and its thermal performance.

The following tasks are foreseen in the frame of this activity:
- Design the High side supply of an LCL based on N-channel MOSFET
- Thermal calculation of the LCL MOSFET when Main Bus capacitance is charged upon switch on
- Develop simulation model with thermal properties for LCL with N-channel MOSFET
- Design of the LCL with N-channel MOSFET
- Design a MOSFET gate drive able to drive many MOSFETs in parallel as needed
- Ensure stability of LCL current loop into BDR and BCR and ensure LCL current loop stability when tested via test connector and external load
- Build and test in Thermal Vacuum an EM

Deliverables: Engineering Model, Report

Current TRL: 3  Target TRL: 6  Duration (months): 24
Target Application/ Timeframe: All type of missions.

Consistent with activity E10 “Improvement of power unit modules”
Annex II, Page 75/160

GSTP Element 1 “Develop” Compendium 2019: Generic Technologies
Date 28/10/2019 Issue 1 Rev 0

Domain: Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

Ref. Number: GT17-343EP
Budget (k€): 800

Title: New packaging techniques to increase power density of power control and distribution units

Objectives: The aim of the activity is to explore new materials and packaging/integration possibilities for power units to in order to maximize heat transfer and minimize volume.

Description: Power units have been using the same integration system since decades. It is based on a vertical module approach that limits considerably the thermal access to the baseplate. Moreover, some of the modules have very low dissipation but still use the same system. As a consequence, these modules occupy some precious space that is scarce for the high power consumers. This becomes a limiting factor in high dissipation units. Power units like Power Conditioning Units (PCDU) and Power Propulsion Units for Electrical Propulsion (PPU) easily dissipate more 300W. At system level (Satellite) a dedicated radiator of 1m² is needed to cool down a unit of 300W with an interface temperature of 50 degC.

The activity will try to find new mechanical concepts that maximize the space allocated to the high dissipative modules by placing the low dissipative ones farther away. To achieve this, new materials and new thermal concepts will be needed. Internal micro-heat pipes or improved thermal paths need to be explored. The main goal is to improve the unit’s power density, making them smaller and lighter. There can be some impacts at system level that need to be studied since, once evacuated from the unit, the heat has to be harnessed to the radiators. If the heat density is higher, there could be limitations on that side. Hence, the heat spread should be better than the current one in order to reduce that density and limit, or even improve the impact at system level. For instance, by eliminating the cold plate or the external heat pipes.

The objective could be achieved if the modularity approach changes from vertical to horizontal (or combined vertical/horizontal) so that there is ample room for power dissipative components to be mounted close to the radiators. Due to this new concept, also components not mounted directly on baseplate can benefit from the “shorter” (=improved) thermal path. Taking inspiration from automotive industry, new packaging techniques have to be studied and tried out on space units. Also new internal (modules) connection concept has to be developed, maybe in the form of “grid” or “matrix”.

The optimized thermal interface between power unit and satellite radiator is expected to lead to mass savings around 30 %, with target unit volume reduction of 25%. The achievable power density could be more than double of the actual one.

The main tasks that will be done in this activity are:

- Define Thermal Mechanical constraints at system level for several study cases
- Study of possible alternative Thermal Mechanical solutions
- Selection of a study case and of the most promising thermo–mechanical concept and define Engineering Model (EM) requirements.
- Detailed Design and Analysis of the Thermo-Mechanical Engineering Model
- Validation of the manufacturing and Assembly, Integration and Test processes using the EM
• EM Thermo-Mechanical Test

**Deliverables:** Engineering Model, Report

**Current TRL:** 2  
**Target TRL:** 5  
**Duration (months):** 24

**Target Application/Timeframe:** Technology push, expected TRL 5 by 2023

**Applicable THAG Roadmap:** Consistent with activity A07 “High power units thermal architecture”
Domain:  Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

Ref. Number:  GT17-344EP  
Budget (k€):  1,000

Title:  Isolated magnetic feedback generator

Objectives:  This objective of the activity is to design, manufacture, test and qualify a component to implement feedback loops based on magnetic coupling in DC/DC converters.

Description:  Most DC/DC converters used in a satellite have to close the loop across primary to secondary power insulation barrier. This is a key feature that enables performance, reliability and stability. However, there are few options to do this with a magnetic system and none is European. The development of this device will have a large open market in Europe and will help improving a large number of power converters.

The most usual way to close the control feedback loop in DC/DC converter across primary to secondary power insulation barrier is to use optocouplers. However, these devices suffer major performance degradation in the space radiation environment. Thus, it is more efficient to implement the feedback loop by means of a magnetic device. In order to implement this system efficiently, an Integrated Circuit (IC) is needed. Otherwise, the discrete implementation will occupy a large area on the printed circuit board (PCB).

The proposed device is designed to solve many of the problems associated with closing a feedback control loop across a voltage isolation boundary. As a stable and reliable alternative to an optocoupler, magnetic coupling devices feature an amplitude modulation system which allows a loop error signal to be coupled with a small RF transformer or capacitor.

High-frequency modulation allows the use of smaller, less expensive transformers which can readily be built to meet the isolation requirements of space power systems. The device should allow an external clock input to synchronize to a system clock or to the switching frequency of the converter. A monitoring and telemetry system should also be implemented since it will allow implementing alarms about the status of the control system.

An < 1% accurate reference, and a high gain general purpose amplifier should be included in order to implement high precision and stable loops.

The implementation of the isolation transformer could even be done inside the IC, simplifying this way even more the feedback loop circuit. In such case, special attention should be taken to meet isolation requirements on the space power system.

The following tasks will be done in the frame of this activity:

- Phase 1 (750 k€)
  - Topology trade off to place the isolation transformer outside or inside the IC
  - Package trade off
  - Design of the die
  - Manufacturing of the 1st run design
  - Packaging the component
  - Component test and characterisation
  - Compilation of issues to be redesigned in the 2nd run

- Phase 2 (250 k€)
o Qualification of the component

**Deliverables:** Breadboard, Report

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<th>Current TRL:</th>
<th>Target TRL:</th>
<th>Duration (months):</th>
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**Target Application/Timeframe:** Generic technology that can be used in all type of missions

**Applicable THAG Roadmap:** Power Management and Distribution Roadmap (2019) Consistent with activity B16 “Isolated feedback loop IC”
Domain: Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

Ref. Number: GT17-345EP  
Budget (k€): 1,000

Title: Immunity to in-band electromagnetic interference for radio-frequency receivers using signal modulation

Objectives: The objective of this activity is to develop a system for quantitative determination of the immunity levels to electromagnetic interference (EMI) for spacecraft radio-frequency (RF) receiver and transponder equipment inside the transmission bandwidth due to the utilization of signal modulation.

Description: Signal modulation influences the susceptibility to various types of EMI. Modulation is used in intentional RF signals transmitted to and received by spacecraft and the receiver for a specific RF transmission is most sensitive to this specific, modulated RF signal, i.e. for example an X-band receiver is most sensitive to a legitimate X-band transmission signal. The sensitivity to other RF signals with different or even without modulation will be reduced, i.e. the immunity to such signal will be higher. Nevertheless the receiver sensitivity for intentional signals is typically used as a worst-case to derive also the susceptibility level for other types of RF signal or unintentional RF emissions within the receiver bandwidth.

To quantify the actual immunity a dedicated test bench system is needed to evaluate susceptibility levels for specific interference signals by test. The functional principle can be verified with generic RF receivers and signal generators, application to space missions requires representative modulated signals and validation on actual spacecraft receivers, e.g. engineering models. With the resulting quantification of actual RF receiver susceptibility the requirements on tolerable radiated emissions of other spacecraft equipment can be tailored.

The activity should contain the following tasks:

- Review modulation schemes in use by RF receivers and transponders and also characteristics of typical interference signals, including single and multiple frequency (comb) continuous wave, pulsed (especially RADARs), Chirp, RF transmission modulation schemes, etc.
- Derive a set of representative test cases for modulated signal transmission as well as typical interference signals and define requirements for test bench equipment, including nominal and interference signal generators and generic test receiver or spectrum analyser
- Procure test bench equipment, implement test bench setup, prepare preliminary test procedure and implement transmission modulation schemes and interference signals in signal generators
- Verify test setup, including characteristics of implemented transmission modulation schemes and interference signals, using generic test receiver or spectrum analyser
- Test susceptibility levels of actual spacecraft receiver(s), e.g. on engineering model(s)

Deliverables: Engineering model, Prototype, Report

Current TRL: 4  
Target TRL: 6  
Duration (months): 24
Target

Application/ Timeframe: Generic technology that can be used in all type of missions / TRL 6 expected by 2023

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Title: Qualification of novel grounding for composite structural panels

Objectives: The objective of this activity is the qualification of effective equipment grounding and structural panels bonding by rivets on modified inserts to the Carbon Fiber Reinforced Polymer (CFRP) structure that leads to improvement of current grounding and bonding RF performances.

Description: The current practice of grounding on CFRP-skin structural panels is to ignore the electrical properties of the CFRP (conductivity approx. 0.001 that of aluminium) and to set-up a network of so-called "ground rails" usually implemented as aluminium strips a few cm wide and a few tenths of mm thick, that interconnect the chassis of the various electronic units.

This recurrent design practice involves constraints in terms of mass and layout and results in a mediocre high-frequency grounding of the electronic units to the panel, with consequences in terms of common mode and radiated emission.

Precursor R&D activities have shown that, unless the rails would be made very wide and would track the harness throughout the satellite, which would virtually result in implementing an aluminium ground plane on top of the CFRP, only the low frequency part of spurious currents (common mode currents) flows through such rails (approximately up to a few 100 kHz). Higher frequency common mode interference actually flows through the panel in spite of its lower conductivity, simply because of its shape as a panel.

As a consequence, the standard design would benefit from being modified by:

- Replacing the flat ground rails with round wires easier to implement and sufficient to handle fault currents and to ensure low frequency bonding;
- Ensuring inductance-free bonding of the electronics units to the CFRP through their feet and rivet connections.

Inter-panel continuity should be ensured by similar techniques.

This activity encompasses the following tasks:

- Requirements specification of the novel grounding method.
- Qualification plan.
- Design and manufacturing of breadboards.
- Characterisation of the grounding before environment tests.
- Mechanical and thermal tests.
- Characterisation of the grounding after environment tests.

Deliverables: Breadboard, Report

Current TRL: 3  Target TRL: 6  Duration (months): 24

Target Application/Timeframe: Generic technology that can be used in all type of missions, expected TRL 6 by 2022.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Title: End of life battery management system

Objectives: The activity objectives are:
- To produce a database of the different scenario that can occur in a passivated power system and their impacts on the battery, based on the different key parameters affecting the battery during the disposal phase;
- To propose hardware solutions and produce a process guideline leading to “make safe” a battery during the disposal phase.

Description: According to ECSS-U-AS-10C it is required that "During the disposal phase, a spacecraft or launch vehicle orbital stage shall permanently deplete or make safe all remaining on-board sources of stored energy in a controlled sequence."

This activity follows previous TDE and GSTP Developments in Clean Space Battery Passivation and Spacecraft Power System Passivation mainly focusing on cells rather than battery modules.

This activity encompasses the following tasks:
- Produce a database of all failures mode of PCDU and/or battery charge regulators during passivation phase and determine the impact on the battery.
- Produce a database of the different scenario that can occur in a power system and the key parameters that may affect the battery (electrical and safety) during the disposal phase. (Including the possible restart of a dead power system upon illumination of the Solar Array due to seasonal change or S/C attitude change). As an example, battery cycling can be caused by changing orbit and S/C attitude. In such scenario, cycling can occur at extreme temperatures beyond the qualification range.
- Propose a list of hardware solutions to mitigate the identified failure mode scenarios, when appropriate
- For different cells suppliers and battery topologies (xSyP or yPxS) representative of on-going programmes, correlate with battery test results the electrical and thermal analyses on battery failure modes in various scenarios during disposal phase
- According to the battery behaviour under various scenarios (including at least electrical, thermal, radiation) during disposal phase, provide a process guideline leading to “make safe” a battery.

Deliverables: Report

Current TRL: 3  Target TRL: 5  Duration (months): 24

Target Application/Timeframe: Space Debris Mitigation for all type of spacecraft in Earth orbit.

Domain: Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

Ref. Number: GT17-348EP

Title: Cell and battery validation approach

Objectives: The objectives of this activity are two folded: define a validation methodology that improves the time and labour efficiency and to define a faster validation process covering raw materials to battery delivery.

Description: The battery market in space versus worldwide is tiny (0.001%), leading to major issues in the management of the raw materials obsolescence and supply chain security. To maintain European competitiveness and maintain European suppliers as the key players in Space based energy storage, it is needed to speed up the qualification time to better face the obsolescence challenges and also answer to the “New Space” initiatives for constellations time and cost driven.

Outside of purely technical challenges, the reliability requirements of space result in extremely long qualification timelines compared to other industry which means innovation cycles in the space battery technology are significantly longer than terrestrial batteries. Moreover, it appears not enough responsive and aggressive with respect to the “New Space” initiatives for constellations (time and cost).

At cell level, the supplier usually define their own 2 steps qualification process (Beginning Of Life - BOL - qualification including environmental tests and then End Of Life - EOL - qualification including cycling and calendar life tests) but it is not sufficient. At battery level, ECSS-E-ST-10-03C specifies acceptance and qualification tests applicable to battery equipment.

From this, there is a strong evidence that standardization and test guidelines specific to the cell and the battery equipment are needed, to address:

- Raw material obsolescence management with a pro-active approach at cell level (faster validation, technical risk mitigation with limited delta qualification, system reliability targets compliance).
- Traditional space versus alternatives approaches (as proposed by new players) attempting to meet changing battery needs:
  - selecting COTS cells submitted to extensive validation campaign, assembled in a be-spoke battery design,
  - developing specific cells for a space applications, to be assembled in a be-spoke battery design,
  - selecting COTS cells, to be assembled in a battery in a mass market approach.

This activity encompasses the following tasks:

- Overview of the current standards and test guidelines applicable to the qualification or validation of cell and batteries (Li-Ion technology), covering at least and not limited to electrical, mechanical, thermal, radiation and safety tests, for space, automotive and grid applications.
- Develop an overall process depending on the selected approach (testing at cell level and/or battery level),
- Develop an appropriate cell qualification or validation methodology addressing the cell evaluation for a space use, the raw materials evaluation in case of obsolescence management
- Submit cells to the proposed cell qualification or validation methodology
- Develop a battery qualification or validation methodology
• Proof of concept for the methodology (is faster, cheaper than the current approach without introducing additional unexpected risks).

**Deliverables:** Report

**Current TRL:** 4  **Target TRL:** 6  **Duration (months):** 24

**Target Application/Timeframe:** Generic technology that can be used in all type of missions. Expected TRL 6 by 2023

**Applicable THAG Roadmap:** Consistent with activity A01 “Cell and battery qualification approach”
Domain: Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC

<table>
<thead>
<tr>
<th>Ref. Number:</th>
<th>GT17-349EP</th>
<th>Budget (k€):</th>
<th>1,000</th>
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</table>

**Title:** Technology improvement for lift-off and transfer processes to obtain light and flexible solar cells

**Objectives:** The objective of this activity is the improvement of the lift-off technology aimed at obtaining lightweight and flexible solar cells by separation of the active layers of the solar cell from the substrate.

**Description:** The present state-of-the-art solar cells are based on triple-junction GaAs configurations, which after successive improvements of the technology have increased the cell performance with efficiencies close to 32% for commercial products. Next steps towards further cost reductions on system level are not only focused on improving solar cell efficiency but also in reducing the solar cell mass. Thus, the ultimate goal is a high efficient, ultra-thin solar cell resulting in a very high power/mass ratio. Further cost reduction can be achieved by increasing the power/stowed volume ratio and one strategy to accomplish this is with the use of solar array architectures based on flexible concepts.

This activity focuses on the improvement of manufacturing processes to obtain ultra-thin cells (20-80 microns). Thereby, it is essential to achieve this lightweight and flexible solar cells without reducing the fabrication yield and, for doing so, it is necessary to improve and further develop two different technological process steps: the epitaxial lift-off and the layer transfer. The epitaxial lift-off consists in the separation of the active layers from the substrate, in a way that the latter can be reused. The layers lifted from the substrate are very thin and sensitive and for that reason, a layer transfer process onto a temporary or permanent substrate is needed to allow the handling of the thin solar cell film during the subsequent processing and assembling steps. Different combinations of lift-off and transfer processes may be necessary for different solar cell technologies.

