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DOCUMENT

# GSTP Element 1 "Develop" Compendium of Potential Activities 2017

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# CHANGE LOG

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# CHANGE RECORD

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**Table of contents:**

# 1. INTRODUCTION

During the Council meeting at Ministerial level held in December 2016, the updated structure of the GSTP was presented *"Declaration on the General Support Technology Programme (GSTP)"* ref. ESA/C(2016)190, and extensively subscribed by the states participating in GSTP with the following framework:

- GSTP Element 1 "Develop" - Technology developments for future missions, ground applications and tools
- GSTP Element 2 "Make"- Development of technology and products for commercial competitiveness and sustainability.
- GSTP Element 3 "Fly"- In-orbit demonstration of new technologies, preparation of future missions, small missions
- Two programmatically and financially distinct Programme components:
  - "Precise Formation Flying Demonstration" component
  - "Asteroid Impact Mission (AIM)" component.

The GSTP E1 "Develop" Compendium is a list of 141 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. The aim of the GSTP E1 "Develop" Compendium is to provide to industry and Delegations a consolidated overview by Application Domain, Competence Domain and Technology Domain of the priorities for ESA in the development of technology within the GSTP Programme.

This document follows the previous GSTP-6 Element 1 Compendia of Potential Activities presented in 2013 and revised in 2016. In particular, the following five documents:

- *GSTP-6 Element 1 – Compendium of Generic Technology Activities - (*ref. TEC-T/2013-007/NP) *issued* in February 2013.
- *GSTP-6 Element 1 – Compendium of Potential Activities - Application-* Domains: Earth Observation, Human Spaceflight, Space Transportation, Navigation, Generic Technologies and Techniques, Space Situation Awareness and Robotic Exploration - *(*ref. TEC-T/2013-028/NP) issued in December 2013.
- *GSTP-6 Element 1 Compendium of Potential Activities Advanced Manufacturing* - (ref. TEC-T/2015-013/NP), issued in November 2015.
- *GSTP-6 Element 1 – Compendium of Potential Activities – (*ref. TEC-T/2016-03/NP) issued in February 2016.
- *GSTP Element 1 "Develop" - Compendium of Potential Activities: Clean Space* - (ref. ESA-GSTP-TECT-PL-003997), issued in January 2017.

This GSTP E1 "Develop" Compendium 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 following Application Domains.

- EO - Earth Observation
- SCI - Science
- ST - Space Transportation
- NAV - Navigation
- GEN - Generic Technologies and Techniques

The activities that belong to the Application Domain - Human Spaceflight and Exploration - are under review and they will be provided in a further revision of the Compendium.

In addition to the core activities in the Generic Technologies and Techniques domain which are dedicated to the development of technologies, building blocks and components for future space missions, the following special areas have been identified.

- **Clean Space:** This is an ESA cross-cutting initiative with the aim to contribute to the reduction of the environmental impact of space programmes, taking into account the overall life-cycle and the management of residual waste and pollution resulting from space activities. The list and descriptions of candidate activities for this special area is provided in a separate document.
Activities corresponding to this specific area are described in the document "*GSTP Element 1 "Develop" - Compendium of Potential Activities: Clean Space*" (ref. ESA-GSTP-TECT-PL-003997), published in EMITs News in January 2017.

- **Additive Manufacturing:** Advanced Manufacturing as a cross-cutting activity captures the opportunity of new manufacturing, materials, processes and creates sustainable competitive advantage for the European Space Industry in the global market. This is achieved by restructuring the supply chain to facilitate faster and more agile entry to the market place and by creating performance enablers thanks to new materials, added degrees of freedom in the design phase and novel manufacturing capabilities.
Activities corresponding to this specific areas are described in the document "*GSTP-6 Element 1 Compendium of Potential Activities Advanced Manufacturing*" (ref. TEC-T/2015-013/NP), published in EMITs News in November 2015.

- **Space Situation Awareness:** The objective of the Space Situational Awareness (SSA) is to support the European independent utilisation of and access to space for research or services, through providing timely and quality data, information, services and knowledge regarding the environment, the threats and the sustainable exploitation of the outer space. The activities within this specific area are structured in three segments - Space Weather (SWE), NEO, and Space Surveillance and Tracking (SST) - as well as a new fourth segment, a SWE mission to the Lagrange points L1 and L5 (LGR).
New technologies and ideas are thereby used or exploited to ensure the evolution of the SSA system towards an efficient system.
The concrete technology activities corresponding to SSA are presented in this document in chapter 3.6.

- **Design to Produce:** Design 2 Produce is an ESA cross-cutting initiative with the objective to introduce innovative techniques and benefit from spin-in from non-space industry in order to improve the space systems end-to-end development process, reducing engineering lead time and budget and serving the competitiveness of the European Space Industry. The challenge to design space systems towards manufacturability, integration and verification, feeding relevant lessons learned from the MAIT process back to the design, requires a multidisciplinary approach.
Activities corresponding to this area are presented in this document in chapter 3.7.

- **Deep Space Optical Communication System.** Optical communication from deep-space has the potential to substantially increase the returned science data volume at the same on-board burden (mass, power) compared to radio frequency communication, or to reduce the on-board terminal mass and power at similar data rates. A Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD) on the Space Situational Awareness (SSA) Space Weather (SWE) L5 mission will demonstrate the technology and at the same time serve as a scientific objective, namely the transfer of high resolution solar imagery.
The first technology activities corresponding to this area are presented in this document in chapter 3.8.

Furthermore, the activities in each Application Domain are also 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 (E2E)
- CD4 - Electric Architecture / Power and Energy / EMC
- CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing
- CD6 - Life / Physical Science Payloads / Life Support / Robotics and Automation
- CD7 - Propulsion, Space Transportation and Re-entry Vehicles
- CD8 - Ground Data 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 participants 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.

# 2. LIST OF ACTIVITIES

## EO - Earth Observation

### CD2 - Structures, Mechanisms, Materials, Thermal

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-001MS | High-fidelity reaction wheel for stable microvibration performance | 675 |
| GT11-002MM | Development and evaluation of curved silicon 2D array | 900 |
| GT11-003MT | Low Noise Miniaturized very high frequency Pulse Tube cooler | 750 |
| GT11-004MT | New Generation Cold Finger for 40-150K application | 600 |
| | **Total** | **2,925** |

### CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-005ED | SpaceFibre multilane optical link prototyping, demonstration and evaluation | 1,000 |
| GT11-006ES | Multi Gb/s payload data transmitter EM for Earth Observation missions | 2,000 |
| | **Total** | **3,000** |

### CD4 - Electric Architecture / Power and Energy / EMC

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-007MP | PPU for all-electric scientific platforms | 700 |
| | **Total** | **700** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-008EF | Radar High Power Amplifier for Ka-band Radar | 900 |
| GT11-009EF | Miniature filter for L-band radiometer | 500 |
| GT11-010EF | Frequency stabilisation of QCL for Supra-THz applications | 400 |
| GT11-011EF | Compact Multi-Frequency Feeds for Multi-Frequency Radiometers | 500 |
| | **Total** | **2,300** |

## CD8 - Ground Data Systems / Mission Operations

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-012GS | Tri-band (S/X/K) feed system design for future EO missions | 500 |
| | **Total** | **500** |

## CD9 - Digital Engineering for Space Missions

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT11-013EO | Data Analytics for EO (DANEO) | 1,000 |
| GT11-014EO | New Generation Virtual Reality for Big EO data sets (VIREO) | 400 |
| | **Total** | **1,400** |

# SCI - Space Science

## CD2 - Structures, Mechanisms, Materials, Thermal

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT12-001MM | Application of Black Silicon surface treatment to photodiodes and silicon drift detectors | 350 |
| GT12-002MT | Low CTE Heat Pipes for Highly Stable Structures | 600 |
| GT12-003MS | Large Aluminium-based Optical Mirrors Processed by Solid State Joining | 800 |
| | **Total** | **1,750** |

## CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT12-004ET | Integrated transponder/PDT for Near Earth Science missions | 800 |
| | **Total** | **800** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT12-005EF | Development of multi-color Kinetic Inductance Detector pixels for CMB applications | 750 |
| | **Total** | **750** |

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

| Activity Title | Budget (k€) | Budget (k€) |
|---|---|---|
| GT12-006MP | Diaphragm Propellant Tanks compatible with MON and MMH for spacecraft applications | 1,000 |
| | **Total** | **1,000** |

## CD8 – Ground Data Systems / Mission Operations

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT12-007GS | 500 W Ka Band Solid-State Power Amplifier | 800 |
| | **Total** | **800** |

# ST - Space Transportation

## CD2 - Structures, Mechanisms, Materials, Thermal

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT14-001MS | Development of New Interface Concepts for Launcher Main Tanks | 1,000 |
| GT14-002QE | Out Of Autoclave (OOA) Manufacture with Very High Temperature Conductive CFRP Resin systems for Launcher Applications | 450 |
| | **Total** | **1,450** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT14-003ED | Time-Triggered Ethernet as Command & Control for launchers and space tranportation applications | 1,500 |
| GT14-004SA | Enhancement of the NGT-ATB: New Generation Launcher and Space Transportation Advanced Avionics Test Bed | 2,000 |
| GT14-005SA | ADAMP Ascent and Descent Autonomous Maneouverable Platform | 3,000 |
| GT14-006SA | End-To-End preliminary design for a Lunar Ascent Vehicle | 1,500 |
| GT14-007MP | Acoustic propellant management for fuel tanks of spacecraft and launcher upper stages | 500 |
| GT14-008MP | 6kN, Deep-throttling, Pump-fed, Bi-propellant Engine | 8,400 |
| | **Total** | **16,900** |

# NAV - Navigation

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT16-001ES | GNSS Receiver Chain Technology Enabler and Integrity Techniques for the Railway environment | 500 |
| GT16-002ES | Definition of multipath and electromagnetic interference scenarios and models for GNSS in railway environments | 500 |
| GT16-003ES | Development of Scenarios, Models and Tools for Simulation of Intentional Interference and Spoofing in Railway Environments | 500 |
| GT16-004ES | Technologies for Resilience Against Intentional Interference and Spoofing in Railway Environments | 500 |
| GT16-005ES | Beam-Forming Technology for GNSS Reference-Station | 800 |
| GT16-006ES | Study and design of a Smart city Living Lab Location Test-bed | 300 |
| GT16-007EF | Technology Validation of a Cold Atom Microwave Atomic Clock (CAMAC) | 1,000 |
| GT16-008EF | Clock Ensemble Monitoring and Switching Unit for Robust Timescale Generation | 600 |
| GT16-009EF | Environment survey and calibration instrumentation for GNSS propagation error sources | 1,000 |
| | **Total** | **5,700** |

# GEN - Generic Technologies

## CD1 - EEE / Components / Photonics / MEMS

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-001ED | SpaceFibre demonstration chip and routing switch ASIC development | 2,200 |
| GT17-002MM | Demonstration of high-performance CMOS image sensor pixels for space applications using advanced technology nodes | 1,000 |
| GT17-003MM | Radiation Testing of a COTS General Purpose CMOS Image Sensor | 400 |
| GT17-004MM | CMOS image sensor based on high-resistivity epitaxial silicon | 1,000 |
| GT17-005ED | New Power MOSFETs development | 700 |
| GT17-006ED | Space evaluation and enhancement of European GaN MMIC offering | 1,500 |
| GT17-007ED | New decoupling capacitors for next generations of integrated circuit technologies | 600 |
| GT17-008QE | Radiation characterization and functional verification of COTS components for ESA space applications. | 1,200 |
| GT17-009ED | Definition and validation of an European source of Flip-chip bump services for 28nm and lower technology nodes | 600 |
| GT17-010ED | Space qualification of a pigtailed InGaAs photodiode @ 1550 nm | 500 |
| | **Total** | **9,700** |

## CD2 - Structures, Mechanisms, Materials, Thermal

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-011MS | Adaptation of industrial actuator for space applications | 800 |
| GT17-012MS | Development of a family of space actuators based on brushless DC motors. | 650 |
| GT17-013MS | Modelization and Validation of the dynamic effect of compressible Xenon in propellant tank | 500 |
| GT17-014MS | Highly accurate measurement techniques of large reflector surface | 500 |
| GT17-015MS | Passive damping for satellite and instrument design | 1,000 |
| GT17-016MT | Integration Simplification of Capillary Driven Heat Transport Systems | 500 |
| GT17-017MT | Efficient mounting of MLI blankets to spacecraft structures | 500 |
| GT17-018QE | Transparent polyimide films for thermo-optical applications | 500 |
| GT17-019MS | Application of new and novel Non Destructive Inspection (NDI) Techniques for Spacecraft and Launchers Critical Applications | 700 |
| GT17-020MS | Morphing Structures Processed by 4D Printing for Space Applications | 1,000 |
| | **Total** | **6,650** |

## CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-021ED | COTS-based highly integrated computer system for mini/nano satellites | 800 |
| GT17-022ED | High Performance Reconfigurable Processing Module (HiPeR-Pro) | 1,000 |
| GT17-023SW | CAN System and SW Stack consolidation | 800 |
| GT17-024SW | SAVOIR Data Storage Services Demonstration | 800 |
| GT17-025SW | Integration of model-based avionics design and FDIR analysis tools | 600 |
| GT17-026SA | Low-cost high reliability wide FoV Sun Sensor EM | 600 |
| GT17-027SA | Object-oriented hybrid modelling of avionics systems using Modelica | 700 |
| GT17-028ES | Miniaturized Space GNSS receiver for microsat and cubesat | 800 |
| GT17-029ES | Nanosat X-band TT&C transponder EM | 1,000 |
| GT17-030GE | SDLS-Flex: Flexible Space Data Link Layer Security Protocol implementation and End-to-End Verification | 1,000 |
| | **Total** | **8,100** |

## CD4 - Electric Architecture / Power and Energy / EMC

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-031EP | Improving density of power modules by up to a factor 2 | 1,000 |
| GT17-032EP | Integrated Power Switch ASIC for small DC/DC converters | 600 |
| GT17-033EP | High Frequency DC/DC converter module with Digital Control | 500 |
| GT17-034EP | Semiconductor Bonded Low-Mass Space Solar Cells and SCAs with 33% Efficiency at EOL | 1,000 |
| GT17-035EP | High Power, long duration Titanate technology batteries | 400 |
| GT17-036EP | Qualification of novel grounding for composite structural panels | 1,000 |
| GT17-037EP | Immunity to In-Band Electromagnetic Interference for Radio-Frequency Receivers using Signal Modulation | 1,000 |
| | **Total** | **5,500** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-038EF | Broadband and low-loss 3D RF micro-structure for high integrated high frequency front-ends and distribution networks | 700 |
| GT17-039EF | Development of High Performance ferrite material very high power switches and isolators | 700 |
| GT17-040EF | Next Generation Temperature Compensated High Power Filters Based on Novel Materials | 600 |
| GT17-041EF | Waveguide switches based on friction-free mechanisms | 600 |
| GT17-042EF | Large center-fed deployable reflector for small satellite | 500 |
| GT17-043EF | Antenna Measurement Methods for Phase-less Gain Pattern Acquisition | 300 |
| GT17-044EF | Fast Diagnostic Methods for Large-Scale Full-Satellite Antenna Measurements | 300 |
| GT17-045MM | Optomechanical mounts for large lenses | 500 |
| GT17-046MM | Diffractive optical elements for metrology | 500 |
| GT17-047MM | Versatile laser terminal for metrology, communication and time and frequency dissemination | 600 |
| | **Total** | **5,300** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-048ED | Independent verification of new Synthesizable VHDL IP Cores for space | 200 |
| | **Total** | **200** |

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

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-049MP | Enabling Technologies for Advanced Orbital Transfer Capabilities | 3,600 |
| GT17-050MP | Development and performance demonstration of a high specific impulse propulsion system for micro/nano/cubesat class spacecraft. | 700 |
| GT17-051MP | High Temperature thruster engine chambers | 2,500 |
| GT17-052MP | Building blocks for enhanced apogee and RCS engines | 2,500 |
| | **Total** | **9,300** |

## CD8 - Ground Data Systems / Mission Operations

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-053SW | RATIO-SIM Rationalization of Simulators | 1,500 |
| GT17-054GI | GEMCAV: Generic Monitoring and Control system for high rate TM / TC including Audio and Video | 500 |
| GT17-055GI | GOSADD (GrOund StAtion Data Discovery) - Ground Station data collection, archiving, integration, correlation, distribution and preparation for post processing | 500 |
| GT17-056GI | C2SoS: Monitoring and Control of System of Systems for constellations of satellites and complex network of Ground Stations | 900 |
| GT17-057GI | C2LOCO Generic MCS / EGSE for smallsats and low cost operations | 800 |
| GT17-058GS | Water cooled 2-10kW X-Band Solid State Power Amplifier (SSPA) | 1,000 |
| GT17-059GS | Enhanced antenna servo controller performance under high wind conditions | 600 |
| GT17-060GS | Automated Laser Ranging for Uncooperative Targets | 3,400 |
| GT17-061GS | Low Cost Pointing Calibration System for Antennas | 500 |
| | **Total** | **9,700** |

## CD9 - Digital Engineering for Space Missions

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-062GE | ADGE - Advanced Digital Ground Segment Engineering | 1,300 |
| GT17-063SW | Information Systems & Ontologies & Semantic modelling for Semantic Interoperability | 1,900 |
| GT17-064GE | E2E Reference Environment for Space Missions (ERES) | 1,500 |
| GT17-065GE | SSE4Space - Secure Systems Engineering for Space Missions | 1,000 |
| GT17-066OS | Data Analytics for multiple Space Applications (DASA) | 1,900 |
| GT17-067GI | FASSADE - Federation of Assets supporting the Storage, Search and Access to spacecraft Data for Engineering analysis | 3,500 |
| GT17-068EO | Microservices to Applications - a Generic Interdomain Composer (MAGIC) | 1,000 |
| GT17-069EO | BlockChain for Space Activities (BC4SA) | 700 |
| GT17-070GE | Automated Fault Root Cause Analysis and Forecasting (ARCA) | 600 |
| GT17-071GE | EuGRA - European Ground Reference Architecture | 600 |
| | **Total** | **14,000** |

## CD10 - Astrodynamics / Space Debris / Space Environment

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT17-072EP | Low resource spacecraft plasma monitor prototype | 500 |
| GT17-073EP | Radiation energy effects on electronic components with very high energy heavy ion and electron beams | 500 |
| GT17-074EP | Radiation monitor data analysis for radiation belt modelling | 700 |
| GT17-075EP | Microparticle model validation based on in-flight data | 400 |
| GT17-076GF | Challenges for the future Flight Dynamics system and processes | 350 |
| GT17-077GR | Large impact detectors for mm-particles resolving impact momentum vectors | 500 |
| GT17-078GR | Advanced Collision Avoidance Techniques | 650 |
| GT17-079GR | Numerical simulation of hypervelocity collisions for breakup model calibration | 400 |
| GT17-080GR | High-resolution spectroscopy of space debris fragments | 500 |
| GT17-081GR | Development of an enhanced spacecraft fragmentation code | 1,000 |
| | **Total** | **5,500** |

## Space Situational Awareness

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT18-001ED | Prototype Remote Interface Unit (RIU) for SWE hosted payloads | 650 |
| GT18-002EP | Solar Activity Onset Modelling | 600 |
| GT18-003EP | Radiation Monitor System in a Package | 600 |
| GT18-004EP | Heliospheric modelling techniques | 1,000 |
| GT18-005EP | Virtual Space Weather Modelling Centre (VSWMC) - Part III | 800 |
| GT18-006EP | Fireball Monitor for Space Situational Awareness | 800 |
| GT18-007EP | Impact effects tool | 500 |
| GT18-008EP | Space Weather Instruments for SmallSat and Hosted Payloads Missions | 1,800 |
| GT18-009EP | 3D Ionospheric Modelling | 600 |
| GT18-010EP | Global Magnetospheric Modelling to Drive Geomagnetic Services | 600 |
| GT18-011L | Data Analytics for Early Warning of Space Weather Events | 300 |
| GT18-012GR | Streak detection algorithm validation through field campaign data | 300 |
| GT18-013GR | Maturing the sub-catalogue debris characterisation capabilities of a space-based optical component | 500 |
| GT18-014GS | Optimisation of L-Band Transmit/Receive Modules used in Surveillance Radar Antenna Arrays | 1,000 |
| GT18-015MM | Compact EUV Imager for the Lagrange Space Weather mission | 1,200 |
| | **Total** | **11,250** |

## Design to Produce

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT1P-001MX | Procedure viewer and authoring tool for ground AIV/AIT applications | 1,200 |
| GT1P-002SW | Optimization by Digital Engineering applied in Projects | 800 |
| GT1P-003SY | Exploring Enhanced Procurement in a Fully Digital Environment | 700 |
| GT1P-004ED | Improvement of design and product, based on analysis of data from embedded sensors | 1,500 |
| GT1P-005ED | Embedded Sensors for AIT | 800 |
| GT1P-006SY | Digital Engineering Hub Pathfinder (CD09) | 800 |
| GT1P-007MX | Multidisciplinary 3D Digital Models for AIT environment | 700 |
| | **Total** | **6,500** |

## Deep-space Optical Communication System

| Programme Reference | Activity Title | Budget (k€) |
|---|---|---|
| GT1D-001GS | Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD) Ground Terminal Technology Developments | 6,500 |
| GT1D-002MM | Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD) Space Terminal Technology Developments | 5,900 |
| | **Total** | **12,400** |

# 3. DESCRIPTION OF ACTIVITIES

## 3.1. EO - Earth Observation

### 3.1.1. CD2 - Structures, Mechanisms, Materials, Thermal

#### 3.1.1.1. TD15 - Mechanisms

| | |
|---|---|
| *Domain* | *Earth Observation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *15 – Mechanisms* |

**Ref. Number:** **GT11-001MS** **Budget (k€):** 675

**Title:** **High-fidelity reaction wheel for stable microvibration performance**

**Objectives:** The objective of this activity is the development and test of a reaction wheel EM, competitive with non-European products in terms of microvibration performance.

**Description:** Some non-European reaction wheel products possess superior properties in terms of microvibration performance. In particular the low frequency content of their noise spectrum (i.e. <100 Hz), which cannot be effectively damped by state-of-the-art wheel isolation systems, appears to be disturbance free. This appears to be due to a high-fidelity rotor balancing process as well as the presence of a viscous damping system at bearing level (i.e. wheel internal damping).

In contrast, European products typically used on Earth Observation missions, show deficits in terms of stability of rotor balancing and bearing noise. In particular, static and dynamic unbalance regularly drift outside of their specified range when exposed to environmental as well as operational loads.

The activity aims at developing techniques to produce reaction wheels with highly stable unbalance and bearing noise characteristics which should particularly include:

- development of a high-fidelity rotor balancing technique,
- development of wheel internal damping features, e.g. on bearing level.

The activity would include production and test of a reaction wheel EM to demonstrate microvibration performance in a relevant environment.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Every three-axis stabilized satellite with fine pointing requirements such as MTG, Metop-SG, EarthCARE. Furthermore, agile Earth Observation missions with high resolution optical payloads (e.g. Pleiades or SPOT 6/7). TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.1.1.2. TD17 - Optoelectronics

| | |
|---|---|
| *Domain* | *Earth Observation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT11-002MM** **Budget (k€):** 900

**Title:** **Development and evaluation of curved silicon 2D array**

**Objectives:** The aims of the activity are to develop/demonstrate a repeatable method to spherically curve existing CCD or CIS detector arrays, characterise the electro-optical performance and compare to the equivalent flat detector and validate the environmental suitability for future space applications.

**Description:** Curved focal plane detectors offer a well-known method for simplifying the optical design without sacrificing performance for many applications. The reduction in mass and volume offered by the utilisation of such detector arrays can clearly help in achieving these key objectives of space instrument design. The objective of this activity is to demonstrate that existing, high-performance 2D detector arrays, already used in space applications, can be successfully curved and still meet both performance and environmental requirements.

This activity encompasses the following tasks:

- Procurement of 4 planar detectors, fulfilling at least the following specifications:
  - backside thinned with a large active area,
  - the array size should be at least 6x6cm to be able for easy adaptation to an existing Schmidt telescope.
- Post-processing of 3 devices (out of the 4) to curve them at a selected radius.
- Electro-optical performance evaluation of all devices to compare the performance before and after the curvature process.
- Qualification campaign for environmental testing following the ESCC 9020, meaning humidity test, thermal cycling, storage, etc. Additional electro optical tests must be performed on all devices during this qualification campaign to access degradation of performances.

The activity should also verify the yield of the post-process which is applied to the devices. For this investigation smaller detector devices could be used.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Future EO and science missions. TRL 5 by 2019.

**Applicable THAG Roadmap:** Optical Detectors, Visible Range (2015).

### 3.1.1.3. TD21 - Thermal

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|---|---|
| *Domain* | *Earth Observation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *21 - Thermal* |

**Ref. Number:** **GT11-003MT** **Budget (k€):** 750

**Title:** **Low Noise Miniaturized very high frequency Pulse Tube cooler**

**Objectives:** The objective of this activity is to develop, build and test a prototype of a miniaturized Pulse Tube cooler that can suit the needs of Earth Observation missions. More specifically small/medium sized SWIR/MWIR missions that require cooling around 120K.

**Description:** SWIR/MWIR is, and will remain in the foreseeable future a detection band of interest for Earth Observation missions (linked to the CO2 detection) and the medium term trend of EO missions will lean toward medium sized satellites with limited resources. In the past period, those missions had to rely on passive cooling (which have an impact at system level e.g. attitude limitation) considering that the current portfolio of European Coolers is more geared toward bigger cooler and cooling power.
One of the potential solutions to answer this type of need is to use miniaturized Pulse Tube coolers. Such coolers are driven at high frequency, which also permits to limit microvibration disturbances to frequencies above 90Hz.

The objective of this activity is therefore to answer this need by proposing a Pulse Tube cooler with the following characteristics:

- Mass: < 750g.
- Cooling Power at 20W input Power and 20degC I/F Temperature: 2.5W@120K.
- Driving Frequency: > 90Hz.
- Exported Microvibrations in piston axis (assuming compensation): <0.1N.
- Exported Microvibrations in transverse axis: <0.35N.

In a first design phase, the contractor shall propose designs and manufacturing solutions for the HFPTC based on existing technologies and on-going developments.
The detail design phase shall close the trade-offs thanks to analysis and breadboarding in key performance area (e.g. cryogenics).
An Engineering/Qualification Model of Pulse Tube cooler 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.
The last task of the activity will be to lay down a comprehensive route to flight plan for the product including critical material and processes qualification aspects and the cooler drive electronics.

**Deliverables:** Prototype

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 36

**Target Application/ Timeframe:** Potentially driven by missions like CarbonSat.

**Applicable THAG Roadmap:** Cryogenics and Focal Plane Cooling (2013).

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| *Domain* | *Earth Observation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *21 - Thermal* |

**Ref. Number:** GT11-004MT **Budget (k€):** 600

**Title:** **New Generation Cold Finger for 40-150K application**

**Objectives:** The objective of this activity is to develop, build in an industrialized way and test a new generation Cold Finger for Stirling/Pulse Tubes coolers that can answer the need of Earth Observation missions in the temperature range of 40 to 150K.
This cold finger should make the maximum use of the latest manufacturing techniques, lessons learnt from past projects and advances in the material domains.
The technical objective of such development is not only to potentially increase the cryogenic performances of the Cryocoolers but also to simplify and render more consistent the manufacturing of the Cold Fingers.

**Description:** Active cryogenic cooling is a critical technology for Earth Observation. The past 10 years saw, in Europe, the developments of coolers (both Stirling and Pulse Tube) that just meet the performance standards of current Earth Observation Missions (e.g. MTG, MetOP).

Nevertheless, due to more and more stringent mission requirements (detection, agility etc.), it is mandatory to prepare the future and to not only improve the efficiency of the cold finger but also to improve the manufacturing process of this performance sensitive part of the coolers.

After a first phase consisting in gathering relevant requirements coming from the current generation of Cryocooler and also from future users, new designs and manufacturing solutions for the Cold Fingers shall be proposed, focusing on the thermodynamic performances (e.g. new regenerator, heat exchanger and flow straightener) but also the manufacturability and the cost of the industrialized product.

Following a detailed design/industrialization phase for a temperature agreed with ESA (e.g. 120K) which will permit to close the remaining trade-offs, an Engineering/Qualification Model of the cold finger 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:** Prototype

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

**Target Application/ Timeframe:** Potentially driven by missions like CarbonSat.

**Applicable THAG Roadmap:** Cryogenics and Focal Plane Cooling (2013).

## 3.1.2. CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

### 3.1.2.1. TD01 - Onboard Data Systems

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|---|---|
| *Domain* | *Earth Observation - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT11-005ED** **Budget (k€):** 1,000

**Title:** **SpaceFibre multilane optical link prototyping, demonstration and evaluation**

**Objectives:** The objective of the activity is to demonstrate the feasibility and performance of the technology as physical layer for SpaceFibre links. To achieve the objective, in the frame of the activity, an optical physical layer for SpaceFibre links shall be made available. An optical transceiver array, multi-fibre connector and multi-fibre cable assembly shall be developed. The components shall be made available to early adopter of the technology and to allow assessment of the properties in the frame of early development stages for future products.

**Description:** SpaceFibre is a multi-Gbit high speed serial link developed for space applications. It runs over copper and fibre-optic cables and allows serial links up to 10Gbps. Multi-lane capability allows to combine several physical links to a single logical link to achieve data rates of several hundred Gbit per second. SpaceFibre has built-in quality-of-service (QoS), isolation and recovery (FDIR) capabilities.
Suitable technologies have already been identified and several potential manufacturers for the technology are available. Laser driver and receive diode transimpedanz amplifier ASICs with multiple channels have been developed in previous activities. Suitable laser and receive diodes are available and the technology to place them in diode arrays for multi-fibre operation is available. The envisaged multi-fibre MT connector has been demonstrated on Proba-V and has been selected for coming optical telecom satellite payloads. Active components of the technology are used by CERN in the LHC detectors.
A SpaceFibre node needs for a single link 2 fibres to be able to transfer data (1x TX, 1x RX). The protocol allows to combine up to 16 links to a single logical link, which results in the goal of 32 fibres for the whole system (16x TX, 16x RX).

Tasks to be performed:

- architecture definition and development, capable to combine multiple fibres (goal:32) in a single cable assembly, connector and optical transceiver array,
- development and evaluation of a laser and receiver diodes array (goal: 16x laser, 16x receiver and corresponding optic),
- development and evaluation of transimpedance amplifiers and laser diode driver array chip (goal: 16x laser driver, 16x transimpedance amplifier),
- development and evaluation of a fibre-optical connector suitable to combine multiple fibres (target:4 goal:32). The connector shall not be bigger than a current single SpW connector. Fibre-fibre connection shall not be allowed and a user without special training in handling optic devices shall be able to mate/demate the connector,
- development and implementation of a demonstrator in chip-on-board technology to show the performance of the whole system.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** TRL 5 as of 2019.

**Applicable THAG Roadmap:** On-Board Payload Data Processing (2016).

### 3.1.2.2. TD06 - RF Systems, Payloads and Technologies

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|---|---|
| *Domain* | *Earth Observation - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT11-006ES** **Budget (k€):** 2,000

**Title:** **Multi Gb/s payload data transmitter EM for Earth Observation missions**

**Objectives:** The objective of this activity is to design, develop and test an EM model of a payload data transmitter, implementing advanced techniques resulting from a previous TRP activity and enabling multi-Gb/s data rate in X- and K-band for Earth Observation missions.

**Description:** The EGRET TRP activity investigated in depth the extension of the CCSDS 131.2-B standard, introducing 128- and 256-APSK modulations and accompanying low complexity coding options, on top of the ones already in the standard covering up to 64-APSK. Making use of these new modulation and coding options, the bandwidth available for Earth Observation missions (both X- and K-band) can be fully exploited in the high elevation regime without saturating the data rate, while still respecting realistic constraints, e.g. limited available power and hardware resources. The use of higher constellations is also in line with the trend followed by other satellite standards, e.g. the extension of DVB-S2 (DVB-S2x).

A payload data transmitter implementing the CCSDS 131.2-B standard as well as the new options introduced by EGRET up to EM level will prepare the way for near-future use of such techniques by missions needing multi-Gb/s data rates.
In this activity, such model will be designed and developed and used to perform a full functional verifications of the specifications out of the EGRET activity.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL6 by 2021.

**Applicable THAG Roadmap:** TT&C Transponders and Payload Data Transmitters (2012).



European Space Agency
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## 3.1.3. CD4 - Electric Architecture / Power and Energy / EMC

### 3.1.3.1. TD19 - Propulsion

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| *Domain* | *Space Science - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT11-007MP** **Budget (k€):** 700

**Title:** **PPU for all-electric scientific platforms**

**Objectives:** The objective of this activity is to develop and test a Power Processing Unit (PPU) suitable for scientific platforms, all-electric, devoted to ultra-low orbits with stringent pointing requirements.

**Description:** In the frame of LISA PF, two PPUs were bread-boarded and tested for Caesium and Indium mN-FEEP thrusters. The use of EP systems for station-keeping and, more recently, orbit raising, allows for a very significant reduction of propellant mass. This reduction can be translated into larger payload mass, or in a reduced total mass, which means significantly lower launch costs. Both of these cases imply economic benefits for the operators, which means a competitive advantage for the satellite manufacturers that can offer EP systems in their spacecraft buses.

For scientific missions, electric propulsion can be an enabling technology, for example in missions like GOCE, where constant drag compensation throughout the mission lifetime is required, due to the presence of air drag at this low orbit, in order to perform measurements in a ultra-quiet environment.
Depending on the application, a wide spread of electric propulsion systems with various thrust levels and specific impulses are being used. Whereas the higher thrust levels are quite well addressed by thruster developments and available electronics, there are not so many alternatives available for the low thrust levels. Especially for small spacecraft, where electrical power typically is quite limited and there are strong constraints in terms of mass and volume for the propulsion system, electric propulsion has still some difficulties to compete with cold gas thrusters. Recently developed and optimized thruster technologies could be promising candidates for small spacecraft, especially where fine thrust regulation, low thrust levels and long lifetime is required.
The Power Processing Unit (PPU), as driving electronics, is a very important item of a propulsion subsystem, which has great influence on its performance, mass/volume and cost. In order to prepare electric propulsion as a real competitive and enabling technology candidate for future scientific missions requiring low thrust levels on small spacecraft with limited resources, a pre-development of the PPU is proposed. Since the development of the electronics is very much dependent on the specific electrical properties of a particular thruster, so called coupling tests between electronics and thruster shall be an integral and essential part of the development.
As a starting point an existing PPU development will be used, which might require adaptions to the selected thruster technology. This approach will allow on breadboard level to identify hard points and to develop a requirement specification for an EM/QM PPU. First coupling tests with a thruster shall confirm the correct baseline of the design.
The second step will focus on the development of an engineering model of the PPU, optimized for scientific platforms (e.g. against the NGGM mission requirements) and taking into account the typical constraints such as power,

mass/volume and cost. Intermediate coupling tests with a real thruster shall safeguard the development and pave the way for a the future.

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| **Deliverables:** | Engineering Model verified in a representative environment | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 5 | **Duration (months):** | 30 |
| **Target Application/ Timeframe:** | Electric propulsion systems for missions like NGGM. TRL 5 by 2021. | | | | |

**Applicable THAG Roadmap:** Electric Propulsion Technologies (2009).

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

### 3.1.4.1. TD06 - RF Systems, Payloads and Technologies

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|---|---|
| *Domain* | *Earth Observation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT11-008EF** **Budget (k€):** 900

**Title:** **Radar High Power Amplifier for Ka-band Radar**

**Objectives:** The objective of this activity is to design, manufacture and test a breadboard of a pulsed HPA (High Power Amplifier) meeting the specification for use in the Ka-band SAR instruments (3.5 kW, 14% duty cycle, 500MHz BW).

**Description:** Recently the interest of Synthetic Aperture Radar (SAR) instruments for Earth Observation purposes at the higher frequencies as Ka-band has significantly evolved. In this band single pass single platform interferometer for land observation and ocean wide swath altimetry have developed strong momnetum.

In particular ocean wide swath altimetry applications have developed high interest at the European Copernicus Marine Services.
Various ESA internal activities on the feasibility of a Ka-band SAR instrument and interferometer have pointed to the need of a European Ka-band high power source e.g. Klystron with capabilities beyond what is currently available on the worldwide market.
The activity will reflect this need by building a vacuum tube demonstrator fulfilling European needs.

The activity will be divided in two phases:
Phase 1 will cover the following tasks:

- critical review of the trade-off and results of the TRP activity on the feasibility study of a pulsed HPA for Ka-band SAR,
- identification of a baseline technology, e.g. Extended Interaction Klystron (EIK) and design,
- performance prediction by analysis/simulation and tests at subassembly level,
- consolidation and update of the preliminary specification.

Phase 2 will be dedicated to:

- manufacturing and testing of a HPA Breadboard according to the baseline design agreed at the end of Phase 1,
- a detailed programmatic description of the necessary development steps needed up to Flight Model, together with a realistic estimation of the duration and cost of each development phase.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Ka-band SAR interferometer. TRL 5/6 2022.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Earth Observation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT11-009EF** **Budget (k€):** 500

**Title:** **Miniature filter for L-band radiometer**

**Objectives:** The objective is to develop miniaturised high performance filter for L-band synthetic aperture radiometer applications.

**Description:** Synthetic aperture radiometer instruments like MIRAS (SMOS) require several similar receivers to be accommodated. In this kind of instrument, the number of elementary receivers correlates with the system performance. Therefore, in order to improve the performance of similar instruments in the future, the miniaturisation and mass saving of the receiver is crucial in order to allow for a larger number of receivers to be accommodated.

One key block in the receiver is the high performance RF filter that has to provide very efficient out-of-band interference protection and on the other hand its transfer function has to be reproducible and uniform from unit to unit. Currently, coaxial resonator filters are employed for this function which, however, are big and bulky and they are not any more in line with the miniaturisation objectives of the other parts of the receiver (Integrated digital receiver TRP WP 2013). However, there are potential technologies that can provide the required degree of miniaturisation while maintaining the performance (Dielectric, SAW, BAW). It is presumed that the RF filter could be located after the low-noise amplifier and the insertion loss is not necessarily a key design parameter. This could open ways for the application of novel efficient design approaches such as pre-distortion and lossy filter theory.

This activity aims first at revisiting the L-band elementary receiver requirements for SMOS follower like missions and then flowing down from there the filter requirements. Secondly, taking into account also the qualification aspects, the best technologies and architectures for the miniaturised filter shall be breadboarded. Based on the breadboarding results, the best concept shall be selected for an EM development. Finally, the EM shall be designed, manufactured and tested.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** SMOS/MIRAS type future instruments: SMOS-Ops, Super MIRAS. TRL 7 for 2022.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.1.4.2. TD07 - Electromagnetic Technologies and Techniques

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| *Domain* | *Earth Observation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT11-010EF** **Budget (k€):** 400

**Title:** **Frequency stabilization of QCL for Supra-THz applications**

**Objectives:** The objective is to demonstrate the feasibility of the frequency stabilization of a Quantum Cascade Laser (QCL) and demonstrate the improvement of a stabilization loop with respect to passive stabilization.

**Description:** The supra-THz (>3 THz) bands have been recently proposed for low Earth orbit THz remote sounding missions such as LOCUS (Low-Cost Upper-atmosphere Sounder). In order to achieve coherent detection, heterodyne receivers at supra-THz frequencies are under development by integrating in a single waveguide cavity a Schottky based mixers fed by a Quantum Cascade Laser (QCL) as Local Oscillator (LO). Thanks to the QCL, enough LO power is available to drive the mixer.
Currently, a simple combination of passive thermal and electrical bias control is proposed for the frequency stabilization of the QCL. In order to achieve the frequency stability that would allow meeting the scientific requirements, phased lock loop systems such as the beating tone of two lasers injected into the QCL shall be investigated.
The activity aims at proposing, manufacturing and testing a frequency stabilization loop for QCLs used as LO of supra-THz Schottky mixers.

The activity will consist in:

- establishing the state of the art survey for the Schottky based supra-THz heterodyne receivers and QCL LO,
- issuing the main mission, receiver and LO performance requirements including frequency stability,
- performing trade off analysis and selecting one baseline frequency stabilization loop solution including its integration with the QCL and Schottky mixer,
- designing and analyzing the selected configuration,
- manufacturing and testing the critical breadboard elements,
- proposing a roadmap and a development plan for the critical elements.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Remote Sounding EO Missions. TRL5 by 2019.

**Applicable THAG Roadmap:** Technologies for Passive Millimetre and Submillimetre Wave Instruments (2016).

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|---|---|
| *Domain* | *Earth Observation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT11-011EF** **Budget (k€):** 500

**Title:** **Compact Multi-Frequency Feeds for Multi-Frequency Radiometers**

**Objectives:** The aim is to develop a compact multi-frequency and dual-polarisation feed horn for future microwave radiometer instruments.

**Description:** Earth Observation radiometers often use multi-frequency feeds to comply to the colocation requirement of certain beams on ground. Besides the colocation requirement there is sometimes also the requirement to have the dual linear polarisation for certain frequency channels. Although this does not impact the design of the feed horn itself, it has a significant impact on the design and complexity of the feed chain excitor part.

Similar design issues can be seen in Telecommunication feed horns with receive and transmit capability and often use dual polarisation as well. The constraint these feed horns have is that they form part of a larger array and hence need to have a very compact feeding chain with the lateral dimensions not larger than the feed horn aperture. In a previous ESA activity a very compact Ka-band feed horn was designed, manufactured and tested operating at 20 and 30 GHz.

In this activity an assessment shall be done to see what simularities exist between the feed requirements for EO radiometers and Telecommunication array feed horns at e.g. Ka-band. If feasible a feed horn shall be designed, analysed, manufactured and tested at 18/23 GHz for a future EO radiometer similar to MWI instrument on Metop SG.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL 5 by 2020.

**Applicable THAG Roadmap:** Technologies for Passive Millimetre and Submillimetre Wave Instruments (2016).

## 3.1.5. CD8 - Ground Data Systems / Mission Operations

### 3.1.5.1. TD12 - Ground Station Systems and Networks

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| *Domain* | *Earth Observation - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

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| **Ref. Number:** | **GT11-012GS** | **Budget (k€):** | 500 |

**Title:** **Tri-band (S/X/K) feed system design for future EO missions**

**Objectives:** The objective of the activity is so far EO missions have been operated in S-Band (TT&C) and in X-Band (payload data). In the future TT&C services will migrate to X-Band and payload data will be transmitted in K-Band. The objective of this activity is to design a feed that will be able to operate in S/X/K-Band to cover running and upcoming EO missions.

**Description:** The layout of the 14m X/K-Band antenna developed under a previous GSTP activity will be used as starting point to define the feed specifications. A trade-off among different feed configuration will be performed. After selection of the preferred solution the feed will be designed including diplexers/filters and tracking couplers. Mechanical drawings will be prepared and critical components will be manufactured and tested in order to de-risk the project.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** All future Earth Observation missions.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

## 3.1.6. CD9 - Digital Engineering for Space Missions

### 3.1.6.1. TD02 - Space System Software

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| *Domain* | *Earth Observation - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *02 - Space System Software* |

**Ref. Number:** **GT11-013EO** **Budget (k€):** 1,000

**Title:** **Data Analytics for EO (DANEO)**

**Objectives:** The objective of this activity is to design, develop, benchmark and implement methods and tools for advanced data analytics capabilities, tailored for the emerging exploitation platforms concept and processing paradigm.