**Task description:**
- Identification of most promising lift-off and layer transfer technologies to satisfy the requirements which are weight reduction, flexibility of the solar cell, reuse of the substrate, high yield of the process and low cost
- Improvement of those lift-off and layer transfer technologies
- Manufacturing of engineering model solar cells using the process steps developed/improved within this activity
- Engineering model tests on solar cells
- Commercial evaluation of costs or savings when implementing the new process steps

**Deliverables:** Engineering Model, Report

**Current TRL:** 3  **Target TRL:** 5  **Duration (months):** 24

**Target Application/Timeframe:** Generic technology that can be used in all type of missions, expected TRL 5 in 2022.

**Applicable THAG Roadmap:** Solar Generators and Solar Cells (2015)

Consistent with activity A10 “Optimisation and industrialisation of processes for ultra-thin solar cells”
3.1.5 CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing

<table>
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<tr>
<td>Ref. Number: GT17-350EF</td>
<td>Budget (k€): 850</td>
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<tr>
<td>Title: Broadband RF absorber coating for space applications</td>
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<tr>
<td>Objectives: The objective of the activity is to develop and validate a coating that has RF absorbing capabilities at frequencies between 28 and 500 GHz and to develop and validate a suitable RF test bench that allows characterisation of the RF performance of the samples, including radiation effects.</td>
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<td>Description: The increasing complexity of RF instruments and antennas and the constant development of new techniques to aggregate more and more functionality while minimising the real estate on the spacecraft is leading to the challenge of controlling RF scattering on the satellite platform. In particular, current technology employs large baffles or other mechanisms to control the unwanted energy in the direction of interest. This activity shall focus on the development of RF absorber coating that absorbs RF energy at high frequencies (i.e. 28-500 GHz), using mixes of vacuum compatible epoxies with high thermal conductivity and absorbing carbon based compounds. The aim is to produce and qualify a thin and lightweight broadband vacuum compatible absorber which can be used to effectively control unwanted RF energy on the satellite platform. In addition, a suitable test bench that allows verification of the RF performance in operational conditions (including radiation) shall be developed and validated. So far, the approach has been to verify the RF performance of the samples, expose the sample to vacuum, temperature and radiation and then test again. Although this approach allows verification of degradation effects due to the exposure to the space environment, it does not yield the performance of the coating in the environment, meaning the performance in operational conditions. This is critical when handling modern coatings which enable high frequencies and high power handling, including the future antennas using advanced manufacturing techniques and RF coatings. Components which will benefit from this development include active and passive instruments and antennas and Quasi-Optical Networks. Benefits will be better control of scattering/straylight and beam efficiency; ground testing of instrumentation (improved test accuracy); radiated ground testing of coated panels inside TVAC chambers characterise the RF performance of the manufactured samples in operational conditions, including radiation effects.</td>
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<tr>
<td>This activity encompasses the following tasks:</td>
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<tr>
<td>• State of the art survey of epoxies, carbon compounds and other space qualified materials for RF absorption</td>
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<tr>
<td>• Preliminary design and manufacture of a set of sample configurations using different materials and shape control for absorber layers</td>
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<td>• Detailed design and manufacturing of samples</td>
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<td>• Design and verify a suitable test bench that allows RF characterisation of the samples in operational conditions, including radiation.</td>
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<tr>
<td>• Characterise the RF performance of the manufactured samples in operational conditions, including radiation effects</td>
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GSTP Element 1 “Develop” Compendium 2019: Generic Technologies
Date 28/10/2019 Issue 1 Rev 0
<table>
<thead>
<tr>
<th><strong>Deliverables:</strong></th>
<th>Engineering/Qualification Model, Breadboard, Report</th>
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<tbody>
<tr>
<td><strong>Current TRL:</strong></td>
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<td><strong>Target TRL:</strong></td>
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<tr>
<td><strong>Duration (months):</strong></td>
<td>24</td>
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<tr>
<td><strong>Target Application/Timeframe:</strong></td>
<td>All missions that required high frequency communication antennas, ground testing facilities.</td>
</tr>
<tr>
<td><strong>Applicable THAG Roadmap:</strong></td>
<td>Consistent with activity L03 “Development and qualification of broadband RF absorber coating for space applications”</td>
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</table>
Validation of the mitigation of plasma effects on RF communications during re-entry

The objectives of this activity are to perform a re-entry plasma impact mitigation experiment to verify the possibility to exploit antennae radiation patterns recombination to mitigate the black/brown-out. The results shall be used to develop, upgrade, and validate a propagation tool that will be used for future re-entry vehicles.

In the ESA Atmospheric Re-entry Demonstrator (ARD) re-entry flight there was an experiment where the S-band telemetry signals were received on the ground during the so-called plasma-induced RF blackout (albeit at a much lower level than expected, in the 15-25dB range). Subsequent studies have systematically analysed the communications black out phenomenon, developing appropriate modelling tools. These tools allowed the identification of a way to mitigate the effect of the plasma on the RF signal and to define an experiment to validate this solution in flight.

This activity will be focused on the upgrade/validation of the propagation tool for the definition of the mitigation techniques. The activity will also provide for the definition and implementation of experiments on-board of the Space Rider missions (low speed re-entry) for the final validation of the proposed mitigation solution.

The main tasks to be covered are the following:

- Propagation tool development: update and upgrade:
  - Design the core and user friendly interfaces.
  - Implement the recombination of different radiation patterns to mitigate the black/brown-out.
  - Evaluate the signal at receivers for different phase shifts between two antennas.
  - Evaluation of the communication improvement in launch and re-entry phases.
  - Definition of the in-fly experiments to measure signal for different phase shifts in activities like Space Rider: Propagation tool validation and mitigation technique validation plan.

In flight validation experiment execution on the Space Rider:

- Definition of the experiment and validation process
- Definition and procurement of required on-board and on ground equipment
- Deployment and use of the equipment (carry on the experiment).
- Post-processing of the data and conclusions.

Deliverables: Report, Software, Breadboard, EGSE

Current TRL: 5  Target TRL: 8  Duration (months): 24

Target Application/ Timeframe: Re-entry vehicles. TRL8 by 2024

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Micro reference oscillator

The objective of this activity is to develop a very compact (1 cm³) low power (tens of milli-watts) oven controlled reference oscillator at 10 MHz and 100 MHz (VHF) for navigation receivers and telecom frequency converters. Micro reference oscillator (uRO) shall replace high performance Oven Controlled Oscillators (OCXO) with a power consumption and size gain of at least one order of magnitude.

Accurate timing and low phase noise are critical parameters for on-board navigation receivers and telecom frequency converters respectively. Those two critical parameters, in many instances, are calling for high performance quartz oscillators namely Oven Controlled Oscillators (OCXO).

The major performance difference between standard quartz oscillators and high-end OCXOs result from the careful choice of the quartz resonator (and the associated electrical components), as well as the fine sheltering of the quartz resonator itself which provides a very stable environment. The major drawback of this improved performance is a significantly increased power consumption as well as larger mass and volume. QMEMS (Quartz-MEMS) oscillators are proving to achieve comparable quality factor with respect to regular X-tal blanks, while being much smaller; “single-chip” integration as compared to hybrid assembly. The purpose of this activity is to aim at OCXO performance while reducing drastically the power consumption benefitting from the Q-MEMS resonator properties.

The activity will be divided in two technical phases:

**Phase 1** comprises the following tasks:
- Literature Review and Patent Survey,
- Preliminary Design of uRO,
- Breadboarding of Critical Building Blocks;

**Phase 2** is organised as follows:
- uRO Detailed Design,
- uRO Fabrication and Testing of 2 Engineering Models for 10 MHz and 100 MHz version,

**Deliverables:** Engineering Model, Report

**Target Application/Timeframe:** Reduction of volume and power consumption for very integrated modules.

**Applicable THAG Roadmap:** Frequency and Time Generation and Distribution (Ground & Space) (2018)
Consistent with activity A05 “Alternative technologies for on-board oscillators”
Ref. Number: GT17-353EF  
Budget (k€): 1,200

Title: Next generation of spaceborne phased arrays

Objectives: The core objective of this activity is to manufacture and test a demonstrator of future spaceborne phased array antennas achieving significant reduction of mass and cost with respect current generation. This shall be based on a system level approach for the identification of novel architectures and technologies with high level of integration, modularity and utilization of analogue and digital functions.

Description: Current active phased array technology is well advanced and achieves remarkable performance as demonstrated in various Earth observation and telecom activities. However all have in common that the antennas are heavy and very expensive. One reason is that the basic designs are meanwhile decades old. Latest technologies are applied on some elements but are not used to improve the overall design and architecture. Miniaturisation and cost reduction in RF systems is currently the domain of commercial markets and has achieved remarkable results. The spin-in from commercial markets will open lots of opportunities to improve spaceborne active array antennas in terms of manufacturing cost and mass. The main challenges to be addressed: 1) cost and complexity of the array 2) mass and volume 3) number of components (radiating elements, phase shifters, power combiners).

Elements of investigation within the activity:

System and subsystem level:
- Critical review of system requirements in interdisciplinary teams (array designer, hardware and AIT engineers, system engineers) in order to reduce the challenges on hardware level.
- Review of classical AIT approaches. Shifting e.g. building block performance verification to higher levels by exploiting the capabilities of digital controlled built-in calibration methods.
- Modular array antenna designs configurable by element building blocks
- Review of relevant commercial technologies and elements and mapping to potential space-borne usage.
- Trade-off Analog vs Digital vs Hybrid Beamforming

Hardware and technology level:
- Higher integration levels by e.g. radiator integration with TR electronic modules
- Higher integration of the TR electronic modules by single chip approaches
- Metal only vs dielectric based trade-off for antenna components
- Reducing the mass of energy storage elements by using advanced power conditioner
- Digital Beamforming pre-processing of data
- Adoption of new advanced manufacturing techniques (e.g. ALM)
- Wireless array element control
- Data transmission within the array by means of optical fibres, optical or wireless free space links.
- Lightweight mechanical structures and deployment technology

The activity will be structured in two phases:
• In Phase 1 the activity will focus on system and subsystem levels and investigate into relevant commercial but qualifiable technologies to set the goal for the mass reduction compared to existing designs. A frequency shall be selected for the activity. The selected goal for mass per square meter (figure of merit) shall then be justified by e.g. the possibility to use a smaller launch vehicle. As well expected cost advantages by applying advanced technologies and AIT procedures shall be predicted. A preliminary array architecture shall be developed. Based on this preliminary architecture a demonstrator for the second phase shall be defined.

• In Phase 2 the demonstrator shall be designed build and tested. Based on the test results the expected performance and cost of full array shall be predicted.

**Deliverables:** Breadboard, Report

<table>
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<tr>
<th>Current TRL:</th>
<th>Target TRL:</th>
<th>Duration (months):</th>
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<td>4</td>
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**Target Application/Timeframe:** Next generation of Earth Observation SAR mission as e.g. Sentinel 1 Next Generation. Next generation of active payloads/antennas for telecom payloads.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic

Ref. Number: GT17-354ES

Budget (k€): 480

Title: Low-cost dongle for enabling satellite radio links on handheld devices

Objectives: The objective of this activity is to develop a breadboard of a low-cost dongle, enabling handheld devices with on-the-go satellite radio communications (satcom, GNSS, search and rescue, etc.)

Description: The evolution of smartphone and their software applications ecosystem, combined to the advent of low-cost wireless technologies, have significantly increased the opportunities to access many wireless capabilities on handheld devices in a cost-efficient way. However, those capabilities do not yet address well the satellite ecosystem.

The proposed concept aims to enable handheld devices and PC with on-the-go access to satellite wireless capabilities thanks to a dongle: only for those requiring it, active only when needed and without impacting the cost of the generic handheld device or PC. The hardware constraints of satellite specific features (new GNSS bands, satellite-specific bands with higher power amplifier, etc.) are outsourced into a dongle, while all the other functions (processor, graphical interface, terrestrial telecom, sensors, etc.) already available in a standard handheld device remain at the lowest cost. The other satellite features would be embedded in the software of the handheld devices (e.g. as an “App”).

Previous activities proved the concept of an L/S band satcom block to be integrated into modular smartphone concepts. The proposed activity will leverage on their outcomes to enlarge the capabilities beyond smartphone modules and to a wider satellite ecosystem including (but not limited to): GNSS, Search and Rescue (SAR) and Automatic Identification System (AIS), digital radio, other satcom, etc.

Such capabilities could reduce Time-to-Market and significantly ease adoption of those satellite specific features by a wider user community. Beforehand, it needs to reach a TRL high enough prior to its adoption by the industry, therefore, the activity will aim the development of a breadboard of the dongle, and then demonstrate its capabilities for several use cases to be consolidated in the frame of the activity (e.g. AIS and SAR beacons, GNSS, etc.). The design will also be future-proof, covering VHF to C-band, which encompass most of the satellite bands associated to handheld or mobile devices.

The intended work includes the following tasks:

- Consolidation of use cases and derivation of the dongle requirements and candidate architectures
- Development of the hardware and integration with handheld devices
- Development of the software features enabling the different selected use cases (software drivers and applications)
- Demonstration with field trials

Deliverables: Breadboard, Reports

Current TRL: 3  Target TRL: 5  Duration (months): 18
Target: Technology push addressing identified mission needs such as the cost reduction of satellite related features for mass-market application and more flexibility to quickly enable new features.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Title: Generic in-orbit interference monitoring unit

Objectives: The objective of this activity is to develop an engineering breadboard of a flexible small-factor space-borne RFI monitoring unit, test the breadboard in a lab environment and develop a prototype of the flexible space-borne RFI monitoring device and pave the way towards an in-orbit demonstration platform (e.g. on board the ISS or a CubeSat).

Description: Spectrum management is a complex task that gets more and more important as new systems requiring making use of the RF spectrum appear. Unauthorized use of RF spectrum and/or out-of-band interferences can significantly affect the performances and the availability of space systems. It is therefore very important to provide European space missions with cost-efficient technologies able to monitor RFI.

Furthermore, the underlying technologies (e.g. versatile SDR, disciplined to orbit determination and synchronisation with reasonable accuracy) can be derived for processing other signals such as Automatic Identification System (AIS) signals (maritime users), Automatic Dependent Surveillance—Broadcast (ADS-B) signals (civil aviation users), etc. and so enable many more potential opportunities for the European space industry.

The unit shall be designed to achieve a small form factor (1U or 2U, compatible with nanosatellites) while preserving reasonable technical capabilities such as modularity, versatility for monitoring multiple bands, etc. Being small, the unit will also be attractive as a piggy-back payload coupled to the receiving antennas used by the main mission, to monitor potential interferers. The design trade-offs will also consider the integration of GNSS processing capabilities in the unit, in order to facilitate the orbit determination and time synchronisation required for allowing proper localisation of the interference sources.

Previous ESA activities have investigated different technologies for RFI detection and localization from space. The activity can leverage on the outcome of such activities in a step-wise approach, with the first step being a breadboard to be tested in the laboratory environment, and a second step being a unit paving the way towards in-orbit demonstrations.

The intended work includes the following tasks:

- Preliminary definition: State of the art review and identification of available building blocks, consolidation of use cases, identification of flights opportunities, derivation of the requirements and candidate architectures
- Detailed design (including definition of the concept of operation)
- Development of the equipment (EM)
- Testing/qualification in laboratory environment.

Deliverables: Breadboard, Reports

Current TRL: 3  Target TRL: 5  Duration (months): 24
**Target**  
Techno push, addressing identified mission needs (cost efficient spectrum management, monitoring and localization of interference in frequency bands used by space assets with a reasonable revisit time)

**Application/Timeframe:**

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
---|---
Ref. Number: | GT17-356ES
Title: | Advanced Remote Radio Head (RRH) module for scalable satellite radio communications stations in L/S/C/X bands
Objectives: | The objective of this activity is to develop a novel Remote Radio Head (RRH) module for scalable satellite radio communications stations, which would combine the advances in Software-Defined Radio (SDR), terrestrial RRH and antenna array / beamforming technologies into an integrated, highly scalable and flexible concept.
Description: | Remote Radio head and base station virtualization are identified among enablers of future terrestrial wireless network, such as 5G, to address needs for cost-efficient enhancement to: scalability, flexibility and more and more important, security. Indeed, the RRH concept allows to centralize all the application-specific functions in a central processing centre, highly flexible and scalable thanks to the ease to parallelize as many processors as required with reduced maintenance cost. This centralization, combined to the simplified external interfaces brings also significant benefits from a security point-of-view. Similar concepts could apply to the wireless links of satellite systems and have been investigated focusing mostly on the "bitgrabber / signal recorder" technology. Meanwhile, antenna arrays and beamforming solutions are more and more investigated and introduced with different motivation in ground infrastructure: management interference for GNSS reference stations, improve agility and reduce cost of gateways, TTC stations for constellations.

This activity aims to converge the two trends into a single technology concept, scalable to multiple use cases and systems operating in L/S/C and X bands. It will breadboard a module combining RRH technologies and capabilities with an elementary antenna array, which could be tailored to different system needs through configuration and combination with other modules. The concept will benefit from the intrinsic flexibility and security of RRH, as well as of the module's scalability, increasing the number of modules to reach the specific mission needs (GNSS, satcom, TTC, etc.) in terms of performances / antenna gain / number of beams / etc.

The demonstration of the breadboard will aim two use cases (to be defined in the frame of the activity), involving elementary modules, as well as the remote processing in the ground segment core or central processing centre. The concept will be designed to cover as many use cases as possible, but will demonstrate 3, including the reuse of the module as a testing capability for satellite wireless links.

Deliverables: | Breadboard, Report
Current TRL: | 3
Target TRL: | 5
Duration (months): | 24
Target Application/Timeframe: | Techno-push addressing identified missions needs (improving cost-efficiency, scalability and security of ground stations used by wireless satellite links : GNSS, satcom, TTC, mission uplink and downlink, etc)
Applicable THAG Roadmap: | Not relevant to any Harmonisation topic
Ref. Number: GT17-357EF  
Budget (k€): 500

Title: Advanced technologies based on Groove Gap Waveguide designs

Objectives: The objective of this activity is to assess Groove Gap Waveguide technology for the manufacturing of RF hardware where metal-to-metal contact is critical (losses, PIM, movable parts, etc.).

Description: RF parts based on waveguides are manufactured in multiple pieces that are later assembled together. When possible, the designs are divided in areas with none or minimum currents in order to, for instance, reduce losses, avoid radiation or minimize Passive Intermodulation (PIM).

Current trend is to move to high frequencies and higher degree of integration. This is translated in a high number of manufactured parts and complex stacked assemblies which, in most of the cases, are translated in increased losses, radiation issues, instabilities in the frequency response with temperature or vibration, PIM, among others. In the last years a contactless technology called Groove Gap Waveguide (GGW) has been extensively studied. It has been demonstrated to be a suitable technology to solve any metal-to-metal derived issue. First prototypes for stacked distribution networks, power combiners or filters can be found in the literature, providing promising results. The technology is especially interesting when considering high frequencies (Beyond 20 GHz).

This activity aims to assess the suitability of GGW technology for RF parts such as filters, waveguide switches, distribution networks, waveguide flanges and power combiners among others. Different parts, topologies and manufacturing approach shall be studied. At least two demonstrators shall be manufactured and validated by test, achieving TRL 5.

The activity shall cover, at least, the following tasks:

- Identification of systems and RF parts where GGW will bring improvements. Clear identification of aimed improvement (RF, Thermal, Mechanical, etc.).
- Review of available manufacturing processes. Assessment of suitability of each of them for the aimed RF parts.
- Detailed design and analysis
- Prototype manufacturing and test
- Conclusions and development plan.

Deliverables: Prototype, Report

Current TRL: 3  
Target TRL: 5  
Duration (months): 20

Target Application/Timeframe: RF Technologies for space applications.

Applicable THAG Roadmap: Consistent with activity D04 “Advanced technologies based on Gap Groove Waveguide designs: filters, switches, waveguides”
Title: Two-way Time Transfer and Ranging: in-orbit performance demonstrator

Objectives: The objective of this activity is to develop and test a compact Two-Way Time Transfer and Ranging (TWTTR) payload at EM level. Two-Way Time Transfer and Ranging (TWTTR) payload is a device enabling to bring a high-quality ground station time to a spacecraft.

Description: Two-Way Time Transfer and Ranging (TWTTR) a technique enabling to bring a high-quality ground station time to a spacecraft. The TWTTR can measure the time difference and range independently of high-rate GNSS data products, clock and orbital corrections. The target timing performance of the system is in order of femtoseconds (at integration time of 1s) in the short term, and in the long term it shall be limited by ageing of calibration cable loops and passive signal paths. The TWTTR technique has a very high potential of being embarked with a small payload on future missions requiring precise and accurate timing and ranging.

In order to demonstrate the capability of TWTTR, one or both of the following payloads shall be manufactured and tested to EM level:
- TWTTR-a: mostly analogue, transparent TWTTR transponder, suitable for integration to LEO/MEO nanosat;
- TWTTR-d: digital, direct wideband sampling TWTTR modem, suitable for integration to LEO Earth observation or MEO navigation spacecraft.

TWTTR-a is an analogue transponder combining the uplink and downlink timing-ranging signals together with a portion of GNSS band received at LEO/MEO spacecraft, and mixing all these signals together with on-board time generated by a miniature atomic clock, sending the mixture via downlink. Due to mission limitations of a generic technology nanosat mission, the TWTTR-a shall use S-band up/down link. The EQM deliverable has to include nanosat-compatible planar antennas. TWTTR-a does not perform any on-board processing of the timing-ranging signals.

TWTTR-d is a modem consisting of an independent transmitter subsystem, transmitting PN-coded timing-ranging signals, and a receiver subsystem which is capable of very high-bandwidth (sub) sampling of input VHF/UHF/microwave signals. The receiver subsystem is based on direct RF sampling and FPGA-based PN-code/carrier tracking. TWTTR-d has to provide the measured observables via a suitable communication interface (SpaceWire) to on-board data handling system. The TWTTR-d shall be versatile enough to allow integration into the Earth-observation mission, and/or navigation spacecraft. The microwave bands used could then include L/S/X-band.

Main tasks to be performed under this activity:
- Develop, manufacture, verification and validation of E(Q)M of one or both of the selected variants of TWTTR
- Carry out on-ground performance measurement campaign of E(Q)M.

Deliverables: Engineering/Qualification Model, Report

Current TRL: 4  Target TRL: 6  Duration (months): 18
**Target Application/ Timeframe:**
Navigation GNSS (Galileo), EO (SAR, Radar Altimeters, Radio Occultation, nanosat, EO, small payloads requiring timing/ranging...), all atomic clock characterization experiments, Science (e.g. Event Horizon Imager).

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
### Domain

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<th>Ref. Number:</th>
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<th><strong>Budget (k€):</strong></th>
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**Title:**
Adaptive interference monitoring technology for ground infrastructure using Software-Defined Radio and Artificial Intelligence

**Objectives:**
The objective of the activity is to develop the breadboard of a RF Interference (RFI) monitoring technology relying on cognitive Software-Defined Radio (SDR) and Artificial Intelligence (AI), for ground infrastructure of space assets.

**Description:**
Space missions are impacted by RFI regardless of their nature (e.g. GNSS, TTC payload and remote sensing telemetry, satcom, etc.) and need means for monitoring, characterization and localization of such RFI in order to adopt proper countermeasures. Other drivers include cost-efficiency, flexibility and scalability to adapt to the different ground segment needs, and ideally, comply with embedded mobile operations (hosted on handheld, vehicle or Unmanned Aerial Vehicle) to ease or expand operations and reactivity of the infrastructure operators.

The proposed monitoring technology and breadboard will leverage on the advent of miniaturized, cost efficient SDR with the recent advances in cognitive radio and AI algorithms. Such versatility and adaptability, combined to cost-efficient SDR, is expected to reduce the cost of deployment and operation, without sacrificing the performances. Use of AI is foreseen and already investigated for wireless systems, in particular for cognitive radio (spectrum management and sharing to enable new resources in satellite communications). This activity will therefore integrate the lessons-learned of the ongoing investigations to identify the most suitable use of AI in the context of interference management (monitoring, characterization and localization). Beyond the tuning to different system needs (e.g. frequency, channels, etc.), such approach will allow tailoring the solution to the specificities of the ground infrastructure, for instance, adapting:

- To the context and the specific needs of the ground infrastructure (e.g. site configuration, steady-state RF environment, etc.)
- To the properties of each RFI properties (waveform signature, trajectory, etc.)
- The geometry and the algorithms of the monitoring system to optimize localization to each RFI (for instance deploying drone to extent line-of-sight, enhance localization geometry, etc.)

The intended work includes the following tasks:

- Consolidation of use cases, candidate monitoring architecture and derivation of requirements for the SDR and its algorithms (leveraging on existing building blocks and low TRL investigations under other programs)
- Development of the monitoring components and training of the features relying on AI
- Testing in controlled environment (laboratory, anechoic chamber)
- Demonstration with field trials (for testing the concept in field trials without degrading the spectrum resources, the interference could be replaced by authorized signals).

**Deliverables:**
Breadboard

**Current TRL:** 3  
**Target TRL:** 5  
**Duration (months):** 24
Target Application/Timeframe: Technology push (novel solution, architecture and AI technologies) to address well identified mission needs

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
3.1.6 CD6 - Life / Physical Science Payloads / Life Support / Robotics and Automation

<table>
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Title: Mobile cleanliness and contamination verification facility

Objectives: The objective of this activity is to design, build and test a mobile test and verification facility for cleanliness and contamination monitoring.

Description: The implementation and verification of cleanliness and contamination requirements is an important part of many space missions. This however can pose significant challenges to industry and R&D institutions, which do not have the appropriate infrastructure. Often the verification needs to be done immediately within the AIT process, sending samples to a qualified laboratory, requires time and may delay the process.

In addition, the standards for verification of cleanliness requirements leaves ambiguity in the implementation and verification for the implementing parties. A mobile “one-stop-shop” to provide support to different stakeholders within a project, using standardized method for verification and skilled personnel may resolve this. It enables as well high quality support e.g. at a launch site which does not have the appropriate infrastructure. Cleanliness verification and health checks w.r.t contamination can be as well performed at the landing site of an interplanetary sample return mission with such a unit. The facility is accommodated in a transportable/shippable container. The lab layout will include a HVAC system ensuring cleanliness inside the container, lab support equipment and all the equipment necessary to verify particular, molecular and biological cleanliness. The operation of this container can be performed by industry and can be developed as a business model.

In order to achieve the objectives, in the activity the following tasks will be performed:

- Requirements Review/refinement
- Planning and design
- Procurement and build
- IQ/OQ of test facility and commissioning
- Application to test cases and operation.

Deliverables: Prototype

Current TRL: 3  Target TRL: 7  Duration (months): 12

Target Application/Timeframe: All missions which will require cleanliness and contamination requirement implementation and verification beyond standard AIT requirements.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Title: Structural health monitoring of space structures subject to creep

Objectives: The objective of this activity is to develop a structural health monitoring (SHM) technology able to detect and monitor creep in space structures.

Description: Creep is a material aging process that consists in a permanent deformation of the component under persistent mechanical stresses, being more severe when the material is subject to high temperatures. This is a recognized issue in materials used in high temperature and high stress structural applications in space where, for metals, the phenomenon starts as grain boundary misalignments/discontinuities and develops into micro-cracks, then cracks and, ultimately, failure.

Currently, there is a large spectrum of non-destructive inspection (NDI) tools commercially available and able to detect damages and defects in most materials and structures. The most suited of these systems can be modified to address micro-cracks occurring in the material at the early stage of the creep phenomenon by having information fed in a PDA tool developed to predict the remaining life of the component resulting in a damage tolerant mechanical system.

The combination of NDI instrument development from previous projects (“NEWSI for Detection of hidden defects in composites and metals”) together with the advancement of virtual testing, opens up the ability to combine both aspects into a new Structural Health Monitoring (SHM). This SMH promises a high potential to customize the detection for specific designs and structures, as well as to improve the sensitivity, and is expected to have applications in the field of launchers and reentry vehicles, where creep is a recognized issue. In addition, the field of human spaceflight safety may benefit from it, addressing remaining life of space structures and damage tolerance topics.

The major tasks to be performed in the activity include:
- Develop a progressive damage analysis (PDA) tool to model creep in materials and structures.
- Definition of test campaign to validate the progressive damage analysis tool.
- Evaluate test results and iterate the previous two tasks as necessary in order to optimize the PDA tool.
- Develop and/or adapt currently available non-destructive evaluation systems for measuring creep in the materials and structures previously identified and for the selected tests.
- Definition of test campaign to verify the SHM system.
- Manufacture Reference Defect Artefacts (RDAs) and control samples as well as provision of test structures.
- Evaluate test results and iterate previous three tasks as necessary in order to optimize the outcome.
- Consolidation and final analysis of results including future exploitation scenarios.

Deliverables: Breadboard, Report

Current TRL: 3  Target TRL: 5  Duration (months): 18
Target Application/Timeframe:

Structures for space applications

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Ref. Number: GT17-362MM

Budget (k€): 5,200

**Title:** Grasping and refuelling system development (TANKERS)

**Objectives:**
The objective of this activity is to increase the TRL of the ASSIST grasping/refuelling system developed under a previous TDE activity.

**Description:**
The previous activity addressed the analysis, design and validation of internal provisions (such as modifications to fuel, gas, electrical and data architecture to allow servicing) and external provisions (such as integrated berthing fixtures with peripheral electrical, gas, liquid connectors, leak check systems and corresponding optical and radio markers for cooperative rendezvous and docking) for a grasping refuelling system.

A fully functional full-scale breadboard of the ASSIST end-effector and grapple fixture was designed, built, tested and served to identify avenues for further refinement and advancement of the underlying technologies. The refuelling system was designed and TRL 4 was successfully achieved. A fully functional full-scale breadboard end-effector and grapple fixture were designed, built and tested. The test program included functional verification of the fuel transfer operations under representative thermal-vacuum conditions using fuel simulant. In addition, a ½ scale dynamic model was built and used in an air-bearing facility to study and characterize the dynamic behaviour of the system during final approach and docking.

The proposed activity is to be split into four phases:

- **Flight System Design (800k, 12 months):**
  - Preliminary design of the flight system provisions (e.g. end-effector, berthing fixture) that was used as the basis for the design of the breadboard models. In the activity, the ASSIST system design is to be updated and refined taking into account the lessons learned in the test campaign.
  - System components upgrade to flight quality that can withstand the on-orbit environment (thermal, mechanical, radiation). Considering the concurring development of the Xenon interface, the activity in subject shall concentrate on bi-prop fuel (2 lines) and a high-pressure gas line (helium).
  - The visual servoing system (used to guide the end-effector during terminal approach) and the interfaces to the robotic arm shall be elaborated and implemented.
  - The design activity is also foreseen to include structural and dynamics loads analyses and design verification in software simulations of the rendezvous and docking operations.

- **Engineering Model Manufacturing and Integration (1500k, 8 months)**
  - Flight system design in a set of engineering models of the complete refuelling system, including the external and internal provisions.
  - The models shall be built using flight representative parts and components according to ECSS standards. The models will be used in the subsequent verification and qualification activities.
  - The engineering models also include the corresponding control software, which handles the internal operation of the refuelling systems as well as the interfaces to the servicer spacecraft. The software is to be
designed and implemented on flight representative processing hardware.

- The unit-level testing and verification of the refuelling system is also included in this part of the activity.

- **End-to-End Functional Verification (1500k, 8 months)**
  - Dynamic verification of the rendezvous and docking, foreseen to be a system-level end-to-end verification, including close-loop visual servo tracking during the terminal approach, using hardware-in-the-loop 6DOF space dynamics simulators.
  - The simulator emulator of the dynamics and attitude control systems of the client and servicer spacecraft, the robot arm and end-effector control systems, the expected orbital lighting conditions.
  - The tests shall also include end-to-end fuel transfer operations; first using simulants, and then using the actual fuels that will be used on-orbit, including both liquid as well as gaseous propellants.

- **Environmental Qualification (1400k, 8 months)**
  - Following the successful end-to-end functional verification, an environmental qualification test program is foreseen to qualify the TANKERS system.
  - The test campaign will include thermal (TVAC cycling), mechanical (shock and vibration), and electromagnetic compatibility (ESD, EMC) qualification tests as required by ECSS the ECSS standards to qualify the refuelling system elements design.
  - The results of the design, development, and verification activities in TANKERS will be captured in an update of the refuelling standard preparation document that was produced in ASSIST. The updates will include design updates, manufacturing drawings, control software libraries, and system performance and qualification limits as determined by test.

**Deliverables:** Engineering and Qualification Model of the refuelling provisions of the services and client spacecraft, Report

**Current TRL:** 4  
**Target TRL:** 7  
**Duration (months):** 36

**Target Application/Timeframe:** Space servicing vehicles.

**Applicable THAG Roadmap:** Consistent with activity C03 “TRL Augmentation Needed to Keep-up European Refuelling Standard (TANKERS)”
Title: Sustainable biopolymers for space applications

Objectives: The objective of this activity is to assess the applicability of biopolymers for space applications. Use cases shall be defined and appropriate tests and mapping of the material properties in relevant environment shall be performed, recommendations shall be given as to how the material properties can be enhanced and adapted to the use cases.

Description: Biopolymers are polymers which occur naturally and are being produced by living organisms. These include essential building blocks like polynucleotides, polysaccharides but as well rubbers, lignines, etc. One biopolymer of specific interest are silk proteins as produced commonly by a variety of arachnid.

Recently advances in bioprocess engineering enabled the production of these polymers using Genetically Modified Organisms (GMO) in a patented batch process. This enables the production of sufficient amounts of raw material. Spinning processes are available on a pilot scale to process the resulting raw material into fibres and then fabrics and garments which demonstrate valuable properties in terms of elasticity, yield strength etc. Spidersilk for instance has similar yield strength than Nylon6,6 but three times as much elasticity and energy absorption capabilities. The use of these materials is already being considered for aircraft applications.