**Description:** Emerging concept of exploitation platforms and network of platforms are fostering and promoting the massive use of EO data, in order to support as much as possible specific applications (like e.g. in thematic platforms, or mission-specific platform, etc.). On their side, these applications require data from a wide range of sensors, and possibly from long time series built with past, current and future missions. Today, all these data are becoming collocated on public cloud platforms, where it is expected to have low-level access to these data.
The proposed activity shall design, develop, deploy and test open-source tools to perform advanced data analytics on such big data sets (in terms of volumes and variety) hosted on these public clouds. They are today only partially applied on small scale data archives, usually stored on a shared file system or in a distributed key/value data store. Therefore, methods and tools to be developed shall permit to support upcoming storage approaches (like e.g. the Object Store, which is currently an issue for many tools), and to provide and benchmark different data analytics capabilities on massive heterogeneous datasets (e.g. EO data complemented with meteorological or hydrological ones). In particular, these methods shall permit to analyze long and dense data time series, infer and derive patterns and trends, and even generate predictions of next values in the time series. The analysis of the differences between predictions and actual measurements can permit to effectively extract the information embedded into data and bring advantages in the context of monitoring, prevention and decision making (e.g. by forecasting the urban expansion, or by assessing the forecasted probability of a fire in a particular area).

To achieve the above objectives, the following functionalities shall be provided:

- data Fusion between the different sensors, in order to obtain more observations in cases of clouds and collect more dense time series,
- machine/Deep Learning (ML/DL) and Artificial Intelligence (AI) methods and algorithms to be applied on such huge and heterogeneous data sets stored on the public clouds (not only from satellite data, but also from complementary or in-situ data); these methods shall permit to analyse long and dense data time series, infer and derive patterns and trends, and even generate predictions of next values in the time series,
- tools to apply and analyse metrics, in order to assess the accuracy across the different data analytics techniques, or to evaluate the predictions once the next acquisition is performed,
- a powerful time series Visualisation Tool (i.e. going much further than the current solutions), targeted to researchers and developers who need powerful

and interactive Web based analytics with built-in map viewer (considering the emerging data cube technology),
- a programming client interface (like e.g. Python) on top of data analytics components, since this is usually extensively used by researchers communities,
- developed software components shall be distributable as open source, with an adequate license, and shall run on cloud-based scalable infrastructures (with data collocated with processing components). Their performance and scalability shall be ensured by demonstration in pilot project areas (to be identified and agreed during the project),

To achieve project objectives, at list the following activities shall be addressed:
- state-of-the-art technology survey (with gap analysis) and analysis of requirements and needs, including formulation of real use cases in pilot project areas,
- development of required data analytics algorithms and design of software components to be implemented,
- integration and verification of implemented components into the selected infrastructure,
- validation and demonstration on identified use cases.

The activity shall be linked and take into account the outcome of parallel activities in order to create synergies between different application domains (like e.g. data analytics on operations or on satellite design data).

**Deliverables:** Prototype

| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** Explotation of Earht Observation Data. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.1.6.2. TD26 - Others

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| *Domain* | *Earth Observation - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *26 - Others* |

**Ref. Number:** **GT11-014EO** **Budget (k€):** 400

**Title:** **New Generation Virtual Reality for Big EO data sets (VIREO)**

**Objectives:** The objective of the project is to develop a new generation of Virtual Reality (VR) technologies enabling immersive and real-time exploration of current Petabyte-scale EO data sets.

**Description:** EO has now fully entered the era of Big Data with Petabytes of data delivered routinely by the new generation of satellites, such as the Sentinels. One of the biggest challenges of Big Data is extracting small information in a way that the human mind can comprehend. Immersive environments (like e.g. Virtual Reality) are now providing a very powerful tool to better capture the information hidden in a large amount of data. There is currently a growing need for scientist to walk through these large data sets, by simplifying as much as possible the visualization to reduce the cognitive load, thus keeping the user less stressed and more able to focus. VR can help guide the scientists and other users to key areas of the data representation.

At the same time, VR technology has also become available to general public, mainly for entertainment purposes. All main high-end mobile phones are equipped with technologies (e.g. Google Cardboard) which allow to turn them in a VR viewer with the addition of a relative cheap external device. Such technology can of course be used to develop EO data visualization apps for mobile phones, both for data analysis or outreach purposes. In addition, combining Artificial Intelligence (AI) with VR permits to find the hot spots where to focus attention. This convergence of technologies represents the next frontier in delivering extracted information and situational awareness to users, allowing them to explore and interact with Petabyte-scale EO data sets (e.g. for finding outliers, exploring trends, correlations, patterns, shared context, etc.).

In this context, the idea of this project is to combine VR and AI to create the new generation of immersive experiences to advance our understanding of Big Data.
The main idea is to integrate these 2 technologies (AI and VR). AI techniques will enable to target the VR gaze to the most interesting 'hot spots'. As an example, when looking at the archive of S2 (several Petabytes), an AI system can tell you the 'Hot Spots' according to user needs, like e.g. changes in forests, ocean and coastal environments, land use, atmosphere, infrastructures, etc. The system will automatically compute the places of changes according to user interest; then the VR will enable to look at it and share it between people.
In particular, one key idea is to investigate the characteristics of the data and visualization methods that most effectively leverage human neurologic capabilities (in terms of what human senses, brain and emotions are optimized to detect, synthesize and model). The advantage of this new technology (AI combined with VR) is to incorporate the science of human visual perception into data visualization techniques. This results in tools that deliver great human comprehension of the data, improving over traditional visualisation techniques. Furthermore, the technology developed in this project shall also be adapted to be used by mobile apps, in order to create ergonomic virtual environments tailored for mobile devices.

The outcome of the activity is a 'Prototype Demonstrator' showing the capability of AI combined with VR to capture the spots of a changing planet (observed by satellite, like e.g. S-1/2/3), with a focus on a series of use cases, related to urban, coastal, ocean, and vegetation changes. The main components to be developed are:

- the AI package enabling to mine the satellite data archive for hot spots of change,
- interface with VR tools to enable immersive dive into the archive and time-lapse of change on demand,
- demonstrator of the combined technologies (AI+VR) on a series of use cases (e.g. cities, coastal, ocean, vegetation changes).

To achieve activity objectives, at list the following tasks shall be addressed:

- state-of-the-art technology survey (with gap analysis) and analysis of requirements and needs, including formulation of real pilot use cases,
- development of required algorithms and methodologies, and design of software components to be implemented,
- integration and verification of implemented components into a consistent software prototype,
- validation and demonstration on identified use cases, including analysis of strategic evolution.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** Exploitation of Earth Observation Data. Q2 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

# 3.2. SCI - Space Science

## 3.2.1. CD2 - Structures, Mechanisms, Materials, Thermal

### 3.2.1.1. TD17 - Optoelectronics

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|---|---|
| *Domain* | *Space Science - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *17 - Optoelectronics* |

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|---|---|---|---|
| **Ref. Number:** | **GT12-001MM** | **Budget (k€):** | 350 |

**Title:** **Application of Black Silicon surface treatment to photodiodes and silicon drift detectors**

**Objectives:** The objective of this activity is to transfer black silicon surface treatment to existing photodiodes and silicon drift detectors.

**Description:** In the recent years, light trapping by nanostructured surface has been successfully applied to solar cells, resulting in excellent performance devices. This technology, in combination with other modifications, has been already proven to be beneficial for silicon photodiode devices. The nanostructure advantages are: a longer optical path, a wider acceptance angle and a close to zero surface reflection. All these characteristics will provide devices with superior performances.

This activity encompasses the following tasks:

- transfer of the black silicon technology to existing photodiode and silicon drift detectors,
- electro-optical performance evaluation to compare standard process and the new technology,
- qualification campaign for environmental testing following the ECSS 9020 standard,
- radiation campaign to assess radiation hardness of the new technology.

The expected deliverables are the devices procured during the activity with the new surface technology transfer.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Application in optical detectors. TRL 5 by 2019.

**Applicable THAG Roadmap:** Optical Detectors, Visible Range (2015).

### 3.2.1.2. TD21 - Thermal

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|---|---|
| *Domain* | *Space Science - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *21 - Thermal* |

**Ref. Number:** **GT12-002MT** **Budget (k€):** 600

**Title:** **Low CTE Heat Pipes for Highly Stable Structures**

**Objectives:** The objective of this activity is to develop Low CTE Heat Pipes that can be mounted to highly stable structures without inducing thermal stresses over the operating temperature range.

**Description:** Structures that are used to achieve a high pointing accuracy requirement are usually constructed using CFRP since it provides a low thermal distortion solution. However, these structures have a low thermal conductivity which makes it difficult to evacuate heat from dissipative components that are mounted to the structure. The current approach to remove the power dissipation via radiation heat transfer since other alternatives as conduction, are not a viable solution. However, radiation heat transfer can only be used for low power density units since higher power units would simply overheat. One method to solve this problem, is to use heat pipes to transport this excess heat to a radiator.

A previous ESA activity studied the option of mounting low CTE Heat Pipes (e.g. Ivar or Titanium) to a CFRP structure. However, the trade-off revealed that the bonding low CTE saddles to the Invar or Titanium tube was too complex and heavy. With the advancement of Additive Layered Manufacturing (ALM), the thermal interfaces or saddles located on the heat pipe, could be made using the ALM process and welded/joined to a standard arterial heat pipe made of the same material as the ALM pieces. The ALM heat pipe sections could also increase the performance of the heat pipe by widening the evaporator or condenser surface area.

The activity will focus the following aspects:

- working fluid selection,
- material selection,
- material characterization and compatibility testing,
- ALM parameters optimization,
- ALM sample manufacturing and testing,
- Engineering Model manufacturing and testing in a representative configuration and environment.

**Deliverables:** Engineering Model

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 28

**Target Application/ Timeframe:** Application in stable structures. TRL 6 2020.

**Applicable THAG Roadmap:** Two-Phase Heat Transport Systems (2009).

### 3.2.1.3. TD24 - Materials and Processes

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|---|---|
| *Domain* | *Space Science - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *24 - Materials and Processes* |

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|---|---|---|---|
| **Ref. Number:** | **GT12-003MS** | **Budget (k€):** | 800 |

**Title:** **Large Aluminium-based Optical Mirrors Processed by Solid State Joining**

**Objectives:** This activity aims to demonstrate the potential of applying solid state joining technologies for the manufacturing of Al-based optical mirrors, in order to increase the achievable Al-based mirror size and allow more complex mirror designs.

During the activity, suitable combinations of Al-based alloys and solid state joining techniques will be identified, with respect to microstructure and surface roughness requirements for optical applications.

An optimum manufacturing route will be identified in terms of base material processing, solid state joining of mirror sub-elements, mirror surface polishing, thermal treatments and surface treatments. An optical mirror demonstrator will be manufactured and characterized.

**Description:** Aluminium-based alloys have been successfully used in optical mirror applications, for space missions. The attractiveness of Al-based alloys comes from their high thermal conductivity, low weight and relatively low cost compared to optical ceramics. Al-based mirrors have been produced both in Ni-clad and bare-polished forms. Alloy 6061 is the most frequently used Al-based alloy in aerospace optical systems.

One of the challenges of using Al-based alloys for mirror surfaces is the achievable surface roughness. Surface processing for these alloys is usually performed by single point diamond turning (SPDT). The final surface roughness is affected by the grain size within the material, as grain boundaries produce irregularities on the polished surface. The use of rapidly-solidified Al-based alloys, such as RSA6061, has led to improvements in the surface roughness of optical mirrors processed by SPDT, as these very fine grain sizes minimize the irregularities on the surface.

However, the size of rapidly solidified Al-based mirrors is currently limited by the maximum size of Al-based material billets which can be produced.

A possible way of increasing the attainable size of Al-based mirrors would be to join Al-based material elements together and process the assembly to an adequate surface condition. This can only be achieved if the joining operation does not adversely affect the fine grain structure of the base material. In addition, the applied joining method should not induce a large amount of residual stresses, which could result in deformation of the mirror assembly. Solid state joining techniques limit microstructure changes in the base metals, as well as residual stresses, as the joint is performed below the melting point of the base metals. Among those techniques, friction welding methods were observed to generate fine grain structures in the joints. The combination of fine grain Al-based materials and solid state joining could therefore allow to produce assemblies which can be processed into large mirrors, with adequate surface finish and dimensional stability. This would increase the achievable size of Al-based optical mirrors and enable new mirror designs, by assembly of smaller mirror elements.

In this activity, suitable combinations of Al-based materials and solid stain joining methods will be identified. Optimum processing route and process parameters will be investigated and a demonstrator will be produced and characterized, to show the feasibility of a large Al-based optical mirror obtained by joining of smaller elements.

The activity will consist of the following tasks:

- conducting a literature review of joining techniques for metallic materials, with respect to their ability to generate or maintain small grain sizes in the joint. This shall include solid state joining and friction welding techniques in particular, but can cover other joining techniques,
- conducting a literature review of suitable Al-based alloys used for optical mirror applications, with respect to their applicability to solid state joining techniques,
- performing preliminary joining trials on potential Al-based alloys with selected joining techniques, in order to assess the effect of joining on the grain size,
- performing a trade-off to identify Al-based alloys and joining methods which will be investigated in this study. Criteria for the trade-off will include maturity of the materials for optical applications, maturity of the joining methods, achieved grain sizes from the preliminary trials and potential for industrialization,
- establishing the requirements of the large mirror demonstrator, at system level, sub-element level and material level. This will include surface roughness, dimensional tolerances, thermal stability, CTE, specific stiffness, mechanical properties. The target size for the demonstrator is 300 mm,
- optimizing the processing route for the mirror assembly. This will consist of producing Al-based mirror specimens, varying the process parameters and testing those specimens, in order to identify the optimum manufacturing sequence (in terms of base material processing, solid state joining, surface treatments, SPDT, thermal treatments, stress relief treatments) and the optimum process parameters for all manufacturing steps,
- producing the large mirror demonstrator and characterizing it, to assess compliance with the requirements,
- performing a critical assessment of the potential of applying solid state joining techniques to Al-based alloys for the production of large Al-based mirrors.

**Deliverables:** Prototype

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|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Duration (months):** | 24 |

**Target Application/ Timeframe:** Optical mirrors. TRL 6 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

## 3.2.2. CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

### 3.2.2.1. TD06 - RF Systems, Payloads and Technologies

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|---|---|
| *Domain* | *Space Science - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT12-004ET** **Budget (k€):** 800

**Title:** **Integrated transponder/PDT for Near Earth Science missions**

**Objectives:** The objectives of this activity are to assess , design and develop an integrated X/X band transponder/PDT unit, able to provide essential TT& C (telemetry, command and ranging) and Payload Data Transmission functionalities (PDT) for Near Earth (NE) Science missions, with a significant reduction of costs, mass and volume for the overall communications sub-system.

**Description:** In a number of cases, NE Science missions are designed coupling stringent requirements on costs/mass/volume and demanding, often variable, data volume.
Traditionally, such missions had often relied on either an X/X band transponder or on the combination of a X/X transponder and a separate (K-band) data transmitter. In the former case, data return is maximized providing a high data rate mode, within the limitations of the available bandwidth (up to 10 MHz available for mission). In the latter, such limitations are overcome by the availability of a separate data transmitter (PDT), with an overall increase of cost/mass/volume. Considering a cold-redundancy scheme, a dedicated PDT would increase the mass by at least 4-5 kg (plus amplifiers, waveguides, switches, for another 4-5 kg) and this, combined with the associated costs may not be acceptable, depending on the required data rate.
To bypass such limitations, it is proposed to assess and develop an integrated transponder/payload data transmitter that would be able to cover, in a single X/X band unit, the functionalities of both the TT&C transponder and PDT. In particular, such unit, should work as a X/X band transponder during the critical phases of the mission (e.g. LEOP, safe mode), providing real time telemetry, telecommand and ranging functionality. During nominal phases, instead, the unit would work as a PDT, enabling an extended flexibility in the supported data rates. To this end, a number of options will be investigated: use of different (suppressed carrier) modulation formats (CCSDS standards beyond OQPSK or GMSK) and different error correction codes and code rates (encoding in the unit) to increase the spectral efficiency (over the limited bandwidth); use of different TX power levels (up to 15 dB variations) to adjust the overall system conditions (including PFD on ground). Advanced techniques such as VCM should be considered, allowing a data return increase up to 100% (LEO missions, e.g. THOR or XIPE). Housekeeping telemetry would be transmitted as a dedicated virtual channel during the PDT mode, while commanding would be guaranteed by the receiver section (always able to receive standard TC signals). Trade-offs will be needed on the ranging functionalities, either suppressing it during this mode (and allowing instead ranging sessions during the initial and last part of each pass, beside the critical phases), or introducing ranging capabilities compatible with a suppressed carrier transmissions The activity will foresee an initial assessment phase, where different trade-offs will be performed to ensure achieving the overall targets. An initial architecture design will complete the study phase. Following that, a functionally representative (EM/EBB) model of the

integrated transponder/PDT will be designed and implemented, to increase the confidence of this novel unit by bringing to a suitable technological maturity.

**Deliverables:** Engineering Model

| **Current TRL:** | 2 | **Target TRL:** | 5 | **Duration (months):** | 18 |
|---|---|---|---|---|---|

**Target Application/ Timeframe:** Near Earth Science missions. TRL 6 by 2022.

**Applicable THAG Roadmap:** TT&C Transponders and Payload Data Transmitters (2012).

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

### 3.2.3.1. TD07 - Electromagnetic Technologies and Techniques

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|---|---|
| *Domain* | *Space Science - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

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|---|---|---|---|
| **Ref. Number:** | **GT12-005EF** | **Budget (k€):** | 750 |
| **Title:** | **Development of multi-color Kinetic Inductance Detector pixels for CMB applications** | | |
| **Objectives:** | The objective is to develop a multi-color, dual polarization sub-array based on Kinetic Inductance Detector (KID) pixels, in combination with an Ultra-Wide Band (UWB) leaky-wave antenna that covers the entire high frequency range of 255-600 GHz, required for the upcoming CMB missions like CORE. | | |

**Description:**

Recently, imaging systems with close to 1000 pixels based upon Microwave Kinetic Inductance Detectors (MKIDs) have been demonstrated, combining high sensitivity, high yield, high dynamic range and a good hardness against cosmic ray interactions. As a result, this technology has been considered for the high frequency arrays of the proposed M5 mission CORE, requiring, in the baseline design, 768 pixels in 7 frequency bands in between 255 and 600 GHz. In its baseline design, CORE uses a single detector per spatial pixel, sensitive to a single linear polarization and 5.3 mm diameter lenses for the 255, 295 and 340 GHz bands, and 3.8 mm diameter lenses for the 390, 450, 520 and 600 GHz frequency bands.
Major improvements in terms of instrument observing speed per spatial pixel are possible by developing a broad-band, dual polarization, multi-band pixel using superconducting stripline technology. In this concept, one spatial pixel consists of a lens-antenna or horn that allows broad band, 2 polarization radiation coupling. On-chip superconducting striplines, Orto-mode transducers and band pass filters are then used to separate the detected radiation in several frequency bands and 2 polarizations. An individual detector is coupled to each filter output. This pixel will be faster than a single band, single polarization pixel as used now in the CORE instrument baseline.

For CORE, which uses MKIDs, this becomes even more promising, since MKID technology allows for 1000 pixels to be read-out with a single readout chain.

This activity includes the following tasks:

- to develop a dual polarization, 255-600 GHz UWB leaky wave antenna,
- to modify conceptual designs available in the literature to operate in the higher frequency band and investigate efficient coupling mechanisms to couple it to MKID detectors,
- to investigate how many frequency bands can be coupled to a single pixel without deteriorating the coupling to the detectors. The baseline would be to develop 2 different pixels to remain close to the CORE pixel design: One for 255-340 GHz, 5.2 mm lenses and one for 390-600 GHz, 3.8 mm lenses. The 255-340 GHz pixel will combine 3 bands and 2 polarizations coupling to 6 MKIDs. The 390-600 GHz will combine four bands and 2 polarizations, coupling to 8 MKIDs,
- to demonstrate a small sub-array that can detect radiation with 2 pixel designs for the entire 255-600 GHz band.

This development will enable to build the entire 255-600 GHz focal plane array of CORE using 2 different pixels. When using the same focal plane area, i.e. 768 spatial pixels, each coupled to 6 or 8 detectors depending on the band, the instrument will be ~7x faster in observation speed, using 2688 MKIDs in total (~7x more than in the baseline design). This would require 3 readout chains. This also implies that it will be possible to reduce the amount of spatial pixels to ~ 110, and keeping 768 detectors. This instrument concept will be as fast as the original proposal, but will use only 1/7th of the focal plane area. It is important to note that the technology, when developed, can be easily scaled to the lower frequency channels of the instrument.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Cosmic Microwave Background (CMB) missions. TRL4 by 2020.

**Applicable THAG Roadmap:** Technologies for Passive Millimetre and Submillimetre Wave Instruments (2016).

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

### 3.2.4.1. TD19 - Propulsion

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|---|---|
| *Domain* | *Space Science - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT12-006MP** **Budget (k€):** 1,000

**Title:** **Diaphragm Propellant Tanks compatible with MON and MMH for spacecraft applications**

**Objectives:** The objectives of this activity are the following:

- Develop a propellant tank diaphragm, and manufacture and integration processes of previously qualified materials, following on from previous activities: under a GSTP contract and under the VEGA upper stage evolution programme (PDR completed in 2017).
- Develop the diaphragm for application to offset acceleration vector due to spin stabilised spacecraft.

**Description:** In the frame of the THOR mission, the specific requirements that have to be considered while assessing the Tank technology TRL are:

- spinning spacecraft: 2-5 rpm;
- bi-propellant: MMH and MON
- in-orbit mission lifetime of 3 years at HEO ~6 x 45 Re
- total propellant load and configuration: ~1 t which drives the need of at least tanks of more than 160L capacity to have them equality distributed, 4 tanks for MON and other 4 tanks for MMH are recommended.

Due to lack of suitable propellant tanks in Europe a development activity is necessary to achieve the Mission.

Due to the offset acceleration vector of the relatively slow spin rate, the currently available surface tension type propellant management device equipped tanks are not suitable. The diaphragm tank technology enables spacecraft propulsion systems to cope with many different acceleration vectors without constraints or limitations, allowing flexibility in mission design and operations.

Materials compatible with bi-propellants have been identified, and undergone a material qualification programme as part of a GSTP activity, completed in 2011 for hydrazine compatibility and for oxidiser compatibility in 2016. The hydrazine compatible material has been manufactured and flown for commercial programmes; however, the oxidiser compatible diaphragm needs to complete a formal qualification programme in an appropriate tank design. Similar needs have also been identified in the VEGA-C programme: materials compatible with bipropellants have been identified, and undergone a material qualification programme as part of VEGA upper stage evolution, completing PDR in 2017. The diaphragm material has already proven long term compatibility, however diaphragm and shell need to complete a formal qualification programme in an appropriate tank design tailored for long term spacecraft applications.

**Deliverables:** Engineering Model

**Current TRL:** 5 **Target TRL:** 6 **Duration (months):** 15

**Target Application/ Timeframe:** THOR. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

## 3.2.5. CD8 - Ground Data Systems / Mission Operations

### 3.2.5.1. TD12 - Ground Station Systems and Networks

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|---|---|
| *Domain* | *Space Science - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT12-007GS** **Budget (k€):** 800

**Title:** **500 W Ka Band Solid-State Power Amplifier**

**Objectives:** The aim of this activity is to develop a Ka Band (34.3 - 34.7 Ghz) solid state power amplifier (SSPA) suitable for Science Research Service and therefore capable of at least 500W of rated power.

**Description:** The development of a SSPA able to support this uplink would provide a much higher reliability to the mission. The final cost of a modular SSPA is lower than the klystron solution since fewer spares are required.
Power Amplifier (PA) technology at Ka Band frequencies is essentially dominated by vacuum tube technologies whenever power above few tens of Watts is required.

A previous TRP activity, driven essentially by missions like Bepi Colombo and Juno (during the cruise), dug into the status of the technology and concluded with the manufacturing of an air-cooled 100W GaAs prototype. Future missions such as Juice will require higher EIRP levels. For distances at around 6AU a PA suitable of transmitting at least 500W is needed. There is no SSPA on the market that has such power capability in Ka Band.

The new development shall take over from the previous TRP - the 100W can be considered as the building block of the 500W SSPA. A trade-off between air cooling and water cooling shall be investigated. Water cooling is indeed favored over air cooling because more efficient (mainly at high altitude), less noisy and will reduce overall size of the amplifier (one of the challenges compared to the previous development). The new amplifier shall adopt modularity concept, the biggest advantage towards Klystron based amplifiers. Modularity will enable soft degradation conversely the klystron is instead a single point of failure. State of the art of GaAs Vs GaN technologies shall also be explored at the time of the development. Previous design favored GaAs towards the more efficient GaN due to reliability considerations based on the relatively young age on the market of the latter compared to the former.

**Deliverables:** Prototype

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 30

**Target Application/ Timeframe:** Science research applications. TRL 6 by 2021.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

# 3.3. ST - Space Transportation

## 3.3.1. CD2 - Structures, Mechanisms, Materials, Thermal

### 3.3.1.1. TD20 - Structures

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|---|---|
| *Domain* | *Space Transportation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *20 - Structures* |

**Ref. Number:** **GT14-001MS** **Budget (k€):** 1,000

**Title:** **Development of New Interface Concepts for Launcher Main Tanks**

**Objectives:** The objective is to redesign the bifurcation area of launchers structural tanks, aiming at both cost and mass reduction. In particular the focus will be on the suppression of the problematic y-ring raw part and structural component machined altogether.

**Description:** The core of the activity is to assess an alternate design of the interface and optimize the selected solution in more detail. This includes both, the geometry of the interface as well as alternative new joining technologies. The objective shall be achieved by detailed design of a scaled demonstrator, including all the necessary manufacturing process samples and breadboards.

The design of the Y-ring area is driven by the high bending stresses that are present in this region: stresses due to tank shrinkage from cryogenic propellants and bending effects from tank pressure. Whilst the first ones are unavoidable, the second ones can be minimized.
Bending effects in the y-ring from tank pressure are induced by the standard European tank dome spherical cap shape, which in turn is required to be able to align the dome gore panel segments for meridional welding.
Thus, to avoid the y-ring raw part the bending stresses need to be reduced, which can be achieved by e.g. Cassini-curve shaped domes. These domes need to be manufactured in one piece without meridional weld seams. The spin-forming technology can be one possibility to manufacture such domes.
Postulating the use of this dome manufacturing technique, and the use of friction-stir-welding, the design of the bifurcation area without y-ring part, attaching the tank dome part directly to the tank cylinder part via one weld seam and attaching the inter-tank non-pressurized tank skirt part via friction-spot welding also to the tank cylinder, shall be investigated in terms of design, strength and buckling analyses and damage tolerance analysis with supporting sample testing of the friction-stir and friction-spot welding.
Standard material AA2219 as used for the more recent Ariane 5 cryogenic tanks should be considered or AlLi 2195, as foreseen for Ariane 6, or a combination.

The tasks to be performed are:

- design and dimensioning of a state-of-the-art reference tank and the alternate tank design,
- investigation into dome forming technologies for a subscale technology demonstrator and a full-scale application,
- scale down of the alternate tank design onto demonstrator dimensions, design and dimensioning of the demonstrator, preliminary test plan,
- production of the demonstrator, preparation of the test setup and test prediction,
- testing of the demonstrator,

- test evaluation and correlation to the prediction,
- evaluation of the mass and cost saving potential of the alternate tank design.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Main tanks for launchers. TRL 5 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.3.1.2. TD24 - Materials and Processes

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|---|---|
| *Domain* | *Space Transportation - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *24 - Materials and Processes* |

**Ref. Number:** GT14-002QE **Budget (k€):** 450

**Title:** **Out Of Autoclave (OOA) Manufacture with Very High Temperature Conductive CFRP Resin systems for Launcher Applications**

**Objectives:** The objectives of this activity are the following:
- resin characterization of Novel Resins (Pthalonitrile or High temperature polyimide, like PETI-3xx) for thermal and space environment performance,
- breadboard demonstrator mechanical performance of part tested at high temperature (up to 500degC).

**Description:** Launcher applications are constantly seeking new material options that optimize performance for reduced mass. Current developments focus on reduced mass of launcher bodies and fairings by using carbon or glass fibre composites. However, one area that could also yield benefit is the development of very high temperature resins that could be used to develop rocket nozzles or structure parts that support high temperature systems. These would otherwise avoid composite parts and instead focus on heavy metallic or expensive ceramic materials.

Two types of resin exist that can benefit very high temperature applications. Phthalonitrile resins are a class of resin that when cured are lightweight, structural/fire resistant, high-temperature polymers that also exhibit low moisture absorption and some electrical conductivity. Hence they are attractive to numerous military and commercial industries. Novel Phthalonitrile resin systems with low melting temperature suitable for RTM processes exist, that claim excellent properties at temperatures up to a Tg over 500 degC.

The other type of resin is under the trade name of PETI-3xx and claims Tg around 330degC, with operational limit to properties around 300degC. This resin also claims stable viscosity specifically designed for RTM and RFI processing for the aerospace industry.

This activity will develop one or both of these resins for OOA RTM manufacture of parts and characterise the mechanical and thermal, electrical conductivity of these materials once manufactured.

Phase 1 (planned duration: 6 months):
- perform literature review on Pthalonitrile resins and PETI-3xx and their high, temperature performance,
- develop a table of potential applications for this technology, including, associated sources of potential contaminants and defects during processing,
- develop matrix of specimens and tests to conduct to determine the feasibility of this concept.

Phase 2 (planned duration: 12 months):
- manufacture trials for specimens (coupon testing at high temperature and room Temperature of CFRP and GFRP with this resin),
- assess performance achieved at target temperatures (500degC or 300degC depending on the resin).

**Deliverables:** Qualification reports, Flight model parts.

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

**Target Application/ Timeframe:** High temperature composites, such as rocket nozzles. TRL 6 by 2020.

**Applicable THAG Roadmap:** Composite Materials (2014).

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

### 3.3.2.1. TD01 - Onboard Data Systems

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|---|---|
| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

| | | | |
|---|---|---|---|
| **Ref. Number:** | **GT14-003ED** | **Budget (k€):** | 1,500 |
| **Title:** | **Time-Triggered Ethernet as Command & Control for launchers and space transportation applications** | | |

**Objectives:** Launchers and Space Transportation are actively working since few years in the definition and development of a new Command &Control (C&C) bus that should preserve the high reliability, large EMI immunity, proven determinism and clear verification and validation strategy of the MIL-STD-1553B but should additionally provide a higher data bandwidth. The Time Triggered Ethernet has been identified as the best candidate for the high data rate-high reliable C&C bus. The aim of the activity is to perform an overview and trade-off of possible solutions available for Ethernet/ Time Triggered Ethernet (TTE) physical layer. The activity will focus on the reuse of already existing cabling/connectors and finding new providers of components.

**Description:** Recently several activities have started to support the definition and the successful deployment on Time Triggered Ethernet in space Furthermore a new ECSS Standardization WG has been created to complete the full definition of Time Trigger Ethernet. In the scope of this activity it is proposed to cover all the areas that require improvement and increase the maturity level of Avionics based on Time Triggered Ethernet. In summary the tasks include:

- requirement consolidation, architectural study,
- development of a demonstrator of an Avionics based on Time Triggered Ethernet,
- assessment of the maturity of Time Triggered Ethernet building blocks,
- characterization of COTS parts in a relevant environment (passive parts as connectors and cable and active parts as transceiver),
- development of a network simulator for TTE based network. The foreseen tool would allow network analysis both on high-level (i.e. unit) and low-level (i.e. bit-wise error injection). The output of this activity will be very useful for designing, verification and validation of TTE networks used for future missions,
- TTEthernet network stress tool. The proposed tool shall allow to test response of TTE network to erroneous/unpredictable traffic. The tool should be able to:
  - drop packet,
  - impose latencies/delays on the line,
  - impose time jitters to packets,
  - modify packets (i.e. transparent clock modification, sequence number),
- complete verification and validation process.

Time-Triggered Ethernet is currently used in launchers and Human Spaceflight applications. Both those applications are safety critical and require high reliability. As for TTE, at this point no standardized verification and validation procedures are available to assure reliable operation of TTE network. Existing standards (i.e. SAE AS6802) do not cover this topic. A demonstrator will be developed at breadboard level (a Time Triggered Ethernet based SAVOIR-SAT) to be integrated with system and sensor/actuator simulator(s) and to be used as a reference architecture in order to test and validate HW, SW and sensor /actuators building blocks. Output of this activity shall provide inputs to future standardization process for verification and validation of TTEthernet.

**Deliverables:** Breadboard

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| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 2019 |

**Target Application/ Timeframe:** Launchers and space transportation applications. TRL 5 by 2018.

**Applicable THAG Roadmap:** Data Systems and On-Board Computers (2016).

### 3.3.2.2. TD05 - Space System Control

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| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *05 - Space System Control* |

**Ref. Number:** **GT14-004SA** **Budget (k€):** 2,000

**Title:** **Enhancement of the NGT-ATB: New Generation Launcher and Space Transportation Advanced Avionics Test Bed**

**Objectives:** The objective of this activity is to upgrade the existing New Generation Launcher and Space Transportation Advanced Avionics Test Bed, raising the TRL level from 3 to 6.

**Description:** The Next Generation Space Transportation System Advanced Avionics Test Bench (NGT-ATB) reached TRL 3, in the frame of a previous TRP (?) activity and allows creating a reference implementation of a space avionics test bench that can be re-used in several ESA projects.
The NGT-ATB facilitates the integration of elements from the three avionics disciplines Data Systems, Guidance, Navigation and Control (GNC), and On-Board Software (OBSW) together with the components of a System Simulation Facilities into a harmonized set of ATB configurations for simulation and verification purposes. Currently, the NGT-ATB includes two different scenarios: 3-stage micro-launcher and active debris removal (ADR) mission.
In order to reach the status of a complete avionics solution, able to cope with modern and demanding avionics verification and validation needs for ESA and future Space Transportation Systems, the NGT-ATB needs to reach TRL 6. At that level, the NGTB will be able to support the full range of verification and the validation of the specification, design, implementation and operations of future space avionics transportation systems.

Building on the previous TRP contract achievements, this activity will provide enhancements in three main areas:

- increase the scope of the missions to be validated in the test bench,
- increase the sensors and actuators suite of the bench,
- expand the simulation tools of the ATB.

To fulfil those objectives, the work will be divided in three tasks:

- Improve architecture and design of the test bench.
  Based on the current design /architecture, the adaptability/configurability of the NGT-ATB bench will be improved to allow a more user-friendly process of creating and adapting new scenarios. Additionally the NGT-ATB will be enhanced to accommodate the use of other modelling tools such as: EcosimPro, Modelica, SimMechanics, DCAP, 20-sim and PANGU 4.0 among others.
  As such, the end-users will have more freedom / capabilities of choosing/using the most convenient tooling for the task at hand, while being still fully supported by the ATB-NGT workflow process:
  - modelling stage,
  - configuration setup (fes, svf, egse),
  - configuration package setup (which test scenario to run),
  - simulation execution (post) result processing.
- Procurement and installation of new elements.

This task will investigate which sensors and actuators are most suitable to increase the fidelity of the NGT-ATB. The following is non-exhaustive list of the elements which will be procured and integrated:
- multi spectral camera,
- infrared camera,
- LIDAR model (using a dSpace box),
- CAMSIM (camera Simulator),
- Beagle-2 board,
- Thruster simulation set (using a dSpace box).

In addition, during this task the NGT-ATB will be enhanced such that it can make use of the GRALS facility (robotic arm) to increase the fidelity of the Hardware-in-the-loop scenarios.

- Design, assembly, integration and testing of the new scenarios.
  This task will test the new improvements on the NGT-ATB by the design, assembly, and integration and testing of at least the following new scenarios:
  - space transportation of humans and cargo to the Moon: both orbiting around the Moon and landing to the South Pole,
  - space Rider type mission.

  In addition to these new scenarios to be developed from scratch, this task will test the migration and integration into the NGT-ATB of two other existing scenarios developed in the frame of previous ESA test bench activities. These migrated scenarios will be:
  - Mars Entry, Descent and Landing scenario (taken from the SAGE and VisNav ESA funded activities),
  - Earth Observation mission, based on EagleEye.

**Deliverables:** Documentation,upgrade of the softwareof NGT-ATB and new hardware to be included in the NGT-ATB facility.

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

**Target Application/ Timeframe:** Space transportation systems (launchers, re-entry, rendezvous missions). TRL 5 by 2019.

**Applicable THAG Roadmap:** AOCS Sensors and Actuators: II - Specific Sensors and Actuators (incl. IMU) (2015).

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| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *05 - Space System Control* |

**Ref. Number:** **GT14-005SA** **Budget (k€):** 3,000

**Title:** **ADAMP Ascent and Descent Autonomous Maneuverable Platform**

**Objectives:** The objective of this activity is to develop an experimental Vertical Take-Off and Landing vehicle, which will be used as platform for the testing, verification and validation of space technologies. A flying platform will be developed where payloads can be hosted in order to support novel autonomous flight operations.

**Description:** The activity will develop an ascent and descent autonomous maneuverable platform (called ADAMP) which will be used as platform for the testing, verification and validation of space technologies.
The vehicle shall be capable of performing vertical take-off and landing. The main performance requirements shall be:

- capable to carry a payload of 60 kg,
- reach a minimum altitude of 2000 m,
- hovering duration of at least 30 min.

It shall allow to test ascent flight (optimal trajectories, robust control) as well as descent and landing technologies (hazard avoidance, high accuracy landing, hybrid navigation). ADAMP will be able to dest GNC, data handling, on-board software, structures and mechanisms, power, thermal, propulsion, etc.
The starting point shall be the EAGLE platform developed by a German National activity, and the INCAS DTV, which have to be further matured with rocket propulsion systems. In contrast to its predecessors, ADAMP shall make use of a thrust vectored throttable rocket engine.
The development of this demonstrator shall be supportedby different ESTEC sections including System, Avionics,Software Propulsion, and Structures, with the objective of serving ESA as test facility for technology acceleration.

**Deliverables:** Hardware: the Ascent and Descent Autonomous Maneuverable Platform. Software: the Avionics SW to control it and connect it to the payloads.

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** Future launcher developments with re-usable stages. Exploration missions with landing phases on the Moon, Mars or asteroids. TRL 6 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *05 - Space System Control* |

**Ref. Number:** **GT14-006SA** **Budget (k€):** 1,500

**Title:** **End-To-End preliminary design for a Lunar Ascent Vehicle**

**Objectives:** The objective of this activity is to perform an End to End (E2E) preliminary design of an integrated set of subsystems for a lunar ascent vehicle for the Human Lunar Exploration Precursor Program (HLEPP).

**Description:** Departing from the work done in Aurora, TRP, GSTP, the HLEPP and E3P ESA programs, this activity shall perform the analysis, design, and preliminary development of an integrated set of subsystems for a Lunar Ascent Vehicle (LAV) for planetary exploration. This activity shall be performed in the frame of the ESA international cooperation in exploration. The main objective shall be to consolidate a multidisciplinary design of the vehicle including mature design, analysis and simulation of the following subsystems: GNC, structures, mechanisms, propulsion, thermal and power.

The following tasks are preliminary envisaged:

- Requirements and trade-off: based on the user and system requirements of the mission scenario provided by the HLEPP (originated from a parallel phase A system-level study in the frame of E3P), this task shall elaborate the technical requirements of the subsystems. This task shall trade-off the impact of including requirements of re-usability and human rating on the choice of the technology and technology development cost.
- Preliminary design at system level: multidisciplinary preliminary vehicle design by means of models of each of the subsystem. The option to use a 6kN bi-propellant, pump-pressurized engine shall be investigated. Structural tanking shall also be analyzed as an option to reduce the dry mass of the vehicle. Flow down the system level requirements to subsystem requirements for GNC, structure, propulsion, thermal and power subsystems. This task shall also provide a preliminary test plan definition.
- Detailed Subsystem Design for the five subsystems: the subsystems design shall include the definition and modelling of sensors, GNC algorithm design, software implementation, thrusters, tanks, valves, structures and mechanisms, thermal and power. This task shall also provide a detailed test plan definition.
- E2E software tool development: this task shall consolidate all the models of the subsystems into a single End-to-End Simulator which will be used to verify and validate the capability of the LAV design to fulfil the mission system and subsystem requirements. This End-to-End simulator shall be implemented using the ESTEC avionics test bed facility (NGT-ATB).
- Validation of the Lunar Ascent Vehicle (LAV) design: testing, verification and validation of the LAV design by means of the ESTEC NTG-ATB Software in the Loop (SIL) and Processor in the Loop (PIL) framework. The activity shall also make use of the GNC Rendezvous Approach, Landing and Ascent Simulator (GRALS) for the Hardware in the Loop (HIL) simulations.
- Assessment of Human Rating Requirements: As the HLEPP ascender is intended as a subscale version of a human ascender, each subsystem shall be analyzed for potential human-rating in accordance with NPG: 8705.2 section 2.5.3 (in lieu of ESA human rating requirements).

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| **Deliverables:** | Documentation. E2E simulator and algorithms. sensors or actuators required for the testbed | | |
| **Current TRL: 3** | **Target TRL:4** | **Duration (months):** | 18 |
| **Target Application/ Timeframe:** | Launcher technologies, planetary exploration. TRL 4 by 2020. | | |
| **Applicable THAG Roadmap:** | Not related to a Harmonisation subject. | | |

### 3.3.2.3. TD18 - Aerothermodynamics

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| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *18 - Aerothermodynamics* |

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| **Ref. Number:** | **GT14-007MP** | **Budget (k€):** | 500 |

**Title:** **Acoustic propellant management for fuel tanks of spacecraft and launcher upper stages**

**Objectives:** The purpose of the activity is two-fold:

- to use an acoustic beam for sounding the fluid location in a tank.
- to show the ability of induce fluid movements and control of the free surface for liquid/gas mixtures, including those of cryogenic flows.

**Description:** Management of fluids on fuel tanks of spacecraft and launcher upper stages under microgravity conditions has always presented a challenge, because it does not naturally accumulate in a neat shape near the exit port. Gauging requires measurement or knowledge of the shape of the fluid free surface in microgravity. Knowledge of the residual quantity and location of propellant is essential for management and control of both satellites and launcher upper stages, for the latter in particular if multiple firings are anticipated. Manipulation of fluids in partially filled tanks serves the purpose to ensure it is connected to the exit port.

In a previous TRP activity, ultrasonic transducers have been used to impose motion in fluids (water, kerosene and LN2), as result of asymmetric flow patterns in the close vicinity of the transducer. This offers the possibility that fluids could be managed with an array of ultrasonic transducers where phase and amplitude control to each unit are used to generate focused acoustic beams, which can manipulate the fluids. Based on those results, it is proposed to implement an array of transducers, and through phased driving of these, to generate a directed acoustic beam. With help of this beam one can sound the fluid location in the tank. Using a range of experimental setups (e.g. tipping the tank to collect the fluid at one end; containing the fluid in balloons, and so on), the effects of varying gas/fluid boundary locations and shapes will be investigated to extend the demonstration done in the first study, using liquid only, to liquid/gas mixtures, showing the ability to induce fluid movement and control of the free surface also under these circumstances.