The objective of this activity is to assess the applicability of these fibres and other potential biopolymers for space applications, such as soft fabrics used for gowing, MDP blankets, parachutes, structural materials. Use cases shall be defined and appropriate tests and mapping of the material properties in relevant environment shall be performed, recommendations shall be given as to how the material properties can be enhanced and adapted to the use cases.

An exploratory de-risk activity may be performed to assess the potential for space specific applications and give recommendations for further work.

For instance, synthetic spider silk is more sustainable in its production and recyclable.

This activity is in line with the requirements for advanced manufacturing and materials and clean space/sustainability.

The activity shall evaluate the feasibility of biopolymers for space applications:

- Review state of the art and industrial capabilities for biopolymers.
- Review possible space applications for biopolymers including space transportation, satellites, and human exploration.
- Develop breadboard demonstrators for at least two space relevant biopolymer applications
- Assess the material properties and performance under relevant space environment
- Assess the potential and establish a roadmap for future technology development needs

Deliverables: Demonstrator, Report

Current TRL: 3  Target TRL: 6  Duration (months): 20

Ref. Number: GT17-363MM  Budget (k€): 600
Target
Application/ Clean Space, use of sustainable materials
Timeframe:

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Dynamics of contamination on nozzle surrounding surfaces as well as water recycling technology

Objectives: The objective is to build and test a setup for the verification of liquid droplet dynamics. This serves on one hand to model better the propulsion nozzle contamination of nearby surfaces, and demonstrates and validates on the other hand the performance of a novel air humidity removal device.

Description: This problem is not well characterised in weightlessness conditions. On the other hand, for applications in ECLS systems, efficiently removing humidity/droplets from a two phase flow is energetically demanding and a recurrent challenge under reduced gravity. This activity targets the development of a microgravity payload up to an engineering model: The payload will support both a scientific study and a technology demonstration. The scientific study is centred on the contamination of the surfaces nearby a propulsion nozzle due to the impingement of droplets expelled from the nozzle itself: first, an analysis and/or simulation of the behaviour of the exhaust mixture will be performed, which will then be compared to the results obtained from the test campaign performed in a relevant environment (parabolic flight). At the same time, the demonstrator is aimed to validate the performance of a novel air humidity removal device (e.g. based on membrane technology) for life support systems. During the test campaign, the moisture produced by the nozzle spray will be removed with this device, testing its efficiency against the theoretical model.

Main tasks:

- Modelling the behaviour of nozzle exhaust droplets and their impingement on surrounding surfaces in representative conditions
- Modelling the humidity removal efficiency of the novel device in representative conditions
- Identification of the most challenging aspects and design of a breadboard model to test them
- Breadboard building and test performing, preferably in relevant environment (parabolic flight)
- Test data analyses, report and future work plan

Deliverables: Breadboard, Report

Current TRL: 3  Target TRL: 5  Duration (months): 24

Target Application/Timeframe: Any new propulsion system and life support systems for exploration

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
3.1.7 CD7- Propulsion, Space Transportation and Re-entry Vehicles

<table>
<thead>
<tr>
<th>Domain</th>
<th>Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles</th>
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<tr>
<td>Ref. Number:</td>
<td>GT17-365MP</td>
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<tr>
<td>Title:</td>
<td>Development of standard test equipment for dynamic thrust measurements</td>
</tr>
<tr>
<td>Objectives:</td>
<td>The objective of this activity is to develop test equipment and a standard measurement practice to enable dynamic thrust measurements (e.g. thrust impulse, noise, response time, Minimum Impulse Bit) of Chemical, Cold Gas and Electric Thrusters.</td>
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<tr>
<td>Description:</td>
<td>With the underway exploitation of nanosats for commercial, science and Earth observation missions, there is a clear need to develop European Propulsion Systems serving these class of satellites. The introduction of propulsion functions on these classes of satellites is enhancing their performances and utilization perspectives. Currently European test facilities mainly allow static measurements, but not dynamic testing. However, one of the key propulsion requirements is to operate the thrusters in pulse mode. This activity intends to define a standard measurement practice and to develop a standard test equipment to enable dynamic thrust measurements. This measurement capability for small thrust levels is not currently available at most test facilities. The test equipment shall be able to be integrated in any European test facility.</td>
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<tr>
<td>The following tasks will be done in the frame of this activity:</td>
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<tr>
<td>• Assess the requirements for dynamic thrust measurements coming from current and future nanosat missions and derive the test equipment specification</td>
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<tr>
<td>• Design the test equipment</td>
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<tr>
<td>• Define a standard measurement practice</td>
<td></td>
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<tr>
<td>• Commission the test equipment with a Chemical Thruster, a Cold Gas Thruster and an Electric Thruster (Test Plan and Test Report)</td>
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<tr>
<td>• Install the test equipment and acceptance test</td>
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<tr>
<td>Deliverables:</td>
<td>Breadboard, Report, user manual</td>
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<tr>
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<td>Target TRL:</td>
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<td>Duration (months):</td>
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<tr>
<td>Target Application/Timeframe:</td>
<td>Diagnostic equipment for ground verification of propulsion for nanosats and of auxiliary propulsion.</td>
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<td>Applicable THAG Roadmap:</td>
<td>Electric Propulsion Technologies (2017) Consistent with activity F01 “Standardization of engineering processes and testing facilities employed in the design, manufacturing and qualification of the current electric propulsion systems”</td>
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## Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles

<table>
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<th>Budget (k€): 500</th>
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### Title:
Novel AIT techniques to lower the price of electric propulsion equipment

### Objectives:
The objective of this activity is to prototype novel Assembly, Integration, and Testing (AIT) techniques and technologies that would drastically lower the price of Electric Propulsion (EP) equipment. The activity shall be focused on thruster assemblies, tanks, and propellant management units.

### Description:
The current price of EP propulsion systems is very high and drives the cost of the development of new spacecraft relying in this kind of propulsion. For the underway development of new nanosats for commercial, science and Earth observation missions, there is a clear need to cut the cost of Electric propulsion systems developed by European providers.

One way to lower the cost (and hence the price) of EP systems is in the areas of Assembly, Integration, and Testing (AIT) techniques and technologies. The AIT process of EP systems is very demanding and represents more than 30% of the complete cost of the entire EP system. The final objective of this activity is to sustain European competitiveness and enhance innovations of European products in the global market.

Within the present activity, the following tasks shall be done:

- Establish a business case for AIT techniques and technologies that have the potential to lower the price of any Electric Propulsion system equipment and for a sustainable supply chain for space applications.
- Apply new techniques and technologies for the AIT processes that could reduce costs in associated to time, manpower, materials and required equipment to complete the processes. This task will look into virtual reality tools, augmented reality, etc.
- Select at least one equipment (Thruster, Tanks and Propellant Management Unit) that will benefit from novel AIT techniques and where AIV efforts, cost, mass, or lead-time can be significantly reduced. Define an end-to-end AIT process and define the corresponding AIT plans and procedures.
- Prototype a new AIT processes with the final objective of rebuilding the selected equipment.
- Verify by test the equipment identifying impacts (if any) on cost, time, performance, qualification and consequences of later design adaptations.
- Critically review and refine the business case and the estimated ROM effort for full flight qualification.

### Deliverables:
Breadboard, Report

### Current TRL: 4  
### Target TRL: 5  
### Duration (months):

### Target Application/Timeframe:
Electric Propulsion systems for nanosats.

### Applicable THAG Roadmap:
Relevant to the Roadmap Electric Propulsion Technologies
Domain | Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles
--- | ---
Ref. Number: | GT17-367MP
Title: | Material point method for sloshing and multiphase flows
Objectives: | The objective of this activity is to develop, test and validate a numerical tool to verify the applicability of the Material Point Method (and/or its derivatives) for the accurate and efficient simulation of sloshing and multi-phase problems in reduced gravity conditions.
Description: | For the accurate modelling of free-surface and multiphase flows (e.g. sloshing) a robust numerical method is required that can handle large surface deformations while strictly conserving mass. Classical CFD methods solve the governing equations on (un)structured meshes, which could decrease accuracy and increase instabilities when the fluid surface is misaligned with the mesh. In addition, surface reconstruction methods are needed to extract the gas-liquid interface, which is not strictly mass-conserving.

Long-duration sloshing simulations are therefore difficult to achieve without artificially adding or removing mass. Mesh-free particle-based methods, like Smooth Particle Hydrodynamics (SPH), are mass-conserving by definition and are theoretically very suitable for these kind of flows. However the pure particle-based SPH methodology makes it difficult to prescribe wall-contact angles, required for low-gravity conditions, and could suffer from numerical instabilities.

The Material Point Method (MPM), and its derivative methods like the Generalised Implicit MPM, could potentially solve both issues by combining the advection of fluid particles with a background mesh for the computation of secondary variables. In addition, the particle-based methodology makes it ideal for massively parallelisation on (cheap) GPU clusters. The MPM is starting to find its adoption in many fields of scientific computing in the last five years, and could potentially enable the long-duration multiphase flow simulations that are currently difficult to achieve.

The following tasks are envisaged:
- Definition of state-of-the-art. This task is devoted to the investigation of the state-of-the-art of the Material Point Method (MPM), its derivative methods like the Generalised Implicit MPM, and other hybrid particle/mesh methods. In addition, a thorough literature research on numerical models for phenomena associated to low Bond number flows (e.g. dynamic wall-contact angle models) will be performed.
- Development and implementation. This task will comprise of the design, development and implementation of algorithms and methods, identified in previous task, in a numerical solver. The solver should be developed to demonstrate the applicability (in terms of accuracy and computational expense) of the method for low-gravity sloshing and multiphase problems in isothermal conditions.
- Testing and validation. This task will provide the testing and the validation of the solver. This task will also provide the validation of the design and the algorithms, as well as the numerical simulations. Comparisons between the developed code and conventional mesh-based fluid dynamic solvers (in terms of accuracy, stability and computational expense) will be made.
• Conclusions and next steps. This task will provide lessons learnt, conclusions and roadmaps for the future activities. Future activities could then build on this developed tool, to extend it to include phase-change phenomena and cryogenic conditions.

**Deliverables:** Report, Demonstrator Software

**Current TRL:** 3  **Target TRL:** 6  **Duration (months):** 12

**Target Application/Timeframe:** All missions that are using chemical propulsion, TRL 8 by 2023

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
## Domain

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<tr>
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### Title:
Computational fluid dynamics acceleration through hardware

### Objectives:
The objective of this activity is to investigate, develop and implement techniques to accelerate computational fluid dynamics by means of GPU and/or reconfigurable hardware and to apply such hardware acceleration techniques to conventional available CFD solvers.

### Description:
High performance computing is advancing at the same pace as the numerical algorithms increase complexity. In order to shorten the design iterations during concurrent design and to speed up troubleshooting by analysis, a fundamental change of the computational paradigm is required. Development of novel optimum algorithms has always been one of the way towards this end, the other being the advances in hardware, namely multiple core / multiple CPUs architectures have enabled speed up by means of job parallelization. General purpose GPU have enabled a significant speed up but oftentimes this comes at the cost of tailoring of the algorithms, thus making this technology only available to some specific methods, e.g. lattice Boltzmann. On the other hand, the use of reconfigurable hardware like FPGA has been suggested or even applied to numerical solvers of fluid dynamics. In this case, the potential speed up may largely trade-off for the added complexity of a simultaneous coding by hardware and software, and may eventually enable real time CFD. Previous works have looked into e.g. the application of FPGA programming to the CFD code TAU.

The activity shall trade-off the different options for hardware acceleration and define the most efficient architecture for implementation of CFD solvers. The ultimate goal shall be decreasing the computational time in one order of magnitude or more. The physical implementation shall require a minimal tailoring of the CFD codes and be as generic as possible to host any CFD while achieving similar levels of high performance. The performance gain shall be demonstrated for both time-accurate and steady state CFD solvers.

The activity will comprise the following tasks:
- Consolidation of the requirements
- Prototype implementation and testing
- Deployment

### Deliverables:
Prototype, Product release, Report

### Current TRL: 2  
### Target TRL: 6  
### Duration (months): 12
Ref. Number: GT17-369MP

Budget (k€): 800

Title: Disruptive conceptual sizing and cost optimization methodology of reusable flight vehicles

Objectives:
The first objective of the activity is to develop a tool able to assess mass, volume, and power budgets of an expandable and reusable vehicle and its on-board system as from the conceptual design phase. The second objective is to develop a tool that can assess the related cost for the overall concept in terms of recurring and non-recurring costs.

Description:
This activity targets both space exploration and space transportation systems in the areas of re-usability for flight vehicle engineering. The space exploration re-usability concepts are required in the exploration activities for example where re-usability of a landing stage on the Moon is a key feature. For space transportation systems re-usability of launch stages is a key feature for launch price reduction. The research goal will be pursued through the implementation and exploitation of ad-hoc surrogate models per each main equipment. Surrogate models are mathematical relationships, which express mass and volume as functions of physical and performance characteristics. Surrogate models will be based on the combination of results coming both from functional simulations and current statistical data.

The economic sustainability shall be considered in this overall process, not only from the point of view of development and production costs but also from the operation and exploitation perspective. Appropriate cost models shall be implemented able to cover development and operational costs, (non)-recurrent costs considering both expandable and reusable applications.

The following tasks are contemplated:
- Definition of the surrogate models: data mining of relevant on-board systems and the creation of a database in terms of performance, size, mass, power, geometry, etc. This task will provide the creation of the surrogate models allowing proper scaling and sizing during the process of the conceptual design.
- Incorporation of the surrogate models into a modular tool. This task will comprise the insertion of the models into a tool that will allow the conceptual sizing and its optimisation. The tool should be robust, easy to use and maintain and should allow quick iterations.
- Development of a costing model in terms of recurrence and non-recurrence for each of the subsystems. This task should also cover the tailoring towards the actuarial sizing of the subsystems.
- Conclusions and next steps. This task will provide lessons learnt, conclusions and roadmaps for the future activities.

Deliverables: Report, Software

Current TRL: 3 Target TRL: 6 Duration (months): 18

Target Application/ Timeframe: Space transportation and exploration missions

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Morphing of aero-thermally loaded structures

The objective of this activity is to develop a demonstrator to adapt an aero-thermal load geometry during operation. This is possible by exploring the potential of adapting the geometry when exposed to high aero-thermal loads.

During the high-speed part of an ascent or descent trajectory, the geometry of the inner or outer flow path needs to be adapted to optimize the operation of the propulsion unit or the aerodynamic efficiency of the vehicle. This could e.g. be a variable intake or nozzle, adaptable leading or trailing edges. This morphing capability would have the additional advantage that gaps or cavities around intake panels or a rudder for example are not any longer present and hence local hot spots and sneak flows can be avoided.

The activity will develop a demonstrator which structure consists of a high temperature resistant non-metallic materials and can adapt its geometry during operation in a high enthalpy flow, e.g. in a plasma or vitiated/connected tube tunnel. This demonstrator would represent e.g. an adaptable nozzle or intake throats, compression or expansion contours, flight control surfaces, etc.

The following tasks are contemplated:

- Definition of the operational conditions for a representative propulsion system, flight vehicle and trajectory path. This task will take into consideration exploration, space transportation and scientific missions whereas the application shall be transferrable to mono- and bi-propellant, cryogenic and air breathing systems and different atmospheres (Air, CO2). The defined operational conditions shall be easily achievable on existing test rigs wrt safety and costs. In that respect, exploiting the flexibility of wind tunnels with stagnation temperatures above 1000K shall be preferred covering both external and internal flow paths (e.g. resp. control surfaces, various atmospheres, air breathing propulsion). Preference is given to propulsion systems.

- Definition and design of a generic morphing-able geometry. This task will comprise the definition and the design of the shape, geometry, and aero-thermo-mechanical loads. This task will also provide the design of the mechanism for the morphing in terms of structures and materials. This task will provide the required algorithms of the morphing.

- Manufacturing of a structural demonstrator with morphing. This model will allow the testing in a high enthalpy wind tunnel.

- Testing and validation. This task will provide the testing inside the wind tunnel. This task will also provide the validation of the design and the algorithms, as well as the numerical simulations.

- Conclusions and next steps. This task will provide lessons learnt, conclusions and roadmaps for the future activities.