A specific set of trials will include an assessment of the viability of mounting the transducer array outside the tank and sounding through the wall using a typical tank wall construction (including Ti and CFRP). Some of the transducers will be immersed in fluid attached to the container walls by surface tension, and some will be in the gas-filled part of the vessel. Further, the test equipment and set-up will be adapted for a future accommodation and operation on board a parabolic flight to demonstrate the technique under micro-gravity conditions. In addition, to show the compatibility of transducers in operation at cryogenic temperature and, if a safe configuration can be designed, first trials with acoustic liquid manipulation and sensing with LH2 will be performed on ground. Finally, the experimental results will be used also to validate numerical tools for simulation of the coupling between acoustics and fluid behavior.

**Deliverables:** Breadboard experimental set-up and technical reports describing the technology for further applications, and quantifying the results for numerical validation purposes.

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

**Target Application/ Timeframe:** Fuel tanks for satellite and launcher upper stages. TRL 5 in 2019.

**Applicable THAG Roadmap:** Fluid Mechanic & Aerothermodynamic Tools (2012).

### 3.3.2.4. TD19 - Propulsion

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| *Domain* | *Space Transportation - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT14-008MP** **Budget (k€):** 8,400

**Title:** **6kN, Deep-throttling, Pump-fed, Bi-propellant Engine**

**Objectives:** The proposed activity will focus on at the preliminary design for a deep-throttlable, pump-fed, bi-propellant engine. An early development model (DM) will be designed, manufactured and tested. Finally, the activity shall provide a clear route for inclusion of the engine as a part of a ground based integrated landing technology test bed.

**Description:** Studies for lunar surface missions (MoonNext, LSR, LLB1, LPSR) have demonstrated a clear need for thrust levels higher than those provided by a single classical apogee boost motor (ABM). This has led to the use of multiple engine configurations, based on classical ABM hardware. Propulsion and structure on such missions can account for over two thirds of the dry mass.
Thrusters for these systems are based on spacecraft technology and are limited to thrust-to-weight ratios (T/W) of around 10. A solution to this problem is to use higher thrust, pump fed, engines that can potentially achieve a unit level T/W of around 60.
In addition, pump fed engines allow the use of low pressure tanking (and potentially low pressure structural tanks). This would result in significant additional mass saving on structure and propulsion and, as a result, a payload capability increase of around a factor of two for the overall lander.
The overall activity will cover the preliminary flight engine design for a pump-pressurized, throttleable 6kN engine for lunar robotic exploration. This preliminary design phase will be supported by the manufacturing and testing of an initial development/engineering (DM/EM) model of the engine. The DM/EM engine shall also be used for ground based demonstration in an integrated flying test bed.

A three phase approach is envisaged in this proposed activity:

- Phase 1 (proposed budget: 400k euros)An initial engine trade assessment will be performed and approaches shall be defined in order to meet the Agency's defined user requirements. The existing 5 kN storable bi-propellant engine shall be considered as a major reference if applicable.
  Design solutions shall be traded. Considerations should include:
  - deep throttling of engines by using new injection and ignition systems,
  - advanced chamber cooling approaches,
  - pump system design including potential for electric pumps and turbogenerators,
  - pressurization approach and cycle choice,
  - mechanical thermal fluidic and electrical interface,
  - thrust vector control approach and strategy.
    - The most promising candidate technologies shall be down-selected and examined in more detail in a further design iteration.
    - The ability to include an early development model (DM) in an integrated earth based landing platform demonstrator

shall be a major objective within the design development and verification plan (DDVP).

- Phase 2 (proposed budget: 3000k euros)The DDVP from phase 1 shall implement elaborating the baseline design of the flight lander engine concept and any technology options carried over.
  Any test bench activities required to expedite the early demonstration of the integrated engine hardware will be defined.
  Elemental development activities (e.g. pump/injector/chamber) including test of critical technologies shall be undertaken.

- Phase 3 (proposed budget:5000k euros)The detailed design of the DM/EM engine will be completed in order to meet the established lander demonstration requirements. before manufacturing the DM/EM engine.

In parallel, any test bench modifications shall be finalized.

**Deliverables:** Engineering Model

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| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 36 |

**Target Application/ Timeframe:** Propulsion systems for space transportation. TRL5 2020.

**Applicable THAG Roadmap:** Chemical Propulsion - Components (2012).

# 3.4. NAV - Navigation

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

### 3.4.1.1. TD06 - RF Systems, Payloads and Technologies

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** GT16-001ES **Budget (k€):** 500

**Title:** **GNSS Receiver Chain Technology Enabler and Integrity Techniques for the Railway environment**

**Objectives:** The objective of this activity is to develop a railway GNSS receiver chain technology enabler, to support the testing and validation of integrity concepts, algorithms, and techniques for receivers in a railway environment. In addition, the activity aims to develop, test and consolidate integrity techniques suitable for GNSS-based virtual balise detection in the European Rail Traffic Management System (ERTMS) / European Train Control System (ETCS).

**Description:** A key issue for use of GNSS in safety critical train control systems is the lack of confidence on the residual positioning error. Errors caused by feared events in the railway environment such as multipath, non-line of sight conditions and electromagnetic interference (EMI) can lead to an increased risk of hazardous misleading information (i.e. position not bounded by confidence interval). Effective barriers are needed to detect and mitigate these feared events such that the threat of under-bounding the residual errors is mitigated to the required level. This activity foresees the development such barriers and the necessary tools to test and validate them.
This activity foresees the following tasks:

- review of the state of the art and consolidation of requirements,
- design and development of an advanced real-time receiver platform comprised of a complete GNSS receiver chain. The platform shall support the testing of mitigation and suppression techniques for feared events in the railway environment at all stages of the receiver chain including antenna, RF domain, DSP domain (pre-correlation, correlation), range domain and position domain. The platform shall also provide support for GNSS/INS integration architectures,
- design and implementation of integrity concepts, techniques and algorithms on the receiver platform to mitigate feared events in the railway environment,
- testing and validation of developed integrity concepts, techniques and algorithms using the receiver platform.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** Future satellite navigation services for railway applications. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** GT16-002ES **Budget (k€):** 500

**Title:** **Definition of multipath and electromagnetic interference scenarios and models for GNSS in railway environments**

**Objectives:** The objective of this activity is to develop comprehensive multipath and electromagnetic interference models and scenarios for GNSS in railway environments. It is expected that this activity will contribute to the development of simulation tools and support future certification efforts for use of GNSS for virtual balise detection within the European Train Control System on-board constituent.

**Description:** A vital tool to support testing, validation and future certification activities for GNSS equipment in safety critical train control systems, is a testbed able to simulate nominal and extreme railway environments. A vital component of the testbed are accurate models of the railway propagation environment including electromagnetic interference (EMI). Such models cannot be derived from existing models that originate from other environments or applications; the environment and threats are very specific to the railway application and intended operations. This activity aims to develop comprehensive models and a set of baseline reference scenarios for a range of representative railway environments that can be used in a simulation testbed. The activity foresees the use of a simulation testbed facility at ESA (output of TRP activity).

This activity foresees the following tasks:

- review of state of the art and consolidation of requirements,
- design and implementation of models for multipath propagation and electromagnetic interference in railway environments,
- validation of the models using field data,
- development of scenarios and comprehensive datasets for simulation of nominal conditions and fault-injection testing.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Future satellite navigation services for railway applications. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-003ES** **Budget (k€):** 500

**Title:** **Development of Scenarios, Models and Tools for Simulation of Intentional Interference and Spoofing in Railway Environments**

**Objectives:** The objective of this activity is to develop comprehensive models, scenarios and tools for simulating intentional interference against GNSS in railway environments. It is expected that this activity will support future certification efforts for use of GNSS in virtual balise detection within the European Train Control System on-board constituent and within the track-side when used in track-area augmentation systems, providing confidence GNSS equipment is sufficiently resilient against intentional interference.

**Description:** The development of tools, models and scenarios is an important step in ensuring GNSS equipment used in safety critical train control systems is resilient against intentional interference and spoofing. This activity aims to develop models and scenarios for intentional interference targeting the safety and availability of the on-board constituent and / or track-side constituent of the foreseen evolution of the European Train Control System comprising satellite-based functions (e.g. virtual balise detection using GNSS and the track-area augmentation system). Incidental interference is also to be considered, where the railway application is within range of interference or spoofing that is targeted at another application (e.g. application on a road parallel to the rail corridor).

The activity foresees the following tasks:

- review of the state of the art and consolidation of requirements,
- design and implementation of models of intentional interference and spoofing in the railway environment,
- development of simulation tools for injection of intentional interference and spoofing to support testing of technologies for improving resilience,
- testing and validation of the models using simulation tools,
- development of scenarios and comprehensive test datasets.

**Deliverables:** Software

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

**Target Application/ Timeframe:** Future satellite navigation services for railway applications. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-004ES** **Budget (k€):** 500

**Title:** **Technologies for Resilience Against Intentional Interference and Spoofing in Railway Environments**

**Objectives:** The objective of the activity is to develop technologies, algorithms and techniques for improving resilience against intentional interference and spoofing in the railway environment suitable for GNSS-based virtual balise detection in the European Trail Traffic Management System / European Train Control System (ETCS).

**Description:** A key issue for the use of GNSS in safety critical train control systems is resilience against intentional interference and spoofing. This includes interference specifically targeting the safety and availability of the on-board constituent and the track-side constituent of the foreseen evolution of the European Train Control System (ETCS) comprising satellite-based functions (e.g. virtual balise detection using GNSS and the track-area augmentation system). This activity foresees the development of technologies, algorithms and techniques to improve resiliency against intentional interference and spoofing.

The activity foresees the following tasks:

- Review of the state of the art and consolidation of requirements,
- design and implementation of technologies, algorithms and techniques to improve resiliency against intentional interference targeting the foreseen ETCS on-board with GNSS functions (dynamic case),
- design and implementation of technologies, algorithms and techniques to improve resiliency against intentional interference targeting reference stations of a GNSS track area augmentation system (static case),
- testing and validation using simulation tools from the proposed activity 'Development of Scenarios, Models and Tools for Simulation of Intentional Interference and Spoofing in Railway Environments'.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** Future satellite navigation services for railway applications. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a HarmonisationHarmonisation subject.

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-005ES** **Budget (k€):** 800

**Title:** **Beam-Forming Technology for GNSS Reference-Station**

**Objectives:** The objectives of this activities is to study and prototype a low cost-low complexity beam forming reference station with superior interference and multipath rejection capability compared to that achieved by current single antenna GNSS reference station equipment.

**Description:** RF interference and multipath are relevant error sources affecting the performance of the GNSS Commercial-Reference-Station equipment. Despite the fact of being the navigation signal of spread-spectrum type, it is visibly vulnerable to interference, due to its very low power at reception. Excessive interference may provoke loss of lock and false lock in the equipment. Multipath may induce ranging errors visibly correlated over time, not easy to mitigate at signal processing level or/and at output-observables processing level. The impact of both interference and multipath could be largely reduced by incorporating beamforming techniques to the GNSS Reference-Station equipment (comprising antenna plus receiver). Beam-forming techniques could enable efficient spatial and time filtering of RF interference and strong multipath. Because of the cost and complexity, current technology is nowadays based on single antenna element, therefore this activity shall demonstrate the viability of beam-forming technology with low complexity. The design shall target the minimization of the overall equipment complexity and technological risk.

The detailed objectives of this activities are:

- To investigate a GNSS Reference-Station equipment (antenna plus receiver) profiting from beam-forming (spatial and time filtering) technology; offering a visibly superior interference and strong-multipath rejection capability, compared to that achieved by current GNSS reference station equipment. The design shall target the minimization of the overall equipment complexity and technological risk.
- To develop a GNSS Reference-Station prototype, fully representative from functional and performance perspective, and to validate it under real GNSS signals.

The target applications of this technology are the commercial reference stations (Geodetic Reference Stations, RTK Reference Stations, Differential-GNSS Stations, etc.).

The activity high level tasks are as follows:

- Consolidation of the equipment specification; namely functional, performance and external interfaces requirements.
  Definition of the equipment physical architecture; namely main physical blocks, related internal interfaces, core hardware blocks transfer function(s) and core processing.
- Definition of the equipment physical detailed design; namely hardware elementary blocks, elementary processing modules, detailed internal and external interfaces.
- Development and verification of the equipment.
- Consolidation of the validation scenarios definition.

- Extensive analysis of the equipment performance (code-phase and carrier-phase tracking errors, probability of loss of lock, probability of false lock, acquisition and re-acquisition time, etc), in the above validation scenarios; which shall include at least the:
  - Operation with real GNSS signals (Galileo & GPS) under nominal RF-environment conditions.
  - Operation with real GNSS signals (Galileo & GPS) under extreme RF-environment conditions, in terms of either interference or/and multipath.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** GNSS Reference Stations. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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|---|---|
| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-006ES** **Budget (k€):** 300

**Title:** **Study and design of a Smart city Living Lab Location Test-bed**

**Objectives:** The objective of this activity is to assess and design a so called 'Smart city Living Lab Location Test-bed' in support of GNSS/4G/5G location service development.

**Description:** The Smart City Living Lab test bed is a tool conceived to support development of current and future GNSS and/or 4G/5G terrestrial location based capabilities and the associated applications. The test bed is based on the deployment of a network of wireless sensors distributed in fixed points and/or vehicles (e.g. taxis and buses, bicycles) over the city. These sensors record RF samples of multiple frequency bands (GNSS, 4G,5G etc.), can be coupled with application specific sensors (e.g. meteo etc.), and stream their outputs to a control center able to process the data enabling any suitable usage, such as cloud-based GNSS navigation,4G location services,5G planned evolution testing, localization of interference, traffic estimation, pollution monitoring etc.

New services and capabilities can be validated with this flexible and open-access architecture able to provide RF field measurements in real-time and to store them in a centralized manner. For this purpose, to ensure the optimization of the system for a large variety of usages, and to be flexible enough to allocate any dedicated experiment, the re-utilization of a Smart City connection resources should be maximized.

This activity shall provide a thorough assessment and design of the architecture and mechanisms required to implement this test bed within a Smart City with distributed and accessible data connection services, with the preliminary identification of the technology and proof of concepts. This will be the first step towards its implementation.

The tasks of this activity are to:

- Identify an existing Smart City that may support a GNSS Living Lab and assess the resources available in such Smart City.
- Assess and design a flexible architecture for the testbed based on a network of sensors and control centers, ensuring open access of data sets to end users.
- Assess the potential reuse of existing infrastructure deployed by the city council and the inclusion of the testbed in the existing Smart City platform.
- Investigate the sensor technology, by trading off accuracy with costs.
- Investigate the resource management and cloud computing strategies.
- Assess the applications and main usages of the testbed, particularly in the GNSS and communication fields.
- Assess the economic exploitation of the test bed and the economic impact of the test bed over the city.
- Demonstration and concept proof of the key elements of the retained concept for implementation in the Smart City selected.

**Deliverables:** Documentation

| **Current TRL:** | 2 | **Target TRL:** | 4 | **Duration (months):** | 12 |
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**Target Application/ Timeframe:** Applications can be numerous e.g. localization of interference, traffic estimation or pollution monitoring. TRL 4 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-007EF** **Budget (k€):** 1,000

**Title:** **Technology Validation of a Cold Atom Microwave Atomic Clock (CAMAC)**

**Objectives:** The objective of this activity is the design update, full characterization and validation of a Cold Atom Microwave Atomic Clock (CAMAC) providing a frequency stability below 1E-13/SQRT(t), for t = 1sec to 10 days.

**Description:** Today, the generation of a reference timescale (like the Galileo System Time or any local realization of UTC) relies on Active Hydrogen Maser, which is a robust and well proven technology, but that needs to be regularly steered to correct for intrinsic frequency drift. This critical steering process requires relevant expertise (mostly available in Metrology Laboratories) and proves difficult to implement and automatize in an operational context like the Galileo Precise Time facility or the ESA Ground Stations, especially when they operate in autonomous mode. The CAMAC technology is expected to have much lower frequency drift than the Active Hydrogen Maser, with similar performances in terms of short-term stability, resources and operability.

The activity shall start with a review of the existing design of the CAMAC and the identification of the design updates required to meet the performance, operational and resources requirements. Second, the design updates shall be implemented and validated. Finally, a full characterization of the clock shall be performed, including short-term stability, reproducibility, sensitivity to environment, and long-term stability.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** Ground segment of all missions. TRL 5 by 2020.

**Applicable THAG Roadmap:** Frequency and Time Generation and Distribution - Space (2013).

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT16-008EF** **Budget (k€):** 600

**Title:** **Clock Ensemble Monitoring and Switching Unit for Robust Timescale Generation**

**Objectives:** The objective of this activity is the design, development, manufacturing and test of a clock ensemble, monitoring and switching unit for robust timescale generation.

**Description:** Current solutions for robust timescale generation, in terms of stability and continuity relies on a distributed and complex hardware architecture with dedicated equipment that require specific skills and experience to operate and maintain. Several alternative solutions relying on a more integrated system have been proposed, and some of them have been investigated.

This activity shall be dedicated to:
Review of Timescale functional requirements in terms of:

- clock ensemble,
- clock steering,
- clock monitoring,
- clock switching in case of failure,
- clock distribution.

The key tasks of this activity include the detailed design, manufacturing (prototype level) and testing.

**Deliverables:** Prototype

**Current TRL:** 3 **Target TRL:** 4 **Duration (months):** 18

**Target Application/ Timeframe:** Ground segment of all missions. TRL 4 by 2019.

**Applicable THAG Roadmap:** Frequency and Time Generation and Distribution - Space (2013).

### 3.4.1.2. TD07 - Electromagnetic Technologies and Techniques

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| *Domain* | *Navigation - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

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| **Ref. Number:** | **GT16-009EF** | **Budget (k€):** | 1,000 |

**Title:** **Environment survey and calibration instrumentation for GNSS propagation error sources**

**Objectives:** Design and development of a multi-frequency multi-instrument facility to evaluate and calibrate propagation error sources of Global Navigation Satellite Systems (GNSS) in fixed and mobile environments. This facility shall be used to measure all required inputs that would allow more realistic characterization of all error sources, including spatial discrimination and direction of arrival, that would allow an eventual replay/simulation in an existing Over-The-Air (OTA) facility for terminal (receiver plus antenna) testing.

**Description:** Current technologies and techniques are not able today to accurately estimate the error sources from fixed and, particularly, mobile GNSS receivers. For example, regarding multipath, the high-frequency components can be estimated together (in addition) to noise and interference, but the slowly varying components are more difficult to separate. In fact, for ionosphere, the ionospheric delay calibration relies on a dual-frequency technique that requires a very good estimation / calibration of inter-frequency bias from the receiver. This is difficult to obtain and often masks other errors. The efficient use of meteorological stations or even radiometers is required for tropospheric calibration. In addition, the effects of the antenna as installed on a given platform are of critical importance for this evaluation. Recently several activities where antenna array processing is used to estimate spatial-dependent contribution or mitigate multipath and interference were successfully completed. However, the contributions of beam-forming network (analogue or digital) and its effects on error source evaluation should be taken into account to properly measure the direction of arrival of interferers and possibly exploited to increase the sensitivity of receivers against propagation impairments (e.g. Ionospheric scintillation).
The activity shall implement very precise GNSS carrier-phase measurement techniques for accurate positioning of mobile users and integration of these techniques with inertial sensors for separating environmental effects from other error sources. Configurations with hemispherical antennas, antenna arrays and possibly beamforming antennas and other sensors like laser ranging may be also considered.

The technique shall enable to evaluate and calibrate error sources in fixed and mobile environments including:

- multipath (bias - slowly varying - and random components, including angle of arrival),
- shadowing,
- ionospheric delay and instrumental inter-frequency biases (for all frequencies),
- tropospheric delay,
- ionospheric scintillation,
- interference (narrowband and wideband, including direction),
- noise.

The developed techniques shall be instrumental to the exploitation of 'record and replay' OTA measurements, to allow more realistic simulation scenarios, which will account for different angle of arrivals during receivers testing.

The following tasks are anticipated:

- Consolidation of the facility definition and identification of instrument requirements, with particular care to OTA interfaces, architectures and processing algorithms.
- Critical evaluation of architectural concepts.
- Development and procurement of hardware and algorithms.
- Facility integration and testing.
- Qualification including in the field experimental campaign.
- Interface demonstration of the facility with an existing OTA lab.
- OTA experimental campaign and validation.

**Deliverables:** Instrumentation Facility prototype and associated calibration algorithms.

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** Future EGNOS and Galileo site survey, user performance evaluation, GNSS site characterization and receiver developments. TRL 6 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

# 3.5. GEN - Generic Technologies

## 3.5.1. CD1 - EEE / Components / Photonics / MEMS

### 3.5.1.1. TD01 - Onboard Data Systems

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT17-001ED** **Budget (k€):** 2,200

**Title:** **SpaceFibre demonstration chip and routing switch ASIC development**

**Objectives:** The objectives of the activity are to make SpaceFibre CODEC and physical layer (high speed serial link, HSSL) available to early adopters of the SpaceFibre standard and demonstrate the viability of the approach in ST 65nm process and to make SpaceFibre network routing switch available to industry to allow for satellite bus architectures based on the ECSS SpaceFibre standard.

**Description:** SpaceFibre is a multi-Gbit high speed serial link developed for space applications. It runs over copper and fibre-optic cables and allows serial links up to 10Gbps. Multi-lane capability allows to combine several physical links to a single logical link to achieve data rates of several hundred Gbit per second. SpaceFibre has built-in quality-of-service (QoS), isolation and recovery (FDIR) capabilities. A SpaceFibre IP core has been developed and is now available to be implemented in state-of-the-art ASIC process.
In the frame of the activity, two devices shall be developed and implemented on the ST65nm process to allow the implementation of SpaceFibre based networks on satellite systems.

Tasks to be performed:

- Phase 1 (1000k Euro):
  - integrate SpaceFibre IP core on ST 65nm process,
  - layout and tape-out of the design,
  - packaging and testing of the chip,
  - design, manufacture and test a SpaceFibre demonstration chip evaluation board,
  - demonstrate the performance of the SpaceFibre technology using the evaluation board,
  - make the evaluation board available to interested industries.

- Phase 2 (1200 kEuro):
  - design the SpaceFibre router architecture,
  - integrate the SpaceFibre router on ST 65nm process,
  - layout and tape-out of the design,
  - packaging and testing of the chip,
  - design, manufacture and test a SpaceFibre router evaluation board,
  - demonstrate the performance of SpaceFibre router using the evaluation board,
  - make the evaluation board available to interested industries.

**Deliverables:** Prototype

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| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 36 |

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| **Target Application/ Timeframe:** | TRL 5 as by 2020. |

**Applicable THAG Roadmap:** On-Board Payload Data Processing (2016).

### 3.5.1.2. TD17 - Optoelectronics

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT17-002MM** **Budget (k€):** 1,000

**Title:** **Demonstration of high-performance CMOS image sensor pixels for space applications using advanced technology nodes**

**Objectives:** The objective of this to design, manufacture and characterize a CMOS image sensor with large pixels using state of the art technology process nodes.

**Description:** Advanced technology node processes (0.13 um and smaller) are typically utilized for CMOS image sensors with pixel sizes of order 1 um or less. In order to meet observation requirements, space applications require pixel sizes of between 10 and 20 um (possibly down to 5 um for Star Trackers applications).

The aim of this activity is to demonstrate that such large pixels can still be designed and manufactured using current and future foundry process nodes, while still retaining the necessary high electro-optical performance.

The activity shall also investigate specific aspects such as robustness to radiation environment (impact of total ionising dose and Displacement Damage). Achievable performance (e.g. read noise, cross talk, FPN, dark current and dark current non uniformity, QE) vs pixel size shall be established.

This activity's added value and potential benefits will be multiple:

- The feasibility of combining in one CMOS image sensor design the state of the art technology process nodes and the observation requirements will be investigated.
- The manufacturability of the designed CMOS image sensor in a European CMOS wafer foundry will be demonstrated.
- A tested and characterised manufactured CMOS image sensor will be available for further qualification.
- An evaluation of CMOS image sensor design and particularly manufacturing capability within Europe will be assessed.
- Foundry processes used and or developed can be made available in the public domain such that these processes can be used by other design houses if needed.

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

- Detector specification and trade-off study.
- Preliminary detector design.
- Detailed detector design.
- Detector manufacture.
- Detector characterization including radiation testing
- Evaluation, conclusions and recommendations.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Earth Observation and Science missions. TRL5/6 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT17-003MM** **Budget (k€):** 400

**Title:** **Radiation Testing of a COTS General Purpose CMOS Image Sensor**

**Objectives:** The objective of this activity is to perform the electro-optical characterization after radiation of a Commercial Off the Shelf CMOS Image Sensor (IS). As a COTS, The CMOS IS should be already available and its design should fit the requirements of Space applications.

**Description:** Commercial Off The Shelf (COTS) CMOS image sensors are available in many different sizes and formats but typically with very small pixels and small footprint, targeted at mobile or automotive technology and are not compatible with space science applications. However, a number CMOS image sensors aimed at the high-end applications, with a larger pixels and larger area are now coming to market.
The aim of this activity is to evaluate the performance of such a sensor in a relevant space environment through characterization and radiation testing. The sensor will be selected based on a number of parameters including suitability for current/future space applications and availability.
A detailed study into the current state-of-the-art COTS CMOS image sensors in terms of electro-optical performance, configuration, qualification and availability will be the first task to be performed. The main focus of this activity is the evaluation of state-of-the-art COTS CMOS image sensors with the use of existing and available sensors, keeping in mind the large pixel and large area requirements for space applications. The activity shall be focus mainly on sensor performances and not on design and/or detector fabrication. It is therefore not within the scope of this activity to undertake specific development of CMOS image sensors.
This activity is performance oriented and does not focus on a particular technology/ architecture in CMOS Image Sensor. Nevertheless, the usage of an off-the-shelf device (scientific, commercial or specific purpose CMOS Image Sensor) is considered prerequisite.
The following tasks will be done in the frame of this activity:

- State-of-the-art review and trade-off analysis.
- Test Plan preparation.
- Test System Development and Sensor procurement.
- Detector radiation test and electro-optical characterisation.
- Analysis of results.
- Roadmap, conclusions and recommendations.

**Deliverables:** Breadboard

**Current TRL:** 3 **Target TRL:** 4 **Duration (months):** 12

**Target Application/ Timeframe:** TRL 4 by 2019.

**Applicable THAG Roadmap:** Optical Detectors, Visible Range (2015).

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT17-004MM** **Budget (k€):** 1,000

**Title:** **CMOS image sensor based on high-resistivity epitaxial silicon**

**Objectives:** The objective of the activity is the design, manufacture and characterisation of a CMOS image sensor based on high-resistivity epitaxial silicon.

**Description:** Visible image sensors with high sensitivity extending into the Near Infrared (NIR) are in high demand for many planned and future Earth observation and Science missions. The benefits of high-resistivity silicon in this area for CCDs has been previously demonstrated.

The aim of this activity is to extend these benefits to CMOS image sensors and subsequently exploit the enhanced read-out capabilities and radiation tolerance which are inherent to CMOS image sensors.

The benefits of the developed technology will be:

- Better electro-optical performance will be achieved, due to the use of thicker starting material e.g. increased Quantum Efficiency (QE) at higher energies (above ~3keV) or at long wavelengths (NIR).
- The possibility to achieve improved MTF performance by using appropriate processes and controlling the photodiode depletion with respect to the total thickness of the material.

Emphasis shall be given to the schematic representation of the pixel layout as well as detailed detector architecture with schematics at transistor level of the main building blocks including pixel, column amplifier, programmable gain amplifier (if applicable), multiplexer and output amplifier. The pixel design with a schematic representation of metal layers and diffusion areas etc is expected to be based on detailed simulations and modelling of predicted performance.

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

- Detector specification and trade-off study.
- Preliminary detector design and pixel simulation.
- Detailed detector design.
- Detector manufacture.
- Detector characterization including radiation testing.
- Evaluation, conclusions and recommendations.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Future EO and science missions.

**Applicable THAG Roadmap:** Optical Detectors, Visible Range (2015).

### 3.5.1.3. TD23 - EEE Components and Quality

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT17-005ED** **Budget (k€):** 700

**Title:** **New Power MOSFETs development**

**Objectives:** The objective of the activity is to develop 2 new variants of European power MOSFETs to complement existing EU MOSFET solutions.

**Description:** The development of a Rad-Hard European MOSFET has been a major step in the power domain. After developing the know-how and the technology needed to achieve radiation tolerance, we now need to tackle the next challenge: European non-dependence by developing a catalog with enough MOSFET types to be able to compete with the main non-European competitors and complement the existing European portfolio.

The main competitors in this area have an extensive list of models and, if European companies cannot offer similar components, it will be impossible to compete adequately.

In terms of power MOSFETs, the new trend in ancillary electronics to turn into digital most of the circuits demand power MOSFETS with low gate threshold voltage (Vth). In order to drive them directly from the digital ICs, a Vth below 3 V is highly requested. With this characteristic, there will be a specific interesting model to develop:

Circuit Polarity VDSS (V)max Drain Current (Dc)(A) Vth (V) RDSon(Ohm) Single N-channel 60 V, 10A-20A, + 2 V, < 50 mOhm.

Another model that is highly demanded is a low current MOSFET that is extensively used in auxiliary circuitry in power systems. The basic specifications are as follows:

Quad MOSFET, 2xN channel + 2xP channel, 100 V, 1A, <1Ohm

The radiation tolerance to be achieved is at least 100 krad (TID) and full Safe Operating Area for SEE up to 37 MeV cm2/mg.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** The proposed variant are not available today from European sources.

**Applicable THAG Roadmap:** Power Management and Distribution (2013).

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT17-006ED** **Budget (k€):** 1,500

**Title:** **Space evaluation and enhancement of European GaN MMIC offering**

**Objectives:** The purpose of the activity is perform ESCC space evaluation of existing European GaN MMIC processes covering power and low-noise applications and boosting the technology towards smaller technology node (0.15 um or lower) to achieve X-Band and V-Band applications. This second part is therefore highly innovative and would strengthen the position of European GaN foundries wrt to the non-European competitors.

**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. At the moment there is no space qualified GaN foundry process in Europe and non-European components fall under export control. ESA is currently performing space evaluation of a European 0.5 um discrete GaN HEMT process to be used in power applications up to C-band. However, majority of satellite applications utilize higher frequency bands and the trend is to further increase carrier frequency to even up to V-band as lower frequency communication channels become congested and more bandwidth is required by emerging high-throughput applications.
The objective of this activity is to perform ESCC space evaluation of GaN MMIC processes to ensure European non-dependence in applications requiring solid state amplification at frequencies above C-band. Based on the technological readiness level of different GaN MMIC processes in Europe, it is proposed to perform the activity in two consequent phases:

- Phase 1 (Duration 24 months, budget 750kEuro): Space evaluation of a European 0.25 um GaN MMIC process to be used in applications up to K-band.
  - Definition of capability domain,
  - design of test vehicles (TCV, DEC, RIC),
  - process space evaluation.
- Phase 2 (Duration 24 months, budget 750kEuro): Space evaluation of a European 0.15-0.1 um GaN MMIC process to be used in applications up to V-band.
  - Definition of capability domain,
  - design of test vehicles (TCV, DEC, RIC),
  - process space evaluation.

**Deliverables:** Report

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 48

**Target Application/ Timeframe:** Space evaluated GaN MMIC processes with gate length lower or equal to 0.25 um are needed in a variety of applications in Telecommunication, Earth observation, Navigation and Science requiring solid state high power and/or low noise amplification. TRL 6 is targeted by 2020 for 0.25 um process and by 2021 for 0.1-0.15 um process.

**Applicable THAG Roadmap:** Critical Active RF Technologies (2014).

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** GT17-007ED **Budget (k€):** 600

**Title:** **New decoupling capacitors for next generations of integrated circuit technologies**

**Objectives:** The aim of this activity is to evaluate and to qualify decoupling capacitor technologies compliant with the requirements of most recent integrated circuit technologies.

**Description:** A lot of effort was put on development of new generation of microprocessor, FPGA or mass memory. The increase of operation frequency and power supply current (up to 7Amps for mass memory) together with the decrease of power supply voltage (1V or less) lead to more stringent impendence matching requirements (i.e. capacitor decoupling).

This new integrated circuits products can only operate if suitable passive devices are implemented. Due to the performance increase of the IC, the following requirements on capacitors shall be considered:

- high capacitance value to provide high current needed,
- low ESR and ESL to assure correct impedance matching on the needed frequency range,
- reduce the distance between high frequency decoupling capacitor and the package. This will reduce the inductance of connection paths. This can be achieved by using small capacitor size.

Capacitor values (16V range 0603 or 0805 case 4,7uF 1812 case 47uF) for these applications are only available in commercial range. At the present there is no space qualified product that meets this requirements. Using commercial products is only possible is sufficient attention is paid during procurement: lot acceptance test, documentation review, additional costs and delay, etc. These drawbacks will be avoided if ESCC qualitied parts are made available.

Therefore, to provide to the space industry the capacitors with the needed performances and mandatory quality level , this activity will encompasses the following tasks:

- benchmark and selection of adequate technology of capacitor,
- manufacturing/procurement of representative samples,
- evaluation and qualification of these components in line with ESCC requirements.

**Deliverables:** Engineering/Qualification Model

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

**Target Application/ Timeframe:** FPGA 65 and 28nm, mass memory, new generation of microprocessor.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT17-008QE** **Budget (k€):** 1,200

**Title:** **Radiation characterization and functional verification of COTS components for space applications.**

**Objectives:** The objective of this activity is to radiation characterise and assess performance of COTS components. Importantly, this activity aims at utilising the spin-in approach to identify promising high-performance (e.g. reduced equipment component count, increased performance, reduced power, etc.) COTS Component candidates screened and characterised for relevant space environmental conditions (mainly radiation: TID, DD, SEE Heavy Ions and Protons). Amongst other the following components shall be considered; Memories, microcontrollers, interface controllers, ADCs/DACs, optoelectronics, CMOS Image Sensors, photodiodes, etc.

**Description:** Based on a preliminary COTS Component list, it is proposed in the frame of this activity to critically survey and select potential component candidates in-line with system requirements (e.g. fault tolerant OBC/Data handling systems). Besides specific requirements for challenging ESA missions, requirements for applications such as Cubesats, Microsats and Minisats shall be considered. Novel EEE Components offered as radiation tolerant by various manufacturers shall also be considered in the survey.

The components selected shall be testable (i.e. possible to de-lidd for SEE testing). The selected components shall be purchased in lots to identify lot-uniformity, and as far as possible including component traceability information (e.g. lot number, datecode, etc.).

Following the component selection process, an irradiation pre-screening (TID and Single Event Latch-Up) to remove weak components shall be performed. The remaining successful candidates shall undergo a comprehensive but relevant irradiation test campaign (TID, DD and SEE). Components shall additionally undergo full functional and electrical characterisation for performance verification vis-a-vis ESA requirements.

For all tests, Test Plans shall be generated. Following completion of tests dedicated test reports shall be generated.

Experiences gained during testing of candidate components shall be submitted to the Component Technology Board Radiation working Group in the form of guidelines for possible inclusion in European Radiation Hardness Assurance standards. When found necessary and within the financial envelope of the activity, additional tests such as outgassing, thermal tests, etc. shall be carried out.

**Deliverables:** COTS Component list / Test plan, test reports / All COTS Components procured / Reports.

**Current TRL:** 3 **Target TRL:** 5 **Duration (months):** 36

**Target Application/ Timeframe:** 2020. COTS Components for Space Applications.

**Applicable THAG Roadmap:** Data Systems and On-Board Computers (2016).

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT17-009ED** **Budget (k€):** 600

**Title:** **Definition and validation of an European source of flip-chip bump services for 28nm and lower technology nodes**

**Objectives:** The objective of the activity is to enable a validated European source for flip-chip wafer bumping for microelectronics packaging for VLSI technology (ASIC, FPGA, Memories, etc.) using a technology node of 28 nm or smaller.

**Description:** Semiconductor industry is moving to technologies (<65nm) where wire bonding will no longer be a suitable solution for components packaging. Flip-chip is seen as the only feasible solution for those technologies combining both low pitch and high I/Os number. Currently this technology with the adequate reliability level is only offered by subcontractors from the Far East which are mainly only accessible to non-European large semiconductor companies (Xilins, Microsemi, etc..)

The work to be performed is to identify, define and validate a European Flip chip technology able to provide wafer bumping services to both large and small semiconductor manufacturers.

Flip-chip technology is widely available to commercial markets, the work to develop is to define and validate an existing flip-chip commercial technology up to space requirements.

The proposed technology must cover both solder bumps and Lead-free bumping. The target wafer dimensions would range from 8 to 12 inches diameter. Outcome of the activity shall be a space validated process identification document describing the technology ready to use in new component developments.

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

- technology identification and selection,
- samples manufacturing and Testing,
- release of a Process Identification Document for Space applications.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** Microelectronics: FPGA, ASICs, Memories. TRL5 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD1 - EEE / Components / Photonics / MEMS* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT17-010ED** **Budget (k€):** 500

**Title:** **Space qualification of a pigtailed InGaAs photodiode @ 1550 nm**

**Objectives:** The main objectives of the activity is the space qualification of a pigtailed InGaAs photodiode @ 1550 nm. Depending on the selected supplier (technology maturity, process reproducibility, nature of the established supply chain (Chip, package assembly and test; lot type qualification or an ESCC qualification will be performed.

**Description:** For various space applications (optical link, optical frequency conversion, signal monitoring 1550 nm photodiode is used. This detector is part of complex photonic systems and presently is primarily procured from non-european companies.

In order to promote a European source, the trade off, assessment and later selection of a fully packaged photodiode from a sustainable supplier is required.

This activity is divided in 3 steps: product trade off and selection evaluation of a suitable photodiode die, followed by a package and associated assembly process development, manufacturing evaluation and space qualification of the chosen solution with potential entry into the EPPL.

In particular, the main tasks will be:

- consolidation of the module technical requirements,
- chip delta design activities for radiation hardness, PDR, CDR,
- prototyping, characterization and radiation testing (TID, TNID, SEE) and endurance testing,
- package design activities, PDR, CDR,
- drafting of a PID (Process Identification Document),
- prototyping and characterization,
- drafting of a Detail specification for the photodiode including storage, damp heat, shocks,
- qualification testing as a minimum using ESCC 5000 as baseline requirement.

**Deliverables:** Flight Model

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

**Target Application/ Timeframe:** Space applications: optical link, optical frequency conversion, signal monitoring. TRL 4 in 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

## 3.5.2. CD2 - Structures, Mechanisms, Materials, Thermal

### 3.5.2.1. TD15 - Mechanisms

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *15 - Mechanisms* |

**Ref. Number:** **GT17-011MS** **Budget (k€):** 800

**Title:** **Adaptation of industrial actuator for space applications**

**Objectives:** The activity aim at adaptation of existing European actuators based on stepper motors with speed reducers from industrial suppliers to space usage.

**Description:** The activity shall aim at competitiveness and independence of European industry wrt actuator based on stepper motor and gearbox, which is commonly used on a wide variety of mechanisms. The main objective is to identify, in collaboration with main primes and final users, the sizes and configurations which are missing on the OTS market and enlarge the catalog of readily available space qualified actuators.

Selection of gear materials, their surface treatments and coatings shall be addressed, in order to improve performances of speed reducers in terms of life and load capabilities.

The foreseen scope of testing shall include vibrations, shock, t-vac cycling and life test in thermal vacuum conditions.

**Deliverables:** Engineering/Qualification Model

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

**Target Application/ Timeframe:** All ESA missions, vast majority of mechanisms. Some very preliminary work has already been done in this field, therefore the initial TRL 4.

**Applicable THAG Roadmap:** Electrical Motors and Rotary Actuators (2015).

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *15 - Mechanisms* |

**Ref. Number:** **GT17-012MS** **Budget (k€):** 650

**Title:** **Development of a family of space actuators based on brushless DC motors.**

**Objectives:** The activity aims at the adaptation of existing brushless motors for space application including enhancement of their commanding strategies.

**Description:** Independence of European space industry and competitiveness in cost and performances shall be fostered with off the shelf products as building blocks for mechanisms. The activity is intended to cover the lack of European brushless motors readily available for space applications.
In close collaboration with primes and end users, the Contractor shall develop 2 EQM actuators based on brushless motors, to cover a large range of applications in terms of size and torque capabilities. Specific attention shall be put into the commutation strategy and in the commanding electronics, which currently remain the limiting factor of brushless selection for common applications. Open loop drive and self-piloting solutions shall be addressed.
The activity work plan 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 commanding strategies optimized with respect to the motor design,
- manufacturing of EQM actuators and their integration 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.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL 6 by 2019.

**Applicable THAG Roadmap:** Electrical Motors and Rotary Actuators (2015).

### 3.5.2.2. TD20 - Structures

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *20 - Structures* |

**Ref. Number:** **GT17-013MS** **Budget (k€):** 500

**Title:** **Modelization and Validation of the dynamic effect of compressible Xenon in propellant tank**

**Objectives:** The overall objective of the activity is the modelization and validation of the dynamic effects of compressible Xenon in propellant tanks. An important particular objective is the clarification of the verification approach within projects. The objective shall be achieved with analytical studies and breadboard testing.

**Description:** Electric propulsion system based on Hall effect thruster has been gaining popularity since a decade or more. ESA missions like Artemis and Smart-1 were successfully flown with such system. The primary propellant for electric propulsion system is Xenon, which is stored in supercritical state inside a pressurized propulsion tank. The tank itself is mostly of COPV type because of its superiority in mass to strength ratio.
Xenon itself being in supercritical state, acts as a heavy, but compressible fluid and the dynamics of this supercritical media in an enclosed environment is not sufficiently known. With more and more electric propulsion system in larger scale being offered, it is important to have a better verified understanding of the coupling effect of the acoustic modes of Xenon (with significant effective mass on interface loads) to the structural modes of the tanks already at the design stage in order to avoid unforeseen amplification of the combined subsystem.

Computations of the coupling effect suggest significant effect on interface loads, indicate the effect to be most predominant in slender tanks. Important benefits brought by the study include improved verification of these tanks and control of schedule within projects.

The tasks of the activity are separated into analytical part and experimental part:

- Analytical Part:
  - to perform literature study of this topic,
  - to perform precise analytical prediction of the dynamic behavior of Xenon in propellant tank,
  - to perform parametric study to support the selection of test configurations,
  - to perform correlation of the predicted responses with test data,
  - to establish analytical procedure on the modeling of Xenon filled tanks.
- Experimental Part:
  - to perform reference vibration and acoustic tests using non-compressible media such as IPA or FREON or equivalent,
  - to validate the existence of acoustic modes of Xenon propellant during vibration and acoustic tests,
  - to establish if there is any real phenomenon of coupling between the acoustic modes of Xenon and the tank structure. Effect in terms of loads at the interface of the tanks shall also be assessed, which will determine whether the effect is significant at spacecraft level,
  - to study the sensitivity coupling in different tank geometries,
  - to study the sensitivity of coupling in regard to different temperature and pressure level.

By the end of the activity, it should be able to establish for spacecraft:

- the necessity of having to perform mechanical test with Xenon or the possibility to use simulant for a given tank configuration,
- the possibility of performing qualification mechanical test with Xenon with lower tank pressure and a procedure to account for Xenon dynamic behavior in numerical model,
- guidelines for the practical implementation of the above.

**Deliverables:** Report

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

**Target Application/ Timeframe:** TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *20 - Structures* |

**Ref. Number:** **GT17-014MS** **Budget (k€):** 500

**Title:** **Highly accurate measurement techniques of large reflector surface**

**Objectives:** The objective of this activity is to analyze and develop techniques to measure large reflector surfaces with high accuracy. The techniques will allow to measure the as-built surface of reflectors in the range of 3 to 5 m projected aperture diameter with accuracies better than 20 microns (3sigma).

**Description:** Recent trend shows that reflectors for space applications are becoming larger and larger and operate at higher frequencies (e.g. Ka or Q/V band) and require very accurate dimensional measurement of their surfaces (less than 20 microns). With an accurate knowledge of the reflector as-built surface, it will be possible to predict with confidence the RF performances of the reflector antenna, and correlate RF pattern measurement to as-built based predictions.

Different measurement techniques shall be identified and studied for their suitability. These techniques shall be compatible with all types of reflectors (solid, mesh). Among available techniques (photogrammetry, laser radar and interferometric measurements), new methods of suitable accuracy and sufficient data processing capability for the dimensions of the reflector, shall be explored. No development of new metrological instruments is required. Existing metrological instruments are to be used by implementation of new measurement methodologies.

A demonstration of the measurement technique shall be performed to prove its accuracy on an existing surface of sufficient representatively. Environmental conditions to consider are room temperature and pressure, but also TVAC testing is necessary. Options for this include the use of instruments inside the vacuum chamber and observation through a glass window.

The activity shall be carried out in the following steps:

- State of the art investigation on surface measurement methods, including as a minimum photogrammetry, laser radar, interferometry, et alter.
- Comparison of different methods on a sample of antenna reflector surface, in ambient conditions and in vacuum chamber.
- Demonstration of measurement on an existing reflector of 3 m as a minimum, in laboratory conditions.
- Demonstration of measurement in a vacuum chamber on an existing reflector of 1 m as a minimum in TVAC conditions.

**Deliverables:** Report

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

**Target Application/ Timeframe:** Surface measurement techniques for large reflectors. TRL6 by 2019.

**Applicable THAG Roadmap:** Reflector Antennas (2016).

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *20 - Structures* |

**Ref. Number:** **GT17-015MS** **Budget (k€):** 1,000

**Title:** **Passive damping for satellite and instrument design**

**Objectives:** The objective of the activity is the demonstration of mass saving potential when passive damping measures are already foreseen in early design of satellite and instrument structures.
This demonstration shall be performed by analysis and tests on breadboards and demonstration models.
The applicability is to all service domains and the target is the improvement of mechanical environment for instruments and equipment, reduction of development cost and life cycle cost and schedule risk of spacecraft, especially during AIV.

**Description:** Passive damping measures are usually only studied and sometimes introduced in satellite or instrument design if problems, e.g. higher loads due to dynamic amplification, are encountered in late stages of the analysis loops or even during testing. At that time it is very difficult to introduce optimized passive damping due to many accommodation constraints, if at all possible. Usually fixing such problems than carries a significant mass penalty. In addition, a recurrent problem on spacecraft is high amplification factor seen for units mounted on brackets (eg. Thruster, antenna, sun sensor).

The aim of this study is to evaluate the benefits of introducing passive damping measures and in particular constrained layer damping in early design phases. With an early introduction of passive damping measures most likely already the load specification for structure design and for satellite equipment or instrument design can be reduced. This should already lead to reduced mass of equipment and instrument design. The study should address modelling of damping systems, predictions with and without damping, and demonstrator testing to confirm the results and expected mass savings.

A precedent of this can be seen in the project Aeolus, where a shock attenuation device was developed in very short time. This development aims however at a wider spectrum of application.

Demonstration shall be performed on standard spacecraft structures:

- primary and secondary structural plates, cylinders, struts, or interface elements, after selection,
- tertiary structure brackets and support elements dedicated to sensors, thrusters, antenna or telescope mounts,
- dedicated additional intermediate structures devoted to the specific function of load attenuation.

Development tests shall consider:

- load damping and structural response attenuation metrics (amplitude for sine response, PSD and RMS for random response),
- stiffness and mass,
- compatibility with thermal environment (thermal cycling and thermal vacuum),
- thermal distortion (particularly for sensitive instruments) and thermo-elastic stresses.

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| **Deliverables:** | Breadboard | | | | |
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 24 |
| **Target Application/ Timeframe:** | TRL6 by 2020. | | | | |

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.5.2.3. TD21 - Thermal

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *21 - Thermal* |

**Ref. Number:** **GT17-016MT** **Budget (k€):** 500

**Title:** **Integration Simplification of Capillary Driven Heat Transport Systems**

**Objectives:** The objective of the activity is to develop and qualify new technologies and methods that would greatly simplify the integration of Capillary Driven heat transport systems. These new technologies and methods can range from connectors to ammonia charging rig allowing the purging and filling of capillary driven loops on the integration floor.

**Description:** Capillary Driven Loops, as Loop Heat Pipes are currently assembled and filled at the loop heat pipe manufacturer. LHPs are used to transport heat from dissipative units where sometimes these units could be in an area that is difficult to access. In these cases, the LHP tubing routing could be very complex which makes the task of inserting these two-phase devices very challenging. Furthermore, the radiators used by LHPs could be an access panel which would need to be opened and closed multiple times. Flex lines could allow the panel to be opened but typically, more than one LHPs would share the same radiator increasing the number of flex lines. In addition, flex line has a negative impact in demanding additional volume of working fluid to be added in the LHP. This demand causes the compensation chamber volume to be increased which increases the overall mass of the system.

If new technologies and methods are developed to allow the LHP to be dismantled at the LHP manufacturer and assembled within the spacecraft, then purged and filled on the integration floor while guaranteed the performance, the life time and safety, this would greatly simplify the design and integration of these products. Similar technologies and methods are currently being used for propulsion systems and the proposed activity is to apply something similar to Two-Phase heat transport systems.

The activity would cover the developments of connectors, quick disconnects, valves, ground support equipment for emptying, purging, filling with ammonia, as well as covering all of the safety aspects of performing such an operations.

It is important to note that there is some qualification needed on flight hardware since the LHP and MPL would need to be designed for charging on-site e.g.(connectors, ports, or even welding on site.) The activity would allow to repeat this filling process multiple times in order to verify that it is repeatable and reliable.

**Deliverables:** Engineering Model

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 28

**Target Application/ Timeframe:** Several applications e.g. Science, EO. As one of the examples, multiple LHPs will need to be assembled on multiple heat sources for the ATHENA mission. TRL 6 2022.

**Applicable THAG Roadmap:** Two-Phase Heat Transport Systems (2009).

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *21 - Thermal* |

**Ref. Number:** **GT17-017MT** **Budget (k€):** 500

**Title:** **Efficient mounting of MLI blankets to spacecraft structures**

**Objectives:** The objective of this activity is to develop a faster and reliable method for installing MLI blankets when compared to the current state-of-the-art methods, to shorten integration time and reduce impact on system AIT, while maintaining MLI integrity and installation constraints. The alternative solutions are expected to offer advantages over the current methods in terms of mass, flexibility, ease of installation and removal, time required for installation and finally the related cost. A breadboard shall be developed and tested for critical function verification in a relevant environment.

**Description:** Satellites have an outer skin of multilayer insulation blankets layer that is needed to control the thermal balance of the spacecraft (S/C). These blankets need to be fixed to the S/C structure to withstand launch loads and provide the required thermal performance taking into account field-of-views of instruments and other payloads as well as access constraints.

MLI blankets are currently mounted to the S/C structure by a cut-to-fit approach of the either MLI lay-ups or at least MLI templates involving bonding of more than 1000 -1500 pcs. of MLI attachments (stand-offs and / or velcros) for a typical satellite. This is a very time consuming task, which takes several weeks to be completed. Furthermore the more disturbances, the more thermal impact on the overall MLI performance is to be expected.

An advanced MLI mounting concept shall be investigated, which minimises the number of attachments needed for a reliable fixation of the MLI blankets taking into account mechanical aspects as exposed to during launch. Focus is on how to ensure that the mechanical and pressure loads can be taken by a reduced number of attachments without impacting the MLI integrity, the field-of-view requirements as well as other precise positioning requirements on the satellite. Contamination and cleanliness aspects need to be addressed. A number of initiatives to develop this new mounting approach have already been carried out by MLI suppliers. Grounding aspects have also been covered. It is now envisaged to develop further

the TRL/maturity on the basis of ESA needs on most projects (strong benefits in reducing system AIT time and cost).

The main tasks foreseen in the frame of this activity are the following:

- characterization and consolidation of state-of-the-art methods and identification / selection of alternative concepts,
- detailed design of these concepts,
- manufacturing of a breadboard with new MLI installation method,
- mechanical testing (incl. depressurization test) of the selected concept,
- breadboard intended for critical function verification in a relevant environment.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Targeted applications are multiple. TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.5.2.4. TD24 - Materials and Processes

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *24 - Materials and Processes* |

**Ref. Number:** GT17-018QE **Budget (k€):** 500

**Title:** **Transparent polyimide films for thermo-optical applications**

**Objectives:** The objective of this activity is the full optimisation of highly transparent (colourless) polyimide hybrid materials and demonstration of the performance improvement for typical MLI and OSR configurations.

**Description:** The polyimide films materials combine the performance of polyimide that is intrinsically radiation stable but exhibit higher solar absorptance (yellow colour) and fluoropolymers that are highly transparent with very low solar absorptance (colourless) but suffer durability in a radiation environment.

Developments in previous contracts showed solar absorptance of such hybrid materials as low as 0.07 in pristine form and between 0.15 - 0.25 after combined radiation environment (UV, e-, p+). The mechanical flexibility of such polymer films and the ease of surface modifications by vapour deposition make them ideal substrates exterior spacecraft applications, such as enhanced MLI performance and low-cost OSRs.

Within this activity the materials matrix shall be fully optimised and performance tested to cover all environmental parameters, i.e. not limited to radiation (vacuum UV, particle radiation) and temperature but also atomic oxygen and synergistic effects to enable full performance assessment for all relevant earth orbits. The performance of the optimised polymer film shall then be demonstrated for an OSR as well as MLI configuration.

The gained improvement compared to conventional applications shall be quantified in terms of technical performance (e.g. thermal efficiency, in-orbit life time), and through a cost/benefit analysis for both, MLI and OSR applications.

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

- building from previous activities, full matrix optimisation of hybrid fluorinated polyimides and performance evaluation for LEO and GEO environment,
- manufacturing of demonstrators for OSR and MLI application for transparent polyimide as well as conventional reference systems,
- full environmental testing of demonstrators, performance evaluation, and trade-off analysis for technical performance and cost,
- demonstration of large-scale manufacturing capability.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *24 - Materials and Processes* |

**Ref. Number:** GT17-019MS **Budget (k€):** 700

**Title:** **Application of new and novel Non Destructive Inspection (NDI) Techniques for Spacecraft and Launchers Critical Applications**

**Objectives:** The objective of the activity is to evaluate the performance of new and novel non-destructive inspection techniques for NDI of critical parts used in space critical applications.

**Description:** The last decade has seen the development of many new high performance materials which can be used for space applications. These include new lightweight metallic materials such as Al-Li based alloys, metal matrix composites such as TiSiC, and non-metallic structures based on CFRP and glasses. In order for these materials to be adopted for space applications, the manufacturing and assembly of these and other advanced materials must be addressed. In parallel to the development of new advanced materials, there has also been a significant improvement in the availability of non-destructive inspection (NDI) techniques which can be used to detect flaws.

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

- Literature review and Trade-off of current state-of-the art NDI techniques: the technology trade-off shall include at least the current detection limits, the handling and the applicability to different metallic, ceramic and metal and ceramics matrix materials.
- Evaluation of novel NDI techniques: NDI techniques currently under development shall be evaluated on their possible improvements on the detectability of flaws and/or their improved handling (e.g. portability of the equipment, accessibility of complex structures). The techniques to be considered for evaluation shall include (but not be limited to):
  - Long range ultrasonic testing.
  - Time of flight diffraction.
  - Phased array ultrasonic testing.
  - Digital radiography.
  - Shearography.
  - Laser UT.
  - Alternating current field measurement.
- Micro-focus X-ray practical testing (with fatigue pre-cracked samples) of novel NDI techniques and comparison to the state-of-the art: Finally, the most promising non-destructive inspection techniques and material combinations shall be compared with equivalent designs inspected by conventional techniques. The trade-off shall at least include detection limits, reliability, industrial efficiency, cost and environmental friendliness aspects.
- Technology evaluation and conclusion: Summaries and assess the technology benefits & drawbacks and create/update of the technology roadmap based on the results and lessons-learnt.

**Deliverables:** Report

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

**Target Application/ Timeframe:** 2019. Spacecraft and launchers.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD2 - Structures, Mechanisms, Materials, Thermal* |
| *Tech. Domain* | *24 - Materials and Processes* |

**Ref. Number:** **GT17-020MS** **Budget (k€):** 1,000

**Title:** **Morphing Structures Processed by 4D Printing for Space Applications**

**Objectives:** The objective of this activity is to investigate how innovative combinations of materials, topological design and additive manufacturing processes can create new functionalities in structures intended for space applications. This shall be demonstrated through the design, manufacturing and characterisation of an adaptive morphing structure demonstrator for a selected space application.

**Description:** Smart materials, i.e. materials which change one or several of their properties as a response to an environmental stimulus, are already being used in various engineering applications, including space products. Among those, shape memory alloys or piezoelectric materials found applications in space mechanisms (e.g. valves, release mechanisms, piezo-actuators), while other smart materials are the subject of advanced research and development (e.g. ferrofluid thrusters for spacecraft propulsion).

Additive Layer Manufacturing (ALM), otherwise known as 3D printing, is having a profound impact on the manufacturing of parts across various industries, due to the significant increase in design freedom that this family of processes offer. Complex geometries and material combinations, not obtainable with conventional processes, are possible, leading to improved designs and resulting gains in performance, manufacturing cost and lead time.
An emerging engineering discipline, colloquially named 4D printing, aims at combining the design freedom offered by 3D printing with the shape-changing ability of smart materials, to produce structures which can evolve in time and change their functions depending on the surrounding environment.

This activity is aimed at designing and producing active adaptive morphing structures, targeting shape-changing reflectors, adaptive mirrors, adaptive propulsion nozzles, morphing solar panels, thermal control parts, antenna pointing structures, deployment systems. A trade-off will be conducted to select the targeted space application with associated requirements, bringing the highest benefits.

Given the multiple aspects involved in this study (materials design and manufacturing, system-level design, space applications) the activity shall be run by a multi-disciplinary team using a concurrent engineering approach.

The tasks to be done in the frame of this activity will consist of:
- conducting a literature review of the state of the art in 4D printing techniques and more generally in the combination of ALM and smart materials,
- conducting a review of available computational tools which can support the design, optimisation and simulation of 4D printed structures,
- performing a trade-off analysis to select an application for which an active adaptive structure demonstrator will be developed in this activity, together with the associated 4D printing process,
- preparing a detailed design of the adaptive structure demonstrator,
- conducting the 4D printing process development,
- manufacturing the active adaptive structure demonstrator,

- characterising the demonstrator to assess compliance with the defined requirements for the selected space application,
- validating the computational model of the adaptive structure with the characterisation results,
- performing a critical assessment of the potential of the selected 4D printing technology for the targeted space applications and the impact on the future design of space systems.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

## 3.5.3. CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)

### 3.5.3.1. TD01 - Onboard Data Systems

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|---|---|
| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT17-021ED** **Budget (k€):** 800

**Title:** **COTS-based highly integrated computer system for mini/nano satellites**

**Objectives:** The objective of this activity is to build a demonstrator based on Zinq 7000 SoC since its radiation performances are suitable for mini/nano commercial services. This type of computer can stem to an ancillary 'OBC helper' unit/board for mini (30+ kg class) satellites or be used as standalone for cubesat-class platforms (as evolution of already existing Zinq-based computers).
The use case for validation shall incorporate some existing AOCS sensor acquisition and pre-processing functions to be optimised for their implementation on the target demonstrator.

**Description:** Data fusion can play an important role in future avionics especially in smart, small and low cost spacecraft. Those platforms require reliable and different types of sensory data, pre-processing and fusing them to obtain better information regarding their objectives, information which cannot be acquired by a single sensor alone with the same level of reliability and availability.
Sensor fusion is particularly applicable for AOCS for object detection, navigation and autonomous maneuvers.
To perform data fusion a performance leap in space-borne control electronics is required, since available (and proposed) processing platforms, like LEON-based SoC (SCOC3, GR712, GR740) are not sufficient. Even current FPGAs, like Xilinx's V5 or Microsemi's RTG4 might not have the right performances and architecture to do this job, since a close optimisation of pure bitstream processing (FPGA-based) and slow control (processor based) is needed.

The activity targets demonstration of use of hi-performance SoC FPGAs in a 'COTS-based platform' (mini/nano/cube etc, but with main target to superconstellations fallout products) to be used as an highly integrated computer to perform an intermediate sensor data processing and fusion step for (e.g) AOCS sensors or payloads with sensor acquisition and pre-processing (calibration, selection, checks, monitoring, fusion), actuators data processing (configuration, parameters monitoring) and newer functions like SW-defined-GNSS, assisted by STR data fusion, in flight orbit and environmental parameters propagation, visual based navigation, autonomous visual based target pointing but also payload data fusion for physical measurement gathered from diverse sensors (e.g. radiation, plasma). Due to the vast number of sensors inputs, such applications pose high demands on the memory capacity and bandwidth.

FPGA-based reconfigurable computing systems are already (in commercial electronics) the most cost and power-effective solutions, in particular in a remote sensing system by means of a commonly employed application and fusion software. Multiple designs for multiscale data-fusion algorithms, developed for FPGA-based platforms, have demonstrated speedup over pure processor-based solutions. Past results of related ESA activities depict that well over an order of magnitude improvement in speed, and two order improvement in power efficiency can be obtained with efficient designs and appropriate hardware resources.

Choice of Zinq7000 series SoC FPGAs as baseline demonstration platform is related to some existing space heritage (GOMSpace, CNES) and knowledge of good radiation performance and may lead to products applicable to the aggressive commercial (cubesat, minisat, telecom constellations) market, with an additional HW+SW layer that takes care of guaranteeing a good dependability after radiation effects.

The target TRL is 5, starting from existing studies that have demonstrated feasibility of high-frame-rate image processing, Star Tracker processing, SW-based GNSS in this type of platform.

The activity includes the following tasks:

- Identify a common, modular architecture, based on Zinq7030 SoC COTS FPGA, that fulfils dependability and budget (size, cost, power) requirements for different COTS based class of missions (cubesat, minisat, aggressive commercial, possibly LEO institutional).
- Detailed design of an hardware proof-of-concept demonstrator.
- Selection and design of a GNC demonstrator use case, incorporating some existing AOCS sensor acquisition and pre-processing functions to be optimised for their implementation on the target demonstrator.
- Manufacturing of the computing system, testing, software integration in field demonstration.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** TRL 5 by 2019.

**Applicable THAG Roadmap:** Data Systems and On-Board Computers (2016).

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT17-022ED** **Budget (k€):** 1,000

**Title:** **High Performance Reconfigurable Processing Module (HiPeR-Pro)**

**Objectives:** The HiPeR-Pro activity aims at providing a high performance and flexible solution for payload data processing tasks using EEE parts which are designed for space applications.
Within this frame, the objective of the HiPeR-Pro development is to design and manufacture a data processing module hosting a high performance processor or DSP, one to several high capacity reconfigurable FPGAs and a SpaceFibre routing switch to interlink the processing nodes. The module will support standardised interfaces (SpaceFibre, SpaceWire, CAN) and lower level digital interfaces used natively or as a bridge to Analog interface devices.

**Description:** The approach while designing a High Performance Reconfigurable Processing Module will follow the general principles organized with the following tasks:

- Implementing real-time data stream processing functions in FPGA firmware.
- Implementing non-real time and lower data rate processing in software.
- Providing a scalable and versatile I/O system supported by flexible software drivers.
- Extending digital I/Os by Analogue Front-ends.
- Developing at EBB level a HW module hosting a high end processor or DSP, high performance and capacity FPGAs, a SpaceFibre router to interlink the processing nodes and corresponding support equipment.
- Implementing and validating on the target with a selection of IP Cores taken from ESA's portfolio.

The selected hardware platform is the combination of a powerful processor or DSP, one or several high-end reconfigurable FPGAs and a SpaceFibre network interlinking the processing nodes, based on EEE parts which are designed for space applications. The platform shall fulfil the following needs:

- Supporting exploratory and evolutionary designs according to mission needs during early development phases. The advantage at this stage is clearly to reduce costs thanks to using a flight representative and stable hardware platform.
- Allowing in-flight reconfiguration for adaptation and to allow for algorithm changes during mission lifetime, different mission phases and modes. For instance, processing algorithms can be tuned according to evolving needs or re-defined during the execution of the mission. This will extend the level of data processing to be applied on board, as acceptance of the science community will be higher in this case than fixing the processing chain before the launch for the whole mission lifetime.
- Allowing in-flight PARTIAL reconfiguration to prepare the processing chain for the next task without service interruption of the on-going task.
- Allowing staggered data processing by using in-flight reconfiguration of the processing chain. This will tremendously reduce the number of processing nodes, if the application allows for staggered processing, as the same processing chain can be used for different tasks.
- Using the same processing chain for different instruments by using in-flight reconfiguration. This is possible when several instruments work in windowing mode and do not need the processing chain all the time.

- Enabling a mission rescue in case of FDIR events or failures that could be overcome by a deep reconfiguration of the data processing functions.

The activity will consist in developing at EBB level a HW module hosting a high end processor or DSP, high performance and capacity FPGAs, a SpaceFibre router to interlink the processing nodes and corresponding support equipment. A selection of IP Cores taken from ESA's portfolio will be implemented and validated on the target.

Potential FPGAs for this activity are the European FPGA BRAVE large and ultra, as well as Xilinx Virtex 5. Potential processors are the ones provided by the BRAVE FPGAs (e.g. Leon4), GR740, SSDP (Dual-Core DSP + Leon3FT) and RC64 (many-core DSP, SpFi interface). The SpFi routing switch can be implemented in Microsemi RTG4 or as ASIC in ST65SPACE 65nm technology.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** TRL5 in 2019.

**Applicable THAG Roadmap:** On-Board Payload Data Processing (2016).

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|---|---|
| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT17-023SW** **Budget (k€):** 800

**Title:** **CAN System and SW Stack consolidation**

**Objectives:** The objective of the activity is to improve the industrial use of the CAN bus for distributed intelligence systems, targeting ramping up use of space grade microcontrollers. Starting from the ECSS-E-ST-50-15 standard, which addresses the use of the CAN protocol extended with some CANOpen features, and from existing hardware (e.g. R-CCIPC CANOpen VHDL IPCore) and software solutions, the activity will draw the landscape of the CAN technology and consolidate some industrial needs.

**Description:** The CAN standard defines the hardware and the communication protocols at the first two layers of the ISO/OSI stack. The software community has identified issues in the use of the various CAN solutions,and a more structural approach to the software must be defined, implemented and disseminated, as well as guidelines on the configuration of the CAN for different types of missions.

The activity includes:

- gathering the problems in the use of CAN in various missions (planetary exploration, robotics, telecom platform and payload, etc)e.g. through networking contacts in European industry,
- clarify identified open issues related to the use of CAN e.g. redundancy concept, use of CANOpen, large data unit transfer, boot loader protocol for remote programming, etc),
- identifying growth potential for CAN (e.g. CAN-FD, multi-master,asynchronous control),
- for those topics, identifying the necessary complementary requirements with the network of contact in European Industry and proceeding with the implementation:
- guidelines on how to use CAN according to the system configuration,
- protocols (independent from the hardware execution [Leon.micro-controller], and from the hardware driver),
- pre-qualified software drivers or test suite.

**Deliverables:** Handbook and software

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

**Target Application/ Timeframe:** TRL5 by 2019.

**Applicable THAG Roadmap:** Avionics Embedded Systems (2016).

### 3.5.3.2. TD02 - Space System Software

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *02 - Space System Software* |

**Ref. Number:** **GT17-024SW** **Budget (k€):** 800

**Title:** **SAVOIR Data Storage Services Demonstration**

**Objectives:** The main objectives of the activity are to apply the concepts and specifications identified during the FMSIS TRP activity and consolidated by the SAVOIR-MASAIS Working Group and develop a reusable library to manage files on-board.

**Description:** The FMSIS TRP activity has led to the production of two documents reviewed by the SAVOIR-MASAIS Working Group. The first document is the 'SAVOIR Data Storage System Requirement Document'. The second document is the 'SAVOIR generic Data Storage Functional Specification'.
The FMSIS activity verified most of the requirements of these two documents through the development of a fully simulated demonstrator. The two reference documents are being updated with respect to the results of the review by the SAVOIR Advisory Group for the 'SAVOIR Data Storage System Requirement Document' and a public review for the 'SAVOIR generic Data Storage Functional Specification'. At this stage, foreseen to be reached end Q2 2017, the requirement documents will be consolidated and allow a first reference implementation. This reference implementation shall be performed on a representative environment in term of execution platform and Mass Memory device.

To achieve the objectives, the activity shall at least include the following tasks:

- Identify a representative Mass Memory equipment that:
  - is compliant to the SAVOIR-MASAIS requirement documents,
  - maximise the number of requirements of the SAVOIR-MASAIS requirement documents that can be verified.
- Identify a COTS FMS library that:
  - is compliant to the SAVOIR-MASAIS requirement documents,
  - can be easily qualified with respect to ECSS-E-ST-40C,
  - has a license scheme compatible with its integration in space flight Software.
- Develop the reusable FMS library:
  - if a COTS FMS library is identified, develop the required interfaces to applications and to Mass Memory,
  - if no such COTS FMS library exists, develop the FMS Services supporting required interfaces to applications and to Mass Memory,
  - the interface to Mass Memory shall allow a quick port on different Mass Memory devices.
- Verify the reusable FMS library:
  - based on test scenarios covering the applicable requirements,
  - based on representative Use Cases, i.e. real scenarios from existing missions,
  - including file transfers, i.e. CFDP.

In addition, the FMS library shall be compliant with the architecture defined in the frame of the Payload Execution Platform Software (PEPS) TRP activity so that it can be easily included and provide FMS services to the Payload developers.

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 5-6 by 2019.

**Applicable THAG Roadmap:** On-Board Software (2014).

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|---|---|
| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *02 - Space System Software* |

**Ref. Number:** **GT17-025SW** **Budget (k€):** 600

**Title:** **Integration of model-based avionics design and FDIR analysis tools**

**Objectives:** The objective of this activity is to create an integrated approach for model-based verification of safety and performability analysis of complex avionics systems, by bringing together recent advances in model-based systems engineering (Capella/Arcadia, AAML, SysML), system verification (COMPASS) and AOCS/GNC design and analysis (GAFE). Integration of these technologies, by coupling of tools, will enable and foster multi-disciplinary design trade-offs early in the life-cycle, which will significantly lower the risk of downstream V&V challenges, in particular w.r.t. FDIR. In this perspective, the Power discipline will be considered in the multi-disciplinary context together with avionics.

**Description:** This proposal brings together results available from a number of completed R&D activities:

- COMPASS is a toolset for model-based verification of safety and performability analysis of complex aerospace systems; it has evolved through a strand of TRP research activities such as COMPASS, AUTOGEF, FAME, HASDEL, CATSY and the COMPASS Harmonisation activity, leading to the recent 3.0 release in 2016. It provides a very rich set of features for analysis of system models defined in AADL using state-of-the-art model checking,
- AAML (Avionics Architecture Modeling Language), which is now part of the VERICOCOS toolset, both developed and funded under the TRP programme,
- the SAVOIR On-board Software Reference Architecture (OSRA) and the TASTE toolset (also part of VERICOCOS),
- the Capella toolset, a model-based notation to describe avionic architectures, supported by the Arcadia methodology, which was initiated from Thales R&D and is now available in open source, supported and used by a large group of industrial stakeholders in the space domain,
- the Generic AOCS/GNC Technigues & Design Framework for FDIR (GAFE) study, a simulation based approach built on top of Matlab/Simulink, an R&D activity that will conclude in 2017.

The MBSSE workshop held in December 2016 clearly showed the potential impact and readiness for usage at scale of these individual technologies, but improvements are currently very localised in the system life-cycle and typically mono-disciplinary oriented. The full power of the technology is therefore not yet exploited, the weak integration currently hampers the up-take in industry, as was confirmed by the SWOT analysis performed during the workshop.

The foreseen GSTP activity will address this need by providing facilities for bi-directional exchange of avionics models, creating a loosely coupled, federated tool integration platform. During the MBSSE workshop, this was identified as the COMPASS* (COMPASS-star) approach, whereby the analysis tools can be applied to a range of modelling formalisms, rather than solely on AADL. The aim is therefore not to physically integrate the existing tools into a single tool (which is not feasible due to the diversity of implementation platforms), but to provide additional facilities for consistent model exchange between these existing tools, much akin to the Open Concurrent Design Tool (see https://ocdt.esa.int) but at a higher level of semantic integration. The tool integration platform is likely to be implemented using existing web and scripting technologies, to allow distributed access and Harmonisation with other on-going developments such as the OCDT (upstream) and TASTE (downstream).

The approach will enable the early analysis of avionics models with those powerful analysis tools, by transferring models and results back and forth. Consistency is enforced as automated model translation is used. As the analysis tools typically address different system aspects using different analysis approaches, they complement each other significantly, further supporting the multi-disciplinary design trade-offs that need to be made during the system design. The approach taken will allow other tools and notations to be added, supporting evolution.

Moreover, the intent is also to formalise the proposed design approach from the SAVOIR FDIR Handbook, which is currently under development, as methodological support into the same tool set. The activity will also produce a relevant (open source, IPR free) case study for benchmarking and dissemination of the approach.

The following tasks will be performed:
- define an approach to harmonize the various existing modeling toolsets,
- define and implement a translation from the harmonized model to the downstream tools,
- demonstrate the resulting federated toolset on a case study, following the SAVOIR-FDIR handbook.

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 6 by 2019.

**Applicable THAG Roadmap:** Avionics Embedded Systems (2016).

### 3.5.3.3. TD05 - Space System Control

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *05 - Space System Control* |

**Ref. Number:** **GT17-026SA** **Budget (k€):** 600

**Title:** **Low-cost high reliability wide FoV Sun Sensor EM**

**Objectives:** The aim of the activity is to design, develop and build a high reliability multi mission sun sensor Engineering Model (EM) with wide field of view, to be used on commercial or ESA missions.

**Description:** The AOCS Sensors and Actuators Harmonisation roadmap has identified the need to develop a second source for high reliability sun sensors in Europe.

The following tasks shall be performed:

- identification of the sun direction detection method (solar cell, photodiodes, pixel array),
- design and manufacturing up to EM level of the Sun Sensor,
- subject the manufactured EM to de-risking tests (environmental and performance), preparing for a qualification [which is out of the scope of this activity],
- development of all the required test equipment required for calibration and acceptance/qualification testing.

The product should target:

- hemispheric FoV (180 deg),
- limited albedo sensitiveness,
- high accuracy if not too detrimental on the recurring price (below 1 degree - 99.7% CL- over the whole FoV),
- digital interface (if the solution is not fully passive).

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL6 in 2019.

**Applicable THAG Roadmap:** AOCS Sensors and Actuators: II - Specific Sensors and Actuators (incl. IMU) (2015).

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *05 - Space System Control* |

**Ref. Number:** **GT17-027SA** **Budget (k€):** 700

**Title:** **Object-oriented hybrid modelling of avionics systems using Modelica**

**Objectives:** The activity will build and consolidate a Modelica Space Avionics Systems Library to adapt it to the needs of ESA projects and it will use the outcome to simulate and verify hybrid avionics systems for 3 key mission scenarios:

- multibody system of the control of an Earth observation satellite with large appendages, high communication data rates, and high pointing requirements,
- hybrid system for on-orbit servicing of spacecraft with robot arms.
- launch vehicle multibody dynamics. The models will be qualified for the SAVOIR open architecture reference implementation of the vehicles avionics.

**Description:** Modelica is an open object-oriented language for modeling of large and heterogeneous hybrid physical systems. The use of Modelica is wide-spread in Europe covering the fields of aerospace, car, ships, trains, and in general automotive industries. Modelica is used to create models for control engineering processes, generation and distribution of electric power, mechatronic models in robotics, automotive and aerospace models that require mechanical, electrical, hydraulic and control subsystems in process oriented applications. Modelica models and component libraries are fully portable between software tools. One of the tools to build Modelica models is Dymola: a commercial modeling and simulation environment similar to MATLAB/Simulink by Dassault Systems.

Modelica allows to model combined continuous time and discrete event systems by a set of synchronous differential, algebraic and discrete equations leading to deterministic behavior and automatic synchronization of the continuous time and discrete event parts. This allows to arrive at safe implementations of real time systems and for deterministic verification purposes. For example, this allows Modelica to perform very well for hardware-in-the-loop simulation campaigns. Other simulation environment do not have these capabilities.

In space, Modelica is widely used across DLR, PoliMilano, TU-Delft, TU-Dresden, etc. DLR has developed an impressive collection of models ranging from gears, gas dynamics, multi-body, noise, faults, estimation filters, sensors, actuators, control blocks, satellite dynamics and kinematics, rockets, rovers, etc.

The following tasks shall be performed:

- Assess the limitations of the current libraries and modelling environements with respect to the upcoming hybrid avionics systems and study how Modelica based methods can be used effectively in ESA. Important for ESA at avionics level is the Modelica synchronous data flow principle in the context of hybrid systems. The activity shall look into the synchronization between the continuous time and discrete event parts that leads to a deterministic behaviour without conflicts (very important for state transition diagrams, etc). The activity shall also consider a multi-physics approach in order to reduce the risks to discover lately in projects the issues of coupling between avionics and thermal or mechanics subsystems, etc. This task shall take into account the potential link with already existing tools (e.g. ESATAN, ESARAD, ECOSIM).

- Provide a thorough set of modelling requirements and needs for hybrid systems in the areas of trajectories, control engineering, data handling, on-board software, estimation and navigation, and TT&C. Links with languages/tools like SysML and Capella shall be taken into account. Interface with FMI will be addressed. Potential evolution towards SysML2 will be considered. The activity will also consider the needs for other related subsystems like structures, propulsion, operations and scheduling.

Consolidation of the performance and environment requirements for the ESA mission needs taking into account the mission objectives and constraints of the 3 cases proposed. The activity shall pay attention to the object oriented modeling, bidirectional flow and direct access to signals, symbolic manipulation of equations, modeling of inverse kinematics and how those are used in Modelica to aid the needs of ESA projects.

- Definition of the models library architecture, including mathematical methods trade-off. This architecture shall also comprise the design of the use and operational modes of the library. The architecture of the library shall take into account the SAVOIR reference architecture.
- Implementation of the library algorithms in a fast, simple, software package that can be used within ESA tools.
- Validation and verification of the library and performance tests by its use in the 3 problem cases: a) multibody system of the control of an Earth observation satellite with large appendages, high communication data rates, and high pointing requirements ; b) hybrid system for on-orbit servicing of spacecraft with robot arms; c) launch vehicle multibody dynamics.

**Deliverables:** Documentation: in the form of Technical Notes. Software: the Modelica Libraries and the simulation of the 3 scenarios.

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| **Current TRL:** | 3 | **Target TRL:** | 4 | **Duration (months):** | 12 |

**Target Application/ Timeframe:** Launchers, In-orbit servicing, Earth observation missions / 2018.

**Applicable THAG Roadmap:** Avionics Embedded Systems (2016).

### 3.5.3.4. TD06 - RF Systems, Payloads and Technologies

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|---|---|
| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT17-028ES** **Budget (k€):** 800

**Title:** **Miniaturized Space GNSS receiver for microsat and cubesat**

**Objectives:** The objective of the activity is to develop an Engineering Model (EM) for a space GNSS receiver for microsat and cubesat. It shall serve two use cases:

- precise relative navigation between S/C,
- precise onboard POD down to submeter level position accuracy and mm/s level velocity accuracy.

**Description:** GNSS space receiver produced by the agency are based on advanced ASIC (AGGA-4) and provide state-of-the-art performances for ESA and third-party missions including EO applications like GNSS Radio Occultation. The form factor and power consumption of those space receivers are not compatible with cubesat and microsat missions. An alternative is the use of COTS professional receivers, however they have not been subject to space qualification and may not provide the necessary reliability in space, not the configurability needed to prove advanced concepts in space.

On the other hand, small satellites (microsats and cubesats) also opens new opportunities with constellations, which may require relative and absolute navigation between S/C with very accurate positioning and timing possibly down to submeter position and mm/s velocity accuracy.

The activity aims at developing a GNSS space receiver, including antenna targeting low cost, low power consumption missions (e.g. microsatellites and cubesats). The target platform should be hosted in a 1U cubesat (target) and it is expected to be based on COTS components and SDR (Software Define Radio) platforms. Particular interest is on the powerful SoC currently adopted for cubesat (eg: GOMSPACE Nanomid7000 SoC). The product shall allow POD (Precise Orbit determination), both on ground (current approach with post-processing as reference case) and onboard in real time with 10 cm pos accuracy and 1mm/s vel accuracy). The real-time part is the novel approach developed for the first time in this activity.

The architecture will likely require triple frequency reception, being the third frequency used for reception of precise GNSS clock and orbit correction.

The activity covers tasks on:

- implementation of the GNSS receiver, including radiation-hardening techniques to improve integrity of the platform, at the expense of reducing availability (that is not the main requirement for IOD and cubesat missions),
- a tailored qualification process (similar to that expected to be followed for space technology on large constellations), and the execution of related qualification tests,
- radiation testing in order to validate the radiation hardening approach,
- select a COTS antenna suitable for space with carrier phase center stability adequate for POD,

- all the necessary steps for qualification of the product for IOD (following tailored version of ECSS for IOD missions).

The target price for the recurrent unit should be around 50Keuro with low power consumption suitable for Cubesats and POD.

The proposed concept of onboard real time POD requires an In-Orbit-Demonstration (IOD) with high modularity and re-configurability (e.g. with FPGAs). This activity should provide here the fundamental step which is to have a product ready to fly for a future IO activity.

If the IOD is successful proving this technique, multiple future missions, including constellations, should benefit from this development. In case the IOD is successful, this will pave the way to port the solution developed in this activity to more robust space qualified hardware.

**Deliverables:** Engineering Model. GNSS receiver and antenna(s) in cubesat format ready for IOD.

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

**Target Application/ Timeframe:** Need date end 2018.

**Applicable THAG Roadmap:** On-Board Radio Navigation Receivers (2013).

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT17-029ES** **Budget (k€):** 1,000

**Title:** **Nanosat X-band TT&C transponder EM**

**Objectives:** The aim of this activity is to make available a micro TT&C transponder embedding all the S/S functionality (namely also HPA, RFDN, input/output filters) for TEC/Science suitable for non-LEO cubesats (i.e. NE and DS) (12U as reference for the whole satellite, M-ARGO study).

**Description:** Historically for TT&C functions most of the cubesats relied on amateur bands (generally VHF/UHF). This is still often the case but for LEO missions the transition to ITU S-Band for SR,SO,EES (2025/2110, 2200/2290) is underway (with some ESA/TEC support, e.g. IOD).

However, nothing is currently in place in Europe to support missions at bigger distances, where X-Band is a need and where more sensitive receivers and more powerful HPA are required. NASA has already built 2 6U cubesats to Mars (MARCO) as InSight companions.

Compliance with standard ESTRAK stations is also necessary (due to the unique performance) and therefore implementation of the air interface as per ECSS-E-ST-50 series is a basic condition: this is not a common standard for cubesat/microsatellite missions and very limited/partial implementations exists as of today.

For LEO, GNSS receiver or simply TLE datasets can ensure orbit determination, therefore integrated Doppler and ranging function (either Tone, Code or PN & DDOR) have never been implemented for such class of mission. This can serve also RadioScience purposes.

In addition, the architecture, either at TRASP and S/S level, must be specially thought in order to achieve the extreme miniaturization requested but boosting the performance at same time. As an examples the TRASP frequency plan: single or even direct conversion to/from X-band vs the more usual 2 or more conversion stages; as result architectures with LNAs/HPA direct connection to each antenna may be envisaged.

Even though the relevant applicable standards for the air interface are not new, a dedicated and completely new integrated TRASP-S/S have to be developed. The CDF M-ARGO is identifying the lack of this unit as a major show-stopper for such class of missions. Industrial studies such as Hel10Nano from Airbus consider the NASA product IRISv2 as solution.

Target mass: <1.5 kg (X/X) for the whole S/S (antenna excluded).
Target power: <4W (RX mode). RF power out (TX mode) up to 15W @ antenna port.

The following tasks shall be performed:

- architecture design at S/S level with definition of main building blocks,
- TRASP architecture definition & preliminary design with Scalability and modularity,
- transponder detailed design,
- develop/build EM modules with technology allowing path to fly, developing also a roadmap for the final qualification (ECSS tailored accordingly to IoD missions req.),
- integrate and test the overall EM model.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL6 by 2020.

**Applicable THAG Roadmap:** TT&C Transponders and Payload Data Transmitters (2012).

### 3.5.3.5. TD26 - Others

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| *Domain* | *Generic Technologies - CD3 - Avionic Architecture / DHS / Onboard SW / (FDIR) / GNC + AOCS / TT&C (E2E)* |
| *Tech. Domain* | *26 - Others* |

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|---|---|---|---|
| **Ref. Number:** | **GT17-030GE** | **Budget (k€):** | 1,000 |

**Title:** **SDLS-Flex: Flexible Space Data Link Layer Security Protocol implementation and End-to-End Verification**

**Objectives:** The objective of this activity is to demonstrate to missions and industry the capabilities of the SDLS standards through the combined development of a full end-to-end SDLS and SDLS Extended Procedures implementation, including operational prototype development both on space and ground side. The space-side SDLS implementation also aims to be flexible and address at the same time stringent safety and security requirements in the context of reconfiguration of FPGAs implementing mission critical safety and/or security functions.

**Description:** The Space Data Link Layer (SDLS) Security protocol has recently been published by CCSDS. It is the first international space-link security standard with the objective to provide authentication, integrity, and confidentiality services on the space link between ground stations and spacecraft. A management addition to this standard, the SDLS Extended Procedures, is currently under finalisation. The Extended Procedures standardise key management, security association management and security monitoring & control services.
In the light of ever-rising global security threats, ESA intends to use the SDLS standards to protect future missions. Some work is already on-going in this area (e.g. development of a classified prototype chip for high security missions and experimental implementations for CCSDS interoperability testing). However, in order to help and lower the boundaries for adoption by missions, it is critical that unclassified operational prototypes for the SDLS standards are available to missions and industry for the space segment and for the ground segment.