Deliverables: Engineering Model, Report

Current TRL: 3  Target TRL: 6  Duration (months): 24
Target Application/Timeframe: Scientific, Space Transportation systems, and exploration missions. TRL 8/7 by 2023

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
3.1.8 CD8 – Ground Systems / Mission Operations

<table>
<thead>
<tr>
<th>Domain</th>
<th>Generic Technologies - CD8 - Ground Systems / Mission Operations</th>
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<tbody>
<tr>
<td>Ref. Number:</td>
<td>GT17-371GD</td>
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<tr>
<td>Title:</td>
<td>Operational migration to multi-mission control system</td>
</tr>
<tr>
<td>Objectives:</td>
<td>The objective is to explore and demonstrate migration approaches for critical operational systems (such as the Mission Control System or the Ground Station Monitoring and Control Systems) from the current generation to the new ground segment developments, hosting and supporting multiple missions.</td>
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<tr>
<td>Description:</td>
<td>Long-lasting missions currently in operations using the old generation of control systems will face obsolescence of these critical systems in the next decade. The adoption of the new generation systems as well as their hosting in shared infrastructure providing multi-mission services will bring a solution to the obsolescence problem while enabling a significantly more efficient process to maintain and evolve the control systems.</td>
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Cloud computing and the “Software as a Service (SaaS)” paradigm has gained momentum in recent years. Instead of dedicated deployments, software and computing resources can be more efficiently provided through centrally hosted services. The same paradigm can now also be applied at application level, using recently developed technologies enabling automated and incremental deployment of scalable systems. The proposed activity will investigate how such models may be adopted at the operational level and how this may be achieved based on the new generation control systems. The main challenges relate to the need of converting data and migrating a system ‘during continuous operations’ as well as to the capability of consolidating multiple independent control systems within the same cloud computing platform. Issues related to the synchronization of common software components shall also be addressed. |

The main output will be an operational demonstrator of feasibility and adequacy of the selected approach. The focus will be on how multi-mission M&C services can be evolved from dedicated mission specific deployments to a model based on shared services and resources. |

The activity main tasks will be:
- Analysis of Cloud technologies and their possible deployments to support the provision of shared (multi-mission) operational services,
- System level architectural design analysing in particular the security and reliability architectural implications for ground segment based systems,
- Definition of processes related to development, maintenance, deployment and operations,
- Analysis and selection of the migration approach for systems in operations,
- Production of an operational demonstrator providing adequate confidence in the adequacy of the select migration approach. |

Deliverables: Software, Reports

Current TRL: 5 | Target TRL: 7 | Duration (months): 15
<table>
<thead>
<tr>
<th>Target Application/ Timeframe:</th>
<th>Currently in operation and future missions / Validated for implementation and deployment 2024</th>
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</table>
### Domain

**Generic Technologies - CD8 - Ground Systems / Mission Operations**

<table>
<thead>
<tr>
<th>Ref. Number:</th>
<th>GT17-372GS</th>
<th>Budget (k€):</th>
<th>400</th>
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</table>

#### Title:

**10Gbit/s protocol ground implementations**

#### Objectives:

The activity aims to implement high data rate (10 Gbit/s) ground spacelink protocol systems with low cost hardware, based on COTS PC hardware, in order to avoid costly implementation on Field Programmable Gate Arrays (FPGAs).

#### Description:

The use of optical and K-band (26 GHz) links for future Earth observation missions will allow data rates up to 10Gbit/s. These high speed data streams need to be handled on ground in terms of protocol implementations. Initial tests and recent developments of PC hardware have indicated that this performance could be achieved on standard PC technology.

New CCSDS protocols like USLP cater for higher data rates by allowing larger frame structures but haven't been exercised at these high rates yet. The activity shall prove the feasibility of PC based high performance protocol implementations on ground.

The use of standard hardware is considered desirable for cost and flexibility reasons and will allow easy integration into existing infrastructure.

EO mission using K-band (26 GHz) and Optical LEO DTE high rate downlinks require processing of data streams on the downlink at high rates, preferably using CCSDS standards. Open CCSDS standards are guaranteeing interoperability and avoid proprietary solutions as well as vendor lock-in. The envisaged protocol layering aims at reducing the on-board implementation complexity by allowing a distribution of protocol implementations among faster implementations at the data link layer and application layer implementations with relaxed performance requirements. In general, optical ground stations will allow high data rates at the expense of less predictable link conditions due to weather, which will be mitigated by opportunistic station scheduling. Higher layer network protocols will allow flexible and efficient use of an optical ground network and ensure automatic delivery to end users and data processing centres.

The following tasks will be done in the frame of the activity:

- Evaluate current PC hardware suitable for high protocol implementation (PCIe 4.0, SAS-4, SSDs, 40Gbit/s Ethernet)
- Build a testbed of 2 PCs and perform a performance assessment in terms of network throughput, disc I/O and processing
- Implement and assess performance using USLP frames (CCSDS 732.1-B-1) for high speed data transfer
- Assess and potentially improve performance of existing protocol implementations over USLP - LTP - CCSDS 734.1-B-1 - Bundle Protocol - CCSDS 734.2-B-1- CFDP - CCSDS 727.0-B-4

#### Deliverables:

Breadboard, Report, Software

<table>
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<tr>
<th>Current TRL:</th>
<th>4</th>
<th>Target TRL:</th>
<th>6</th>
<th>Duration (months):</th>
<th>14</th>
</tr>
</thead>
</table>

**Target Application/Timeframe:** Missions with need of high data rates up to 10Gbit/s.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Title: Correlator for array of deep space large aperture antennas

Objectives: The objective of the activity is to develop a prototype of a real-time correlator that implements the arraying of several large aperture antennas with the result of enhanced reception capability (3 dB better with two antennas). This enhanced reception capability can be used to receive higher telemetry data rate or to receive data from spacecraft with limited resources at an acceptable rate for the mission objectives.

Description: Future plans for ESTRACK include the possibility of a second antenna to be built in New Norcia and/or Malargüe opening the possibility of implementing an array with the two 35-m antennas at those locations and build the reception capacity equivalent of a 50m antenna. ESA deep space 35 m antennas are the state of the art for telemetry deep space reception. Future missions will demand an even better sensitivity or reception capabilities (the G/T of the antenna).

All deep space science missions will benefit from the enhanced reception capability. The double of the data can be received using the same on board resources. Alternatively the on board resources can be reduced (e.g. less RF power that implies less power requirements and less solar panels/batteries on board) but keeping the same data rate.

The outcome of the ESA GSP study "Future Architecture of ESA Deep Space Stations for Enhanced Mission Support" showed that the most effective way to increase the ground station sensitivity to get a higher TM downlink rate is via arraying of large aperture antennas. The plans of ESTRACK of building a second antenna at New Norcia and/or Malargüe open the possibility of implementing such arrays at these locations. Presently the only missing element to be developed is the array correlator.

The TDE activity T212-052GS “Prototype of off-line correlator for Arraying of large aperture antennas” has successfully developed the concept and arraying techniques required to implement this correlator but in an off-line configuration. The final correlator shall provide real-time performances at much higher data rates.

The activity shall comprise the following tasks:
- The design of a correlator suitable to combine signals from large aperture antenna arrays impaired with the phase instabilities (atmospheric effects, interferences, electronic/mechanical antenna equipment and satellite movement) present in the system.
- The building of a prototype (likely implemented with FPGAs), conceived for a minimum of 4 channels (including delay lines) to demonstrate the implementation of the function and validate in a laboratory environment the performances.
- The verification and validation of the correlator.

Deliverables: Prototype, Report

Current TRL: 3  Target TRL: 6  Duration (months): 24
Target Application/Timeframe: All missions will benefit from the enhanced reception capability, double of the data can be received using the same on board resources. Deep space science missions.

Applicable THAG Roadmap: Ground Station Technology (2015) Consistent with activity C02 “Prototype of correlator for Arraying of Deep Space Antennas”
Prototype of deionised cooling system for 80kW High Power Amplifier (HPA)

The objective of this activity is to develop the deionized cooling system required to operate an 80kW HPA. Together with the klystron tube the cooling system, providing deionised water to the klystron and to critical waveguide components, is one of the most critical sub-systems.

Present ESA deep space stations are equipped with a 20kW X-Band High Power Amplifier (HPA). Future missions will demand larger uplink power levels, for distant spacecraft or for critical phases like entry descending and landing or for emergency situations. A previous GSP activity “Future architecture of ESA deep space stations” concluded that the only viable way to increase the Uplink performances is providing the deep space terminals with an 80kW transmitter. A key element (together with the klystron tube) of these very high power amplifiers is the cooling system that shall provide deionised water to the critical components such as the klystron and the waveguide run.

The requirements of the different elements of the HPA are defined in the frame of a previous TDE activity T212-053GS “X-Band 80 kW Amplifier Pre-Development” where the initial assumptions for the cooling system have been derived from the present Deep Space klystron requirements.

This activity shall start from the specifications prepared in the TDE activity, and it will be structured as follows:

- Consolidation of the design and identification of critical and long lead items
- Definition of a test bench reproducing all thermal and hydraulic loads present in the 80 kW Klystron Power Amplifier
- Definition of a basic KPA M&C simulator to interface the cooling system
- Procurement of all components comprising the simulators and the cooling system
- Writing of all the codes for the controllers
- Assembly of the cooling system and the simulators
- Testing and acceptance of the prototype system.

Prototype, Report

Current TRL: 3  Target TRL: 5  Duration (months): 24

All deep space missions related to Science missions (i.e. JUICE mission in 2022), Space Weather missions, and Space Situational Awareness missions.

Not relevant to any Harmonisation topic
Domain: Generic Technologies - CD8 - Ground Systems / Mission Operations

Ref. Number: GT17-375GS

Budget (k€): 600

Title: Reconfigurable wideband ground station transceiver

Objectives: The objective of this activity is to develop a reconfigurable wideband transceiver for ground station applications. The wideband transceiver will be capable of sampling and synthesizing signals directly in the microwave range.

Description: The wideband transceiver will allow a complete re-configurability and flexibility of the microwave front end depending on the mission requirements. The digital interface will simplify the antenna architecture (by removing all the frequency up and down converters) and it will be directly connected to the back-end digital modem or digital correlator (for antenna arraying applications). The wideband transceiver will include ultra-high speed A/D and D/A to directly convert RF signal to the digital domain or convert digital signal to the RF domain. The bandwidth of the transceiver will include S, X, Ka and potentially Q/V band.

With the standard narrow band architecture the ground station equipment needs to be upgraded each time a new mission needs new requirement and the equipment need to be replaced regularly due to obsolescence. The new wideband transceiver will cover the overall frequency range (from X to Ka band) and will adapt to any new mission bandwidth or frequency. Moreover the wideband transceiver hardware architecture is generic and will be reconfigurable by software. This way the transceiver architecture will not depend on the hardware platform and the obsolescence management of the equipment will be much cheaper.

This activity is in direct continuity with the following technology development activities:

- New microwave sampling concepts for future TT&C architecture
- X-Band sampling technology demonstration (TDE)
  Electro-photonic transceiver bread-boarding for ground stations application (TDE)

The tasks of the activity will include:

- Transceiver architecture definition
- Transceiver detailed design
- Transceiver prototyping and test

Deliverables: Wideband transceiver prototype, Reports

Current TRL: 4  Target TRL: 7  Duration (months): 24

Target Application/Timeframe: All new missions will benefit from the flexibility improvement (i.e. Solar Orbiter, Juice, Euclid).

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
**Domain** | **Generic Technologies - CD8 - Ground Systems / Mission Operations**
--- | ---
Ref. Number: | GT17-376GS
Budget (k€): | 1,200

**Title:** Generic flight operations segment for HAPS

**Objectives:** The objective of this activity is to evaluate adaptation needs of a space mission ground segment infrastructure for the operation and exploitation of High Altitude Pseudo-Satellites (HAPS), develop a generic reference architecture and implement, test and validate a prototype of the main functional software elements of a generic flight operations system for HAPS.

**Description:** Significant synergies between HAPS and space assets and missions have been identified, underlining the role of HAPS in the design of a future system of systems (SoS) concept including space assets.

In the past decades, ESA has developed an extensive mission operations infrastructure for the satellite operations segment. It encompasses simulation, communications, mission planning, automation, monitor and control, flight dynamics, network interfaces, data archive, data analytics and data distribution elements. This infrastructure represents significant investment and captures the operational knowledge of many missions. It is freely available to all European entities and has been used successfully by a number of companies for providing competitive commercial solutions and services.

So far, industry-led HAPS development activities have largely focused on flight hardware. Analog to this, it is proposed to reuse satellite ground segment elements to create a generic, robust Flight Operations Segment (FOS) and software subsystems design for HAPS.

Re-use from satellite ground segments and related standards may be considered for relay operations, communication protocols, operations services, system and data link security and procedures definition, preparation and execution.

The objective of this activity is to assess and adapt existing standards and mission operations software and infrastructure for the purpose of supporting a generic, platform-agnostic FOS for HAPS. It encompasses the following tasks:

- Analysis of previous ESA HAPS studies results, design of existing platforms and driving mission requirements
- Derivation of FOS system requirements and a functional gap-analysis against existing space ground segment standards, assets and software systems
- Derivation of software requirements for the core FOS elements
- Prototype development, verification and validation of core software elements

**Deliverables:** Report, Software

**Current TRL:** 4  
**Target TRL:** 7  
**Duration (months):** 15

**Target Application/Timeframe:** A generic FOS architecture and software core for future missions including HAPS.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
3.1.9 CD9 - Digital Engineering for Space Missions

<table>
<thead>
<tr>
<th>Domain</th>
<th>Generic Technologies - CD9 - Digital Engineering for Space Missions</th>
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<td>Ref. Number:</td>
<td>GT17-377QQ</td>
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</tbody>
</table>

**Title:** RAMS in-orbit data exploitation (RIDE) operational tool

**Objectives:** The objective of this activity is the development of an operational tool for the utilization of in-orbit data exploration as available in spacecraft operation centres to support RAMS assessments of future spacecraft, risk informed design, and operations of future missions.

**Description:** The data collected along the operation of ESA spacecraft by ESOC and similarly by partnering organizations contains highly valuable information on a large number of RAMS characteristics like achieved reliability, observed failure modes and mechanisms, compatibility of technologies or designs with mission environments and specific operations, observed performance degradation over the lifetime and usage profile. Some of these are currently exploited through tools such as Mission Utility and Support Tools (MUST -- TEC-MUST) focusing on performance but with potential to cover also RAMS applications.

The proposed RIDE tool interfacing with existing tools such as MUST and ARTS (Anomaly Reporting Tracking Tool) is an element for the collection and dissemination of knowledge and lessons learned within the Agency and open to European national space agencies and European industry. It is intended to systematically collect observed behaviour of ESA spacecraft, their subsystems and equipment during operations (anomalies/successful lifetime, performance degradation characteristics, etc.) and to allow a structured and customized access to this information by development programmes, spacecraft operations teams, anomaly investigation teams and technical experts. RIDE enables data collection focused on information regarding observed performance and its evolution/degradation, reliability and observed failures and its dissemination across directorates and programme boundaries.

With the added value of allowing to perform risk-informed decision making, reliability centred design, selecting minimum risk operational scenarios as well as for anomaly resolution and supporting technology development and assessment.

The activity proposal is based on the outcome of two previous successful R&D contracts, namely RIDE 1 (basic principles of in-orbit RAMS data exploitation) a TDE activity and RIDE 2 (Proof of Concept) a GSP Activity.

**Deliverables:** Report, Software

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<tr>
<th>Current TRL:</th>
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<th>Target TRL:</th>
<th>6</th>
<th>Duration (months):</th>
<th>24</th>
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</table>

**Target Application/Timeframe:** Spacecraft operations.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Title: Nanosat on-orbit prognostic and health management SW

Objectives: The objective of this activity is to develop an on-board SW in order to increase the reliability of COTS-based nanosats through identification and in-orbit verification of suitable data-driven and/or model based diagnostic and prognostic degradation/failure algorithms.

Description: Since the early 2000s an increasing number of nanosats have been launched per year showing serious limitations in terms of reliability. 2019 will witness more than 500 nanosats launched. The launch rate is expected to continue increasing in the coming years due to the commercial, educational and governmental interest in this kind of platform and the proliferation of launch service providers. Although a considerable number of nanosats have been launched so far, the data acquired are incomplete and insufficient to allow to derive consistent information regarding reliability metrics and failure mechanisms. The use of recurrent COTS and the number of nanosats launched per year are two key conditions that make favourable in-orbit reliability data exploitation to increase design robustness and reliability growth. CURE will in-flight test a new payload designed to maximise the return of experience for reliability-centred design. Use of edge Artificial Intelligence accelerators will allow in-flight demonstration of a machine learning–based fault management strategy.

Data-driven prognostics algorithms (based either in parametric/non-parametric approach and machine learning). Model driven prognostics algorithms based on physics of failure (PoF) or Industry recognised models. Artificial Intelligence based Health Management modules.

The developed SW shall be used on-board of the IOD payload nanosat in-orbit RAMS Exploitation (CURE) currently pre-selected as IOD payload host of GOMX5. In addition, the activity will verify the efficiency of the fault management solutions suggested by CURE embedded Artificial Intelligence module.

The technology pushes are enabling increase of performance (i.e. reliability and lifetime) of COTS based architecture and define a reliability and robustness assessment strategy for Small planetary platforms.

This activity encompasses the following tasks:
- Identification of suitable models for the development of prognostics algorithms.
- Identifications of minimum sub-set of TMs/sensors for relevant prognostics/diagnostics data identification
- SW Development
- SW Testing and Validation.

Deliverables: Software, Report

Current TRL: 3 \hspace{1cm} Target TRL: 6 \hspace{1cm} Duration (months): 12
Target
Application/Timeframe: All nanosat missions. TRL 6 in 12 months.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Title: **Augmented, mixed and virtual reality for space safety use cases**

Objectives: The objective of this activity is to develop tool for advanced and intuitive visualisation of Space Safety Data by means of Augmented, Mixed and Virtual Reality to be used in Collision Risk Assessment applications and Space Weather.

Description: The technologies related to AR and VR have been assessed in a previous ESA activities. The focus use cases were on Human and Robotic operations. A tool chain and demonstration setups for this domain has been deployed at EAC and at ESOC AGSA Lab. A number of use case scenarios have been implemented and integrated with some of operational systems.

Based on this experience, the application of Augmented, Virtual and Mixed Reality for a new domain, namely Space Situational Awareness (SSA/Space Safety) has been envisaged. Initial in-house assessment of feasibility and usefulness of these use cases have been started at AGSA Lab.

The proposed activity shall investigate the best methods for application of AR/VR/MX for two concrete use cases:

- **Space Surveillance and Tracking: Collision Risk Assessment**
- **Space Weather Data visualization and interaction**

The activity is focused on the visualisation aspects not on the actual modelling and computation. The proposed activity will focus on the visualisation element and the operator involvement in the process.

The proposed activity will focus on two use cases of Space Weather and Space Subservience and Tracking. It will however provide the base framework for implementing other already identified use cases of the Space Safety (including NEO).

For Space Weather there are all three possibilities: AR, VR and MX:

- **VR:** is clear, fully immersive,
- **AR:** Hololensic view of the e.g. Sun and its solar flares, or ionosphere density around earth, etc.,
- **MR:** A dark room with physical bodies (spheres for Sun, Earth, ...) placed on correct ration distances, then AR overlays and people can walk around and explain the effects, etc.

Deliverables: Report, Software

Current TRL: 4  
Target TRL: 7  
Duration (months): 18

Target Application/Timeframe: Collision Risk Assessment, Space Weather and Space Situational Awareness. / TRL7 in 18 months.

Applicable THAG Roadmap: Relevant to the Roadmap Functional Verification and Mission Operations Systems
Ontology for ground segment and operations

The objective of this activity is to develop the key elements of an ontology for the Ground Segment and Operations engineering domains in order to support a model-based engineering approach, interoperability and information exchange for improved collaboration and efficiency.

Reliable information exchange between all disciplines, stakeholders and associated engineering tools is essential for space system development. The European Cooperation for Space Standardization (ECSS) explained, within ECSS-E-TM-10-23A, the complexity of developing reliable information exchanges and identified the need for a new generation of information modelling methodologies and tools that capture and manage the semantics.

Recently, ESA has become more active in the pursuit of this goal, forming an advisory group together with National Space Agencies and industry primes with the objective to harmonize the approach towards wide adoption of Model-based systems engineering (MBSE). As part of the associated roadmap, the development of a conceptual data model and ontology for space system engineering is on-going. The approach foresees an incremental evolution through the development of several ontologies, gradually integrating different disciplines and engineering domains with the top system-level skeleton. The intention is that this approach shall enable semantic interoperability between domains and a significant step towards multi-disciplinary and collaborative digital systems engineering. This activity shall develop a compatible sub-ontology for the ground segment systems and operations engineering domains.

The activity encompasses the following tasks:

- Analyse and benchmark existing developments
- Select the most suitable tool and language for the ontology development (accounting for the applicable ECSS and Operations Quality Management System processes that shall be supported)
- Develop the key elements of a ground segment and operations engineering ontology covering Ground Segment Systems Engineering and the subsystem domains of Ground Stations, Flight Dynamics Systems, Mission Data Systems and Operations Engineering
- Analyse the existing tools and sources of the data represented by the ontology and propose next steps for data model adjustment or model-mapping capabilities
- Validate the developed ontology through demonstration of information exchange across domains

Deliverables: Report

Current TRL: 3               Target TRL: 5               Duration (months): 12

Target Application/Timeframe: Ground Segment and Operations.

Applicable THAG Roadmap: Relevant to the Roadmap System Data Repository
Domain: Generic Technologies - CD9 - Digital Engineering for Space Missions

Ref. Number: GT17-381SY  Budget (k€): 400

Title: MBSE applied to complex nanosat projects

Objectives: The objective of this activity is to apply a full Model Based Systems Engineering (MBSE) approach to a nanosat mission development as showcase for application in bigger missions.

Description: ESA has supported several developments in the field of MBSE in the last decade. Although MBSE has started to be used in early phases, it is still not yet fully applied in current projects throughout the full life-cycle. Lack of an established and accepted overall methodology, in addition to a steep learning curve for some of these methods and tools are a stumbling block, as they require too much time for systems engineers to use the available frameworks which often have their roots in the software domain. By identifying suitable areas of early application of MBSE aspects - and their continuation in the development phase - will allow benchmarking and focus related developments, also providing evaluation of benefits and lessons learned.

Application of multidisciplinary modelling to support analysis and optimization in a real project is considered a suitable use case to demonstrate feasibility and benefits of the consistent application of modelling at system level. It will also identify areas for further improvement/developments, based on the solution for the multidisciplinary aspects.

The activity aims at implementing one of the first steps towards the creation of the end-to-end digital model of the space system. The goal is to collect and connect all the data contributing to the development of a space system in a central repository (or federation of repositories) which would act as single source of truth, reducing inconsistencies and increasing efficiency.

Focus on a small mission (e.g. a nanosat mission) would reduce the risks associated to the introduction of novel methods, high level of complexity would enable higher benefits and return of investment.

This activity encompasses the following tasks:

- Identify a representative subject for the application of MBSE activities and multidisciplinary optimization, depending on the system criticalities.
- Adopt and apply a consistent model based approach to perform a system engineering process and a multidisciplinary optimization exercise involving at least 3 disciplines plus the system engineering coordination layer.
- Demonstrate coherency and consistency of data and information for the selected scenario by performing the multi-disciplinary optimization, based on the linked models.
- Document the method and process for the model based systems engineering process and multidisciplinary optimization workflow, the data exchange strategy across stakeholders.
- Assess benefits compared to standard practices and identify gaps and areas for further developments, expanding – where possible – considerations from nanosat to additional missions categories.

Deliverables: Reports.

Current TRL: 4  Target TRL: 6  Duration (months): 36
<table>
<thead>
<tr>
<th><strong>Target Application/Timeframe:</strong></th>
<th>All nanosat missions.</th>
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<tbody>
<tr>
<td><strong>Applicable THAG Roadmap:</strong></td>
<td>System Data Repository (2014)</td>
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<td>Consistent with activity C01 “Adaptation and Demonstration of MBSE for a real project”</td>
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Domain: Generic Technologies - CD9 - Digital Engineering for Space Missions

Ref. Number: GT17-382EO

Budget (k€): 300

Title: 3D visualization of fluid surfaces (3DFLUS)

Objectives: The objective of the activity is to develop and deliver a new Open Source Software (OSS) library to expose open APIs for providing interactive visualization mechanisms of 3D fluid surfaces in web browsers and supporting data-driven analysis.

Description: One of the common problems in the visualization of scientific datasets is the visualization of 3D information. In many application domains, it is important to properly and efficiently visualize changes in 3D space over time. The true 3D information gives possibility to explore the planets as a globe and visualize relevant information about their surroundings. This allows displaying detailed information about the weather throughout the atmosphere as well as about the satellites, space debris and space weather surrounding the planets and the stars.

The current technology allows mapping global surface areas with high accuracy and in high frequency; this permits to generate large datasets that require suitable and effective 3D visualization. The information obtained through the surface mapping is usually exposed using some of the standard OGC interfaces (such as WCS, WFS, WMS and others) and mostly the 3D part is either neglected or visualized in 2D, using e.g. colour-based coding or a 2.5D approach, adding some simplified information about intensity for specific products.

The most important part is the visualization of changes. The visuals then resemble the fluid 3D model deforming over time. This allows to display the changes in the surface regardless of whether it is a layer drawn on the globe, visible in the atmosphere or a pure 3D object such as a model of the bridge or a satellite. At the same time, another important issue (related to a very common constraint, at least in the European context) must be taken into account: the used libraries should be available under Open Source Software (OSS) license, which significantly limits the choice of the current 3D mapping libraries.

With respect to the problem and limitations stated above, there are no libraries at the moment for simple and effective development of interactive visualizations, focused on the dynamics of the changes of 3D surfaces. And this is even more valid in case of integration with the OGC interfaces. The aim of the activity is to develop and deliver a new Open Source library (based on Web World Wind framework) to expose open APIs focused on the needs of application experts (EO, Space Science, Space Weather), in order to provide interactive visualizations of the fluid surfaces in web browsers. The library will properly integrate with various OGC standards. Some attractive demonstration cases will be proposed to show the benefits and potential of the new library, like e.g. the use of datasets available via WCS protocols from the various Data Cube solutions.

The solution shall contain abstraction of the 3D visuals such as pure 3D models and the integration of typical charts into the 3D space surrounding the 3D models. In the globe scenarios the application of mental frameworks known from the geographical domain will simplify the use for the scientists without the 3D graphics library knowledge. To properly display the changes using the true 3D model the toolbox shall enable the visualisation using the combination of animation, colour coding and vector interpretation of changes on the 3D model surface.
The proposed activity shall include the following tasks:

- Identification of the main requirements to be satisfied and analysis of current approaches, and their potentiality with respect to the identified requirements, leading to the selection of the framework to build upon;
- Definition of use cases for demonstration, in order to prove that the developed solution satisfies the needs for visualization of the changing 3D data;
- Design and prototyping of the API and software library;
- Actual development of the API and the software library, including definition of Test Plan for their verification;
- Demonstration of the developed solution on the selected Use Cases.

**Deliverables:**  Prototype, Software

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<th>Current TRL:</th>
<th>Target TRL:</th>
<th>Duration (months):</th>
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<td>3</td>
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**Target Application/Timeframe:**  Potential benefit for Earth Observation, Science and Space Weather 3D data visualization and Robotics (path planning and data feed into an AR/VR systems) / TRL 6 by 2021

**Applicable THAG Roadmap:**  Relevant to the Roadmap Big Data from Space
Domain | Generic Technologies - CD9 - Digital Engineering for Space Missions
---|---
Ref. Number: | GT17-383G
Budget (k€): | 500

Title: Space mission digital twin

Objectives: The objective of this activity is to develop an E2E Digital Twin, including the different simulated segments of a Space Mission, for E2E demonstration and validation of new models required to meet present and future mission objectives.

Description: All missions will benefit from this development. It will provide the capability to assess, validate and demonstrate new space mission concepts, standards, applications, to perform E2E simulated test campaigns on main stream developments, and consequently support innovation, standards adoption, IV&V efficiency and effectiveness for software intensive domains, ultimately reduction of risks and costs for missions.

E2E simulation of capabilities required to meet present and future mission objectives is critical for successful mission preparation, assembly, integration and testing. For this purpose, the use of simulated environments confined to segment level or even discipline level within each segment entails a number of shortcomings:

- Replication of validation efforts, different maturity and representativeness for system components creating potential gaps;
- Late identification of sub-system and system level problems, incompatibilities, inconsistencies, increasing IV&V effort later in the mission lifecycle;
- Limited capability for E2E simulation, validation and demonstration of innovation, new concepts and standards prior to mission adoption.

The end result is often increased risk and cost for space missions, but also higher resistance and longer lead time to innovation.

In order to overcome the above mentioned shortcomings it is necessary to move towards a reference, representative simulated environment, spanning across the different segments and disciplines of a space mission, enabling effective and efficient integration, validation and demonstration activities of new concepts and technologies at system level.

This activity will develop a Space Mission Digital Twin (SMDT) by providing a simulated E2E Space Mission environment, including space, mission operations and science simulated segments initially, for which elements of existing local simulated environments can be taken as input building blocks, specifically from the ESTEC Avionics Test bench (ATB), the ESOC E2E Simulated Ground Segment (GSTVi, Operational Simulator infrastructure), the ESAC/SOC Reference Environment and/or ESRIN/PDGS (Payload Data Ground Segment)).

SMDT shall be open and scalable, in order to be able to extend to other simulated elements (e.g. network delays) and future elements (e.g. Ratio-SIM) to enable new capabilities. All stakeholders shall have the means to access and control modules, interfaces, parameters and models at the maximum extent, ideally in a virtual space. Due to the diversity, complexity and distribution of the current simulated solutions at hand, additional simulated aspects of environment poses non-trivial challenges that new technologies could help addressing. The activity will therefore also include the development of new simulated systems that will act as nodes, providing
continuous and adaptive simulator capability. The results of the activity shall be demonstrated on a straw man mission.

The activity shall be split into two Phases. Phase 1 (300 k€) contemplated tasks are:

- Detailed system requirements specification;
- Development of the simulation architecture, including interfaces support and new simulation capabilities;
- Definition of a straw man mission and demonstration scenarios;
- Implementation and deployment across the different ESA Sites;
- Demonstration.

The activities contemplated for Phase 2 (200 k€) are:
- Development of the Space Mission Digital Twin.

**Deliverables:** Software, Reports

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<tr>
<th>Current TRL</th>
<th>Target TRL</th>
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<td>6</td>
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**Target Application/Timeframe:** All missions. TRL 6 by end 2021

Domain  |  Generic Technologies - CD9 - Digital Engineering for Space Missions
--- | ---
Ref. Number:  | GT17-384SY  
Budget (k€):  | 500

**Title:** Instrument design models development

**Objectives:**
The objective of this activity is to develop Instrument Design & Development (D&D) Models as part of a concurrent design environment, interfacing with mission and spacecraft system models, in support to instrument design at conceptual level and model based reviews in concurrent environment.

**Description:**
The demand to study instrument concepts and new designs, either in the frame of a mission level feasibility study or as a self-standing activity, has been growing continuously, especially in the early design phases. Currently this demand has been answered with ad hoc spreadsheet solutions or over-complex, time consuming detailed models, which are generally self-standing and not integrated in overall design environments. In order to integrate the instrument development into overall system and mission studies, the development of coherent conceptual design models and their integration to existing infrastructure in the Agency is required in order to provide this capability to a wide scope of users in different programmes.

Based on previous internal and external activities (Space Instrument Design Modelling of Optical Active and Microwave Instruments - SIM & SIM2) that have developed active optical development models and initial identification of design parameters for passive optical and active microwave the activity shall focus on identifying and critically reviewing methods, models and tools, in particular commercial off-the-shelf (COTS) tools, that can support instrument design at conceptual level in early phases in the categories and types of Passive Optical and Active Microwave. Adaptations, modifications and enhancements of existing models and tools shall also be performed by building on the previous work in this area, review the key parameters critical for instrument conceptual design identified in previous studies but, in particular, derive key parameters for interface with the mission and spacecraft system model (parameters influencing platform design and performance). Where necessary, update existing design models and review tools integration in the digital environment including the interfaces to COTS SW tools.

During the activity, development of missing Instrument models shall be performed: for those instrument not covered by the modification and enhancement of existing models, develop Instrument Design Models to be integrated in the digital mission system design environment including interfaces to COTS SW tools.

Integrate the models into the mission system digital design environment, capable of interfacing with mission system design environment (ECSS-10-25 / OCDT / CDP4 / ...). Taking in consideration particularly the implementation of the models into the instrument design process in early phase design studies.

Define a process and demonstrate the feasibility for the Instrument D&D model to support concurrent model based reviews for Instruments, in the perspective to augment the concept at system level (define a list of KPI per domain and per milestone, covering at least SRK and PDR; develop dashboards and overall system views to display compliance to requirements / work progress / ...and relevant information typically checked during a review)
Deliverables: Software, Report

Current TRL: 4  Target TRL: 6  Duration (months): 12

Target Application/Timeframe: All missions, CDF. / TRL 6 in 12 months.

Applicable THAG Roadmap: Relevant to the Roadmap System Data Repository
Domain | Generic Technologies - CD9 - Digital Engineering for Space Missions
---|---
Ref. Number: | GT17-385SY
Budget (k€): | 400

Title: Model-based system engineering for AIV (MBSE 4 AIV)

Objectives: The objective of this activity is to link Assembly Integration and Verification / Testing (AIV/AIT) processes to a coherent system model in an Model Based System Engineering (MBSE) environment in order to optimise requirements traceability and provide consistent reporting after the execution of operational procedures and functional tests.

Description: The on-going shift towards digital system modelling and use of coherent MBSE tools have raised the question of the potential utilization of the models also for later phases of the development cycle. A specific demand for the use of coherent and controlled models has been identified for the AIV process. While generally applicable to any project AIV phase, this demand has been particularly flagged in the frame of the Mars Sample Return missions, which are planning to apply a coherent MBSE approach and therefore identified this capability as a clearly mission development enhancing element.