The objective of this activity is to demonstrate to missions and industry the capabilities of the SDLS standards through the combined development of a full end-to-end SDLS standards implementation, including operational prototype development both on space and ground side. The prototype can be used by ESA and industry as a baseline for future operational developments.

It is expected that the space segment implementation will be a combination of hardware and software development and the ground segment development will be in software. The space-side SDLS implementation also aims to be flexible and address at the same time stringent safety and security requirements in the context of reconfiguration of FPGAs which implement mission critical safety and/or security functions. A key design element is the isolation of the functions required for FPGA reprogramming in a strictly isolated SAVOIR-SAT OBC partition with exclusive memory areas and exclusive access to the IO interface used to reconfigure the FPGA.
In order to be fully representative, the development will be integrated into space and ground verification environments (the ESA Engineering Development Lab for ground and the SAVOIR-SAT and Secure Systems Engineering test beds for space). This will ensure that the developments integrate directly into the state-of-the art ground and space segment systems (e.g. EGS-CC for ground). These environments are then connected to allow a full end-to-end verification and testing campaign for the SDLS standards implementations. A full test campaign

is performed as part of this activity to validate the suitability to deploy SDLS in future ESA missions as a default security layer.

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

- analysis of the SDLS and SDLS Extended Procedures CCSDS documentation and relevant legacy space-link security implementations (e.g. Sentinels),
- requirements Specification for space and ground implementations based on the relevant state-of-the-art technologies,
- architectural Design taking into account (1) The seamless integration of the prototype into the relevant verification environments (2) The key design element related to function isolation for FPGA reprogramming,
- implementation of space and ground prototypes,
- deployment into an end-to-end verification and testing environment composed of the space and ground segment reference implementations (the ESA Engineering Development Lab for ground and the SAVOIR-SAT and Secure Systems Engineering test beds for space),
- execution of a full test campaign.

**Deliverables:** Software and Hardware.

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** TRL 6 by 2019.

**Applicable THAG Roadmap:** Avionics Embedded Systems (2016).

## 3.5.4. CD4 - Electric Architecture / Power and Energy / EMC

### 3.5.4.1. TD03 - Spacecraft Electrical Power

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *03 - Spacecraft Electrical Power* |

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| **Ref. Number:** | **GT17-031EP** | **Budget (k€):** | 1,000 |

**Title:** **Improving density of power modules by up to a factor 2**

**Objectives:** The present activity is meant to boost dramatically the capability of power modules by targeting the performance bottleneck constituted by the flat derating rules applied on electronic components. A PCDU module design that is representative of all the main component families used in power system shall be taken as a reference. A power conversion, distribution and/or thermal knife modules are the possible target options. The activity objectives are the following:

- Re-formulate the derating rules for key components in view of the relevant life test results.
- Assess the impact at module level of applying the newly derived derating rules.

**Description:** The rationale behind the proposed activity is that the currently applied derating rules are in general de-correlated from the way the ratings of components have been selected, resulting in a situation where even some component manufacturers report that derating rules should be disregarded for their components.

For electronic units developed for space applications, it is well known that the application of required derating rules to some key EEE components constitute a performance bottleneck.

These components can be e.g. capacitors or MOSFET's, owing to derated temperature allowance, or connectors due to voltage derating limitation.

On the other side derating rules applied in Europe for space electronics have been established long ago for component technologies that now have evolved, and a precise correlation between expected reliability in time versus derating coefficients has not been established.

While derating rules are meant to secure the operational lifetime of the spacecraft, it is striking to note that derating coefficients are still applied as flat rules to component families with no exhaustive regard to specificities such as the maturity of the technology, the process of a given manufacturer or the way the rating limits have been determined by the manufacturers. Moreover, derating rules were derived many decades ago and, since then, technology, materials and processes have radically evolved. Thus, it is unlikely that the same rule could be applied to completely different devices.

In this context, derating rules are reported even by some manufacturers as unnecessary to secure the lifetime of their components. Such a situation may conceal huge margins which we can no longer afford to ignore nowadays, in an environment of fierce competition for better performances and lower costs.

While it is not demonstrated that operating a MOSFET up to its rated temperature is going to be compatible to its lifetime, this exercise illustrates anyhow the tremendous potential of the proposed activity.

In this context, a three steps shall be follow:

- First the components, or component families, for which derating rules recurrently result in bottleneck from one design to another within products are to be identified.

- Secondly, information is to be collected with component manufacturers on how rating limits have been stated and how derating rules make sense in the respective cases.
- Thirdly, the rationale for application of derating rules is revisited for these components, supported wherever needed by appropriate life testing campaign to complement insufficient or missing information. This is going to result in new electrical allowance being given for the usage of components within space electronic units.

Accordingly, the key technical objectives of the activity are the following ones:

- boosting functional performances (do more with same hardware),
- lowering dissipation levels (relaxing derating on components allows their better utilisation),
- reducing volume and mass (lower relaxing derating on components allows have higher density),

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

- Electrical design performance bottleneck identification.
- Design or identification of a PCDU Module based on traditional derating rules
- Critical analysis of rating limits versus derating rules.
- Revisiting components qualification for better derating application.
- Manufacturing of the selected module with the new derating rules.
- Benefit analysis at unit level and way-forward.

**Deliverables:** Report

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 30

**Target Application/ Timeframe:** 2020.

**Applicable THAG Roadmap:** Power Management and Distribution (2013).

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *03 - Spacecraft Electrical Power* |

**Ref. Number:** **GT17-032EP** **Budget (k€):** 600

**Title:** **Integrated Power Switch ASIC for small DC/DC converters**

**Objectives:** The objective of this activity is to develop, build and test in relevant temperature conditions a prototype of an ASIC for space environment. The ASIC prototype shall include: a driver, a PWM, an oscillator, an OP-Amp for control loop implementation, start-up circuitry directly from the bus and the power switch.

Description: The activity aims at developing an IC that includes the power switch, the driver, the oscillator, a simple PWM, an Op-Amp for the control loop and a start-up circuit. It should have a built in overcurrent protection, over temperature protection and an enable pin to turn-off the switch.

In this IC, the main target is not performance but having a device to simplify as much as possible the design of simple DC-DC converters for local small power supplies, auxiliary supplies, etc. The target topology is mainly a Flyback converter. If this chip was available, it will enable the possibility of simplifying many designs by making power available where is needed. Only the magnetic component, the output diode, the output filter and the feedback network will be needed to build a power supply. As a consequence, issues like having isolated power supplies for upper side drivers, start up systems, etc. will not be a problem anymore. In fact, the high compactness of the IC would allow having multiple supplies in one board if needed. This would enable more complex electrical systems with a wider supply voltage range of options.

The key advantage is the ability to be connected directly to the bus voltage and start switching immediately without external circuitry. Thus, the input voltage characteristics should be compatible with the typical bus voltage levels used in European satellites: 28 V, 50 V and 100 V.

The development plan shall include:

- Consolidation of the set of requirements.
- Conceptual functional block design.
- Development of all blocks to achieve radiation tolerance.
- Design of the prototype with all functionalities.
- Manufacturing of a prototype.
- Test campaign.

The test campaign shall include:

- Functional electrical tests.
- Thermal cycles at ambient pressure.
- TID/SEE radiation campaign to assess the validity of the design.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** This is an activity to push technology. TRL 5 by the end of 2019.

**Applicable THAG Roadmap:** Power Management and Distribution (2013).

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *03 - Spacecraft Electrical Power* |

**Ref. Number:** **GT17-033EP** **Budget (k€):** 500

**Title:** **High Frequency DC/DC converter module with Digital Control**

**Objectives:** The objectives of the activities are to:

- develop an Array Power Regulator (APR) DC/DC converter module for the Primary Power System,
- reach a switching frequency of at least 600 kHz. The end target is 1MHz,
- implement the control system of the converter with a digital device,
- integrate the TM/TC and the intra-unit communications in the same digital device,
- rationalise the external interfaces in view of having more modules connected in parallel.

**Description:** The future of DC/DC converter systems points at two main targets:

- High switching frequency
- Digital control

At the moment, state of the art DC/DC converters used in European Space applications lag far behind in terms of innovation. The typical switching frequency is still below 200 kHz in most of the cases and the ancillary electronics are mainly discrete analogue. As a consequence, the power density is still quite low and the topological implementations are still relying on the heritage-rich old designs.

This activity aims at developing knowledge and technology to come up to speed and get closer to the technologies that will be state of the art in the near future. The objective is to develop a DC/DC converter module switching at high frequency. The ambition is to reach 1 MHz since this would enable very compact designs. As a minimum, the switching frequency shall be 600 kHz to be a valid exercise. As an option aside in this activity, GaN devices might also be used since, in principle, they are especially suitable for high frequency switching.
In order to show the highest impact at PCDU level, the Array Power Regulator (APR) is the target module. Thus, a non-isolated topology will be the best candidate to suit this application.

Moreover, this activity will serve a second purpose which is to test the performance of digital control in a more demanding scenario. The validity of the concept has been proven many times in terrestrial applications where the situation is mature now. Digital control has not replaced analogue control in small standalone converters. However, it has become more and more used in more complex applications where, apart from the converter, there are other systems running. This would be the case of power units in space systems where, apart from the conversion itself, there are many other functions.
In principle, an FPGA seems to be the best candidate for this application. However, a microcontroller based system could also be a valid option of the computing performance is fast enough.

Since the digital device is going to be there for control purposes, this activity will also explore the possibility of using that device for as many additional functions as possible. Typically TM/TC and monitoring functions. Note that protection functions cannot be implemented in the same device because, reliability wise, it is not acceptable.

Linking digital control to DC/DC converters can enable the use of more complex topologies like multi-phase converters or topologies with soft-switching properties that would enable higher switching frequencies. Hence, having both concepts together in the same activity could potentially give place to very advanced concepts in power supplies.
Since the next step would be to integrate this module with other modules to build a power unit, this activity shall pave the way by rationalising the interfaces that will be used to interconnect modules. Mainly the power interface and the intra - box communication interface. Thus, potential follow up activities building other modules could be connected to this one to perform a unit level demonstration in the future.
This proposal aims at a proof of concept and, as a consequence, the target is to build an elegant breadboard with flight equivalent commercial components.

**Deliverables:** Breadboard

| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** This is an activity to push technology. TRL 5 in 2018.

**Applicable THAG Roadmap:** Power Management and Distribution (2013).

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *03 - Spacecraft Electrical Power* |

**Ref. Number:** **GT17-034EP** **Budget (k€):** 1,000

**Title:** **Semiconductor Bonded Low-Mass Space Solar Cells and SCAs with 33% Efficiency at EOL**

**Objectives:** The objective is to develop the technology building blocks for a high efficient, cost competitive solar cell based on the semiconductor bonding technology (SBT).

**Description:** Within this activity all technology building blocks required for a full SBT based device including an optimized wafer bonding process shall be developed, optimized and an industrialization plan shall be established.
Ground-breaking efficiency leaps are only possible by combining semiconductor materials that are perfectly aligned to each other in terms of their optical and electrical characteristics. Since for space solar cells the end of life (EOL) efficiency is the key performance parameter, this means that materials shall be selected that demonstrate a high tolerance towards particle irradiation in space. In addition, the selected materials have to be matched in terms of their end of life capabilities to produce the required photocurrents for an optimized solar cell design. Semiconductor bonding technology is believed to allow for combining the best suited materials with each other while at the same time maintaining highest quality in the electrical characteristics of the solar cells. However, the activity does not exclude alternative solar cell designs that would allow to meet the high EOL efficiency targets of 33%.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL 6 in 2020.

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

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *03 - Spacecraft Electrical Power* |

**Ref. Number:** **GT17-035EP** **Budget (k€):** 400

**Title:** **High Power, long duration Titanate technology batteries**

**Objectives:** The objective is to assess High Technology Readiness Level (TRL) and Commercial Off The Shelf (COTS) terrestrial Lithium Titanate cell technology against typical Low Earth Orbit (LEO) and Launcher mission profiles,

**Description:** Lithium Titanate (LTO) is a form of Lithium ion technology that has a reduced energy density (typically 60-80 Wh/Kg@ Cell translating to 50 Wh/kg at pack) but has considerably higher power density(1-4kW/kg), durability over a higher temperature range and can sustain higher lifetime energy throughput compared to a classic LMO/Graphite li-ion technology, while utilising a wide Depth of discharge window. LTO also has the benefit of lower severity failure modes than traditional Li-ion and increased shelf life.

When compared to operational usable energy density of typical LEO missions(10-50 wh/kg during mission phase) LTO could represent a credible alternative with potential benefits in durability and performance.

The tasks of the activity include:

- characterise electrical performance across a range of temperatures,
- assess lifetime degradation behaviour over a limited set of representative cycles,
- characterising failure modes vs. typical abuse conditions.

The assessment would primarily concentrate on the merit of the chemistry rather than a specific COTS supplier at this stage.

**Deliverables:** Report

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

**Target Application/ Timeframe:** TRL6 in 2019.

**Applicable THAG Roadmap:** Electrochemical Energy Storage (2014).

### 3.5.4.2. TD07 - Electromagnetic Technologies and Techniques

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT17-036EP** **Budget (k€):** 1,000

**Title:** **Qualification of novel grounding for composite structural panels**

**Objectives:** Qualification of the grounding of equipment housings to the structural panel through their feet by the way of modified inserts implementing direct electrical connection to the CFRP via rivets. Improvement with respect to current practice (bonding stud + grounding strap + dedicated insert), which results in poor grounding at high frequency.
Qualification of the electrical bonding between structural panels by the way of direct electrical connections to the CFRP via rivets.

**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.

The tasks of the activity include:

- 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:** Prototype

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

**Target Application/ Timeframe:** Industrial competitiveness (All Spacecraft)/2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD4 - Electric Architecture / Power and Energy / EMC* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT17-037EP** **Budget (k€):** 1,000

**Title:** **Immunity to In-Band Electromagnetic Interference for Radio-Frequency Receivers using Signal Modulation**

**Objectives:** 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.

**Deliverables:** Prototype

| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** All spacecraft and satellites receiving RF signals / TRL 6 by 2021.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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

### 3.5.5.1. TD06 - RF Systems, Payloads and Technologies

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** GT17-038EF **Budget (k€):** 700

**Title:** **Broadband and low-loss 3D RF micro-structure for high integrated high frequency front-ends and distribution networks**

**Objectives:** The objectives of this activity are to investigate and develop low loss compact microstructure for microwave routing and interconnection with active components.

**Description:** High frequency systems (Ka-band and beyond) are characterized by high losses, high integration density and, in most of the cases, stringent thermal properties. Potential solutions are based on purely waveguide technology which, although is performing low loss features, is bulky and does not allow a high integration level. Additionally, when moving to high frequency it could be beneficial to be able to work in multi-band by using the same hardware. This is not possible with the traditional waveguide technology, where the mono-mode operation is narrow. The customization of the waveguide cross-section together with the operational mode (e.g. TEM mode) can provide wider band features.
This activity aims to develop low-loss wide band micro-structures for high integrated systems (front-ends, Solid State Power Amplifier combiners, distributions networks, BFN, etc.). Both RF design and manufacturing challenges must be carefully studied in the frame of the activity considering the limitations imposed by one of them into the other.

The integration of components (active and passive) shall be also considered together with suitable interfacing with external modules.

Thermal issues shall also be reviewed and considered during the design phase.

As proof of concept, a high integrated 4-port Wilkinson divider/combiner at high frequency shall be designed, manufactured and validated with adequate test campaign.

**Deliverables:** Breadboard

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| **Current TRL:** | 2 | **Target TRL:** | 5 | **Duration (months):** | 30 |

**Target Application/ Timeframe:** Combiners for Solid State Power Amplifier, T/R modules, BFN. TRL 5 by 2021.

**Applicable THAG Roadmap:** Additive Manufacturing (2015).

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT17-039EF** **Budget (k€):** 700

**Title:** **Development of High Performance ferrite material very high power switches and isolators**

**Objectives:** The objectives of this activity are to investigate and develop high performance ferrite materials able to feature high linearity, low losses and low de-magnetization for radar and telecom applications.

**Description:** A need for high power ferrite components such as high speed switches and isolators has been identified for future EO and other missions where the switches and isolators will be subjected to very high peak powers (> few kW) and high CW powers (> few hundred W).

The design challenges are exacerbated at high frequencies (Ku, Ka), where the increasingly small physical size of the devices, together with a limited selection of suitable ferrite materials, introduce additional problems with linearity, multipaction and thermal dissipation.

This activity aims to develop a suitable ferrite material (European source) for high power ferrite components. The material shall exhibit high thermal stability of saturation and residual magnetization. This last parameter is especially critical in ferrite switches where the residual magnetization shall ensure the junction stays permanently biased after the removal of the biasing magnetic field.

The suitability of the developed material shall be validated through a full test campaign in two switch breadboards.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Beam-hopping systems, scatterometers, SAR. TRL 5 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT17-040EF** **Budget (k€):** 600

**Title:** **Next Generation Temperature Compensated High Power Filters Based on Novel Materials**

**Objectives:** The objective of this activity is the development and evaluation of novel concepts for temperature compensated High Power Filters making use of advanced materials.

**Description:** High power filters are key elements at the payload output section to filter signals previously amplified. The ohmic losses of the materials contribute to increase the temperature in the device. Thermal issues related with these losses in high power operation dictate the complexity of the design, which, in turn, impacts the overall mass. Classical materials are aluminium in configurations with thermal compensation mechanisms and INVAR for medium/high power.

INVAR has a low thermal expansion coefficient but it has very high density and low thermal conductivity. This leads to bulky solutions. Aluminium has lower density and higher thermal conductivity than INVAR but it presents a very high thermal expansion coefficient. This high thermal expansion dictated the need for temperature compensation mechanisms to achieve the required frequency stability for high power levels. These compensation mechanisms introduce an added risk/complexity that is preventing the commercial widespread of these solutions.

Novel materials, like those based on metal-matrix composites or advanced alloys, offer the possibility to overcome current limitations and eliminate the need for complex temperature compensation mechanisms while also exhibiting mass reductions up to 30% in comparison to INVAR designs.

In this activity, two strategies will be investigated, one based on using the novel material locally as an insert in the complete structure, and another one based on using the novel material as the material for the complete structure.

**Deliverables:** Breadboard

**Current TRL:** 2 **Target TRL:** 5 **Duration (months):** 30

**Target Application/ Timeframe:** High Power Filters (OMUX, Narrow-band diplexers, Output filters, etc.). TRL 5 by 2021.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *06 - RF Systems, Payloads and Technologies* |

**Ref. Number:** **GT17-041EF** **Budget (k€):** 600

**Title:** **Waveguide switches based on friction-free mechanisms**

**Objectives:** The objectives of this activity are to investigate and develop an RF waveguide switch with high RF, thermal and mechanical performance without friction and need of lubricant.

**Description:** Waveguide switches are extensively used in microwave systems for space. Mechanical switches are mostly used when a low number of actuation are required such as performing redundancy for Solid State Power Amplifiers (SSPAs), Low Noise Amplifiers (LNAs) or implementing gateways smart diversity. Thanks to their excellent low insertion loss characteristics, waveguide switches are preferred.

In the last years, longer lifetime for satellites in space but also extended on ground storage for some Earth observation missions is required (e.g. MTG, METOP, etc.). Switches manufacturers are struggling to satisfy customer requirements in terms of lifetime operation due to risks such as contamination, degraded lubricant or risk of sticking.

In the last years mechanisms concepts based on pivots have been developed which replace traditional solutions based on bearing surfaces. The new solution perform friction-free, non-contamination and non-lubricant actuator which make the approach suitable for long lifetime missions.

In this activity waveguide microwave mechanical switches based on flexible pivot shall be designed, manufactured and tested. As a proof of concept, two waveguide switches (Ka-band downlink for two different application concepts ) shall be selected.

**Deliverables:** Breadboard

**Current TRL:** 2 **Target TRL:** 5 **Duration (months):** 30

**Target Application/ Timeframe:** High Power Redundancy switches (SAR, Scatterometers, KAT, etc). TRL 5 by 2021.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.5.5.2. TD07 - Electromagnetic Technologies and Techniques

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT17-042EF** **Budget (k€):** 500

**Title:** **Large center-fed deployable reflector for small satellite**

**Objectives:** The objective of this activity is to design and develop a large center fed deployable reflector antenna for small satellite.

**Description:** Space applications such as Earth Observation, Science and Navigation are more and more based on small satellite platforms of typically 1 m^3 volume. In order to save on-board power resources that are inherently limited due to the platform size, and consequently relax requirements on the active amplification stage in transmission or reception, there is a need to have large aperture based passive antennas. This very often results into a difficult accommodation exercise since the relatively large aperture antenna need to installed on small platforms. This exercise is in general concluded by the need to have the aperture antennas to be deployed in-orbit.

In this activity, it is proposed to design and develop a large center fed reflector with very low stowage ratio. It is proposed as baseline that the antenna shall be able to operate in any frequency band from L to Ka-band, and its radiating aperture shall range from 10 to 20 m^2.

A mission scenario shall be identified and selected and the associated antenna requirements shall be derived.

Several reflector antenna concepts shall be investigated and traded off. The selected concept of large reflector antenna shall then be designed and analyzed in detail.

The reflector antenna shall be manufactured and tested. The testing campaign shall include as minimum a reflector surface accuracy measurement, a demonstration of the antenna deployment repeatability, and a RF test (absolute gain, pattern) of the antenna.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Radar/radiometer applications for various missions like Earth Observation or Science. TRL5 by 2020.

**Applicable THAG Roadmap:** Reflector Antennas (2016).

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT17-043EF** **Budget (k€):** 300

**Title:** **Antenna Measurement Methods for Phase-less Gain Pattern Acquisition**

**Objectives:** Key objective of this activity is the development of a software based on a near-field-to-far-field transformation method, solely requiring measured electromagnetic field magnitude (i.e. scalar) information.

**Description:** Accurate antenna gain measurements based on near-field data currently require a precise knowledge of the amplitude as well as the phase of the electric or magnetic near-field over a certain measurement sampling grid. This results in high costs for correspondingly suited RF measurement equipment. For upcoming space applications, this will significantly limit the achievable measurement accuracy, as especially for sub-millimeter wave antennas, an accurate phase determination over the entire sampling grid is not possible due to the necessary relative movement of measurement probes and attached waveguides during the antenna measurement.

In this activity, a software based on phase-less near-field-to far-field transformation shall be developed. In a first step, the state-of-the-art of phase-less transformation methods shall be investigated and a method best suited for sub-millimeter wave applications shall be justified. A corresponding software package shall be developed and presented demonstrating a sample measurement application.

The targeted improvements of this activity are the following:

- reduction of antenna measurement equipment costs by a factor of 5,
- increase of the maximum possible frequency for accurate far-field gain measurements by a factor of 2.

**Deliverables:** Software

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

**Target Application/ Timeframe:** Sub-millimeter wave antenna measurements, low-cost and low-complexity antenna measurements. TRL 4 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *07 - Electromagnetic Technologies and Techniques* |

**Ref. Number:** **GT17-044EF** **Budget (k€):** 300

**Title:** **Fast Diagnostic Methods for Large-Scale Full-Satellite Antenna Measurements**

**Objectives:** The key objective of this activity is the development of a software based on fast source reconstruction for full-satellite antenna measurement diagnostics.

**Description:** Modern space satellites show an increased density of instruments and equipment with a variety of different materials and hence various electromagnetic properties. Whereas the single instruments can usually be well-characterized in the design phase, the complex electromagnetic environment on platform level can usually not be entirely characterized. The trend towards increased frequency sub-millimeter wave instruments further complicates the accurate modelling of the antenna platform. When anomalies during final antenna measurements on spacecraft level occur, it is hence not possible to identify unintended scattering or coupling effects out of the measurement data with reasonable computational demands and in limited time. As these problems usually occur in late project phases close to the proposed launch date of the respective space mission, very fast diagnostic methods are required.

In this activity, a fast source reconstruction method for very large-scale electromagnetic problems, i.e. sub-millimeter wave full-satellite platform analysis, shall be investigated, developed and software-implemented. Out of measured far-field as well was near-field data, equivalent sources like electric or magnetic surface currents shall be computed, which shall help identifying sources of anomalies at final spacecraft antenna measurements. Although asymptotic assumptions can be considered for sub-millimeter modelling of parts of the spacecraft platform, the method shall capture near-field coupling effects where unneglectable. The software shall be demonstrated with a real large-scale measurement example.

Targeted improvements:

- reduction of full spacecraft computation time by factor 100,
- increase of maximum transformation frequency on platform level by a factor of 10,
- evaluation of such large-scale electromagnetic field transformation on single workstations with a maximum memory demand of 150GByte RAM.

**Deliverables:** Software

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

**Target Application/ Timeframe:** Full-spacecraft and full-wave high-accuracy RF diagnostics, fast radiation source reconstruction for RF anomaly detection, sub-millimetre wave instrument RF diagnostics. TRL 4 by 2020.

**Applicable THAG Roadmap:** Not related to the Harmonisation subject.

### 3.5.5.3. TD16 - Optics

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *16 - Optics* |

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| **Ref. Number:** | **GT17-045MM** | **Budget (k€):** | 500 |

**Title:** **Optomechanical mounts for large lenses**

**Objectives:** Develop and optimize in Europe the methods to mount large optical lenses and elements requiring high accuracy and thermo-mechanical stability. The peculiarity of mechanical mounts of lenses for space is to achieve the mechanical robustness while keeping low contamination and stress on the glass when the optical systems are exposed to temperature variation, vibrations and shocks.

**Description:** The technology for the mounting of optical components has become more challenging in the past years due to the more stringent requirements for positioning accuracy and long-term stability. In addition, requirements on cleanliness limit standard mounting techniques used on commercial optics based on adhesives.
Space missions that are becoming more and more demanding tend to use larger refractive elements, such as lenses and gratings. Furthermore, the materials used in the UV or infrared wavelength spectrum have poor mechanical properties, and are susceptible to plastic deformation.

The following tasks shall be performed:

- design and development of mounts for large lens, e.g. 200 mm diameter,
- breadboarding activities of at least two mounting concepts to cover UV and infrared applications,
- perform thermal-vacuum and vibration tests of the breadboards,
- perform optical tests as stability of the wave front, polarization, birefringence, stress measurement at the interface between the optical element of the mount.

The lessons learnt of the activity will be used for the definition of the methodology for mounting large refractive elements for space.
The methodology will cover:

- description and design files,
- manufacturing process and procedures,
- recommendations and guidelines.

**Deliverables:** Report on the Optical Mount Methodology that covers: description and design, files, manufacturing process and procedures, recommendations and guidelines, test results.

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

**Target Application/ Timeframe:** Any optical system using refractive elements. TRL 6 by mid-2019.

**Applicable THAG Roadmap:** Not related to the Harmonisation subject.

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *16 - Optics* |

**Ref. Number:** **GT17-046MM** **Budget (k€):** 500

**Title:** **Diffractive optical elements for metrology**

**Objectives:** This activity aims to develop and optimize technologies using Diffractive Optical Elements (DOEs) to simplify the alignments and calibration of a spherical and free form optical systems.

**Description:** Recent progress in the design and manufacturing of complex Diffractive Optical Elements (DOEs) allows the manipulation of a laser beam. The use of DOE can greatly simplify the AIV of innovative optical designs based on non-rotationally symmetric elements, as free form mirrors. The technology can free the optical designers from the necessity to purchase Computer Generated Holograms (CGH), that are costly and with long delivery time. Differently from the CGH, the DOEs can be used for any optical system. Furthermore, this method can also be used to achieve high accuracy alignment of multiple instruments, as telescopes and spectrometers.

The benefit of the optical metrology using DOEs is the miniaturization of the setup, the possibility to work at sub aperture. Finally, DOEs can also be mounted inside of flight optical instruments to verify alignment of the optical elements after launch and during operations.

The activity will target two applications:

- Shearing interferometry to check the collimation or focusing of an optical beam using diffractive elements,
- modulation of the wavefront to check the co registration, the alignment and pointing accuracy between several telescopes or spectrometers.

The following tasks will be carried out within the project:

- design of a Diffractive Optical Element and its optimization to generate the shearing effect in collimation or focusing mode,
- manufacturing, assembly and test of the DOE. The DOE will be tested on a conventional telescope to assess the quality and the reliability of the measuring system,
- test of the DOE to align the line of sight of multiple imaging systems, as telescopes or spectrometers.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** Any complex optical systems using non-rotationally symmetric optical elements. Payloads requiring very accurate alignment of optical instruments. TRL 5 by 2020.

**Applicable THAG Roadmap:** Not related to the Harmonisation subject.

### 1.1.1.1 TD17 - Optoelectronics

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| *Domain* | *Generic Technologies - CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT17-047MM** **Budget (k€):** 600

**Title:** **Versatile laser terminal for metrology, communication and time and frequency dissemination**

**Objectives:** This activity shall pave the way to extend the capabilities of laser communication terminals to:

- time and frequency dissemination,
- laser ranging.

The possible impact on the communication link performance shall be assessed.

**Description:** To develop two building blocks, one for ranging and one for time and frequency (T&F) dissemination that can be added to an existing optical communication terminal with a minimum of changes. These building blocks shall be implemented into a proof-of-concept demonstrator. In addition to the communication link, the ranging capability shall be used to improve knowledge of the orbital trajectory of the spacecraft, while the T&F dissemination shall allow for accurate synchronization of the on board clocks.

The sequence of implementation shall be:

- Implementation of time and frequency (T&F) transfer, which requires a modulation scheme (RF signal at 12 GHz was proposed) to the existing optical communication link. Within the current implementation of optical inter-satellite links (EDRS), T&F transfer will provide high-accurate time synchronization of timestamps generated on board of the two spacecraft. An engineering model shall be built to demonstrate the T&F transfer and to assess its impact on the communication performance.
- Once a common time base is established between two optically interlinked spacecraft, the measurement of time difference shall be used to measure relative distance and perform ranging. This is a key parameter for formation flying spacecraft to improve orbital parameters and shall also be applicable for a bi-directional links from space to ground. An engineering model of the ranging building block shall be developed to demonstrate its accuracy and to assess its impact on the communication performance.

The contractor shall design the ranging and T/F building blocks in collaboration with a manufacturer of optical communication terminals in order to harmonize the interface requirements and to minimize their impact on the overall design.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** TRL 8 by 2021.

**Applicable THAG Roadmap:** Optical Communication for Space (2012).

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

#### 3.5.6.1. TD01 - Onboard Data Systems

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| *Domain* | *Generic Technologies - CD6 - Life / Physical Science Payloads / Life Support / Robotics and Automation* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** GT17-048ED **Budget (k€):** 200

**Title:** **Independent verification of new Synthesizable VHDL IP Cores for space**

**Objectives:** The objective of this activity is to offer the possibility to the European Industry that could have a special interest in using one or more of the existing ESA VHDL IP Cores ( e.g. Space Fibre, CCSDS Lossless Image Compression, DSP fixed and floating point, SpW Node etc.,) , and have them perform an independent validation of the quality of the source code and documentation The ESA IP Cores Service has been facilitating the re-use of many IP Cores (e.g. LEON, CAN, SpaceWire, Telecomand decoder, Telemetry encoder, EDAC, etc.) since 2002, and European space industry has re-used hundreds of times these valuable ASIC and FPGA building blocks, in particular inside Data Handling and Control systems of payloads and platforms.

**Description:** After selection of one or more of the existing new ESA IP Cores on which the independent validation will be performed, the following tasks will be carried out:

- assessment of quality and completeness of the documentation (IP user manual, IP specification...), and improvement if gaps, errors are found,
- source code inspection, analysis, behavioral simulation,
- for several technologies (FPGA, ASIC) to be agreed with contractor based on ESA's interests and contractor access to FPGA and ASIC Design Kits:
  - gate synthesis,
  - gate simulation,
  - timing analysis,
  - power consumption analysis,
  - area / resources occupation analysis,
- instantiation in FPGA technology to validate through hardware test the correct functionality and expected performance,
- improvement and correction of source code, as errors or weaknesses can be found,
- improving and expanding as needed the simulation test bench environment (more test cases to approach 100% functional and fault test coverage) to be provided to IP users to run their own independent validation of the IP, and to facilitate success in IP modifications and integration in larger IC designs.

**Deliverables:** Validated IP Cores (VHDL code, test bench environment, documentation), validation reports (multi-technology analysis, simulation, synthesis, tests).

**Current TRL:** 4 **Target TRL:** 5 **Duration (months):** 12

**Target Application/ Timeframe:** Scientific instruments / Rovers. TRL 5 by 2019.

**Applicable THAG Roadmap:** Microelectronics: ASIC & FPGA (2016).

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

### 3.5.7.1. TD18 - Aerothermodynamics

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| *Domain* | *Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *18 - Aerothermodynamics* |

**Ref. Number:** **GT17-049MP** **Budget (k€):** 3,600

**Title:** **Enabling Technologies for Advanced Orbital Transfer Capabilities**

**Objectives:** The objective of this activity is to systematically assess by means of dedicated breadboards, the main technologies needed to validate advanced Orbital Transfer Capabilities for the transfer of satellites from low Earth orbit (LEO) to geostationary Earth orbit (GEO) and return to LEO.

**Description:** Mission scenarios involving orbital transfer are many, from space transportation to exploration. The present study focusses on technologies needed for a reusable vehicle for orbital transfer technologies of e.g. communication satellites, from LEO to GEO and return to LEO. In order to optimize the economic benefits of such a system, a reusable orbital transfer vehicle could be realized adopting an air-breathing electric propulsion, i.e. an electric propulsion system in which the lifetime is considerably extended by adding propellant, capturing the molecules from the atmosphere at the front of the spacecraft, compressed them with an appropriate intake and feed them into the engine.

Further, in the way back from GEO to LEO, the excess of delta V of the OTV can be adjusted taking advantage of the Earth atmosphere by means of braking manoeuvres either aero-assisted (by means of deployable or inflatable systems) or using retro-propulsion. In all the cases a re-usable Thermal Protection System will be required.

The purpose of the activity is many-fold:

- to provide with first evidences of a long life serving possibility on LEO-GEO-LEO missions, via the transfer vehicle with an air-breathing electric propulsion,
- to demonstrate the feasibility of performing aero-braking manoeuvre by asymmetrical deployment of a retractable TPS membrane, or inflatable devices,
- To demonstrate the feasibility of drag modulation by hypersonic/supersonic retro-rocket deceleration.

The proposed activity aims to demonstrate: (The realization of a reusable OTV by means of a breadboard of the air-breathing electric propulsion system, optimized in a ground facility. The design will be a result of dedicated engineering models and algorithms to address the insertion methods and operation of the spacecraft throughout its lifetime. Optimization of the on-board propellant and altitude/orbital changes as result of a trade-off between the assisted braking devices, the associated TPS, and the propulsion system, will be carried out. The modelling will also account for external perturbations like electrical power drop during the orbit raising, e.g. eclipses, and will also account for internal perturbations like momentum wheel imbalances, etc.

The realization of aero-braking manoeuvres using asymmetrical deployment of a retractable TPS membrane or inflatable device. For both cases, breadboard systems will be developed and dynamically tested in ground facilities under conditions similar to those encountered during flight. Transient effects during the deployment/inflation, as well as potential flow impingement on body/payload will be studied. Limitations on the applicability of aero-braking manoeuvring due to CG displacement will be determined. Lifetime of the deployable/inflatable membrane and thermal protection ageing capability will be assessed.
The realization of braking manoeuvres using hypersonic/supersonic retro-rocket deceleration. A breadboard system will be developed and tested in a ground facility to analyze if supersonic retro propulsion can provide significant deceleration benefits, at the expense of the fuel required to generate the thrust. The investigation will discuss also the propulsive-aerodynamic interaction, to determine the flight implications of employing such system.

**Deliverables:** Breadboard elements will be developed for every one of the objectives of the activity. The breadboards will be tested on ground in representative environment;

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

**Target Application/ Timeframe:** Space transportation, exploration. TRL 6 by 2020.

**Applicable THAG Roadmap:** Fluid Mechanic & Aerothermodynamic Tools (2012).

### 3.5.7.2. TD19 - Propulsion

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| *Domain* | *Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT17-050MP** **Budget (k€):** 700

**Title:** **Development and performance demonstration of a high specific impulse propulsion system for micro/nano/cubesat class spacecraft.**

**Objectives:** The objective of this activity is to identify candidate thruster technology from existing developments. Once the technology is selected, the objective will be to develop a sun-beam to ion-beam system specification and unit level specifications compatible with cubesat requirements and constraints, and to develop to an EM standard for characterization.

High specific impulse EP (Isp > 1000s) is enabling for micro/nano/cubesat class of spacecraft. A number of miniaturized thruster concepts exist ranging from TRL3 to TRL5. In some instances prototype power conditioning and flow control systems also exist for specific applications, e.g. NGGM, but these are incompatible with the requirements and constraints imposed by the micro/nano/cubesat class of spacecraft.

**Description:** For the purposes of this activity the sun-beam to ion-beam system shall be comprised of:

- thruster and Neutralizer,
- power conversion and control,
- propellant storage and management,
- cabling and any necessary pipework.

The following tasks are foreseen in the frame of this activity:

- mission analyses and requirements derivation.
- development of system and unit level specifications. These shall be developed collaboratively between propulsion system specialists and a system integrator with practical experience in the integration of cubesat systems. A system requirements review will be held to finalize specifications and once completed the design and development of the system will commence.

detailed design of the system elements. Prototypes, structural thermal models and components shall be manufactured and tested as necessary to de-risk final designs, and validate design/performance models. A complete EM standard system shall be manufactured and tested to characterise coupled system performance, validate performance models and initial lifetime analysis. The latter shall be achieved via an endurance test of the thruster and propellant system of at least 3000hrs duration. This shall conclude with a system CDR.

**Deliverables:** Engineering Model

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

**Target Application/ Timeframe:** Electric Propulsion systems. TRL 6 by 2020.

**Applicable THAG Roadmap:** Electric Propulsion Technologies (2009).

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| *Domain* | *Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT17-051MP** **Budget (k€):** 2,500

**Title:** **High Temperature thruster engine chambers**

**Objectives:** The objective of the activity is to identify and mature technologies for the next generation of in-space chemical propulsion combustion chambers

**Description:** Current in-space engines are performance limited by their combustion chamber material. Many are historically derived from the gas turbine industries and are not optimized for the higher in-space engine temperatures required for maximum performance. Those that are not derived from the gas turbine industry tend to use expensive commodity metals and have a history of cost volatility. Many of the options are from export controlled countries and raise European non-dependence issues. Previous efforts to advance the material options for engine evolution have been tied to specific engine designs and have typically been an approach preferred by the industrial entities. This selection was based on availability, rather than an objectively validated option. In most cases the material failed to reach maturity for programmatic reasons and the technology was left uncompleted.

In recent years there has been an improvement in the production processes and new candidate materials are emerging such as high entropy alloys and new ceramic formulations. These materials would include both ceramic and metallic materials and ablatives. Non-traditional cooling strategies (alternatives to regenerative or radiation cooling) that could be reasonably adopted for in-space propulsion; such as heat sink materials or external augmented cooling systems should also be assessed in the frame of this activity. Many of these exotic materials would require ancillary technologies to enable their applications. Topics such as joining methods; surface treatments for erosion resistance; improved cooling and the associated production techniques, would also be necessarily covered in this activity.

The overall plan for this activity is to conduct an in depth survey and assessment of the candidate materials at sample level, downselect and develop the most promising candidates into chamber battleships, for testing under highly representative, production and test conditions. It is imperative that these tests produce the highest fidelity conditions. Shortcomings in the materials must be identified early and addressed fully at this level before application to a specific project. Failure to do this in the context of a general material study and deferring the industrialization issues will jeopardize the application.. In parallel the necessary ancillary technologies need to be identified and demonstrated at a sufficient level to similarly minimize the application risks. This will result in a well justified catalogue of candidate combustion chamber materials of sufficient maturity that they are ready for implementation into the next generation of European chemical propellant thrusters with a high degree of confidence. The final aspect would be to identify and provide the development planning for any spin out materials that have been assessed over the course of the activity, for example erosion resistant ceramics could have applications in electric propulsion and other non-space domains.

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

- survey candidate materials, design approaches and processes,
- test large field at sample level (torch testing),
- test best candidates at chamber level.

**Deliverables:** Prototype demonstration of the chamber is a relevant environment

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| **Current TRL:** | 2 | **Target TRL:** | 6 | **Duration (months):** | 36 |

**Target Application/ Timeframe:** Next generation of chemical propulsion engines. TRL 6 by 2021.

**Applicable THAG Roadmap:** Chemical Propulsion - Components (2012).

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| *Domain* | *Generic Technologies - CD7 - Propulsion, Space Transportation and Re-entry Vehicles* |
| *Tech. Domain* | *19 - Propulsion* |

**Ref. Number:** **GT17-052MP** **Budget (k€):** 2,500

**Title:** **Building blocks for enhanced apogee and RCS engines**

**Objectives:** The objective of the activity is to identify and develop the technology building blocks for the next generation of European chemical propulsion engines.

**Description:** Apart from advanced combustion chamber materials, the next generation of chemical engines will require a suite of new technologies. Current chemical propulsion systems are facing existing and emerging challenges. Cost is an ever present challenge, however the regulatory challenge of REACh threatens a fundamental overhaul of the entire chemical propulsion sector in Europe. Many of the REACh propellant options are not well understood. Only one potential monopropellant replacement is fairly mature. No bipropellant candidates have been developed beyond TRL 4, most are at lower levels. Many of the bi-propellant candidates suffer significant limitations when compared to the current bipropellants. One major element, for example, is the need for reliable ignition systems. These systems need to function in a vacuum and to do so, for both the low number of firing cycles associated with the apogee engines and the very high number of cycles required of the reaction control thrusters. This technology does not exist yet.

The goal of this activity is to develop the components other than the combustion chambers that will be needed for the next generation of in-space engines. The activity will capture all the relevant technology strands that are emerging from the green space and cost re-evaluations currently underway in the propulsion sector.

The objective l is to advance a collection of building blocks for the next generation of engines: components, design approaches and processes. These will enable the uptake of the technologies for the next generation of in space engines. This would include the obvious items such as such as the afore mentioned igniter but also include items such as low cost injectors, new catalysts, low cost flow control valves, lower thrust and lower cost apogee engines for smaller satellites used for constellations, and alternative green bi-propellants to replace the current storable combinations.

The means to achieve this would be to identify and prioritize the emerging technologies and to develop the individual items de-risking the technology for the European industry.

The proposed activity includes the following tasks :

- generate an agreed prioritized building block list,
- develop and demonstrate the high priority elements to a relevant level to lower the risk of implementation for industry,
- complete a technology catalogue incorporating all the elements and their associated development status.

**Deliverables:** Processes validation.
Breadboard demonstration in a laboratory environment.

**Current TRL:** 2 **Target TRL:** 4 **Duration (months):** 36

**Target Application/ Timeframe:** Next generation of chemical propulsion engines. TRL 4 by 2021.

**Applicable THAG Roadmap:** Chemical Propulsion - Green Propulsion (2012).

## 3.5.8. CD8 - Ground Data Systems / Mission Operations

### 3.5.8.1. TD08 - System Design & Verification

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| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-053SW** **Budget (k€):** 1,500

**Title:** **RATIO-SIM Rationalization of Simulators**

**Objectives:** The objective of this activity is to rationalize the European simulators development, integration, validation and execution support tools to enable a smooth process covering the complete project life cycle and allowing cross-tool as well as cross-missions building blocks exchange, improve overall functionality and quality while reducing cost and development time and increase the commercial viability. The activity should select those components or buildings blocks that are beneficial to jointly develop and or maintain. Adoption of relevant standards (e.g. SMP E-40-07) as well as definition of a Reference Architecture (SSRA/REFA) and process model (ETM-10-21) are relevant elements. The type of simulators targeted in this activity are the System level Simulator tools not the domain specific ones (thermal, power etc.).