Based on the results of previous activities, in particular MARVL and Automated Test Reporting, which have developed system data model exchange platforms and established artefacts for standardised test reporting, and complementing the related activity on the Model Based Engineering Hub, this activity shall integrate the available information into a system model to employ the consistency enforced in a coherent system model to the verification close-out process. For that purpose, the activity requires to implement those key critical output parameters used in the AIV / AIT process flow into a system model reference platform that are required for the overall system and project management. These artefacts, which are standardised as output of testing and verification activities, are then linked to the respective system model elements to trace the fulfilled requirements, the verified function, test cases and the tested product element.

This will also provide configuration control of the as-built status of each model, incl. representation and link to requirements and standardise feedback from operational procedures, test results, and verification close-outs into the system models to allow for coherent reporting. This traceability shall be available in a user-friendly dashboard environment and provide appropriate views for individual users and make available standardised test reporting.

This integration will be tested with a Mars Sample Return (MSR) system model test case in order to prepare implementation into project use. It shall be based on the previous work from the atomized test reporting and the development in MARVL and shall be complementary to the MBSE Model Hub development.

Deliverables: Software, Report

Current TRL: 4 | Target TRL: 6 | Duration (months): 12
Target Application/Timeframe: All missions, CDF / TRL 6 in 12 months.

Applicable THAG Roadmap: Relevant to the Roadmap System Data Repository
Domain: Generic Technologies - CD9 - Digital Engineering for Space Missions

Ref. Number: GT17-386G

Budget (k€): 500

Title: Failure root cause analysis automation

Objectives: The objective of this activity is to develop a set of artificial intelligence and machine learning building blocks to allow automated failure investigation, prediction and prevention in software based environments.

Description: A Space Mission is a complex System of Systems, requiring extensive Integration and Testing (I&T) effort to meet the requirements of the mission objectives. The proliferation of hardware and software products, interfaces, test environments and tools as well as users make I&T activities at Space Mission level challenging due to the number of involved experts and their scattered locations. Space Mission level failure can result from a chain effect of the initial failure at the level of any hardware or software product part of the Space Mission, their interfaces, technologies and implementation specificity. The cause of the failure is effort intensive and time consuming to be identified, analysed and remediated.

With today artificial intelligence and machine learning based data processing and data analysis techniques, an advanced step in failure prediction and investigation can lead to drastic hardware/software product quality improvement and testing efficiency gains throughout their lifecycle. Intelligent and automated failure analysis and forecast building blocks are expected to bring benefits in IT domain. Building upon the already advanced concepts like data mining, machine learning, multi-agent systems, testing optimisation techniques, and big data technologies to apply those which are promising to core building blocks for the benefit of the different space mission segments.

The activity will start with a survey of the different existing prototypes and proof of concepts in ESA, followed by the analysis of the relevant technologies and assessment of their suitability for the purpose. It will prototype relevant methodologies and orchestrate them into a set of building blocks to be applied both at hardware/software product level and Space Mission level in the different space missions segments. The results shall be demonstrated on representative scenarios and data.

The tasks contemplated for this activity are:
- Review of already existing ESA solutions, prototypes and proof of concepts
- Survey of relevant technologies and down-selection;
- Prototyping of a set of building blocks to investigate, detect, predict and prevent failure;
- Demonstration in representative environments.

Deliverables: Prototype, Reports

Target TRL: 5
Duration (months): 18

Current TRL: 3

Target Application/Timeframe: Applicable to all missions, in particular for automation of Integration and Test (I&T). TRL 6 by 2021

Consistent with activity B14 “Advanced Test management”
**Domain** | **Generic Technologies - CD9 - Digital Engineering for Space Missions**
--- | ---
**Ref. Number:** | GT17-387G
**Budget (k€):** | 300

**Title:** **Big data challenge in space mission design**

**Objectives:** The objective of this activity is to develop an efficient and effective preparation procedures for early development phases of new space missions by accessing heterogeneous sets of databases and online sources on existing space system designs and related knowledge.

**Description:** The preparation phase prior to a multidisciplinary feasibility assessment (i.e. a Concurrent Design study) is the foundation of a well-established project. A good early phase increases the likeliness of better estimates and issues identification, reducing costly design changes and non-conformances to be dealt with in the later project phases.

A considerable part of the time required during a feasibility study preparation phase is dedicated to the mining of information about reference and heritage missions from internal databases and online sources. Moreover, maintenance of a database is a cumbersome task and it is instrumental to avoid data obsolescence.

The activity here proposed has the aim to develop an application able to analyse space mission data from heterogeneous databases and online sources in support to initial estimates typical of the early design phases of a project. In particular, the developed application shall:

- Harmonize and centralize information access
- Decentralize maintenance of the databases/knowledge, moving that to the responsible entities for the online sources of information (scientific journals, agency reports, agency databases).

A considerable amount of information on previous space missions and mission concepts, launchers and platforms can be found online. The online information has already an intrinsic structure, either designed by the entities maintaining the online resources or given by the domain specific language that can be inferred with more advanced knowledge discovery techniques.

The solution here proposed shall:

- Reduce the time needed to the engineer to gather and combine all the necessary information
- Provide new insight on information not previously found
- Reduce the internal maintenance needs
- Provide a mechanism for vetting the quality and validity of information by experts

An initial study aiming at integrating semi-structured online databases is currently ongoing in the frame of the Network Partnering Initiative (NPI) "Design Engineering Assistant activity" (University of Strathclyde, UK)

This additional project will allow processing a larger scale of heterogeneous data accessible online, raising the TRL of the developments of the NPI. The activity encompasses the following tasks:

- Analyse data and data models from the existing Database (i.e. internal to the Concurrent Design Environments like the CDF and available on-line)
Investigate how to make efficient use of existing databases / tools and their potential synergies in order to support early design assessments

Develop interface links among existing databases and analyse the potential of the logically structured information repository to ensure:

- centralized information access
- decentralized maintenance

Produce the complete specification addressing:

- User requirements and user stories, infrastructure specification, architectural design
- Develop a demonstrator of a Product application enabling to infer knowledge and data by integrating it into a ECSS-E-TM-10-25 compliant design environment

Deliverables: Prototype, Reports

Current TRL: 4  Target TRL: 6  Duration (months): 12

Target Application/Timeframe: Applicable to all missions. TRL 6 by 2021.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic.
Domain | Generic Technologies - CD9 - Digital Engineering for Space Missions
--- | ---
Ref. Number: | GT17-388G
Budget (k€): | 400

**Title:** System engineering model-based information exchange

**Objectives:** The objective of this activity is to gather and characterize the information to be exchanged at the system engineering milestones in view of its integration in an MBSE hub infrastructure through an ontology.

**Description:** This activity will build on the initial work performed within MARVL which identified broad categories of information that would need to be exchanged.

The activity shall identify and characterize relevant information to be exchanged in the space system engineering lifecycle through models rather than documents.

The topics of information exchange and/or model infrastructure interoperability have been identified as key to enabling a more effective and streamlined space engineering project execution for more than a decade. These topics have been partly addressed in various undertakings both initiated by the Agency and by space industry. Nevertheless, the much-dreamed results have not been achieved yet, mainly due to the difficulty of federating the plethora of stakeholders around a manageable, well-defined information set to be exchanged and a set of scalable and stable technologies. As such, so far the results are of limited scope. They may address very specific engineering problems, satisfy a limited set of stakeholders, or be usable only in particular development phases. The information that needs to be shared or exchanged must be defined at an agreed conceptual semantic level. This activity is key to the space ontology and model-based engineering hub tracks of activities, identifying and characterizing the information that must be shared / exchanged in the system engineering lifecycle.

Moreover, the space system primes and suppliers have started to use various modelling languages (sysML or DSLs) to support their in-house tailored engineering processes. In this context, it would be useful to have a common agreement on the information to exchange through models rather than documents at relevant milestones.

The expected benefits are:
- Reduction of the manual workload related to documents generation and review at system level
- Guarantee consistency between data used by the various stakeholders
- In line with the MB4SE roadmap and complementary to the space ontology and MBSE hub

The activity shall contain the following tasks:
- Starting from the ECSS E-ST-10 series requirements, analyse the types of information to be shared/exchanged at each project milestones from phase 0 to phase E
- Map the information on the relevant types of models, and describe their content in detail
- Extend the space ontology resulted from other (currently ongoing or initiated) studies in view of the integration of all the concepts and relationships
- Implement a case study addressing the major system engineering artefacts and the verification process.
**Deliverables:** Reports, contributions to the space ontology, models

**Current TRL:** 2  
**Target TRL:** 4  
**Duration (months):** 12

**Target Application/Timeframe:** Applicable to all missions.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
3.1.10  CD10 - Astrodynamics/Space Debris/Space Environment

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<tr>
<th>Domain</th>
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<td>Ref. Number:</td>
<td>GT17-389EP</td>
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**Title:** Shape Effects in hypervelocity impacts

**Objectives:**

The objective of this activity is to develop a software able to evaluate the risk or satellite missions represented by hypervelocity impacts with projectiles having nonspherical shapes and porosity.

**Description:**

Space debris and meteoroids are considered a relevant threat for spacecraft. They are a risk for mission success and planetary protection. In impact risk assessments typically spherical solid projectiles of a given density are assumed to impinge on a satellite design and the corresponding risk of causing failures, as for example penetration of structure wall or pressurized vessel walls, is determined.

The underlying ballistic limit equations, quantifying the critical particle size above which a certain failure is occurring, are derived from ground-based tests or computer simulation in which again spherical projectiles are utilized.

The understanding of space debris and meteoroid environments indicates that the likelihood of observing perfectly spherical shaped debris and meteoroid particles of homogeneous density is very low. These projectile properties potentially have a high relevance for the damage created when hitting a spacecraft. It is not evident yet whether this would result overall in a higher or lower risk for satellite missions.

This activity shall encompass following tasks:

- Review of shape effects in space environment and on ground satellite fragmentation testing (DebriSat)
- Test plan (covering at least three shape categories 'rod', 'disc' and 'nugget', semi-infinite, single wall and double wall shielding geometries and additional input test settings porosity and projectile orientation at impact)
- Test execution (anticipated as Light Gas Gun or other impact facilities)
- Test analysis and report (including comparison to and adaptation of computer simulations, which are necessary for extrapolation to higher velocities)
- Model development to describe shape effects in hypervelocity impacts (anticipated as analytical model developed on large parameter scales provided by tuned simulation tools)
- Implementation of derived models in risk assessment software
- Application to reference use-cases in LEO, GEO and interplanetary space.

**Deliverables:** Software, Report

**Current TRL:** 2  **Target TRL:** 5  **Duration (months):** 12

**Target Application/Timeframe:** Relevant for all space missions, especially high reliability (e.g. Mars Sample Return), large surface area (e.g. MPCV) and long duration missions (e.g. ISS and Lunar Orbital Platform Gateway).

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Domain: Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment

Ref. Number: GT17-390EP

Budget (k€): 800

Title: Nanosat rated booms and deployment systems for space environment electro-magnetic fields sensors accommodation

Objectives: The objective of this activity is to design and improve small platforms/nanosat rated booms and associated deployment systems in order to accommodate Electric and Magnetic (EM) fields sensors for space environment monitoring, on 3-axis stabilized or spinning platform.

Description: An increasing number of small satellites based missions and experiments are designed in Europe and proposed to operate in e.g. Low Earth Orbit (incl. telecom, Earth observation, space weather), a number of which accommodating environment sensors. While long (wire) booms accommodation and deployment technology for small satellites already exists in non-EU states and is protected, this is not the case in Europe. The proposed activity will fill that gap.

A/C and in particular D/C fields (electric and magnetic) measurements from nanosatellites using booms are very challenging due the EM contamination of the signals sensed by the probes when located at 1m or less from the satellite body. Such contamination occurs due to the generation of background fields during attitude control and thrusting operations for instance. Hence reaching the sensitivity required to detect environmental (especially electric) fields is not possible. On standard platforms such sensors are placed on long booms of 3-4 to 10m in Low Earth Orbits (LEO), higher orbits usually requiring even longer booms due to the increased plasma Debye Length. However no boom technology and deployment system are currently available in Europe to reach those requirement with a current state of the art enabling typically 1m booms on 3U 3 axis stabilized nanosat.

The proposed activity aims at filling this technological gap by designing, producing and testing a (e.g. wire) boom system including deployment mechanism enabling the positioning of sensors at a minimal distance of 5m on 3-axis stabilized or 10m on spinning platforms from the satellite body, compatible with limited volume and mass available in the Units before deployment. The resulting (significant) sensitivity gain for both EM field sensors shall be demonstrated in relevant environments on both type of platforms. EM field sensors shall be existing instruments based on already flight proven designs, as the technology development target the boom system itself. The following activities are foreseen:

- Requirements and technologies trade-off.
- Conceptual design.
- Detailed designs including analysis wrt radiation assurance, vibration etc.
- Fabrication of boom and release mechanism Engineering Model.
- Functional testing.

Deliverables: Engineering Model, Report

Current TRL: 3  
Target TRL: 6  
Duration (months): 24

Target Application/Timeframe: Low Earth Orbit missions accommodating environment sensors.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Domain | Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment
---|---
Ref. Number: | GT17-391EP |
Budget (k€): | 700 |
Title: | Global radiation belt model improvement by radiation monitor data |
Objectives: | The objective of this activity is to develop new radiation belt models exploiting the data available from the network of space radiation monitors by using it for validation and improvement of processes. |
Description: | Following the development in GSTP of the PFM next generation radiation monitor (NGRM), which will fly on EDRS-C, further procurements are in advanced preparation for several missions. In addition, data is still returning from the SREM network, the Energetic Particle Telescope (EPT) on Proba-V, the SATRAM pixel detector on Proba-V, and the CNES-funded ICARE instruments. Data is also collected from the Environmental Monitoring Unit (EMU) instruments on Galileo. The data from all these sources will be processed into usable quantities: particle fluxes, doses, etc. Thereafter the data will be analysed in a coordinated way and consolidated into reference database and new empirical models of the radiation belts. Where they occur, data on Solar Particle Events will also be analysed. Calibration and simulation metadata will be secured for all instruments. This will then allow consistent processing via established means (SVD, NN, etc.) into fluxes in a transparent way. The database will be established via ODI and will be a reference database, version controlled and with community open access. Radiation belt models will be established as part of a unified system, with careful attention to data merging issues. At low altitude, account will be taken of steep gradients and atmospheric control, as well as strong anisotropy. At high altitude, external source magnetic field models will be employed. Space weather induced enhancements will be dealt with statistically. Comparisons with existing models will be made and differences explained in detail. Development of the system and software will be carried out. Validation of the system and the data products will be performed, together with maintenance and updates. |
Deliverables: | Software |
Current TRL: | 3 |
Target TRL: | 6 |
Duration (months): | 24 |
Target Application/Timeframe: | Space Science and Earth Observation. TRL 7 by 2024 |
Title: Atmospheric models applied to operations

Objectives: The objective of this activity is to enhance the atmospheric model used in flight dynamics system tools used in operations systems, in terms of: the used mathematical atmospheric model, the used indices, and the source of index future predictions.

Description: Earth observation satellites flying lower and lower are pushing the limits of atmospheric density prediction. Missions flying at 320km and even in the low solar activity cycle that we are (in a minimum) is causing a lot of operational troubles, increasing the cost of the operational support for increased frequency of operations, and on-call support. Future missions with strict requirements in prediction are also expected. The next solar maximum is expected to peak at around 2024, having high solar activity between 2022 and 2027, which would make things worse for low flying missions (like AEOLUS), or missions with strict prediction requirements (like EarthCare and BIOMASS). Improving the current baseline for atmospheric modelling and prediction is critical for the efficient support to these missions.

Atmospheric forces are the largest non-gravitational effect acting on Low Earth Orbit (LEO) satellites. The better the drag force can be estimated, the better it is possible to estimate the satellite trajectory. Improving the knowledge of the future trajectory of the satellite bring some direct benefits, such as:

- Longer manoeuvre cycles; and then reducing the frequency of manoeuvres (because it is possible to make better use of the deadband).
- Better capability to estimate collision probabilities in case of close approaches to debris (which would lead to a decreased number of collision avoidance manoeuvres).

The problem of estimating the drag force can be separated in several points:

- Which atmospheric model to use.
- Which indices, and from which source, to feed the atmospheric model.
- How to predict the evolution of future indices.

These three points are interrelated, because the choosing of one atmospheric model, determines the indices to be used (or a subset of them), and restricts the possibilities of how to obtain index predictions.

The proposed activity would consist in several tasks:

- Analysis of available atmospheric models.
- Comparison of performance of atmospheric models with real satellite trajectories.
- Analysis of solar and geomagnetic indices necessary for each atmospheric model. Identification of sources of each index. Analysis of reliability of each source.
- Machine Learning applied to prediction of indices: Generating an algorithm to predict solar and geomagnetic indices.
- Final recommendation on model/s, index, and index prediction based on accuracy, availability and reliability.
- Integration into ESOC FD system.
• S/W validation and integration tests.

**Deliverables:** Report, Software

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**Target Application/Timeframe:** LEO missions and in particular Earth Observation missions.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Annex II, Page 150/160

Title: Characterising the radar cross section (RCS) of space debris

Objectives: The objective of this activity is to create a database of RCS distributions for objects (fragmentation debris and intact bodies) and to derive a mapping between RCS distribution and object size ((e.g. estimate min./max./average size).

Description: Size estimates of debris are crucial information for a realistic assessment of collision risk for ESA operated satellites. The ESA DISCOS (Database and Information System Characterising Objects in Space) serves database contains size and shape information for most intact resident space objects and is extensively used for operational conjunction assessment (internally and by external entities). However, the size of debris generated in fragmentation events is unknown and must be determined directly from measurements such as the radar cross section (RCS).

Measurements of radar-cross section vary dramatically for each object from observation to observation e.g. depending on viewing angle. However, the overall distribution of RCS values follows a typical target model curve, e.g. a Swerling target model. The distribution differs depending on object type, e.g. between rocket bodies and complex satellites. While the RCS is not a direct measurement of the size, a distribution derived from a larger sample provides more information to at least bind the object dimensions. Single values, such as the median, can fail to represent the actual span of the object, e.g. when the shape is complex or one dimension is significantly larger than the other.

An estimated range of RCS values furthermore helps to discriminate observations of closely spaced targets when monitoring debris. It allows scheduling future observations by computing the probability of detection. This helps to calibrate and monitor the performance of a sensor system by testing whether a missed detection is feasible according to the specified performance or faulty behaviour.

This activity encompasses the following tasks:
- Survey and analysis of empirical models for RCS distributions based on measurement data and/or approximate size and shape information
- Estimate RCS models from given combinations of simple shapes as stored in the ESA DISCOS database
- Derivation of methods for size or bounds estimation (min./max.) based on empirical RCS model
- Extended to optical data (magnitude): two independent methods available for the same object increasing the confidence
- Exploit time-series information: e.g. peak-magnitude and period in RCS and light curve as an indicator for object dimensions
- Implement methods as baseline for operational process
- Test and validate implementation using ESA provided past data acquisition campaigns and shape and size estimates
- Assess RCS estimation performance using reference data and numerical electromagnetic simulation codes

Deliverables: Software, Report

Current TRL: 4  Target TRL: 6  Duration (months): 18
Target
Application/ Timeframe:

All missions that present collision risks.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Domain: Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment

Ref. Number: GT17-394EP  Budget (k€): 500

Title: Plasma analyser for spacecraft charging characterisation

Objectives: The objective of this activity is to design and prototype a plasma analyser able to carry out long-term observations of the electron and ion populations that are responsible for hazardous spacecraft surface charging environments. The analyser should be compatible with a range of operational spacecraft and so must employ standard interfaces and have minimum requirements for mass and power.

Description: Spacecraft charging is known to be the cause of damage and anomalous performance of many European spacecraft. Higher sensitivity of electronic components due to smaller feature size makes them more susceptible to upset by electrostatic discharge. Also electric orbit raising is increasing the number of satellites in areas of the trapped plasma that have not been well characterised. However, there is a lack of systematic observations, particularly in Europe, on the plasma populations that cause spacecraft charging. Such observations are needed for future environment specifications, to support mission operations and for space situational awareness. Most European plasma analysers have been flown for scientific observations on specialised spacecraft. In this development, high resolution in time, angle and energy are not essential and could be sacrificed for a simpler design.

A prototype of a plasma analyser will be created that can characterise the ambient electrons and ions in the energy range 30eV-30 keV, targeting the plasma population of the ring-current region around GEO and below. Minimisation of both mass and power and the use of standard power and telemetry interfaces will be explored. As well as measuring the plasma populations that affect spacecraft electrical charging, the instrument shall be able to infer the potential of the spacecraft with respect to the ambient plasma.

The following activities are foreseen:
- Requirements definition and technologies trade-off
- Conceptual design
- Detailed design including analysis wrt radiation assurance, vibration etc.
- Fabrication
- Functional testing in a plasma chamber.

Deliverables: Prototype, Report

Current TRL: 4  Target TRL: 6  Duration (months): 18

Target Application/Timeframe: All missions, Space Situational Awareness. TRL6 by 2022.

Applicable THAG Roadmap: Relevant to the Roadmap Radiation Environments & Effects
Domain: Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment

Ref. Number: GT17-395SD  
Budget (k€): 500

Title: Thermomechanical fragmentation model for re-entry break-up simulation tool

Objectives: The objective of this activity is to develop a tool used for re-entry safety assessments able to predict and observe fragmentation debris created during the atmospheric re-entry of a large artificial objects.

Description: Re-entry safety requirements are applicable to all ESA missions and world-wide. They depend on the modelling of the break-up of an object when it re-enters the Earth atmosphere under aerothermal and structural loads, and the determination where surviving fragment will impact. Such analyses are currently largely procedural, as the physical understanding of the break-up of large structures is limited at best. During the qualification of Ariane 5, ESA, CNES, and Arianespace performed remote observations of the upper stage re-entry to establish the re-entry risk and confirm safety aspects. Currently ESA pursues the development of designed for demise components for spacecraft. This work indicated that validation data from actual destructive re-entries of real structures is largely absent yet urgently needed to develop simulation and modelling software as the re-entry regime can’t be faithfully reproduced on Earth for almost all objects.

The controlled re-entry of large upper stages provides a recurring data source for model development in this multi-physics research field for a large yet aerodynamically well-understood vehicle. Comparison with Ariane 5 and ATV-1 data allows to mitigate the risk of performing a low number of re-entry observations, which has shown to be a limiting factor in using the scarce data sets available worldwide. The procedural re-entry safety assessment performed during the development of the launcher can be evaluated based on actual measurements. Such a validation of ESA methodologies, and those in its member states, would put them in a leading position world-wide.

This activity shall close the gap in fragmentation modelling of large structures by capturing the thermomechanical re-entry break-up phenomenology and associated fragment trajectories into simulation software. It is foreseen that available hardware sensors, across the electro-magnetic spectrum, are to be upgraded, calibrated and tuned for a remote observation of a controlled re-entry to ensure the provision of provide benchmark quality validation data for the simulation software and break-up simulation software upgraded to faithfully represent the observations.

The activity should contain the following tasks:
- Re-entry break-up simulation review and gap analysis to compare with Ariane 5 and ATV-1 data.
- Development of a state-of-the art thermomechanical fragmentation model for inclusion in re-entry break-up simulation, with identification of remotely observable phenomena.
- Definition of an airborne observation campaign observing the 100 - 50km altitude range in support of the developed fragmentation model.
- Analysis of the campaign data to derive break-up phenomenology and the fragment impact zone, and iterate on the fragmentation model and its implementation.
- Upgrade of ESA procedural re-entry risk verification software to match the developer higher fidelity fragmentation model.
Deliverables: Report, Software

Current TRL: 4  Target TRL: 7  Duration (months): 12

Target Application/Timeframe: Space debris and space environment. TRL 5/6 would be needed at the end of 2023

Applicable THAG Roadmap: Not relevant to any Harmonisation topic.
Domain | Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment
---|---
Ref. Number: | GT17-396SW
Budget (k€): | 1,000

**Title:** Low cost radiation monitor for large cooperative satellite missions

**Objectives:** The objective of this activity is to develop a radiation monitor to be flown as a hosted payload for Space Weather monitoring on large commercial large cooperative satellite missions.

**Description:** The aim is to develop a new radiation monitor with low mass and power budget measuring the spectrum of electrons (100 keV to 8 MeV), protons and ions (1 MeV/nuc to 500 MeV/nuc). The cost of recurring units of the new instrument should be reduced by an order of magnitude compared to currently available designs, while taking mass production of the instrument into account.

The deployment of commercial large cooperative satellite missions offer interesting opportunities for hosted payload missions. The large number of satellites in various LEO would allow an unprecedented measurement coverage of the near-Earth radiation environment which would constitute an important asset for operational Space Weather monitoring.

To provide the large number of instruments necessary to achieve this coverage the recurring unit costs need to be reduced by an order of magnitude compared to currently available instruments capable of registering and categorising single particles of the desired energy range.

This activity includes a detailed study of cost drivers for the price of recurring units of available radiation monitoring instrument designs. A trade-off analysis between the costs and the reliability of components or measurement capabilities shall be performed. The feasibility of the use of COTS to reduce the development and production costs will be studied. A modular instrument design could be considered to allow tailoring of each instrument series for specific measurement characteristics. The overall measurement requirements would then be covered by deployment of series of instruments with differently tailored measurement capabilities over a large number of satellites and constellations.

This activity will select the most appropriate technology and components from recent R&D in the space and high energy physics domains to design and develop a new low cost radiation monitor with limited power and mass budgets. An engineering model will be built and tested and characterisation with electron, proton, and ion particle beams shall be performed. Two prototype flight models shall be provided, which could then be qualified and used for IOD missions as a next step. A plan for FM mass production and testing shall be established.

**Deliverables:** Engineering/Qualification Model, Flight Model, Report

**Current TRL:** 3  
**Target TRL:** 7  
**Duration (months):** 24

**Target Application/Timeframe:** Space weather and space safety.

**Applicable THAG Roadmap:** Not relevant to any Harmonisation topic
Enhancement of physical and assimilation modelling of radiation belts

The objective of this activity is to develop and demonstrate an enhanced prototype service to predict the state of the radiation belts in response to solar-terrestrial disturbances known to cause large variations in the radiation belt fluxes - drop-outs, injections, energisation, radial transport, etc. The starting point will be physics-based models of the radiation belts, supported by assimilation of in-situ data. The prototype will conform to requirements related to execution efficiency and usability, and will be validated through data comparisons.

Accurate monitoring and prediction of the Earth's trapped radiation belts are essential space weather service components for spacecraft operators active in these regions. Both rely on accurate modelling of a highly dynamic environment. Through improved modelling in combination with data assimilation, the aim of this activity is to further develop and demonstrate the underpinning tools which will enable future service enhancements.

Improved understanding of radiation belt physics, aided in part by better data availability and increasing computational power, has allowed the establishment of complex multi-dimensional simulation capabilities that have shown some success at simulating and predicting radiation belt dynamics, particularly for the very dynamic "outer" electron belt. High fluxes of energetic electrons in the outer belt are the main sources of radiation dose to electronic components but also give rise to electrostatic discharge and solar array degradation. Affected orbits include GEO and MEO, but also the orbits foreseen for some large communications satellite constellations under development. There is a need to predict the state of the outer radiation belt over long and short timescales and scientific efforts have led to understanding of the key processes responsible and an ability to simulate them.

However, these scientific capabilities need to developed into robust user-oriented systems that can deliver data to users in a reasonable timescale in response to input on the state of the solar-terrestrial system. The service prototype will be able to take as input data on solar wind magnetic and plasma properties, geomagnetic indices and magnetosphere wave conditions. Where input data are unavailable, for example on wave conditions, the data will be derived from statistical correlation analyses. Data from particle measurements (fluxes, counts) will be assimilated into the system to allow improved predictions. The output will be a forecast of the global state of the outer radiation belt as a function of time, and tailored outputs for key user orbits (GEO, MEO, and constellation orbits). Rigorous validation will be undertaken with well-characterised case studies.

Deliverables: Prototype

Current TRL: 3  Target TRL: 7  Duration (months): 24

Accurate monitoring and prediction of the Earth's trapped radiation belts are essential space weather service components for spacecraft operations active in radiation belt regions.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic
Deep-Space Optical Communication System

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**Title:** 2m-class segmented optical antenna prototype

**Objectives:** The objective of this activity is to validate the design of a cost-effective optical ground antenna comprising a segmented primary mirror, scalable to larger apertures, providing optical space communications from deep-space distances in day & night operations.

**Description:** Technologies for a cost effective 4/6 m class Optical Antenna are under development. The main challenge is to provide a cost-effective Optical Ground Station that ensures robust and required performances in day and night operations (implying high background conditions and thermal load related to the potentially small Sun-Earth-Probe angles).

The development would rely on previous and planned specific activities such as a) "Deep Space Low Cost 4m Monolithic Optical Antenna for Day /Night Operations" and b) "Manufacturability of Low-Cost Mirror Cell for Large-Aperture Optical Antenna". The successful GSTP activity a) has converged towards a larger aperture (6m) segmented design yielding advanced conceptual design parameters thereof.

Critical elements to be validated as a stepping-stone towards the full 6m antenna have been identified leading to the present prototype of reduced aperture (nevertheless capable to support optical links with a corresponding link-budget)

The proposed activity shall integrate all technology elements into a small-scale prototype of 3-7 segments to demonstrate operation and performance in real conditions including an optical deep-space link from NASA's Psyche mission, as well as planned LEO-DTE in-orbit demonstrations (such as T-Osiris on ISS). It is intended to integrate as 'back-end' the detector and modem resulting from the following ongoing and planned activities:

- "Photon-Counting Ground Based Optical Communications Detector"
- "High Photon Efficiency (HPE) optical ground modem",
- "Photon-counting 2D Tracking and Communications Detector Demonstrator".

The Tasks include:

- Development of manufacturing process for a series of segmented mirrors (also for larger telescopes): step-by-step optimized procedures, definition of tools, measurement setups,
- Manufacturing of 7 segments demonstrator including cells and structure support- Full segmented mirror position control loop,
- Development of segmented mirror calibration system, based on standard optical metrology tools,
- Design of a 2m optical antenna (optical design, mount design, ...),
- Integration of the segmented mirror in an antenna prototype, with full optical path (M2, M3, M4),
- Performance tests of the system with respect to gravity, thermal load, wind with the intended deployment on the Observatorio del Teide on Tenerife as per the Agency's agreement with IAC (Instituto Astrofisico de Canarias).
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<th><strong>Deliverables:</strong></th>
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<td><strong>Target Application/Timeframe:</strong></td>
<td>Providing technology capability / Available to respond to missions need in 2025</td>
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<td><strong>Applicable THAG Roadmap:</strong></td>
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Domain | Generic Technologies - Deep-space Optical communication System
---|---
Ref. Number: | GT1D-302GS | Budget (k€): 3,000

Title: Autonomous deployable high-power uplink beacon system for deep space optical communication

Objectives: The objectives of the activity are the design and development of an autonomous, transportable high-power (order 5 kW) ground beacon system prototype for Deep Space Optical Communication compatible with the CCSDS Blue Book Recommended Standards for Optical Communications Physical Layer (CCSDS 141.0-B-1) and Optical Communications Coding and Synchronization (CCSDS 142.0-B-1).

Description: The autonomous transportable ground beacon system shall be capable of operating at remote sites in the vicinity of any astronomical telescope which may be used as a temporary ground receiver for a deep space optical communications demonstration, or operationally, to provide a ground beacon and optional telecommand signal capability.

The proposed activity shall encompass the development of a High Power (order 5 kW) autonomous, transportable Uplink Beacon System including the optical terminal, laser transmitter, control and safety systems. The Uplink Beacon System shall satisfy all requirements of the CCSDS Blue Book Recommended Standards for Optical Communications Physical Layer (CCSDS 141.0-B-1) and Optical Communications Coding and Synchronization (CCSDS 142.0-B-1). The optional low-rate uplink signalling capability shall be implemented. Suitable transmission lasers, modulators, and signal generators shall be procured and implemented.

In order to mitigate fading at the space receiver caused by the atmospheric shower curtain effect, multiple transmit apertures (on the order of 10 cm aperture diameter) are to be realized either by transmission through at least four separate launch telescopes or sub-apertures of a larger launch telescope, using mutually incoherent sources and a combined power on the order of 5 kW. A control system shall be implemented that allows remote monitoring and control, scheduling of passes, and autonomous tracking of satellites from LEO to solar system orbits. All safety systems required for legal operation according to national regulations of countries hosting major astronomical telescopes shall be studied and implemented for at least two sites (e.g. Spain and Chile). The system shall be hosted in one or two containers, allowing transportation between telescope sites, and requiring no infrastructure for installation beyond a hard, flat surface for placement, electrical power, water, and network connectivity.

The activity main tasks will be:
- Consolidation of the design requirements,
- Design, manufacture and test of a Prototype,
- Deployment beside an existing astronomical telescope or future ESA antenna prototype,
- Validation using a ‘deep-space’ optical terminal (such as the NASA Psyche mission to be launched 2022, or the planned Lunar missions – O2O, LOP-G, etc.).
Deliverables: Prototype, Report

Current TRL: 3  Target TRL: 6  Duration (months): 24

Target Application/Timeframe: Space weather, DOCS / TRL 6 available by 2022

Applicable THAG Roadmap: Optical Communication for Space (2017)
Consistent with activity D20 “Deep-space high power (5 kW) uplink beacon laser (DOCS-G7)”