**Description:** The ECSS-TM-10-21 System Modelling and Simulation (ETM-10-21) describes the different types of System level Simulator tools. No single tool but a tool chain is required today to support full life-cycle, with associated increase in cost for licensing, maintenance and training.

Current Simulation infrastructures are more than 10 years old, some technology is not first choice, time to look into future. Long term maintenance (>5 years) of such software infrastructure is difficult.

Commercial tools (e.g. Mathwork) are often vendor depended (vendor lock-in) or implementation specific which does not always guarantee long term backward compatibility, availability and support (upward version) specifically considering the space domain.

There exists on European level no (conceptual) data model to capture all the simulator configurations definitions and settings to allow data interoperability and exchange. Also an agreed simulator reference architecture for all type of system level tools doesn't exist as mentioned in ETM10-21.

For the different workflow phases, it is the Archiving phase that lacks the most in terms of methods and tools based on standards to enable re-use, exchange and later analysis.

The SMP (Simulation Modeling Platform) is currently standardized for level 1 while level 2 will be worked on in near future. This standard enables but does not mandates, impose nor guarantees successful model re-use and exchange. A reference architecture is required to guide scoping and selection of possible components or building blocks to be developed.

With next generation of simulator(s) new added value features can be introduced based on state-of-the art technology.

By identifying the most appropriate rationalisation/re-use level and by sharing among the stakeholders the effort of maintaining the common building blocks the overall costs will be reduced. Not only for the corrective (fixing errors) and preventive (increasing maintainability or reliability) maintenance but also for adaptive (modifying to cope with changes in environment) and perfective (new functional enhancements) maintenance.

By using the same components or building blocks the interfaces by definition are standardized and allow for extension of third party entities or vendors. The aim is to improve overall functionality and quality while reducing cost and development time and increase the commercial viability.
This activity aims at preparing an agreed approach with stakeholders and outlining a development plan and high level requirements. It should address as a minimum the related process, reference architecture and attractive technologies to be considered. The type of simulators targeted in this activity are the System level Simulator tools as defined in the ETM-10-21.
More specifically the FES (Functional Engineering Simulator), SVF (Software Validation Facility), AIVS (Assembly Integration & Verification Simulator) and TOMS (Training, Operations and Maintenance Simulator). The SCS (System Concept Simulator) and MPS (Mission Performance Simulator) are out of scope for the moment. Models and modelling methods are also not to be considered.
Different workflow phases are to be considered: Preparation, Execution, Post-processing and Archiving. Each phase could have specific tooling.

From the ETM-10-21 generic architecture the following first-cut components can be identified:

- Database
- Facility M&C
- Generic Infrastructure Control
  - Test Procedure Executor
  - OBSW debug
  - Visualisation
- Simulation Infrastructure
  - Simulation Engine executing models
  - OBC Emulator
- Front-Ends Equipment/SCOE
- Mission Control System
- Archive/Information repository

Depending on the targeted scope, a possible solution could be to select one existing implementation and improve it, to select different implementations, merge and improve it or develop a new implementation. Note that existing implementations could either be proprietary or COTS products. One specific, obvious aspect to be considered is the inclusion of the EGS-CC building block, currently under development, for the monitoring and control functionality.
This is a collaborative proposal between TEC-SWG, OPS-G and SCI-OP.
The proposed activity includes the following tasks:

- Analysis of current Simulation Infrastructure.
- Survey / Selection of technologies.
- Reference Architecture.
- Reusability analysis (e.g. potential reusability of EGS-CC building blocks foer M&C).
- Selected Building Blocks Design & Implementation.
- Prototype.

**Deliverables:** Software

| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |
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**Target Application/ Timeframe:** All missions. This is a European strategic initiative. TRL 7 by 2020.

**Applicable THAG Roadmap:** Not related to the Harmonisation subject.

### 3.5.8.2. TD09 - Mission Operation and Ground Data Systems

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| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT17-054GI** **Budget (k€):** 500

**Title:** **GEMCAV: Generic Monitoring and Control system for high rate TM / TC including Audio and Video**

**Objectives:** The objective of this activity is to define and deploy a pre-operational EGS-CC based generic multi-mission monitoring and control system enabling the acquisition, distribution and processing of very high incoming and outgoing data rates. The incoming and outgoing data may be heterogeneous and require distinct levels of storage, distribution and processing.

**Description:** The future EGS-CC based MCS infrastructure will support different levels of performance for the various stages of the data reception and processing chain. Telemetry data can for example be received at a relatively high data rate (up to 50 Mbps) but the full data processing is expected to take place at a significantly lower rate (up to 0.5 Mbps), two orders of magnitude smaller. This difference in the EGS-CC guaranteed performance levels may not necessarily be compatible with the need of processing high data volumes (e.g. all data generated by a spacecraft in one day and received via the playback datastream in a visibility pass) within short times.

The required analysis encompasses the:

- reception, routing, storage and distribution of heterogeneous data incoming at high-rates (including audio/video transfers),
- high-level design of an optimised processing engine enabling the quick look analysis of playback data based on fast processing data techniques. A target performance of 3 Mbps (corresponding to the capability of processing one day of HK TM generated at 120 kbps) within 30 minutes following downlink completion shall be considered,
- generation, multiplexing and release of high rate outgoing data originating from heterogeneous sources,
- ability to achieve a seamless integration of the high-rate modules on the top of the (unmodified) EGS-CC,
- automatic generation of reports and corresponding alerts summarising the outputs of the playback data processing following a visibility pass,
- support infrastructure of EGS-CC based mission control support infrastructure (e.g. raw data archive, file archive, engineering data archive) such to enable an efficient and performing management of the massive amounts of data required by future missions.

This activity will include among others:

- support of 'application S/W free' data layer,
- support of modern storage and retrieval technologies,
- support of powerful and efficient data back-up and restore capabilities,
- support of efficient (as far as possible automated) data archives administration capabilities.

The proposed activity includes the following tasks:

- conceptual Specification and architecture,
- high level design,

- an operational prototype to be deployed on top of EGS-CC based MCS to demonstrate the capability to process high incoming and outgoing data rates.

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 7 by 2020.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

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| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT17-055GI** **Budget (k€):** 500

**Title:** **GOSADD (GrOund StAtion Data Discovery) - Ground Station data collection, archiving, integration, correlation, distribution and preparation for post processing**

**Objectives:** The objective of this activity is to develop a pre-operational system to allow the Ground Station systems data collection, archiving, integration, correlation, distribution and preparation enabling data analytics.

**Description:** Every ESTRACK Ground Station is composed by ca. 15-20 Subsystems (e.g. receivers, High Power Amplifier, Frequency Converters, Front End Controller, Tracking, Telemetry & Command processor, Frequency and Timing systems, Delta-Differential One-way Range Correlator, Station Computer, Weather Station, etc.). Each subsystem produces daily an important amount of data that is stored in different distributed filing systems (i.e. databases, files) across different hardware and servers. Some data is categorized and arranged to allow its easy access for the monitoring and control of the Ground Station. The rest of the data is scattered and accessed either locally and remotely. ESOC is currently performing a very limited Ground Station data post processing. New big data technologies allow to improve the forecasting of events, the improvement of decision quality and the optimization of mitigation risks for Operations.

The first step to achieve these goals is to guarantee a systematic data collection, archiving, integration, correlation, distribution and preparation for post processing.

It is becoming imperative to analyze the variety of Ground Station data to allow a post processing analytics to anticipate the potential future systems behavior. In order to perform this, the data has to be:

- collected from several types of data sources, including engineering, logging, quality, reliability and weather conditions data,
- archived at the Ground Station, into distributed databases (e.g. physical infrastructure or a private Ground Station Cloud),
- distributed, to the ESOC Control Centre via different means (e.g. near real time, file based),
- integrated and stored at ESOC, by categorizing and arranging the data on the basis of structured, unstructured and semi-unstructured data (e.g. annotation, cleansing, transformation, preservation, segregation),
- correlated with data generated by the different Mission Control and Flight Dynamics Systems..

The activity shall consist of the following tasks:

- perform the system-level analysis of the required capabilities (e.g. definition of Use Cases, volume of data, variety of data from all Ground Station systems including a wide range of sources and formats, speed at which the data is generated and processed),
- determine the content and the format of all data structures and of processing products at each stage of the acquisition and processing chain, identifying the required historical data and its correlation requirements,
- produce the pre-operational prototype of the end-to-end acquisition and processing chain by:

- defining the architectural design of the end-to-end system. This activity shall make use, to the possible extent, of existing OPS-G infrastructure products (i.e. LMS -Lightweight Monitoring System-, GFTS -Generic File Transfer System-, EDDS -EGOS Data Disposition System-, ARES -Alarm reporting System-, etc.),
- develop/assemble the complete end-to-end acquisition and processing chain,
- perform the full validation process, based on the data of one sample mission,
- produce the complete set of Test Reports, which will include a catalogue containing samples of each processing product.

One of the most important use cases to address is the Spacelink communications link performance monitoring and analysis. In order to allow the analysis of TT&C link margin values and planning of proper data rates during mission phases, it is required to monitor the performances of the space link during operations. To this end, a set of data processing elements is required, which provide: configuration, performance and weather conditions data collection from the ground stations and from other elements of the ground segment (on-board parameters from mission control system, orbit information from Flight Dynamics System, navigation data etc.).

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 8 by 2020.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

| | |
|---|---|
| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT17-056GI** **Budget (k€):** 900

**Title:** **C2SoS: Monitoring and Control of System of Systems for constellations of satellites and complex network of Ground Stations**

**Objectives:** The objective of this activity is to enhance the functionality of the new ESA M&C infrastructure to allow a radical simplification (i.e. additional layers) of the monitoring and control of large 'systems of systems' (e.g. constellations, complex network of Ground Station's).

**Description:** The EGS-CC has been designed in order to be scalable in both directions i.e. to support monitoring and control of basic systems as well as the complex compositions of controlled systems. The EGS-CC doesn't however natively provide the functional layer which is necessary to introduce a radical simplification of the monitoring and control tasks for operators responsible for 'systems of systems' (e.g. constellations, complex network of ground stations).
Description
When executing operations of a 'system of systems' appropriate attention needs to be given to the following aspects:

- Layering of supervision and monitoring tasks, enabling a few operators to monitor a large number of systems by being presented with relevant information in a properly aggregated manner. E.g. :
  - Constellation Model.
  - Constellation Management.
  - Network of Ground Stations Management.
  - Central Logging.
  - Constellation Archive and post-processing Management.
- Fully automated operations cycle (from planning up to report generation), complemented by the ability to effectively supervise the execution of the planned operations in order to achieve a fully automated monitoring of the operations lifecycle execution, whereby the operator is only presented with detected anomalies related to the management / execution of any request, operation or mission product. E.g.:
  - Constellation Schedule and Status.
  - Constellation Ground Segment Infrastructure Monitoring and Control.
  - Constellation Anomaly / Alarm Management.
- Ability to share operations artefacts (such as data definitions, procedures, displays, plan templates) among the individual systems belonging to the System of Systems' (e.g. satellites belonging to a constellation).
- Progressive integration of the full 'system of systems' by seamless addition of individual systems to an existing system instance.
- System services and deployment model to support the necessary scalability and availability as well as an optimal use of the computing resources. The aim is to have the following type of services for the full EGS-CC based 'System of Systems' control infrastructure:
  - EGS-CC Platform-as-a-Service (e-PaaS).
  - EGS-CC Software-as-a-Service (e-SaaS).
  - EGS-CC Infrastructure as a Service (e-IaaS).

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

- conceptual specification,
- high-level design,

- an operational prototype (beta version) of the 'System of systems operations service' layer to be deployed on the top of one or more EGS-CC based applications supporting the monitoring and control of the individual controlled systems.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** To be used by future Earth Observation / Science / Navigation (i.e. Galileo next Generation) constellations, large formation flying, and large network of ground stations. TRL 7 by 2020.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

| | |
|---|---|
| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT17-057GI** **Budget (k€):** 800

**Title:** **C2LOCO Generic MCS / EGSE for smallsats and low cost operations**

**Objectives:** The objective of this activity is to provide an end-to-end solution based on the new ESA Monitoring and Control infrastructure enabling a radical simplification of the monitoring and control of different types of small satellites (e.g. nanosats, cubesats, smallsats, recurrent OPSSATs, EO low cost missions, etc.).

**Description:** Low Cost Operations can only be achieved if the overall mission is designed in a way which enables a radically different approach to be adopted. The low cost principles are expected to be applied across the board, including the space and the ground segment, in particular the elements which attract the majority of the development, integration and validation costs. The EGS-CC provides a generic and powerful platform to develop full monitoring and control applications for a specific controlled system. The development effort to provide an EGS-CC based system is expected to be minimum if the controlled system (in particular the spacecraft) complies to the relevant standards. However, the effort to deploy, customize and validate EGS-CC based solutions can be seen as prohibitive for very small and low budget missions. The availability of sufficient help and training material and/or example reference missions will contribute to the acceptance and adaptation.

The main objective of this activity is therefore to identify the possible approaches enabling the adoption of EGS-CC based solutions for low budget missions i.e. missions which are prepared to sacrifice aspects such as the reliability and the mission return in favour of a reduction in the budgetary needs to set-up and operate the full mission.
Possible ideas / approaches to be explored are (non-exhaustive list):

- 'Installation free' Operations Services, whereby the mission / test operators are provided with Internet based access to an EGS-CC based system providing the necessary M&C access to the controlled system. The operations or test team is not at all involved in the design, development, deployment, validation and operation of the mission control system but rather only provides the necessary inputs, such as the M&C data definitions according to an agreed format/standard. This approach could be very attractive for organizations which do not have a critical mass of missions to manage in parallel or do not have EGSE product lines.
- 'Shared M&C systems', whereby a low cost mission is 'added' to an existing EGS-CC based system instance through configuration/tailoring (no software). This is considered as the most promising approach e.g. to deal with many low cost missions all managed within the same organization.
- End-to-end File based Distributed Operations Services', whereby the interactions between the controlling and the controlled system only take place via discrete data units such as files. This approach would allow that exactly the same system instance is set-up (customized, configured, tailored, deployed) and used across all mission preparation, validation and operational phases. This could be achieved by leveraging on the EGS-CC concepts of commanding and reception routes, whereby exactly the same (file based) operation could be executed in the pre- and post-launch phases by interfacing with the controlled systems using different communication protocols.

The tasks to be done in the frame of this activity are the following: Analysis and tailoring of EGSE / MCS requirements for smallsats and low cost operations.

- Identification of EGSE / MCS building blocks and design architecture for smallsats and low cost operations.
- Build prototype of a system EGSE / MCS for a selected smallsat demonstrating its capability and the required low cost operations.

**Deliverables:** Software

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|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 12 |

**Target Application/ Timeframe:** All future EGSE. MCS for smallsats and low cost operations. TRL 7 by 2020.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

### 3.5.8.3. TD12 - Ground Station Systems and Networks

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|---|---|
| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT17-058GS** **Budget (k€):** 1,000

**Title:** **Water cooled 2-10kW X-Band Solid State Power Amplifier (SSPA)**

**Objectives:** The objectives of this activities are:

- to design a modular water cooled X-Band SSPA based on high efficiency semiconductor technology,
- to manufacture and test a prototype able to deliver 2kW output power,
- to design an X-Band SSPA able to deliver 10kW output power.

**Description:** Presently in ESA Deep Space Antennas X-Band uplink capability is achieved by different power amplifiers: Solid State Power Amplifiers (400W), Low Power Amplifiers (2kW) and High Power Amplifiers (20kW). X-Band Low Power Amplifiers (X-LPA) and X-Band High Power Amplifiers (X-HPA) are Klystron amplifiers while the X-Band Solid State Power Amplifiers (X-SSPA) are amplifiers based on solid state GaAs technology. Both X-LPAs and X-SSPAs are air cooled while X-HPAs are water cooled (deionized water).

In order to improve the reliability of the present 2kW LPAs, limited by the use of klystron technology (single point of failure) and cooling system based on a powerful air turbine, a new 2kW amplifier shall be developed based on a combination of solid state amplifiers modules, e.g. in GaN or GaAs technology, providing higher power efficiency and reliability, cooled with a water system (more efficient than air cooling). This machine will have a graceful degradation (output power) in case of failure based on the modular design.

Water cooling has the following advantages over air cooling: higher cooling efficiency (especially at high altitude station sites), less noisy, reduced size of the overall amplifier and better frequency stability (Allan deviation).

The development of the new 2kW amplifier will allow reduction in running costs being both the present 400W SSPA and 2kW LPA replaced by only the new 2kW SSPA.

It is intended to further extend in the future the output power range up to 10kW, thus the preliminary design of the 10kW amplifier will also be performed in the frame of this activity.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** 2019. Deep Space Antennas.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

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|---|---|
| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT17-059GS** **Budget (k€):** 600

**Title:** **Enhanced antenna servo controller performance under high wind conditions**

**Objectives:** Due to the large diameter of the main reflector of ESAs deep space antenna, high wind conditions (above 50 km/h) degrade distinctly the antenna pointing performance.
The activity aims at improvement in 2 domains:

- select a servo control algorithm best suited for wind gust rejection without compromising the controller robustness,
- consider suitable metrology to include the wind effect in the servo controller.

**Description:** The best suitable antenna servo controller shall be selected using the Quantitative Feedback Theory (QFT). The method presents a toolbox, which helps to find the best controller (e.g. PI, PID, LQG, etc.) considering the dynamics of the structure and the relevant boundary conditions. Servo controllers with promising wind behavior investigated in an earlier study revealed severe stability issues. It is expected that with QFT, this stability issues can be successfully tackled.

Numerical models (Matlab/Simulink) of the antenna system will be used to study the newly proposed control algorithms and metrology. Furthermore, empirical data (servo position errors / motor torque, etc. versus wind speed / direction) is partially available to enhance the servo controller performance under high wind conditions using additional sensors (metrology).

As part of the activity, the predicted performance enhancements shall be verified by applying the new concept to an ESA deep space antenna. This testing with a real antenna requires the implementation of the newly proposed algorithms into an antenna controller software/hardware.

**Deliverables:** Breadboard

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** Improved pointing of ESA deep space antennas at Ka-band during high wind (up to 100 km/h) conditions. TRL 6 by 2019.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

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| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT17-060GS** **Budget (k€):** 3,400

**Title:** **Automated Laser Ranging for Uncooperative Targets**

**Objectives:** The objective of this activity is the additional technology development as the next step to be implemented on the first Laser Ranging Station Prototype for Cooperative Targets (planned to be operational before end of 2019) in order to achieve the next level of capability that encompasses the following:

- fully automated operation without any operator intervention,
- laser ranging to known non-cooperative (space debris) objects during both day and night,
- hand-over from passive survey observations (e.g. Testbed Telescope developed under GSTP) of un-known non-cooperative targets of <1m for follow-on laser tracking at least in the most congested 800-km altitude band (note that this capability is a necessary first step towards a potential future system for the laser-based removal of ~10cm objects).

**Description:** This activity is a substantial capability upgrade of the prototype of a Laser Ranging Station for Cooperative Targets (to be developed in the previous first step which is currently under IPC approval). It is the second step in the step-wise approach to move towards ranging to non-cooperative targets during both day & night as well as to fully automated operation.

The overall activity to arrive at the desired functionality consists of the following interwoven building blocks:

- High Pulse Energy Laser Transmitter (1,200 K€): development of a high pulse energy laser transmitter for ranging to non-cooperative space objects (space debris),
- Laser Safety Sub-system (500 K€): development of a laser protection system to meet regulatory eye-safety and air traffic requirements,
- Photon-counting, time-gated ranging detector (700 K€): development of a time-gated ranging detector for 1064 nm wavelength, i.e. infrared instead of visible spectral range,
- Automated Laser Ranging Station Control System (500 K€): development of a fully automated Laser Ranging Station Control and Echo Processing, and
- Real-time Orbit Determination Algorithm for Handover to Laser Tracking (500 K€): development of a real-time, first order orbit determination to allow real-time handover from passive space object detection (optical survey telescope) to Laser Tracking.

**Deliverables:** Prototype

**Current TRL:** 4 **Target TRL:** 7 **Duration (months):** 20

**Target Application/ Timeframe:** TRL 7 by 2021.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

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| *Domain* | *Generic Technologies - CD8 - Ground Data Systems / Mission Operations* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT17-061GS** **Budget (k€):** 500

**Title:** **Low Cost Pointing Calibration System for Antennas**

**Objectives:** The objective of this activity is the development of a low cost pointing calibration system for use primarily at 26 GHz for antenna in the range of 6-35 meter diameter.

Besides a simple software to control the antenna and drive the radiometer, a low cost radiometer breadboard shall be developed, suitable to measure the system noise temperature between 8 - 32 GHz.

**Description:** Antenna pointing calibration system are currently tailored for each individual antenna system. The core of the proposed system consists of a generic low cost total power radiometer covering 8 - 32 GHz. This will include EO (26 GHz) and SCI (8 GHz, 26 GHz, 32 GHz).

The software part consists of a basic software to control the radiometer and the antenna control unit of different types/manufacturers. The software shall simplify the collecting of pointing data required for the subsequent generation of the pointing error model. It is assumed that already available software packages are used for the evaluation of the data.

The overall system shall be mobile and shall be of plug-and-play type. No down-converter is required as the interface is directly after the LNA.

The software shall have a library with radio stars/ planets suitable also for 6m class antennas.

**Deliverables:** Breadboard

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** Calibration of pointing for antennas operating at 8/26/32 GHz. TRL 6 by 2020.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

## 3.5.9. CD9 - Digital Engineering for Space Missions

### 3.5.9.1. TD08 - System Design & Verification

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|---|---|
| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-062GE** **Budget (k€):** 1,300

**Title:** **ADGE - Advanced Digital Ground Segment Engineering**

**Objectives:** The objective is to develop a digital framework for ground engineering processes that provides the capabilities to enable missions to migrate to a fully model-centric operations and science ground segment engineering approach.

**Description:** Currently ground segment engineering applied in the operations and science ground segments is a largely document-centric process. This approach leads to information being distributed in a large number of documents, often redundant and inconsistent. It is rather cumbersome to retrieve the information. With mission operations and science ground segment engineering becoming more complex with each mission, moving the engineering processes from a document-centric to a model-centric system engineering approach, is a necessity. It will improve efficiency and robustness of the process.

The Paperless E2E Ground Segment Engineering TRP study is establishing a technology baseline for digital, model-based operations ground segment engineering. On the science side, the Science Operations Configuration Control Infrastructure (SOCCI) provides a single, highly customizable platform for E2E system engineering. These precursor activities define an initial concept to move ground segment engineering processes away from the current document-based engineering approach to a model-centric one that revolves around a central engineering data repository/ model. ADGE will develop a unified generic ground segment engineering model concept for the mission operations and science operations centres. On the basis of this model, tools and applications for model data import, model manipulation and model data export/ model exploitation will be developed. They will allow real-time collaborative engineering and efficient paper-less execution of system development activities such as reviews, requirements generation & traceability, test automation, and general validation. Where possible, existing engineering tools shall be re-used and provided with a generic interface to access the engineering model. It is envisaged that synergies are pursued between the technologies across the Digital Model Hub initiative and ADGE activity in order to ensure the capability to exchange models also with the space segment engineering.

- Phase 1: The main conceptual and development phase (900 K€, 12 months) tasks are to:
  - assess the achievements under the precursor TRP activities and identify gaps,
  - define use cases and the associated requirements,
  - assess the technology baseline, prototype and Lessons Learned both from an engineering and end-user perspective,
  - produce a digital framework for operations and science ground segment engineering,
  - define the models, considering the layering between generic elements and mission specific elements,

- integrate engineering tools and implement new tools where necessary.

- Phase 2: The Use Case Demonstration Phase (400 K€,4 months) tasks are to:
  - demonstrate the framework, possibly as a shadow engineering environment,
  - provide recommendation for the further integration of model-centric engineering.

**Deliverables:** Software

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** Applicable to all future ground segment engineering capabilities. TRL 6 by 2020

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

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|---|---|
| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-063SW** **Budget (k€):** 1,900

**Title:** **Information Systems & Ontologies & Semantic modelling for Semantic Interoperability**

**Objectives:** Develop a key methodology and tool to solve the problem of sharing and exchanging digital information between partners (customers and suppliers) in a space system project, where the partners use different tools, and where the tools handle similar, in principle map-able information, in different representations..

The goal is to finalize a rigorous knowledge representation formalism that is founded on formal logic and called Object Role Modeling (ORM), as a semantic model of concepts that precisely capture the information to be shared and exchanged.

A secondary objective is to assess how the ORM methodology can be integrated with, and leverage the use of, the mainstream semantic web technology (such as the Resource Description Framework (RDF), or the Web Ontology Language (OWL)), including automated reasoning.

**Description:** Reliable and efficient exchange of knowledge between all partners participating in a space system project over the whole lifecycle has always been a critical issue, for ESA, industry and national agencies. With more than 120 standards, ECSS is a major enabler in facilitating the communications between all partners but this is not sufficient. Digital information/knowledge still does not flow seamlessly between customers and suppliers and this causes inefficiencies, information loss and error-prone manual rework.

Today know-how is supported by many software systems and information systems/data repositories. Knowledge is everywhere but knowledge exchange, true sharing and reuse of information is far from optimal. This results in major problems when developing and operating 'large systems' implying a waste of resources, additional risks and delays, and therefore very significant cost increases. The major cause for this is the inadequate way in which information and knowledge is modelled.

Decades of academic research - related to fact based modelling (FBM), ontology definition languages, common / formal logic as well as controlled natural languages - have permitted to develop information modelling methodologies enabling capturing the semantics of the information, i.e. capturing all stakeholders' knowledge representation needs at the 'what?' level without committing to a particular 'how?' a solution might be implemented. This is a prerequisite for reaching semantic interoperability.

In the context of the FAMOUS TRP activity, the Agency has played an important role to capture worldwide academic expertise into a methodology that can be used to develop new or adapt existing information systems, ensuring their semantic interoperability. In the frame of this activity, the demonstration has been made on how powerful transformation engines can (semi-)automatically generate solutions based on different information modelling technologies: e.g. object-oriented, relational, hierarchical networks, data serialization formats such as XML (Extensible Markup Language) or JSON (JavaScript Object Notation).

In the last ten years also semantic web technology (e.g. RDF(S) / OWL, SparQL) has been developed, mainly under the auspices of W3C (World-Wide Web Consortium), that adhere to the same formal logic as the semantic information modelling methodologies described above. It has focused on augmenting the world-wide web with machine readable semantics. Powerful and mature

modelling tools and automated reasoners are available as COTS and Open Source software tools. A smart combination of the Fact Based Modelling methodology and semantic web technology has the potential to unite the more academic Fact Based Modelling approaches with mainstream semantic web technologies that are known to and used by a much wider community of practice.
The activity consists of the following tasks:

- complete the FAMOUS methodology specification, extending the currently existing conceptual data modelling specification to encompass all means to model at global level in order to achieve the stated goal of semantic interoperability,
- complete the mapping to RDF/OWL and develop conceptual models reasoners to assist and facilitate the verification of produced models,
- specify and develop means to transform conceptual information models into logical and physical data models to facilitate the production of software applications,
- specify and develop means to reverse engineer existing solutions (implemented at logical or physical data model level) in order to construct conceptual information models that can be integrated to the global model, i.e. realizing semantic interoperability,
- verify the adequacy of the new specifications by prototyping (i.e. adapting existing tools/prototypes),
- formulate alternative development strategies for the realization of the FAMOUS tool, taking into account re-use of existing FBM tools/modules, new development, re-use of / integration with RDF(S)/OWL frameworks, and perform a trade study to select a preferred strategy,
- develop a version one of the FAMOUS tool that supports conceptual modelling at local and global level,
- verify and validate the FAMOUS methodology and tool through use of representative test cases.

This activity aims at implementing the first version of a tool supporting the ECSS-E-TM-10-23 Space System Data Repository. Addressing the knowledge at semantic level ensures persistency of that knowledge within and across projects and independency of any implementation technology that by nature is not long term stable. Using formal logic representation, the captured knowledge can be used to automate the development of products i.e. reducing in a long term their development and maintenance cost.

**Deliverables:** Enhanced specification of the FAMOUS methodology, System and software specification of the associated FAMOUS software, Space system representative test cases specifications, development and evaluation reports including prototype demonstrators.
First version of the FAMOUS software with associated documentation.

| **Current TRL:** | 3 | **Target TRL:** | 6 | **Duration (months):** | 30 |
|---|---|---|---|---|---|

**Target Application/ Timeframe:** All ESA missions. TRL 6 by 2020.

**Applicable THAG Roadmap:** System Data Repository (2014).

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|---|---|
| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-064GE** **Budget (k€):** 1,500

**Title:** **E2E Reference Environment for Space Missions (ERES)**

**Objectives:** The objective of this activity is to develop an E2E Reference Environment, spanning across the different segments of a Space Mission, for E2E demonstration and validation of capabilities required to meet present and future mission objectives.

**Description:** End-to-end (E2E) demonstration and validation of capabilities required to meet present and future mission objectives is critical for mission success. The utilization for this purpose of environments confined to segment level or even at discipline level within each segment entails a number of shortcomings like:

- replication of validation efforts and different maturity for system components,
- late identification of sub-system and system level problems, increased IV&V effort later in the mission lifecycle,
- limited capability for E2E 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 environment, spanning across space segments and disciplines as far as possible, which enables E2E integration, validation, demonstration activities in an efficient and effective manner.

This activity will develop an E2E Reference Environment for Space Missions (ERES), including space, mission operations and science segments initially, for which elements of existing local environments can be taken as input building blocks, specifically from the ESTEC Avionics Test bench (ATB), the ESOC E2E Ground Segment Reference Facility (GSRF), the ESAC/SOC Reference Environment. ERES will be open and scalable, in order to be able to extend it in the future to enable new capabilities. It shall be remotely accessible by all stakeholders and support collaboration at the maximum extent, ideally in a virtual presence space. Aspects of security, privacy and other legal constraints shall be suitably managed. Due to its complexity, distribution, multiple and remote access, parallel activities etc. the management and control of this environment poses non-trivial challenges. The activity will therefore also include the development of a system that will act as its control centre, providing continuous and shared situational awareness and control capability. The results of the activity shall be demonstrated on or more straw man missions.

- For Phase 1 (1000 KEuro), the tasks are the following:
  - detailed system requirements specification,
  - development of the system architecture, including collaboration support and monitoring and control capabilities,
  - definition of straw man mission(s) and demonstration scenarios,
  - implementation and deployment at the different ESA Sites,
  - demonstration.

- For Phase 2 (500 KEuro), the task is the development of ERES monitoring and control system and advanced collaboration capabilities.

**Deliverables:** Study report, reference environment and demonstrator.

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|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** All missions will benefit from this development. It will provide the capability to assess, validate and demonstrate E2E new concepts, standards, applications, to perform E2E 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. TRL 6 by end 2019.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

| | |
|---|---|
| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-065GE** **Budget (k€):** 1,000

**Title:** **SSE4Space - Secure Systems Engineering for Space Missions**

**Objectives:** The aim of this activity is to consolidate and expand existing secure systems engineering technology building blocks and create a Secure Systems Engineering framework of methodologies and tools for unclassified space missions.

**Description:** ESA has invested in recent years to improve the security of the software systems by providing a Secure Software Engineering standard along with a number of tools that help developers and technical officers to implement it. The SSE4Space proposal moves the concept one level up to the system engineering domain, where security engineering methodologies and tools are equally important.

Today, there is no generic approach to support secure system engineering processes for space mission systems. This leads to the production and operation of systems that are vulnerable and ultimately the risk to lose or damage the Agency assets.

The European community has invested in the development of a Secure Software Engineering Standard which assumes that Secure Systems Engineering is applied at Mission System level and flown down to sub-system level. So far the Agency has been developing a number of Secure Systems Engineering technology building blocks, with the purpose of efficiently and effectively enabling secure systems engineering as defined in the standard. The tools have been designed to implement the secure system engineering processes in an efficient and effective way and thus allowing security to be addressed with a minimum overhead. SSE4Space will consolidate and expand these elements in a comprehensive and easy to use Secure Systems Engineering framework of methodologies, tools, and data. This framework will support all cyber-security related systems engineering processes as defined by the standards. The framework will be accessible through a set of connected software tools intended to be used by system engineers.

The tools will support the engineers and provide templates and patterns wherever possible to allow for efficient and effective implementation of security processes. A low-complexity security certification concept and toolset will be developed. SSE4Space activity will also prepare for a future integration with the developments towards digital engineering, tying the security engineering information into the engineering model.

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

- review of existing technology components and secure engineering standards,
- identification of technological and formal gaps,
- consolidation of the existing technology components into an overall framework of methodologies, software tools, and supporting data,
- specification and implementation of a certification concept and tool,
- demonstration of the framework in a real mission to be pre-selected,
- future concepts initial analysis.

**Deliverables:** Software

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** Applicable to all ESA systems. TRL 6 by 2020.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

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|---|---|
| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT17-066OS** **Budget (k€):** 1,900

**Title:** **Data Analytics for multiple Space Applications (DASA)**

**Objectives:** The objective of this activity is to design and implement Data Analytics applications for specific space problems and assess the impact of using those applications. Recommend further exploitation of data analytics in suitable space domains.

**Description:** Data Analytics is the science of examining raw data with the purpose of drawing conclusions about that information, to enhance productivity and business and to support smart decision making. Data analytics develop very quickly in a wide range of applications.

European space industry and space mission operations have a big potential to benefit respectively in their competitiveness and in the (scientific) return by better exploiting their large set of data. Operational assessment of precursor space related data analytics activities is very promising.

Significant added value can be created from extraction of useful information out of big data stores and data streams, supporting knowledge building and decision making for space Industry, National Agencies and ESA. Target space processes that can benefit from data analytics and machine learning include:

- space strategies decision making,
- space scenarios assessment,
- spacecraft & components design,
- spacecraft assembly, integration and testing,
- spacecraft and ground operations,
- risk assessment.

Available data repositories for such applications include satellite/module design and test data, operations data (spacecraft, mission control system, ground stations, flight dynamics, navigations), earth observation data and crew data.

DASA targets the implementation and validation of a suite of data analytics applications for space. Examples are:

- image analysis and knowledge extraction, to enhance the classification and identification of feature of interests (automatic discarding of cloudy pictures, automatic recognition of solar events precursor, rover image/sensors in-situ processing for opportunistic science),
- time series analysis applied to knowledge extraction, model behavior to make prediction of spacecraft performance and sensors, anomaly root cause identification, early detection and prevention of security issues (e.g. space cyber security),
- decision making in design (e.g. which component is most suitable for a specific mission), in testing (which tests are more effective and how to optimize the test plan), in operations (optimal allocation of resources, optimization of science return data, mitigation of operational risks),
- enhanced monitoring, early anomaly detection, support to diagnostics, from preventive maintenance to predictive, dynamic assessment of probability of failure/reliability, availability and maintainability characteristics,

- data visualization, by performing synthesis of data into information to have full awareness of complex system status.

Many technical challenges typical of data analytics, in order to implement features outlined above include:

- how to efficiently use deep learning, random forests, support vector machines for time-series and images analysis,
- how to effectively perform knowledge extraction and dependency analysis for a variety of applications,
- how to visualize and present extracted information and knowledge from data in an effective way for decision makers,
- how to optimize the contribution of data analytics in mission design, mission operations and quality.
- For Phase 1, the tasks are the following:
  - analysis and classification of initial suite of use cases; assessment and selection of suitable data analytics technology,
  - selection of use cases for phase 1, with higher level of readiness (mature requirements, availability of use case data and identified suitable technology),
  - parallel iterative prototyping, validation and assessment,
  - parallel development of final applications for the selected use cases; evaluation of impact of implemented applications, and lessons learnt.

- For Phase 2, the tasks are:
  - lessons learnt from phase 1 applied to refinement/update of additional use cases (now ready to be implemented),
  - iterative implementation, validation,
  - evaluation of impact of implemented applications,
  - final assessment and recommendation of future adoptions.

Adoption of data analytics in sectorial space areas: e.g. earth observation, science and exploration, operations, space situation awareness, etc. Spin-off of data analytics space applications.

**Deliverables:** Software

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|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 7 | **Duration (months):** | 24 |

**Target Application/ Timeframe:** All ESA and industry participating. TRL 7 by 2019.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

### 3.5.9.2. TD09 - Mission Operation and Ground Data Systems

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| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT17-067GI** **Budget (k€):** 3,500

**Title:** **FASSADE - Federation of Assets supporting the Storage, Search and Access to spacecraft Data for Engineering analysis**

**Objectives:** The objectives of this activity are:

- federate and preserve all space related data assets (common approach):
  - payload / user data (e.g. Earth Observation, Science),
  - S/C design lifecycle data,
  - operations/housekeeping, ground segment data (telemetry, mission planning / execution, flight dynamics) including in-orbit failure/anomaly data.
- Enable easy access and max. exploitation of data assets (institutions, industry, public):
  - end users: enable open portal solutions and complex processing, enable new data products and services,
  - industry / Agencies: improve quality in design, development, modelling, AIV, support fully digital engineering, manage risk and margins,
  - operators: support increased level of autonomous operations, increase mission life time / reliability, enable data analytics (across-system and across-mission knowledge).

**Description:** Currently, the storage, retrieval and post-processing of engineering data generated by space missions relies on proprietary solutions which are specific of individual projects, organisations and data source. This means data is generally scattered through many disconnected archives and databases, which discourages any analysis across projects, organizations or systems, meaning the data is not sufficiently exploited to target improvements in existing and future missions. In many cases, engineering data is only captured in documents and cannot be easily retrieved.

This engineering data contains inherently highly valuable information on a large number of characteristics like achieved performance and reliability, observed failure modes and mechanisms, compatibility of technologies or designs with mission environments and specific operations, observed performance degradation by life time and usage profile. This data is currently rarely and by no means systematically exploited to provide an information repository that could be used by the development teams of future spacecraft or operators of current missions in their decision making on design concepts, technology selections, mission planning or anomaly recovery. Thanks to the application of new advanced data analytics methods, the stakeholders can extract value from this data and generate a body of knowledge from historical events.

The added value is to allow easy distributed access to historical engineering data generated by different organisations and projects. The envisaged user communities are all the European industrial, research and institutional teams involved in the analysis and post-processing of engineering data generated throughout the various phases of a given mission as well as by previous missions. Provide stakeholders with a practical decision-support tool by:

- omparing and aggregating non-homogeneous data,
- producing a high level representation of complex results,

- identifying patterns and dependencies for new anomalies detection,
- predicting trends and preventing recurrences of failures,
- promote knowledge information sharing between experts of different disciplines.

The main functions of the FASSADE system are:
- secure the storage of and the access to engineering data in the long term (i.e. preservation), up to decades after the end of the mission, along with sufficient metadata enabling their unambiguous interpretation,
- federate geographically distributed archives through a single service interface point,
- search and navigate the available catalogue information at a high abstraction level,
- provide basic post-processing/visualisation capabilities of the retrieved data.

Several technical challenges typical of big data / cloud based systems are to be faced in order to implement the features outlined above, e.g.:
- characterise and define the engineering data at semantic level so that they can be interpreted and post-processed without an a-priori specialist knowledge,
- store any relevant context information which is necessary in order to properly assess the engineering data (e.g. environmental conditions, events/operations history),
- federate potentially heterogeneous archives to act as a single source of data,
- ensure adequate performance in the searching of data matching a given set of criteria,
- ensure scalability of the storage capacity and the ability to manage the huge amount of data in the long term (decades),
- ensure inter-operable access to and dissemination of data stored using heterogeneous technologies,
- achieve an adequate level of data segregation and ensure secure and controlled access to the historical data without endangering integrity and confidentiality,
- ensure scalable and real-time processing to permit optimal visualization of large stored data-sets or live-stream data,
- design appropriate interface points that can allow post-processing applications to access the available data in a convenient and performing way.

The tasks for Phase 1 (1 Meuro, 9 months) are:
- analysis of relevant existing solutions,
- conceptual definition, use cases definition,
- technology analysis,
- inter-operability standards analysis, data model definition,
- high-level technical specification and architectural concept,
- proof of concept prototyping.

The tasks for Phase 2 (15 months, 2.5 Meuro) are:
- development of a pre-operational system based on FASSADE Building Blocks,
- tailoring and Population of a mission pilot sample archive at ESA and Prime different sites, including selected historical engineering / payload data,
- final demonstration.

This activity will prepare the path for an operational development and deployment of a FASSADE based federation of data archives.

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|---|---|---|---|---|---|
| **Deliverables:** | Software | | | | |
| **Current TRL:** | 3 | **Target TRL:** | 7 | **Duration (months):** | 24 |
| **Target Application/ Timeframe:** | All ESA and Primes sites Archives participating in the Federation. TRL 8 by 2021. | | | | |

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

### 3.5.9.3. TD26 - Others

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| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *26 - Others* |

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|---|---|---|---|
| **Ref. Number:** | **GT17-068EO** | **Budget (k€):** | 1,000 |
| **Title:** | **Microservices to Applications - a Generic Interdomain Composer (MAGIC)** | | |

**Objectives:** Develop and implement a methodology and related tools to simplify the definition of complex applications by allowing composition of existing processing services, creation of new processing microservices, and interactive analysis.

**Description:** As many processing platforms emerge, it becomes common to perform part of the computation by invoking a processing service on a platform, analysing the output with a standalone application, then send it to another processing service and perform final presentation steps on the downloaded output. This workflow paradigm is sometimes supported by modern processing platforms, but the difficulty of composing a complex processing chain out of services running on multiple, interdomain distributed platforms (incl. running intermediate interactive analyses) are currently on the shoulder of the user. What is commonly lacking is the possibility to interactively compose processing, merge and customise different processing tasks. Past and current Service Oriented Architectures (SOA) and cloud paradigms like e.g. the Software-as-a-Service (SaaS) have made available initial building blocks and pilot environments to ease this task. Nevertheless, they have not led to an end-to-end solution that could enable the above described workflow, due to technical and administrative limitations (poor scalability and cost effectiveness, security issues, demanding resource management, etc.).

The most recent technology developments in the fields of software architecture and cloud computing, namely microservices architecture and containers, are showing potential to solve these issues, promoting an even stronger decomposition of functions into independent blocks that perform very specific functions, enabling scalability and dynamic provisioning of underlying IT resources. The MAGIC project shall adapt and further develop such technologies to provide a domain-independent and platform-independent generic model for the composition of processing services and interactive applications, including:

- a notation to specify the workflows of Processing Services and interactive applications, including a semantic component to manage and enrich the catalogue of processing services,
- a simple way (e.g. containerization of executable programs) by which user can provide new microservices as building blocks of the workflow, exposed as new, on-demand services,
- a workflow execution engine that is able to instantiate new microservices on different computing infrastructures (e.g. cloud environments but also local machines) and control the execution of the workflow services, including the interactive steps, if required,
- an Application Manager capable to run and manage applications on a computing cluster, sharing the cluster resources between the users and use lightweight virtualization to minimize platform overhead,
- an open repository of microservices (like e.g. downloaders, uploaders, data transformers, data converters, interactive applications) that can be shared among the users for reuse.

The tasks are the following:

- state-of-the-art technology survey (with gap analysis) and analysis of requirements and needs, including selection of real applications that will be demonstrated with the proposed approach of composition of (micro)services and interactive applications,
- design of the workflow notation, possibly reusing and extending existing notations,
- design of a platform-independent workflow execution engine, featuring a modular and open source architecture,
- development of needed software components and integration onto selected infrastructures,
- validation and demonstration on identified use cases in multiple domains (Earth Observation, Space Science, Operations).

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *26 - Others* |

**Ref. Number:** **GT17-069EO** **Budget (k€):** 700

**Title:** **BlockChain for Space Activities (BC4SA)**

**Objectives:** The aim is to develop and prototype a set of new technologies to enable secured and traceable exploitation of data from space related activities, adapting and capitalizing the emerging BlockChain technology.

**Description:** The growing availability of large volumes of data, in particular from upcoming missions such as the Sentinels, Euclid, Galileo, etc., represents a huge opportunity to further develop the market of space related information. At the same time, the involvement of new communities represents a huge challenge as new users (with own domain knowledge, and having specific community language) cannot easily discover, and process the right information from the large volumes of available data. This aspect has been partially addressed in the past through the development of tools based on semantic knowledge and ontology.

Nevertheless, one of the main issues still open is related to the availability of huge commercial and private datasets, combined with the availability of data exploitation environments, where data can be processed remotely, without moving them. It is therefore required to apply methods to enforce that this process is done in a secured manner, to avoid any leakage of sensible data. At the same time, data and corresponding metadata shall be verifiable. In this context, new technological approaches are critically needed to overcome the technical barriers and information gaps, that prevent from effectively connecting end-users to tailored and secured information, permitting to meet their specific needs and to ensure traceability of the data. The new technology shall empower new capabilities for both end-users and data providers, in particular from private sector.

This project aims at designing and developing a BlockChain Technology (originally developed for cryptography and virtual money) for space applications (like e.g. in EO and SCI); such technology shall ensure full traceability and security of data, in particular from commercial and private sources, hence supporting transfer of space applications to the marketplace. As an example, the BlockChain technology will be used to guarantee 'smart & light contracts' among a community of practitioners (farmers) who share an asset (land) that can be monitored from space (by S-2 and Vegetation), and a third party (banking industry) that can provide an economic value (lend money) to the community.

The idea of the activity is to explore how the combination of monitoring from space (of land parcel) and digital certification through the BlockChain technology can enable new type of transactions (e.g. bank landing micro-credit to poor farmers). The concept illustrated in this example can be extended to any community (fishers, builders, wetland managers), and any other asset (infrastructures, buildings, water bodies, cultural heritage sites, forests) that can be monitored from space while representing an economic value for third party (e.g. insurance industry, development agencies, ethical investors), with the idea to ultimately create new types of digital marketplaces enabled by the intersection of space data, digital technologies and BlockChain. The developed technology shall be demonstrated on a set of use cases, like e.g.:

- insurance industry, dealing with secured risk information, where an in-depth understanding of both user practices and geospatial data access protocols is required,
- GNSS Science collaboration, dealing with secured risk information, where an in-depth understanding of both scientific practices and data access protocols is required.

This will promote:

- more effective uptake of space related data and services in existing and new markets, as well as market access for new suppliers;
- development of the new generation of innovative and agile secured ground segment infrastructures, with 'smart' contract components effectively linking secured and traceable user applications to satellite data;
- exploitation of upcoming satellite missions and integrated information services, in particular with integration of open data and commercial data and full traceability.

The activity is composed of the following tasks:

- State-of-the-art technology survey (with gap analysis) and analysis of requirements and needs, including selection of real applications for demonstration,
- design and development BlockChain functions, which shall establish the 'trust' among the community for sharing of the data,
- integration of developed software components onto the selected infrastructures,
- validation and demonstration on identified use cases.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *26 - Others* |

**Ref. Number:** **GT17-070GE** **Budget (k€):** 600

**Title:** **Automated Fault Root Cause Analysis and Forecasting (ARCA)**

**Objectives:** The aim is to develop a toolkit for automated fault root cause analysis and forecasting in software intensive environments. The toolkit will constitute a key building block towards automated, intelligent integration and test environments.

**Description:** The more Space Systems become complex Systems of Systems (SoS), the more their Integration and Testing (I&T) is critical and instrumental to ensure that the SoS meets its requirements in support of the final mission objectives. In turn I&T itself becomes complex, it requires multidisciplinary expertise in a variety of disciplines, is very effort intensive and therefore costly. If a fault is detected the first difficulty is to identify where the fault has originated within the many systems comprising the SoS, then the root cause of the fault needs to be identified in order to be able to provide meaningful information for addressing the problem and finding a solution.

System test engineers have limited visibility of what is really happening in the systems under test. Nevertheless they must produce meaningful fault reports, targeting these reports to the correct system component and providing information about the potential cause(s) of the fault This is a big challenge. Incorrectly targeting a fault report to the wrong system component generates unnecessary workload for software developers and produces waste, which is in direct conflict with the efficiency principles being actively pursued both by ESA and Industry. An even more advanced step is fault prediction, in the attempt to strive to improve systems quality and testing efficiency through the employment of predictive models able of timely identification of fault-prone systems.

Intelligent and automated fault root cause analysis and forecasting is expected to bring huge benefits in this domain. Research on fault root cause analysis and forecasting has been conducted since more than a decade. Also data mining, computer learning, multi-agent systems, testing optimisation techniques, big data technologies have surfaced and can be applied to the development of solutions in this area.

The activity will start with a survey of relevant technologies and assessment of their suitability for the purpose. It will prototype methodologies and tools for fault root cause analysis and forecasting and orchestrate them into a toolkit that can be applied both at subsystem and system level. The results shall be demonstrated on representative scenarios and data.

The activity is composed of the following tasks:

- survey of relevant technologies and down-selection,
- prototyping of a toolkit for fault root cause analysis and forecasting,
- demonstration in representative environment.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** All software intensive domains and all missions. Instrumental to advance automation of Integration and Test (I&T) environments and enable higher I&T efficiency and effectiveness to reduced cost for missions. TRL 6 by 2020.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

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| *Domain* | *Generic Technologies - CD9 - Digital Engineering for Space Missions* |
| *Tech. Domain* | *26 – Others* |

**Ref. Number:** **GT17-071GE** **Budget (k€):** 600

**Title:** **EuGRA - European Ground Reference Architecture**

**Objectives:** The aim is to define a European Ground Reference Architecture covering all elements and processes from Assembly, Integration and Testing (AIT) to operations.

**Description:** Europe is currently lacking of a common Ground Reference Architecture. Without a common reference architecture, interoperability among different European stakeholders is in many cases difficult to achieve. The European Harmonisation on Functional Verification and Mission Operations Systems (FV and MOS) roadmap has identified the need for a Ground Reference Architecture at European level as one of the top three Harmonisation priorities.

EuGRA will enable shared AIT as well as operations preparation and execution across European players. This is particularly important given the increasing complexity of future missions and the increasing distribution of mission operations.

A ground reference architecture offers a number of benefits:

- direct support for collaborative ground system development and operations capabilities,
- establishing interoperability and synergy between many different and evolving sub-systems, enabling a plug-and-play-like interchange concept for ground systems,
- enabling large-scale re-use of components and the flexibility and expressiveness to define complex, federated systems for specific missions quickly and efficiently,
- enabling and justifying priorities for the development of architecture elements and patterns and thus also supporting efficient decision making through facilitation of trade-off analysis and evolution projections,
- reducing development and lifecycle costs.

The activity will select a Model-Based System Engineering framework, development platform, and standards to define and model the EuGRA and a common ontology and taxonomy. The chosen modelling framework will be used to specify a high-level ground reference architecture based on the European Ground Segment Common Core (EGS-CC) and other European architectures, spanning all processes from AIT to operations. The need for different views for Mission Control Systems and Electric Ground System Equipment / Software Validation Facility with common elements shall be clearly identified. This also includes the definition of interfaces and re-usable patterns to ensure a plug-and-play-like capability. Documentation such as architecting principles and modelling best practices shall be produced. In order to achieve Europe-wide agreement on the reference architecture, the whole activity will be performed under the lead of a steering board at European level.

The task list is the following:

- analysis of the current generic ground architecture and identification of main building blocks. Organization of workshops with mission operations engineers and stakeholders,

- selection of the MBSE framework, development platform, and standards. Definition of a common taxonomy and ontology for the architecture,
- modelling of the European Ground Reference Architecture,
- definition of re-usable patterns in line with the specified interfaces.

**Deliverables:** Software

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|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 5 | **Duration (months):** | 16 |

**Target Application/ Timeframe:** Standardisation and interoperability around a shared architecture will allow synergies and seamless exchanges and cooperation among European space partners. This will enable extended joined capabilities and increase efficiency. TRL 5 by 2019.

**Applicable THAG Roadmap:** Functional Verification and Mission Operations Systems (2014).

## 3.5.10. CD10 - Astrodynamics / Space Debris / Space Environment

### 3.5.10.1. TD04 - Spacecraft Environments and Effects

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|---|---|
| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT17-072EP** **Budget (k€):** 500

**Title:** **Low resource spacecraft plasma monitor prototype**

**Objectives:** The objective is to create a prototype plasma monitor with low requirements for mass and power, suitable as a standard equipment for spacecraft anywhere in the Earth's environment where hazardous charging levels may be encountered.

**Description:** Spacecraft plasma interactions are frequently the cause of anomalies and malfunctions on spacecraft. Particularly orbits that encounter hot electron populations, including GEO, MEO/Galileo and PEO are hazardous. There is a good heritage of science quality instruments that can measure the plasma environment and which can be used to infer the charging state of the spacecraft. These instruments generally have a performance that far exceeds the requirements for assessing charging hazards. However, they are demanding in terms of mass and power.

In this activity, a prototype of a plasma monitor will be created that will aim to achieve a mass of around 1kg or less, that can characterise the ambient electrons and ions in the energy range 30eV-30 keV. Miniaturisation of electronics and the electro-optics will be explored to reduce both mass and power requirements.

The prototype will be able measure the aspects of the plasma environment that control the spacecraft potential and to infer the potential of the spacecraft with respect to the ambient plasma. Rapid measurements, complete angular coverage and high energy resolution are not essential and could be sacrificed for a simpler design. A design that can easily be accommodated on different spacecraft and could, with little modification, be used in a range of orbits is preferred.

The following activities are foreseen:
- requirements and technologies trade-off,
- conceptual design,
- detailed design including analysis with respect to radiation assurance, vibration etc.
- fabrication,
- functional testing.

**Deliverables:** Engineering Model

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** TRL6 by 2020.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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|---|---|
| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT17-073EP** **Budget (k€):** 500

**Title:** **Radiation energy effects on electronic components with very high energy heavy ion and electron beams**

**Objectives:** The objective is to evaluate the behaviour of advanced component technologies in very high energy accelerators that realistically represent the space environment, and compare with experiments at traditional radiation facilities of lower energy that are routinely used for radiation hardness assurance. In addition, it is aimed to investigate single event effects caused by energetic electrons, and effects in COTS components through irradiation of complete units.

**Description:** Through collaboration with the GSI accelerator and in the scope of the ESA-CERN collaboration agreement, access has been gained to very high energy ion beams. These have already shown that components exhibit different single event effect (SEE) behaviour than in lower energy facilities because of various different physical processes at play. This activity will further investigate these effects in new generation technologies such as power transistors and systems, integration devices, micro-processors/controllers, FPGAs, ASICs and all types of memories used in space systems. At high energy, the risk of multi-bit upsets in digital technologies is increasing, thus decreasing the efficiency of ECC and EDAC, and new failure modes (gate rupture, burnout and several clock-cycle disturbances) will significantly affect the operation of power and integration technologies.
Experiments will be performed over a range of ions and energies. In addition, facilities will be used to irradiate complete functioning units, also including COTS components, to observe the behaviour in flight conditions. Finally, energetic electron facilities will be used to investigate single event effects due to energetic electrons of relevance to MEO, GEO and EPOR environments, and quantify the processes responsible. All these experiments will be supported by Geant4 simulations. The activity will create, where necessary, recommendations for changes to radiation hardness assurance processes and standards.
The activity includes the following tasks:

- select technologies for investigation through a consultation process; establish availability of appropriate facilities,
- perform experiments at high energy facilities, including GSI and CERN, and also using traditional space RHA facilities,
- evaluate the results, derive the mechanisms involved with the help of Monte-Carlo particle simulations, with reverse-engineered technology definitions,
- propose ways forward in technology selection for space; propose updates to test method and standards where appropriate.

**Deliverables:** Analysis reports and possible change requests/new item proposals for methods, processes and standards.

**Current TRL:** 3 **Target TRL:** 6 **Duration (months):** 36

**Target Application/ Timeframe:** 2020.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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|---|---|
| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT17-074EP** **Budget (k€):** 700

**Title:** **Radiation monitor data analysis for radiation belt modelling**

**Objectives:** The objective is to exploit data from the expanding network of radiation monitors in orbit for validation, new engineering models, and improvement of processes. Inter-compare where conjunctions occur, consolidate calibration data and establish a reference database of counts and fluxes. The fluxes will be derived using the appropriate response information and various algorithms. With the consolidated database, process statistically to derive new radiation belt models, adapted where necessary for different spatial domain.

**Description:** Following the development of the Prototype Flight Model of the next generation radiation monitor (NGRM) that will fly on EDRS-C, further procurements are in advanced preparation, (e.g. for MTG and Metop-SG). In addition, data is still returning from the SREM network, the EPT on Proba-V, the SATRAM pixel detector on Proba-V, and the CNES-funded ICARE instruments. Soon data will emerge from the EMU instruments on Galileo, augmented by data from EMU units flying on Japanese spacecraft.

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.

Models will be established for specific regions 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 pre-formed, together with maintenance and updates.

**Deliverables:** Software

**Current TRL:** 5 **Target TRL:** 7 **Duration (months):** 30

**Target Application/ Timeframe:** TRL 8 by 2019.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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|---|---|
| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT17-075EP** **Budget (k€):** 400

**Title:** **Microparticle model validation based on in-flight data**

**Objectives:** Develop a software framework to compare the data collected by in-flight monitors with the predictions of microparticle models. The produced tool shall be developed with the aim to analyze DEBIE-1 data that is collected continuously on board the Proba-1 mission. Nevertheless, the development should also aim to keep the tool versatile to allow the processing of other instrument/mission data.

**Description:** Microparticles pose a significant risk to spacecraft and in some parameter regions the flux of microparticles is not well known. Dedicated monitors in space collect data on hypervelocity particle impacts. The collected instrument data at spacecraft location and attitude can help to validate/improve existing microparticle models. The DEBIE-1 detector is operational for about 15 years on board the Proba-1 mission and is collecting hypervelocity impact data. The data is collected on ground and has not been analyzed since about 2005. This activity should develop a framework to compare the DEBIE-1 detector data with existing microparticle models.

Following steps are anticipated to be necessary in this activity:

- analysis of DEBIE-1 data to derive particle flux properties over the full mission,
- comparison of observed particle flux data with various flux model predictions,
- feedback of observed fluxes into flux model development (e.g. MASTER for space debris).

Previous work on DEBIE-1 data has been performed. The work indicated various noise sources and a need for sophisticated data processing methods. These methods shall be revisited in this complementary assessment and the data analysis extended to the full mission duration.

The outcome is expected to validate/improve microparticle flux models and reduce the related uncertainties. The long-term evolution of the flux over about 15 years is expected to provide valuable information on the time evolution of the debris and improve predictions for future missions, covering Earth-observation, science and telecommunication missions (esp. future constellations).

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL-6 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 1.1.1.2 TD10 - Flight Dynamics and GNSS

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *10 - Flight Dynamics and GNSS* |

**Ref. Number:** **GT17-076GF** **Budget (k€):** 350

**Title:** **Challenges for the future Flight Dynamics system and processes**

**Objectives:** With its continuously evolving Flight Dynamics (FD) system, ESOC has successfully supported a large number and variety of missions. This evolution of the FD system has to continue to face the future challenges related to changing ground segment system environment, new technologies, cost pressure and small missions.

The objective of this activity is to come up with recommendations for concrete changes to be made to the Flight Dynamics system and its processes in order to properly respond to these challenges.

**Description:** The activity shall start with reviewing, detailing and analysing the impact of the following challenges:

- the core business of FD will remain the support to ESA science and Earth observation missions. For this, the FD system will have to adapt to and interact with the ESA ground segment systems of the future (MCS, MPS, GS),
- there is an increased demand to provide tailored FD support to external control centers, particularly in the area of missions analysis, orbit determination and orbit control. These demands can be on short notice e.g. to respond to contingencies or in case of small projects with short life cycle. It is therefore important that the FD system and its external interfaces can be configured quickly and with minimum effort,
- cost reduction, and in particular mission specific development cost remains an important challenge,
- the FD system is a single multi-mission system. This significantly simplifies support and maintenance. As changes in the system impact all the supported mission, long term stability is very important. This has to be considered when using opportunities offered by new technologies and introducing dependencies on external systems,
- for small and short track projects it is anticipated that operations preparation and testing will be less consolidated as in the past and thus more flexibility will be need during operations to respond to unforeseen situations. This requires a high level of responsiveness not only in terms of operational procedures, but also in terms of updates to the FD system.

Subsequently it shall be identified which changes have to be made to the Flight Dynamics system and its processes to properly respond to these challenges. Critical changes and developments, in particular the ones related to external interfaces, shall be prototyped and evaluated in terms of performance, effort to implement, operational simplicity and compliance with the Flight Dynamics system and its mode of operation.

It shall be considered that the FD system operates according to a predefined schedule and procedures. This guarantees the consistency of the entire data set exchanged via the external interfaces for a particular scenarios.

**Deliverables:** Prototype Software

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

**Target Application/ Timeframe:** Flight Dynamics systems for future ESA missions. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.5.10.2. TD11 - Space Debris

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT17-077GR** **Budget (k€):** 500

**Title:** **Large impact detectors for mm-particles resolving impact momentum vectors**

**Objectives:** This activity shall expand on sub-solar cell conductive grid technology that allows to use the whole area of a satellite covered by solar cells. The goal is to gain additional information on the impacting objects by combining impact position and crater size (obtained from the wire grid), with accurate attitude rate measurements and sound detectors for a full characterisation of the impact. The idea is to draw from the flight proven SOLID technology and expand it for attitude rate and sound-based measurement units.

**Description:** In recent years, novel types of impact detectors have been developed. In order to increase the sensitive detection area, which is essential to detect within the important mm-size regime, these novel detectors make use of the large solar array areas. For this, they are deployed between the solar arrays and the solar panel structure. The detectors consist of wire grids under voltage to measure also impact location and crater size. First prototypes are currently under test (e.g. SOLID onboard of the TechnoSat mission). In order to understand the space debris environment in the size range above 1mm size (where current space debris models deviate by a factor of 100), large detector sizes are required and the technology needs to involve in order to compute the impact vector. For this the detector design needs to be extended to combine impact location detection with attitude rate change measurements. The feasibility of computing impact momentum vectors from attitude rates has recently been demonstrated by the analysis of the Sentinel-1A impact into its solar arrays.

Further, small piezoelectric detectors have been developed to analyse sound waves in the structure induced by the impact. With this it will be possible in a multilateration approach to determine the location of impactors that do not reach the wire grid. This study shall prototype and prepare for flight test in a large ESA mission in LEO an extended impact detection scheme combining the proven wire grid technology, with to-be-developed sound detection and evaluation of AOCS data.

**Deliverables:** Prototype

**Current TRL:** 5 **Target TRL:** 7 **Duration (months):** 12

**Target Application/ Timeframe:** Flight model by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT17-078GR** **Budget (k€):** 650

**Title:** **Advanced Collision Avoidance Techniques**

**Objectives:** Upcoming mega-constellations for telecommunications in LEO, the upcoming use of electric orbit raising with long residence time in densely populated region in combination with a growth of the tracked space debris population to the increase of the population itself but also due to the introduction of the new US space fence poses a challenge for the current operational approach to collision avoidance since it would trigger a far larger number of avoidance manoeuvres with their associated costs of fuel, mission interruption on on-ground operations efforts. This activity aims at maturing approaches for automated decision taking, advanced collision risk algorithms and avoidance manoeuvre approaches.

**Description:** With the introduction of the new US space fence the catalogue of tracked objects in Low Earth Orbit will increase by an order of magnitude and with it the frequency of known close approaches with operational spacecraft. This and the upcoming mega-constellations for telecommunications in LEO and the upcoming use of electric orbit raising with long residence time in densely populated region in combination with a growth of the space debris population, will make automation in collision avoidance necessary. While a surveillance system will be required, the time consuming data monitoring, decision taking and on-call availability is subject to automation on-ground to achieve significant cost savings. This need has also been recognised in a recent council working group paper.

This activity shall implement algorithms aiming at automating decisions on whether or not to perform collision avoidance manoeuvres and test them on the database of past close approach events by comparing with actual decisions taken, thus providing a basis for further automation of the operation collision avoidance process in preparation of the future 10-fold increase in the number of catalogued objects. Furthermore, the activity aims at testing advanced techniques to compute collision risks (e.g. taking realistic SC shapes and attitudes into account) and to perform avoidance manoeuvres (e.g. attitude manoeuvres or thrust profile modulation for low/continuous-thrust missions) with a view on their efficiency in reducing the overall collision risk for a mission when compared to traditional approaches

**Deliverables:** Prototype Software.

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

**Target Application/ Timeframe:** 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT17-079GR** **Budget (k€):** 400

**Title:** **Numerical simulation of hypervelocity collisions for breakup model calibration**

**Objectives:** The objectives are to:

- use numerical hydrocodes to simulate hypervelocity collisions for different impact geometries and spacecraft configurations,
- show that hydrocodes can be validated, e.g. via impact tests, and that the obtained results can be used to extrapolate for configurations that were not tested,
- revise current state-of-the-art breakup models for satellite collisions and propose an improved model which benefits from hydrocode analysis.

**Description:** The analysis of the long-term evolution of the space debris environment requires to model collision events between on-orbit objects. The current approach is to apply an empirical breakup model which was calibrated on real breakups in space or hypervelocity impact tests under laboratory conditions. While the former approach was only feasible for a very small number of events and subject to possible observational errors, the latter approach suffers from having to select a small subset for the test setup from a wide range of possible breakup conditions.

Deriving model parameters from such analyses renders unobserved conditions non-applicable to the model. Numerical hydrocode analyses allow to sample from a significantly larger space of breakup conditions and therefore to assess model parameters more accurately or even derive additional parameters for previously unmodelled effects. In this activity, numerical hydrocodes shall be used to simulate hypervelocity impacts for a broad range of impact geometries and spacecraft configurations. It shall be shown that the employed hydrocodes can be validated, for example via several impact tests and the extrapolation errors for other conditions can be evaluated. A new breakup model shall be proposed which benefits from a better knowledge of parameters also known to former breakup models but also covers breakup conditions that were not covered before.

The general application of numerical hydrocode to the problem of hypervelocity impacts in spacecraft structures has been studied in a previous activity in GSP with the title 'Numerical Simulations for Spacecraft Catastrophic Disruption Analysis'.

**Deliverables:** Prototype: existing software for numerical hydrocode analysis shall be applied to a specific problem of hypervelocity impacts. The deliverable will be a model derived from the numerical analysis.

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** Models for satellite breakups are used not only to evaluate past events, but also to assess the evolution of the space debris environment. The model developed in this activity shall improve the current state-of-the-art and be used in the context of evolution models. TRL 5 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT17-080GR** **Budget (k€):** 500

**Title:** **High-resolution spectroscopy of space debris fragments**

**Objectives:** A proof-of-concept of optical reflectance spectroscopy of space debris fragments in orbit was achieved with ESA's Optical Ground Station in 2008/2009 with a low-resolution spectrograph originally designed for observations of comets. This activity shall extend the data acquisition to other spectrographs, potentially also using other sensors, such as, e.g. the Nordic Optical Telescope (NOT).

The hand-over of precise short-time predictions for space debris fragments shall be implemented first (including also high area-to-mass (HAMR) objects), possible improvements of using new instrumentation allowing for high resolution (in time and wavelength) of spectra of debris fragments shall be assessed, tested, and mounted (on loan). A larger sample of spectra from fragments in higher altitudes shall be acquired and stored in a easily accessible database. Based on initial work done with ESA on the change of material characteristics of objects after prolonged periods in space, a model to explain the observed reddening of spectrographic observations shall be proposed. Concepts to distinguish between debris fragments subject to reddening or inerts ones shall be derived.

**Description:** For the modelling of the generation and evolution of the population of small-size debris at high altitudes, especially after the discovery of high area-to-mass-ratio (HAMR) objects, not only astrometric and photometric data but also optical reflectance spectroscopy has proven to provide crucial and complementary data. Nevertheless, the origin of HAMR objects is still not fully understood, and further progress will provide very valuable information to satellite design and manufacturing, as well as to satellite operations.

Spectroscopic observations provide access to the material composition of the surfaces of satellites and fragments. Such observations of several faint HAMR debris have been demonstrated as proof-of-concept in 2008/2009 with a low-resolution spectrograph mounted at the RC-focus of the 1-meter ESA telescope at the Optical Ground Station at Tenerife. The spectrograph was originally designed for observations of comets and was not optimised at all for space debris observations.

Based on these previous findings the observation concept shall be revisited and generalised for different configurations of spectrographs. The baseline concept calls for support observations from other telescopes to acquire the study objects in the narrow field-of-view of a spectograph. Data exchange and timely hand-over processes and efficient interfaces shall be developed and tested. In parallel, the best suited available spectrographs for researching faint space debris in high altitudes shall be reviewed and suitable mounting options, not limited to ESA's OGS or the Nordic Optical Telescope (NOT) shall be studied. The activity shall then plan and conduct a first test campaign with the spectrograph on loan. From the findings of the test campaign the planning shall be revisited for a full campaign. The aim of the full campaign is acquire a substantial sample of measurements that allows to characterise the material properties of surfaces of small debris in high altitudes, in particular of HAMR objects. In the processing of the data significant effort shall be foreseen for the correction of the atmospheric extinction as the dominating error source, and that only photometric nights are used where enough observations of well distributed solar analog calibration stars are acquired. Different approaches to correct the extinction shall be studied, and also a sufficient number of intact, attitude controlled spacecraft in GEO as references objects for the material characterisation are acquired.

The activity shall access and as well conduct lab measurements of reflection spectra of different relevant materials. All results from the labs and the conducted observation campaigns shall be made available in an easily accessible database. The database shall the allow to characterise materials, but shall also describe (based on earlier research) the change of material characteristics of objects after prolonged periods in space. Finally, with the help of the database models to explain the observed changes (such as reddening) of HAMR objects in GEO shall be proposed. These models shall then be employed to derive first concepts to distinguish between debris fragments subject to reddening and inerts.

**Deliverables:** Observational and lab data, database and numerical models.

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

**Target Application/ Timeframe:** Space object characterisation, of prime importance to extension of the statistical small debris population models as well as model describing their genesis for future environment evolution. Distinguishing between deep space artificial and man-made objects. TRL 6 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 1.1.1.3 TD20 - Structures

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| *Domain* | *Generic Technologies - CD10 - Astrodynamics / Space Debris / Space Environment* |
| *Tech. Domain* | 20 - Structures |

**Ref. Number:** **GT17-081GR** **Budget (k€):** 1,000

**Title:** **Development of an enhanced spacecraft fragmentation cod**

**Objectives:** The objective of this activity is to accurately predict the fragmentation of a spacecraft during demise by developing a code that encompasses the aerodynamics, thermal and structural phenomena contributing to such event. This code will be used to improve the SCARAB tool so allowing for a better spacecraft design for demise and an improved calculation of the casualty risk probability.

The specific objectives of the activity are the following:

- Review of the existing aerothermodynamics/flight-mechanics coupled methodologies and tools employed currently as well as flow/structure coupled methodologies and tools. Identification of improvement and further development.
- Provide with a validated aerodynamic/flight-mechanic/thermal/structural analysis methodology and code, as part of and in support to the fragmentation analysis tools.
- Provide with an interface tool for re-defining and re-meshing the resulting geometry after each time step of the cycle analysis
- Provide with a communication platform for the interconnection of the different modules above mentioned within a time simulation strategy.
- Review of the existing structural analysis methods and tools employed currently as part of the fragmentation analysis tools. Identification of improvement and further development.
- Development of a validated structural analysis methodology and tool, as part of and in support to the existing fragmentation analysis tools.
- Integration of the structural analysis tool with the full analysis cycle.

**Description:** Nowadays the aerodynamic and aero-thermal characterisation of demisable objects is performed with the so-called engineering methods (e.g. panel methods and/or newton methods) coupled with trajectory codes. Although these methods are computationally faster, they are not able to predict in a proper way, the pressure and heat fluxes resulting from complex multi-body configurations, embedded in high temperature thermo-chemical phenomena. Therefore, from these engineering methods it is difficult to assess the uncertainties on their aerothermodynamic predictions, while their validation is very cumbersome since their accuracy is strongly case dependent.

In this proposal, those engineering methods shall be replaced in the rarefied and transitional regime with a DSMC code for reacting flows, and if it is considered an advantage, with a CFD code for reacting flows in the continuous regime. While time dependent solutions of the body motion (coupling between aerodynamic and flight mechanic) are preferable, a loosely coupling where the aerodynamic module will provide the forces and the flight mechanics module will return the spacecraft attitude, is also acceptable.

Furthermore, a loosely coupled aerothermodynamics, thermal and structural analysis shall be performed. There, the aerothermodynamics module will provide the heat fluxes and surface pressure. Based on the heat fluxes the thermal model will derive relevant temperature ranges, which will have to be mapped into the structural model. Relevant mapping techniques will have to be assessed and, in case, be adopted or developed.

The code should be able to account for main shape changes due to thermal demise and / or major shape changes due to structural splitting. An interface tool shall be provided, in order to redefine, if necessary, the new geometry resulting from each time step. The computational effort could be reduced by means of smart interpolations of the high fidelity solution towards the next time interval. An assessment will have to be done on whether and how chemical deposition processes (e.g. resins) will have to be reflected in the thermal model. Such functionality may eventually only be added in a future evolution, but should be considered already within this activity.

Structural analysis is required to determine the mechanical failure sequence during a re-entry into the atmosphere, which describes ultimately the fragmentation of the vehicle, i.e. the size, mass, momentum of fragments and the time of their appearance. The structural analysis is intended to determine the sequence of failure modes in the real configuration as a consequence of the time-dependent aero-thermodynamic loads (pressure and temperature). Additional inputs to the structural analysis are provided by the thermal analysis, in terms of temperatures of all parts and materials subject to failure. The structural failure modes shall be analysed taking into account the thermal dependence of the materials allowable loads.

Inputs to the structural analysis are the Spacecraft geometry (CAD model) in operational configuration, FEM or similar model of SC in operational configuration, aerodynamic profile (pressure distribution on outer surfaces as a function of time), thermo-dynamic profile (temperatures of structural joints and structural members such as plates, beams, brackets as a function of time), allowable values related to the failure modes. The outputs shall include the failure sequence and time history, and the stress tensor time history of the critical parts. A validation of the methodologies and predictions of the code shall be performed by using existing data and ground testing.

**Deliverables:** Software, plus development and validations reports

| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

# 3.6. Space Situational Awareness

## 3.6.1. Space Situational Awareness

### 3.6.1.1. TD01 - Onboard Data Systems

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *01 - Onboard Data Systems* |

**Ref. Number:** **GT18-001ED** **Budget (k€):** 650

**Title:** **Prototype Remote Interface Unit (RIU) for SWE hosted payloads**

**Objectives:** The objective is to design and develop a prototype remote interface and data handling unit for hosted payload instruments and SmallSat missions.
Miniaturisation of instrumentation for Space Weather (SWE) measurement systems is typically limited by the need to provide the interfaces to the spacecraft, in particular the power conditioning and voltage conversion. A flexible interfacing to the S/C bus and the isolation of potential failures within the instruments are necessary for the acceptance of payloads on-board of commercial hosting satellites in particular to realise flight opportunities with short notice. The activity shall develop a low-resource processing and interface unit that is optimised for space weather purposes and suitable for a variable set of instruments selected depending on the flight opportunity.

**Description:** This activity shall develop a Payload Interface & Data Handling Unit (PIDHU) for SWE hosted payloads which shall provide power supplies at various voltages required by space weather/environment instruments limiting the mass required for individual instrument voltage transformers. The PIDHU shall receive data streams from instruments through various protocols including UART (RS-422/485), SpaceWire, MIL-STD-1553 and CAN Bus and provide data though a single data interface adaptable to hosting spacecraft requirements. As an option, the PIDHU will include on-board data processing and storage capabilities to reduce the data bandwidth required and therefore increasing the volume of useable, processed data to be downlinked. As a further option, the system will include an interface to a dedicated transmitter allowing for independent downlink of data to a SSA or other ground stations. The design phase shall also consider the desired compatibility with a SmallSat mission which is currently under study.

The mass, volume and power requirement of such an PIDHU will depend strongly on the number of instruments to be supported, the ratio of the power conversion needed and the amount of on-board processing capability required. The baseline PIDHU to support more than 5 instruments and convert power from a 28 V (TBC) supply shall have a mass less than 2 kg and a volume envelope of less than 200 x 200 x 200 mm, which can be traded versus recurrent costs versus a modular building blocks approach. The power required by the instruments will be further investigated during the design phase of the study.

A proto-flight model of the PIDHU shall be built to conform to the requirements of an identified flight opportunity to test a selection of space weather/environment instruments presently under development. This proto-flight model shall undergo standard space environment tests and end-to-end qualification tests with the instruments identified as part of the payload.

**Deliverables:** Prototype

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** 2019. Space Weather Payloads.

**Applicable THAG Roadmap:** Data Systems and On-Board Computers (2016).

### 3.6.1.2. TD04 - Spacecraft Environments and Effects

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

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| **Ref. Number:** | **GT18-002EP** | **Budget (k€):** | 600 |
| **Title:** | **Solar Activity Onset Modelling** | | |

**Objectives:** Solar eruptions are at the source of almost all major space weather events. Including flares, Coronal Mass Ejection (CMEs) and filament eruptions, they constitute an explosive release of excess magnetic energy in the solar corona with the potential to drive conditions observed at Earth. Resulting space weather disturbances include geomagnetic storms and substorms, enhancement of the Earth's radiation belts, solar particle radiation storms and increased ionisation of the Earth's ionosphere. This activity will take existing physics-based models of solar active region magnetic fields, test/verify these in terms of ability to reproduce observed eruptive conditions and further analyse the computing resources required to run them in (near) real-time.

**Description:** A software prototype shall be developed and verified in order to complement Space Situational Awareness (SSA) programme's existing products incorporated as part of its Space Weather element. Specifically, this activity shall be harmonised with developments taking place as part of ESA's Virtual Space Weather Modelling Centre (VSWMC) as it will form the first, crucial, element in a chain of space weather models. Following an assessment of relevant SSA and VSWMC requirements, a consolidated set of requirements for physics-based models of the evolution of the solar magnetic field and resulting eruptive processes in the solar corona shall be established to determine the development of the underpinning modelling to be carried out as part of this activity. These requirements will be focused on improving the prototype's forecast capability towards meeting the reliability requirements of SSA space weather customers. These requirements shall be driven by the corresponding data requirements of other elements in the end-to-end space weather modelling system to enable more accurate modelling of phenomena extending into the interplanetary medium, particle radiation propagation and energetic electromagnetic particle flux enhancements.

The development shall take existing proven modelling concepts which describe processes in the corona, chromosphere and photosphere to build a model implementation including all established required functionality. It shall be possible to operate the developed model in near real-time based on a defined set of observables which are measured routinely as part of existing solar observations. The model operation shall be verified with a reproducible set of test data in order to ensure correct operation within a pre-defined parameter space of input variables. The model results shall then be validated against pre-defined observables in test data. The resulting model shall then be implemented on the SSA system via integration with the VSWMC and a final verification shall be performed to confirm the implemented model behaves as expected. The output of this model development will be harmonised with activities of the SSA Solar Weather Expert Service Centre (S-ESC) to facilitate integration.

**Deliverables:** Software

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

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| **Target Application/ Timeframe:** | TRL 5 by end 2019. Space Weather. |
| **Applicable THAG Roadmap:** | Not related to a Harmonisation subject. |

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-003EP** **Budget (k€):** 600

**Title:** **Radiation Monitor System in a Package**

**Objectives:** The aim is to develop a general-purpose radiation monitor with small size, easy interfacing and low unit cost that is capable of registering and categorizing single particles.

**Description:** Traditional radiation monitoring based on discrete components usually results in relatively heavy instruments with relatively high procurement cost. However, recent advances in Systems In Packages (SIPs), ASICs and Monolithic CMOS sensors allows the development of highly integrated packages containing the detection and processing electronics, and avoiding high voltages.

This activity will select the most appropriate technology from previous R&D in the space and high energy physics domains, and design and prototype a radiation monitor that can distinguish particle energy deposits in well-defined volumes, as a basis for general purpose monitoring of electrons, protons and heavy ions. Spectroscopy may be implemented in follow-on development with add-on selection techniques based on shielding, stacking or magnetic field selection, but the baseline should be a stand-alone minimal single sensor system. Target mass for the system is <100g.

The activity tasks are to:

- review miniaturization technologies in space and HEP, in context of measurement requirements,
- select appropriate technology,
- perform bread-boarding and develop prototype, if necessary with ASIC/detector fabrication runs,
- screen with cosmics and Co-60; full characterisation in p, e beams,
- establish FM design, development plan and costing.

**Deliverables:** Prototype, beam characterization, FM design, development plan and costing.

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

**Target Application/ Timeframe:** 2020. Space Weather.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-004EP** **Budget (k€):** 1,000

**Title:** **Heliospheric modelling techniques**

**Objectives:** Development of a physics-based models for operational prediction of the propagation of CMEs and solar energetic particles to the Earth.

**Description:** The background solar wind and solar eruptions, such as coronal mass ejections (CMEs) and High-speed Solar wind Streams (HSSs), propagate into interplanetary space are drivers for space weather phenomena. Resulting impacts include geomagnetically induced currents (GICs), ionospheric disturbances interfering with GNSS systems, spacecraft charging, single event effects on spacecraft and launchers resulting from accelerated Solar Energetic Particles (SEPs) and aurora especially at high latitudes. Many physics-based models have been developed for simulating parts of the Sun-to-Earth space weather system, consisting of plasma, fields and energetic charged particles. Depending on the problem, these use a variety of modelling techniques (magneto hydrodynamics, particle-in-cell, etc.). At this time such models exist in the form of scientific codes but require additional technical development before a transition to operations.

This activity shall develop and enhance existing physics-based models of Coronal Mass Ejection (CME) structure, propagation and evolution creating a full global 3D code. Outputs shall include the prediction of arrival times of CMEs and HSSs, event-time profiles of the plasma density along with the magnetic field strength and direction in the heliosphere from a few solar radii up to and beyond 1 AU. The inclusion of an SEP propagation model driven by the modelled CME-driven shock shall be explored. Efforts to unify such codes have been previously undertaken as part of the ESA SEPEM project and the FP7 SEP Server projects but
the creation of a physics based European operational model for SEP onset and evolution is lacking.

The model(s) will be integrated into the SWE Network via the Virtual Space Weather Modelling Centre.

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 6 by end 2019. Space Weather.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-005EP** **Budget (k€):** 800

**Title:** **Virtual Space Weather Modelling Centre (VSWMC) - Part III**

**Objectives:** The objective is to continue the development of a system based on coupled, geographically-distributed models and data sources to provide space weather forecasts and specifications. The system couples models of space weather event initiation at the Sun, their propagation and acceleration, and the complex interactions with the Earth's magnetosphere, ionosphere and thermosphere leading to hazardous conditions such as hot plasma and radiation belt enhancements. Models and data sources will couple in assimilation methods. The distributed paradigm allows expert centres to maintain and develop components of the system transparently from end users. This part III activity is intended to extend the modelling chain, develop further the development environment for interfacing models, expanding visualisations and incorporating additional data sources.

**Description:** The Virtual Space Weather Modelling Centre (VSWMC) Part 1 has successfully developed and demonstrated distributed, coupled model architecture and methods. This architecture has been enhanced to a software prototype level in Part 2 and is being integrated into the Space Situational Awareness (SSA) programme portal for exploitation by SSA users. The focus in these phases has been on coupling the high solar corona with propagation of resulting phenomena through the interplanetary medium to drive models of the Earth's magnetosphere and radiation belts. In Part 3, the system will be expanded to include additional models with a focus on extending the VSWMC capability to cover the lower solar corona, solar energetic particle propagation, the Earth's ionosphere and thermosphere, and models of variation in ground level magnetic field. As part of the activity the VSWMC outputs shall be interfaced to effects tools for spacecraft and ground-systems.

Real-time data streams are critical for the effectiveness of such a system and observational data integrated into the system shall be expanded with a focus on new data provided by the SSA programme. A further development of the VSWMC architecture shall expanding the model coupling interface to cover a range of computing languages and incorporate virtualisation where necessary in order to make the system more flexible. Focus will also be given to coordinated validation and establishing suitable end-to-end modelling concepts based on the available models.

In Part 2 the user interface was developed to deliver data output by models and visualisations to scientists, spacecraft operators and designers and operators of ground-based systems vulnerable to space weather effects to exploit the system and provide feedback. In Part 3 this capability shall be expanded but specific focus shall be placed on the enhancement of the VSWMC development environment allowing developers of space weather models to easily integrate their models into the VSWMC thus rapidly expanding the scope of the system.

At the end of Part 3, the updated system will be deployed by the SSA programme providing a key element of the SSA space weather service allowing timely end-to-end simulations of space weather events, while allowing parallel development of the system and the models. This will require an increased focus on hardware availability and load distribution, system reliability and system monitoring. The VSWMC web interface shall be updated considering evolving SSA portal requirements and the development team shall interact with scientists on the advisory team and SSA expert groups responsible for delivering products and services to end users.

**Deliverables:** Software

| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** TRL 6 by end 2020. Space Weather.

**Applicable THAG Roadmap:** Radiation Environment and Effects (2015).

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-006EP** **Budget (k€):** 800

**Title:** **Fireball Monitor for Space Situational Awareness**

**Objectives:** Design and develop an optical monitor and related image processing software to detect, measure and record fireballs from large meteoroids/small Near-Earth Objects when entering the Earth atmosphere. The monitor shall be designed to observe Earth from a high space altitude (e.g. GEO) in order maximize detection area and thus observation statistics.

**Description:** The Earth is constantly bombarded by objects in all size ranges coming from space. The smaller the objects, the more frequent they are. Ground-based video camera systems typically record several to several tens of meteors per hour. These events are generated by particles in the size range from micrometers to centimeters. Objects in the size range of tens to hundreds of meters are called asteroids and are typically observed far away from the Earth using telescopes equipped with CCD cameras. Objects in the intermediate size range of several decimeters to several tens of meters in size cause so-called fireballs in the atmosphere. They are too rare to have produced statistically significant observations to date and the precise number flux of particles in this size range is not known very well. On the other hand, they can produce damage on the Earth, like e.g. the impact of the Carancas meteoroid on 15 Sep 2007, an object of about 1 m diameter which produced a 13 m diameter crater very close to a small town in Peru. A better knowledge of the expected impact flux is important to assess the impact risk on the Earth and this study will contribute to this task.

To get a statistically significant number of observations of fireballs, the detection area has to be as large as possible. One solution is to put a camera into geostationary orbit and monitor the complete visible atmosphere of the Earth for fireball events.

An optical/IR monitor will be designed and developed to detect fireballs from small (about 1 m or larger) near-Earth objects when they collide with Earth. The monitor will be optimized for operation from a location in GEO. It will be able to monitor one complete hemisphere and to determine size and trajectory of the impactors. Starting point of the design will be two completed studies for the development of a wide-angle visible light camera for faint meteors. The optics will be optimized for a field of view covering the complete Earth from GEO (about 18 degrees full angle). The design of precursor activities, which are optimised for large field of views from LEO altitudes, has to be modified for this purpose. Different wavelength for the detection of fireballs (infrared or visible) shall be investigated. An important aspect is the on-board data processing and storage which has to cope with a large amount of data and with false events(e.g. city lights, lightning flashes). The study shall include the design and development of the fireball camera and corresponding on-board software up to the level of TRL 5. The experience gained from the previous studies (Smart Panoramic Optical Sensor Head (SPOSH) and SPOSH-IR) should be used as a starting point for the activity.

**Deliverables:** Breadboard

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

**Target Application/ Timeframe:** To derive population models for large meteoroids and small Near Earth Asteroids; needed for the NEO segment of SSA and to derive better meteoroid flux models which are applicable to all missions. The instrument will be an attached payload to a mission in high Earth orbits, preferentially GEO.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-007EP** **Budget (k€):** 500

**Title:** **Impact effects tool**

**Objectives:** Determine the effects of an impacting Near Earth Object (NEO) on assets and population when impacting our planet depending on its size, composition, the impact trajectory and velocity and the impact location. When a potential impact risk from a NEO has been identified it is important to know if the object could cause damage on the ground and the extent of such damage. Engineering-type tools are needed to analyze the complete process from atmospheric interaction, break-up and energy release in the atmosphere, assessment on which size objects can reach the ground and impact effects on ground. A number of mainly scientific related models and tools are available. A review of the existing relevant knowledge and tools was performed during the SSA preparatory phase (contract SSA SN-VII) and a roadmap for the development of missing tools was established.

In addition to state of the art scientific tools an operational tool for a quick assessment of impact effects and potential damage is required. This tool shall be able to provide easy to understand but reliable results within minutes.

**Description:** An operational tool for the quick assessment of effects resulting from impacting asteroids shall be developed. It could be based on a large number of reference cases which are stored in a database. A higher level tool with a user friendly interface should interpolate the stored results for the specified input parameters.

This activity will consist of 3 main tasks:

- develop capabilities which are missing in the existing tools as recommended by the SSA roadmap. Examples are: Electromagnetic pulse effects, acoustic effects, realistic object break-up modelling and the treatment of smaller objects,
- produce the database of reference cases covering the full range of realistic impact parameters,
- develop the operational tool for a quick impact risk assessment including the user interface.

**Deliverables:** Software

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

**Target Application/ Timeframe:** For SSA-NEO precursor services. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-008EP** **Budget (k€):** 1,800

**Title:** **Space Weather Instruments for SmallSat and Hosted Payloads Missions**

**Objectives:** SSA is working towards a monitoring system that has the aim of providing services that are requested by the space weather community. Enabling all identified services demands a comprehensive set of measurements from ground, from airborne systems and from space. ESA has based on these studies recently proposed a system that is expected to enable in future, although not all, a majority of the identified and needed services by the implementation of an observational system that intends to make use of developments which have been initiated by ESA in the past for the monitoring of the environment in particular in the Earth space proximity. This system will make use of hosted payloads and potentially a SmallSat system carrying miniaturised instruments dedicated for the monitoring of the space weather conditions and its impact on the Earth. The system under development is therefore expected to be compatible with the elements needed for the establishment of a distributed Space Weather Sensor System.

**Description:** The measurement requirements for an enhanced space weather monitoring system have been established by preparatory studies initiated within the SSA preparatory programme. In order to provide the necessary data enabling the requested services, it is necessary to perform a number of measurements at several observation points preferably in low, medium and high Earth orbits. The required set of instruments can be accommodated either as hosted payloads or as part of a payloads suite of a SmallSat mission. The assessment of the required instrumentation has been performed within the first part of a Space Weather SmallSat Phase 0 study.

Potential candidates for the in-situ instrumentation are currently: Atomic Oxygen sensor, magnetometer, radiation monitor (energetic electrons, protons, and ions), plasma analyser, Langmuir probe, energetic neutral atom imager, or a subset. To fit the resource constraints of hosted payload missions and a SmallSat mission all instruments are expected to have a high degree of miniaturisation. It is therefore expected that the developments will serve a dual purpose.

After completion of the PCR of the Space Weather SmallSat study, the foreseen payloads will be known and sufficiently defined to start the development of the instrumentation. The budget allocation includes the production of flight models, but will finally depend on the selected payload complement and number of instruments. It is expected that other ESA instrument developments can be reused and that this activity would focus on the adaptation to the foreseen architecture and to make the instruments flight ready. The instruments shall be developed towards the same interface requirements will be controlled and interfaced by a remote interface unit, which shall also provide data processing capability, so that the resource demands of the instruments can be minimised. The activity may include the production of the necessary hardware and qualifications, which would make them ready for inclusion in a flight opportunity. The actual production of the flight models can then be considered for realisation within the SSA programme.

**Deliverables:** Engineering/Qualification Model

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** TRL 6 by 2019 or earlier. Space Weather Instruments.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-009EP** **Budget (k€):** 600

**Title:** **3D Ionospheric Modelling**

**Objectives:** This activity will develop a prototype ionospheric service concept based on 3D ionospheric modelling. The assimilation model itself will assimilate data from multiple different sources, and will be tested in the frame of providing nowcast and forecast products.

**Description:** Characterising the ionosphere is crucial for radio link users. Most models currently in use for ionospheric weather nowcasting and forecasting applications approximate the ionosphere using a single thin-shell approach with a fixed height of e.g. 350 km, which is an approximation suppressing the vertical structure of the ionosphere. 3D modelling has the potential to provide resolution of more complex structures and their evolution in electron density, particularly during disturbed conditions and hence improve overall accuracy.

The software prototype shall be developed to demonstrate how the inclusion of a 3D model at the core of space weather service provision can improve the space weather services for satellite navigation and telecommunication users and complement existing 2D products such as TEC mapping. A set of priority requirements will be defined for further development of the underpinning modelling.

The development shall take existing proven modelling concepts, particularly the results of the TRP study (3-D Ionospheric Total Electron Content Modelling), which describe properties of the ionosphere to build a model implementation including all established required functionality.

The development shall target a model that can be operated in near real-time and utilise measurements from ground based observations systems and also GNSS radio occultation measurements. These observations are measured routinely and the measurement data is already part of the SSA SWE system. The model operation shall be verified with a reproducible set of test data in order to ensure correct operation within a pre-defined parameter space of input variables. The model results shall be validated against pre-defined observables in test data and in test campaigns with other models with similar capability. The model developed in this activity shall be implemented on the SSA system and a final verification shall be performed to confirm that the implemented model behaves as expected.

**Deliverables:** Software

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

**Target Application/ Timeframe:** TRL 6 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *04 - Spacecraft Environments and Effects* |

**Ref. Number:** **GT18-010EP** **Budget (k€):** 600

**Title:** **Global Magnetospheric Modelling to Drive Geomagnetic Services**

**Objectives:** The objective is to advance geomagnetic forecasting models that describe and predict the Earth magnetosphere, its interaction with the solar wind, and related space weather conditions.

**Description:** Global Magnetohydrodynamics (MHD) simulations are used within the research domain to gain a global view of the dynamic processes taking place in the coupled solar wind-magnetosphere-ionosphere system. Increasingly, efforts are underway to apply these codes to the application of space weather specification and forecasting. Operational applications require that the models that can utilise and process solar and solar wind measurement data and produce forecasts of the geomagnetic conditions faster that the observed space weather event progresses. Most currently available scientific MHD models are focusing on the accuracy of the physical processes of the solar wind-magnetosphere-ionosphere interaction. While this is extremely important for scientific research, the execution times of these models are longer than the duration of the actual space weather event. Thus, these models cannot be used to forecast the geomagnetic conditions or predict the impacts.

This activity will develop an advanced geomagnetic conditions forecasting prototype targeting the users operating and maintaining ground based infrastructure. The target user communities include in particular operators of the electric power systems and resource exploitation systems. The prototype will be utilising the results of the global 3D MHD magnetospheric modelling developments in Europe.

The forecasts from developed prototype will be validated by comparison with existing empirical modelling techniques employed by the SSA SWE network in terms of forecast accuracy. The validation results will be used to identify areas for priority development of the underpinning models. The trade-offs in computing resources vs model accuracy and timeliness of product delivery shall be evaluated and recommendations for both coding improvement and future implementations shall be reported.

**Deliverables:** Report

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

**Target Application/ Timeframe:** TRL 5 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.6.1.3. TD09 - Mission Operation and Ground Data Systems

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *09 - Mission Operation and Ground Data Systems* |

**Ref. Number:** **GT18-011L** **Budget (k€):** 300

**Title:** **Data Analytics for Early Warning of Space Weather Events**

**Objectives:** The objective is to demonstrate the potential use of data analytics techniques in space weather forecasting. A prototype system will be established and tested. The system will provide the forecast along with confidence level forecast and indicate how this varies with lead time.

**Description:** Space Weather events have a huge impact on spacecraft and other space and ground systems. Therefore, an early warning system is needed so that spacecraft can be put in a safe configuration as well as ground assets.

As the science behind space weather is becoming increasingly multidisciplinary, the volumes of data to be considered are rapidly expanding and new techniques being developed in other domains to analyse large volumes of data may bring potential benefits in terms of both forecasting and stimulating targeted research.

This study will build on activities already carried out in the field of Space Weather Prediction, particularly, those using a data-driven approach. It will bring together experts in large volume data analytics and experts in the space weather domain to address data from a variety of sources including space weather parameters and spacecraft telemetry data. The results will be used to assess the potential use of data analytics in a forecast capacity and also the potential value in terms of future space weather development through stimulating targeted research.

**Deliverables:** Report

**Current TRL:** 3 **Target TRL:** 5 **Duration (months):** 15

**Target Application/ Timeframe:** TRL 5 in 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.6.1.4. TD11 - Space Debris

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT18-012GR** **Budget (k€):** 300

**Title:** **Streak detection algorithm validation through field campaign data**

**Objectives:** The activity shall acquire a substantial set of ground-based and space-based optical observations that contain streak features for space objects. Opportunities for dedicated and 'piggy-back' observations using optical systems, such as telescopes and star trackers shall be evaluated, tested and finally exploited. The acquired data shall be reviewed and shall be arranged in a new database structure. The development of this database in the activity shall support design, test and validation of streak detection algorithms and generate the required processing software for space surveillance and tracking (SST) applications and for the characterisation of the small-sized space debris population.

**Description:** Novel planned ground-based and space-based optical observation systems for space objects, especially space debris, will often provide observations of streak-like features. The astrometric and photometric reduction (processing) of such features has been addressed in a TRP study that delivered a prototype algorithm tailored for the detection and processing of weak signals as resulting from faint objects. Such objects are of particular interest when either small objects or fast objects in LEO are observed. This is the case for larger field-of-views of survey systems in Space Surveillance and Tracking (SST), and for space-based sensors acquiring a statistical sampling of very small centimetre to millimetre-sized objects.

An on-going GSTP activity 'Optical In-situ Monitor' develops a test-bed and breadboard instrument for a space-based mission to support SST needs and the small-sized space debris characterisation. The activity also implements starting from the TRP prototype the on-board detection and processing algorithm and trains the algorithm with simulated data.

It has been found essential to support the design and development of large ground-based sensors, as well as of the space-based instrument, with an extensive set of real streaks and other features, such as cosmic ray events and detector defects, as acquired from a field campaign. Some existing sensors can be configured or temporarily modified or operated in a way to provide such data, as well as it is possible to access the raw data from star trackers of operational missions. It is nevertheless of paramount importance to support this evaluation of existing data sources with expertise from the optical instrument engineers developing the instrument for the planned novel observation systems, too.

The evaluation of the data and review of planned use cases in the new observations system shall result in the design of a database of test data. This shall ensure the easy and seamless access through appropriate interfaces to the acquired data. From agreed existing sensors a large data set of streak features shall be acquired and inserted into the database. A final task shall be the documentation of the dataset, the database and in particular the interface for the subsequent use in the engineering activities for ground-based and space-based instruments.

**Deliverables:** Test Data, Software, Reports

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

**Target Application/ Timeframe:** TRL 6 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *11 - Space Debris* |

**Ref. Number:** **GT18-013GR** **Budget (k€):** 500

**Title:** **Maturing the sub-catalogue debris characterisation capabilities of a space-based optical component**

**Objectives:** This activity shall further develop the data acquisition and processing approach of a space-based optical sensor to acquire statistical data of small-sized space debris in LEO. Based on the matured system design of the instrument (from the SSA programme focussing on space surveillance and tracking (SST) needs) and the processing algorithm (from an on-going GSTP study developing a breadboard and test-bed for the in-situ monitor) the data flow from the acquired observations to the space debris environment model improvement and validation shall be simulated and tested.

**Description:** Previous activities revealed that a space-based optical instrument dedicated to space surveillance can provide substantial contributions to the observation and statistical characterisation of small-sized millimetre and centimetre particles that may cause the of end a mission. A significant knowledge gap and also disagreement for LEO debris between 1 mm and 10 cm size has been identified in the debris models used by ESA and NASA.

In the SSA workplan, dedicated activities target at preparing and implementing a hosted payload development and mission assessment addressing SST needs. SSA will conduct related activities including the Systems Requirement review and consolidation of a space based optical component in SST, development of an engineering model of the payload, development of the related ground segment, and development and qualification of components. In parallel and close coordination an on-going GSTP activity (Optical In-situ Monitor) develops already a test-bed and breadboard infrastructure of the payload, as well as pursues the development of on-board detection algorithms starting from a previous TRP-developed prototype.

Based on these preparatory and related activities, the data acquisition and processing approach of a space-based optical sensor to acquire statistical data of small-sized space debris in LEO needs to be further matured. This applies in particular to the data flow from the acquired observations to the space debris environment model improvement and validation. This activity shall simulate and test the on-board processing of the data and focus on modelling the data flow based on matured system design and detailed expertise on the optical performance model, addressing no-show events interpretation and data reduction from observed brightness and object counts to a statistical model, as in ESA's MASTER (Meteoroid and Space Debris Terrestrial Environment).

It is important to include optical and system engineering expertise in the industrial team to validate the data flow. The activity shall create and use simulated data for observations of small-sized space debris in LEO. The activity shall finally develop and deliver the science data processing chain for the sub-catalogue debris characterisation function of the planned mission as a secondary use case to the SST use case.

**Deliverables:** Software

**Current TRL:** 4 **Target TRL:** 6 **Duration (months):** 18

**Target Application/ Timeframe:** TRL 6 by 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.6.1.5. TD12 - Ground Station Systems and Networks

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| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

**Ref. Number:** **GT18-014GS** **Budget (k€):** 1,000

**Title:** **Optimisation of L-Band Transmit/Receive Modules used in Surveillance Radar Antenna Arrays**

**Objectives:** SSA Radar antennas will be composed by thousands of radiating elements. Each element will include a Transmit/Receive module. This module needs to be optimised in terms of power efficiency, mechanical integration, cooling, industrial manufacturing, and cost. This activity shall develop an optimised module that provides the best performance for the final radar system.

**Description:** The SSA final surveillance radar will require very powerful transmitters (order of Megawatts). Each 1% increase in the power efficiency means tenths of kilowatts saved on electrical power with the associated operations costs reduced. The dissipation will be lower and the cost of the cooling systems will drop accordingly. State of the art topologies for solid state power amplifiers (SSPA) (like Class D, E and F) show theoretical efficiencies up to 80%, but still at academic level and there is no information available about phase stability and phase linearity.

The SSA radar will be based on dual-polarisation receivers to cover unknown backscattering behaviour of space debris and the depolarization effects of the ionosphere. Compact Receive antenna elements capable of receiving the two polarization components shall be developed. The digital receiver is in charge of Analog/Digital conversion, Digital Down Conversion, and (Adaptive) Digital Beamforming.

Physical constraints of a phased array antenna (spacing between elements) ask for a demanding mechanical and thermal design. The design shall also consider the cost savings during manufacturing, testing and future maintenance phases. A prototype shall be built both for the transmitter and receiver. A first batch of 5 to 10 pre-series units will be manufactured after prototype acceptance to analyse the yield of the production process.

**Deliverables:** Prototype

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

**Target Application/ Timeframe:** SSA radar systems. TRL 6 by 2021.

**Applicable THAG Roadmap:** Ground Station Technology (2015).

### 3.6.1.6. TD16 - Optics

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|---|---|
| *Domain* | *Space Situational Awareness* |
| *Tech. Domain* | *16 - Optics* |

**Ref. Number:** **GT18-015MM** **Budget (k€):** 1,200

**Title:** **Compact EUV Imager for the Lagrange Space Weather mission**

**Objectives:** The aim to perform the pre-developments of the EUV imager for the Lagrange Space Weather Mission. The purpose of this instrument will be to image the complex low solar corona for monitoring active region magnetic complexity to assess likelihood of flares or CMEs. From the L5 position, the emphasis would be on monitoring the development of active regions before they rotate into the Earth impacting zone. Current heritage instruments are not optimised for Space Weather purposes and the observation of the Sun from the Lagrangian Point L5. Previous studies have indicated that more than one wavelength are desirable for Space Weather applications and observations in the EUV spectral region. Furthermore it is desirable to cover a larger Field of View (FoV) in order to cover the gap between the Sun disk observations and the FoV of the Coronagraph starting at a distance of 2.5 Sun radii from the Sun.

**Description:** This activity will demonstrate the feasibility of a EUV imager with appropriate field of view covering the Sun disk and preferably multiple wavelengths. The initial design phase and review of heritage instruments shall explore the ability to expand the field of view well beyond the size of the Solar disk as has been demonstrated to some degree with SWAP on Proba 2. This may employ the use of state-of-the-art detector technology combined with a special operating mode that allows detecting the signal decreasing with increasing distance from the Sun. The spatial resolution according to the mission requirements shall be 2 arcsec as a goal and 5 arcsec as a threshold value. Possible designs of the instrument are a Cassegrain or an off axis Newtonian, with mirror coatings, and multilayer coatings to provide sufficient reflectivity for one or more EUV emission lines of the sun.

These lines (to be confirmed in the Phase A studies) are expected to be the Fe XII 19.3 nm, the He II 30.4 nm, the Fe IX 17.1 nm and the Fe XIV 21.1 nm lines. The instrument may draw heritage from past missions such as SOHO/EIT, SDO/AIA, PROBA-2/SWAP, STEREO/EUVI and Solar Orbiter EUI, as well as ESIO, a recent development by ESA. The study shall investigate compact solutions that would allow the implementation of observations with more than one wavelength while maintaining a high reliability of the instrument for operational purposes.

The study shall be incorporated into the Lagrange Mission Phase A/B system and instrument studies and pre-developments, and the instrument shall be compatible with during the study agreed performance specifications. Within the budget an optical engineering model or elegant breadboard shall be built, which allows the demonstration of its critical performance to reach TRL 6 before the PDR. Critical technologies shall be validated or prepared where necessary.

**Deliverables:** Engineering/Qualification Model.

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

**Target Application/ Timeframe:** EUV imager for the Lagrange Space Weather Mission. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

# 3.7. Design to Produce

## 3.7.1. Design to Produce

### 3.7.1.1. TD08 - System Design & Verification

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| *Domain* | *Design to Produce* |
| *Tech. Domain* | *08 - System Design & Verification* |

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| **Ref. Number:** | **GT1P-001MX** | **Budget (k€):** | 1,200 |

**Title:** **Procedure viewer and authoring tool for ground AIV/AIT applications**

**Objectives:** The main goal is to collect and connect all the data contributing to the development of a space system in a central repository (or cloud of repositories) which would act as single truth source, reducing inconsistencies and increasing efficiency and making this information available to the location where it is needed at the time when it will be required.

The activity aims to contribute towards the creation of the end-to-end Digital Model (or Digital Twin) of the space system by establishing the necessary link to the as-built and as-tested configuration of the space system, including traceability to test execution and results.

**Description:** The international procedure viewer is well established and used by astronauts to access all operation procedures from a central server. The system provides beside the task descriptions also reference information that is required for the correct step. It supports the execution of the procedures and allows the tracking and recording of the accomplishment of the procedural steps. In the field of the AIT/AIV activities, people continue to use paper version for the execution of procedures (as run). Some experiments and studies were run in the recent years by several institutions and companies investigating a full digitization of the AIT/AIV process enclosing of various numerical models and of various input sources. No full implementation has succeeded yet. A tool based on a harmonized standard covering the digital handling of procedural information in combination with the creation of numerical as-run information, compatible with the full process of traceability, configuration & verification control and quality management is considered beneficial.

A similar system as iPV onboard ISS, tailored for ground AIV/AIT activities is considered beneficial to manage and control various procedural information. The introduction of such a tool together with a centralized repository of AIV/AIT related procedures and the enables a fully traceable and transparent end-to-end, design to produce validation and verification flow. Moreover, the introduction of paperless procedures inherits potential cost savings related to the reduced archiving and configuration control needs when compared to printed information. Using less printed paper in cleanroom and integration areas reduces the risk of undesired contamination and serves a more sustainable execution of AIT/AIV activities. The evolution of the international procedure viewer holds the potential to be deployed in space industry as well as internationally across Agencies by setting common AIV/AIT exchange standards.

Based on the existing international procedure viewer capabilities develop a procedure viewer tool and related recording and authoring capabilities for ground based AIV/AIT activities on spacecraft. This tool shall allow a user friendly and easy generation of procedures that are typically used during spacecraft assembly, integration and test. Tailor the resulting prototype towards a typical assembly procedure and to an integrated test procedure with the functionality of multiple teams working on the same procedure simultaneously. The development shall be based on the existing (ESA-owned) execution environment, establish the necessary modifications to ingest and modify existing procedures, and enhance the user interface as required by the AIT/AIV needs. It shall provide all relevant data interfaces to existing repositories in test centres. Where applicable, recommendations for the development of new or adaptation of existing standards concerning electronic procedures shall be established together with main AIV/AIT stakeholders within ESA, industry and other agencies.

For certain instructions in test and assembly procedures, application of virtual and augmented reality (VR/AR) will improve overall assembly and test performance and quality. In a second phase the interfaces to allow such capabilities shall be developed for tight integration with the procedure viewer. Note that the availability of this feature is also beneficial for training of staff involved in the S/C assembly and test processes, as well as early procedure validation through simulation support.

The first phase of this activity encompasses the following tasks (750kEuro):

- review the capabilities and identify constraints of existing numerical procedure handling tools and processes applied in space and aeronautic industry and define requirements for the procedure viewer tool to be developed covering user, functional, hardware and software aspects,
- establish and propose a harmonized standard for data repository and information exchange covering the main formats used during a space system AIT/AIV process,
- develop a generic interface standard for procedures between satellite production centres, test centres, projects in consultation with industry and European space agencies,
- develop authoring capabilities including import functionality and a publishing capability compatible with the current test centre documentation repository.
- implement concurrent support of multiple AIV/AIT teams at multiple locations,
- tailor the system to two (2) application scenario (including hardware), one in the ESTEC test centre and one in an AIT/AIV scenario of an ESA project,
- convene a usability test with real end users about 2/3 into the study time and demonstrate both tailored applications in a final presentation,
- provide a training session on the use and administration of the system.

In a second phase 450kEur (phase 2 AR/VR interface), the task is to

- develop authoring capabilities for VR and AR content and a module for AR/VR execution that shall integrate with the main procedure viewer.

The activity aims to study and identify goals, objectives, tools, needs and constraints for a numerical procedure handling tool for AIT/AIV activities and derive harmonized requirements in consultation with ESA AIV and industry experts of major spacecraft prime. Based on this develop procedure authoring capabilities that allow a quick, user-friendly, easy, MS-office-like or web-based authoring of procedures tailored to the needs of the AIV/AIT community. This shall include an import functionality allowing the use of existing procedures that are currently available in pdf and MS-word format. The new system test procedure authoring and execution tools shall allow traceable monitoring of the evolution of products e.g. procedures used in production, in cross-validation up to the as-run procedures of final acceptance and exhibit an on-the-fly procedure variation capability with related multi-disciplinary approval i.e. red marking of as-run procedures. Moreover, the system shall allow the coordination of multiple AIV/AIT teams to work at multiple locations on the same procedure simultaneously. The system shall work seamlessly with the current documentation management systems and provide an interface to a planning/scheduling tool. The output results and documented information produced by the system shall be in common, open standard formats with the aim to allow the future exchange with other tools of the end to end system development process.

The activity aims to contribute towards the creation of the end-to-end Digital Model (or Digital Twin) of the space system by establishing the necessary link to the as-built and as-tested configuration of the space system, including traceability to test execution and results. The evolution of the international procedure viewer holds the potential to be promoted and deployed in space industry as well as on international level across Agencies by setting common AIV/AIT exchange standards.

**Deliverables:** Standard for data repository and information exchange covering interface standard of the procedure viewer tool, Procedure viewer tool for AIV/AIT activities, Complete procedure authoring and publishing software , Complete content for 2 demonstration scenarios as outlined above; System installation, administration and user manual, Training material, Hardware.

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| **Current TRL:** | 5 | **Target TRL:** | 7 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** TRL 7 by December 2018. AIV/AIT applications.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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|---|---|
| *Domain* | *Design to Produce* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT1P-002SW** **Budget (k€):** 800

**Title:** **Optimization by Digital Engineering applied in Projects**

**Objectives:** The objective is to define and apply digital engineering methods to support system engineering aspects and design optimization between different domains at system level.

**Description:** ESA has supported several developments in the field of Model Based Systems Engineering (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 cloud of repositories) which would act as single source of truth, reducing inconsistencies and increasing efficiency.

This activity encompasses the following tasks:

- Adopt and apply a consistent model based approach to perform a multidisciplinary optimization exercise involving at least 3 disciplines plus the system engineering coordination layer. A suitable subject for the multidisciplinary optimization should be defined and is depending on the system criticalities. Typical problems are e.g. combination of thermal, mechanical and functional challenges, driven by complex operational scenarios.
- Demonstrate coherency and consistency of data and information for the selected scenario to ensure system level benefit by coordinating at model level. Perform the multi-disciplinary optimization, based on the linked models. This task can be based on commercial tools, but will require additional work to map models and analyses to the ECSS-E-TM-10-23 for further interchange.
- Based on the results, document the method and process for the multidisciplinary optimization workflow, the data exchange strategy with the customer, and the margin philosophy and uncertainty management strategy.

**Deliverables:** In native format and in established open standard format: Product Tree, Functional Architecture, Objective Functions used in the optimisation exercise and Budgets Methodology: Report on multi-discipline optimisation method, Report on data exchange strategy, Report on margin philosophy and uncertainty management.

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| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 9 |

**Target Application/ Timeframe:** Ready to be applied to the project processes of future missions. 2018.

**Applicable THAG Roadmap:** System Data Repository (2014).

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|---|---|
| *Domain* | *Design to Produce* |
| *Tech. Domain* | *08 - System Design & Verification* |

**Ref. Number:** **GT1P-003SY** **Budget (k€):** 700

**Title:** **Exploring Enhanced Procurement in a Fully Digital Environment**

**Objectives:** The objective is to explore, through a practical pilot, enhancements to the procurement process that are enabled by moving to a fully digital environment. A particular focus is on removing barriers in information sharing that cause inefficiencies between the contracting, project management, product assurance and system engineering domains of expertise.

**Description:** The current (ESA) procurement process follows the patterns described in the top-level ECSS standards: ECSS-S-ST-00C 'ECSS system' (in particular the generic customer-supplier pattern), ECSS-M-ST-10C 'Project planning and implementation', ECSS-Q-ST-10C 'Product assurance management' and ECSS-E-ST-10C 'System engineering'. In the classical document-based approach, many document types (compliant with ECSS DRDs) are used to capture and exchange all information needed to successfully implement the procurement and execution of a space system project.

Each document type has a clear owner, who is either the contracts responsible, the project management responsible, the product assurance responsible or the system engineering responsible. However, there is a lot of information that is shared between different documents. e.g. the complete set of technical and non-technical requirements, the product tree and the work break down structure, cost decomposition, schedule information, etc. All this information should be consistent and complete. In particular on larger complex projects this is not trivial to achieve.

In addition in many programmes there is a split across separate but related projects, e.g. for a splits into platform and payload or space and ground segment contracts, or between a main space system project and a number of contributing technology development projects. In such cases the consistency of information across multiple contracts / projects needs to be defined and maintained in sync. Similarly consistency between prime and sub-contracts needs to be maintained which is a joint interest and responsibility of both the main customer and the prime supplier.

A fully integrated digital procurement methodology promises to substantially improve the process by enabling much more efficient, agile and seamless information sharing between the main responsible actors in a space system project: contracts, project management, product assurance and system engineering (including cost, risk and integrated logistics engineering). Clearly such a methodology cannot be developed, let alone imposed, in one go. Prototyping and validation of possible approaches is needed in a non-critical application pilot.

The initial step is to develop an integrated digital procurement methodology (supported by sufficient tooling at lease at prototype level) that allows for an iterative and agile, but still well-controlled, process. The methodology should take into account the reality of changing requirements and progressive insights, both on the customer and supplier sides, while taking into account rules concerning policy and accountability. A small but representative procurement action shall be selected as a pilot project and the new methodology shall be applied to it, if necessary along-side the standard procurement in order not to cause extra risk to the project. Finally, the execution of the procurement aspects

of the pilot shall be evaluated and a final report with practical recommendations on how to improve the procurement process shall be produced.
The activity includes the following tasks:

- Conceive an integrated digital procurement methodology, that allows for an iterative and agile, but still well-controlled, process.
- Prototype a collaborative / concurrent digital environment, that:
    - supports the procurement process and paperless exchange of multi-disciplinary data of contractual, managerial and technical nature,
    - ensures version control and exchange of data across the customer-supplier chain following a 'single source of truth' principle,
    - enables assessment and monitoring of cost, risk and integrated logistics in support of project management,
    - addresses the digital approval process across the supply chain and along the lifecycle milestones.
- Find and describe a representative (but sufficiently small) procurement activity that is suitable for a pilot execution. This could be a procurement at e.g. component or unit level, or related to a cubesat mission. Define evaluation criteria to assess the new approach.
- Apply the methodology and prototype to the pilot procurement activity and evaluate with respect to the established criteria.
- Produce a final report and executive summary that document the evaluation, provide recommendations to improve the space system procurement process (ESA procurement process, ECSS, other standards, etc.), and describe the lessons learned from the study.

The main information areas to be addressed are:

- ITT and business agreement (contracts),
- project plan/schedule, WBS and configuration item list (project management),
- product assurance artefacts,
- concept of operations, technical requirements specification tree (including tailoring of ECSS/external requirements), function tree, product tree, interface control, technology development planning, MAIT/V&V planning (system engineering, including cost, risk, integrated logistics engineering).

There are a number of project activities that play a major role in the procurement process, namely: ITT production, tender evaluation, contract negotiation, project milestone review and final acceptance. The pilot shall as much as possible address how integrated digitalization and collaborative/concurrent work flows can help make each of these more efficient and effective.
The prototype environment should as much as possible make use of open standards for exchanging and sharing data.
The activity aims at making a further small step towards the realization of an integrated digital procurement process in which the collaboration between the four major discipline areas of contracts, project management, product assurance and engineering is improved. The long term future perspective is an integrated end-to-end process and digital environment. In this environment all necessary views (e.g. web forms, dashboards, diagrams, documents and any other presentations) on the totality of information needed to successfully conceive and execute a space system project, are consistent with a single source of truth. Such a fully digitalized model including a so-called Digital Twin of the eventual space system product - would also enable capture of, and access to, corporate knowledge that is hitherto impossible to realize.

**Deliverables:** Digital procurement methodology white paper, Prototype digital environment, Pilot procurement activity description.

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

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| **Target Application/ Timeframe:** | All programmes. TRL 6 by 2020. |

**Applicable THAG Roadmap:** System Data Repository (2014).

### 3.7.1.2. TD23 - EEE Components and Quality

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| *Domain* | *Design to Produce* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT1P-004ED** **Budget (k€):** 1,500

**Title:** **Improvement of design and product, based on analysis of data from embedded sensors**

**Objectives:** The objective of this activity is to design and produce a suite of embedded sensors to be flown on our future space craft (just like standalone radiation monitors today) in order to analyze the real space environment seen by EEE components and use the collected data to save on the margin of today's requirements.

**Description:** The aim is to design a suite of embedded sensors aiming at being embarked on future space craft and allowing to collect accurate in flight data information to further refine ESA requirements related to EEE components for spaces application. When reviewing new types of space missions (e.g. constellations or even mega constellations) today, it is becoming more and more evident that the margin taken until now on EEE parts were comfortable and nice to have. Due to time and cost constraints nowadays, they have probably become 'luxury' requirements that deserve serious review and refinement.

The aim is to review 3 major sets of requirements, namely radiation environment (as already being done but now taking the actual shielding into effect), the need of hermeticity (by accurate monitoring of the pressure evolution inside a given cavity) and last but not least the temperature range definition which is today far away from the actual need considering the thermal control and compensation.

It is also important to note that this activity is expected to speed up the acceptance of COTS EEE parts for space applications as a precise redefinition of actual space requirements may reveal that a significant number of COTS (as for example automotive EEE parts are already by nature suitable candidates for space applications.

The activity will be established in 3 different phases:

- Phase 1: (200K): Review of existing sensors (Radiation, pressure, temperature) and suitability for space application followed by selection of the most attractive solution (including also back-up solutions).
- Phase 2 (800K): Procurement of the selected sensors (Radiation, pressure, temperature)development of a common electronic control and command platform, breadboarding and testing. Assembly and packaging of the complete embedded sensor suite and final test and validation.
- Phase 3 (500K): First flight demonstration, collection of data and refinement of applicable EEE requirements in terms of radiation , hermeticity and temperature.

**Deliverables:** Breadboard

**Current TRL:** 4 **Target TRL:** 7 **Duration (months):** 30

**Target Application/ Timeframe:** Refine requirements with respect to the Space environment for COTS EEE parts acceptance. 2020.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Design to Produce* |
| *Tech. Domain* | *23 - EEE Components and Quality* |

**Ref. Number:** **GT1P-005ED** **Budget (k€):** 800

**Title:** **Embedded Sensors for AIT**

**Objectives:** The objective to improve Assembly & Integration Testing by developing the use of 'disposable' wireless sensors for the monitoring of the spacecraft during AIT. The 'disposable' wireless sensors shall replace the existing wired sensors. The activity will focus on a maximum of 4 types of sensors considered as the most relevant when it comes to time and cost during AIT. These are: temperature sensors, strain gauges, accelerometers and contaminations monitors.

**Description:** It is absolutely vital to permanently improve Assembly & Integration Tests process in order to be competitive. The R&D axis proposed here is focused on the use of 'disposable' wireless sensors for the monitoring of the spacecraft during AIT with the objective to replace the existing wired sensors. It has been demonstrated that self-powered wireless sensors offer significant benefits in terms of flexibility, time consumption, easiness of integration with subsequent cost and schedule reduction. Such sensors are generally installed several months before the beginning of test and the measurement campaign may last one or two months. Since these test devices are highly invasive and represent a significant weight they cannot be left inside the satellite and have to be removed before launching.

The installation, management and removal of such an infrastructure introduce critical issues concerning the time for deployment and removal of probes, the risk to damage the satellite devices under test, and the overall high cost of involved staff and instrumentation. There is therefore a recognized need to move from a wired architecture to a wireless one, involving very low power autonomous sensors with aim to simplify the on-board accommodation with great freedom in sensors placement, to enable last minute implementations, to simplify the hardware interface and, on the whole, to speed-up the integration schedule, reducing drastically the cost of the AIT. Innovative technologies using MEMS or even Nanomaterials based devices are small, low cost have the potential to be so light that they could be used as consumable devices which if correctly attached to the structure could be left on the spacecraft once the AIT is completed, leading to the notion of 'disposable' AIT sensors. The invaluable asset of those AIT sensors is that being used for on ground testing only, they do not need to be Rad-Hard or even Rad-Tolerant, allowing the use for purely commercial technologies and among others COTS sensors.

The activity will address 4 sensors: accelerometers (for shock and vibration monitoring), temperature , strain gauges and contaminations monitors and will be divided in 4 major tasks:

- Feasibility and compatibility of wireless sensors usage with the AIT environment, this task should deliver a go/no-go with respect to the usage wireless sensors during AIT activities.
- Disposable sensors trade-off and selection addressing accelerometers (for shock and vibration monitoring, temperature, strain gauges and contaminations monitors. Depending on the conclusions reached during Task 1the wireless candidates will be considered or discarded. Focus will also be put in the availability of self-powered sensors when they exist. Due to the fact that radiation is not an issue when looking at sensors for on-ground AIT,

preference will be given to existing low cost COTS sensors today available for testing, instrumentation or other on ground applications.

- Development of the required accompanying architecture and hardware and the prototyping of a first couple of AIT embedded sensors suites ready for use.
- Demonstration phase to be conducted at ESTEC test centre as the team is one of the partner involved in this activity. deployment to other non ESA test centres may also be envisaged for accelerating the pilot cases and acceptance.

**Deliverables:** Engineering Model

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| **Current TRL:** | 3 | **Target TRL:** | 7 | **Duration (months):** | 24 |

**Target Application/ Timeframe:** Reduce AIT duration and associated cost. 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

### 3.7.1.3. TD26 - Others

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| *Domain* | *Design to Produce* |
| *Tech. Domain* | *26 - Others* |

**Ref. Number:** **GT1P-006SY** **Budget (k€):** 800

**Title:** **Digital Engineering Hub Pathfinder (CD09)**

**Objectives:** The objectives are the following:

- Ensure seamless exchange and sharing of engineering information between all disciplines in teams that develop space systems in order to facilitate and enhance the digitalisation of the space system lifecycle processes, starting in the early lifecycle phases 0, A, B.
- Foster an interoperable and future-proof (community-)open-source evolvable eco-system in which ever more capable data exchange solutions become available to run European space projects more effectively.
- Ensure that the data exchange capabilities will scale from the early lifecycle phases to the complete space system lifecycle (i.e. phases 0 to F).

**Description:** As written in clause 4 of ECSS-E-TM-10-23: 'Reliable electronic exchange of the data needed during the lifecycle of a space system is essential to further improve the efficiency and effectiveness of the engineering processes, and indeed all other lifecycle activities and processes. Unfortunately, as many projects have experienced too often, getting the right data at the right moment to the right stakeholder is an enormous challenge. Finding the right version of the data and details of changes from previous versions can be very inefficient. Now that all individual disciplines, both engineering (e.g. mechanical, electrical, optical, radio-frequency communication, software) and non-engineering (e.g. cost, project management) in space projects have well established methods and tools, the next round of improvements needs to come from better integration of the lifecycle processes and the project teams.

A major enabler for successful digitalisation of the engineering processes at the core of Industry 4.0 is the exchange and sharing of engineering models and associated data between multiple disciplines. There will always be a large variety of tools and data formats to be supported. Top-down standardization on tools (per discipline) or integrated toolsets (across disciplines) has been attempted in the past but will never work for the following reasons:

- Tools are selected by engineering organizations for their optimal use in their processes by their own workforce.
- Many organizations work simultaneously in multiple projects with different top-level customers / prime contractors. In addition, many space projects run for years and typically try to avoid the risks of changing (versions of) tools during the project.
- No organization can afford to be effective in many alternative tools that essentially cover similar functionality. The costs (licences, training and building up proficiency) are too high.
- Newcomers on the tool market should have a fair chance of success.

Data exchange based on open standards is the only viable way forward. The open standards must be comprehensive, fit for purpose and long-term stable. In the past 20 years many standards have been developed, with varying degrees of success. For example, ISO 10303 'STEP' (in particular AP 203, 214, 242, 239) and OMG SysML version 1 (XMI format), de facto industrial or open source standards like Excel CSV, Universal File Format (originally by SDRC), Matlab results formats (MAT, JSON, HDF5), Hierarchical Data Format v5 (HDF5), Common Data Format (CDF), Eclipse

Modeling Framework (Ecore) XMI, OMG ReqIF, OSLC, ASN1.There is no single standard that solves completely the multi-disciplinary engineering data exchange problem, but there are many partial solutions. Within the European space sector two very relevant ECSS TMs have been developed:

- E-TM-10-25 'Engineering model data exchange (CDF)' implemented in the Open Concurrent Design Tool (OCDT) and in Concurrent Design Platform v4.
- E-TM-10-23 'Space system data repository' validated in Virtual Spacecraft Design (VSD) and used as a basis for EGS-CC.

For the conceptual design phase, OCDT is in operational use since 2014 in the ESA CDF studies and has proven to be a successful and very stable implementation of E-TM-10-25. A number of initial bi-directional interfaces have been developed with MagicDraw v17 / SysML v1 (SW TRL 4 Alpha), ESA-AF (SW TRL 4 Alpha), Matlab (SW TRL 4 Alpha), Catia v5 (SW TRL 5 Beta), DOORS (SW TRL 4 Alpha via ReqIF by RHEA Group), VSD (SW TRL 4 Alpha).

With E-TM-10-25 and OCDT, highly suitable technology governed under ESA Community Software Licences has become available. A Digital Engineering Hub based on the proven E-TM-10-25 / OCDT implementation can be used as an evolvable eco-system to start realising the benefits of an integrated MBSE / Digital Engineering approach. The precursor to a standard as well as the implemented software have matured to Software TRL 6 to 7, and provide a solid basis to make substantial and scalable improvements on the kind of engineering data that can be reliably exchanged between a very relevant multi-disciplinary set of engineering tools. It will also serve as valuable input to future standard.

Within this activity, a selection of engineering tools frequently used in European space projects will be connected through adapters to the 'Hub' for instantaneous data exchange and data sharing. Initially there will be a single persistent data store database, but the OCDT architecture is designed to allow for a distributed federation of databases that form together one logical database. With suitable adapters other kinds of databases could be integrated. The capabilities of the 'Digital Engineering Hub Pathfinder' and the number of integrated tools will be incrementally increased. In addition to data exchange and sharing use cases, also long term archiving of data will be addressed. It is proposed to first start with the integration of typical system engineering tools like MagicDraw/SysML (v1) and Arcadia / Capella. An interface with DOORS for requirements engineering is already taken care of in the frame of the Flexible Wiki-Based Requirements Engineering activity that will be completed in 2017. In addition, the following engineering tools are to be considered: Matlab/Simulink, EcosimPro, OpenModelica, Rhapsody SysML, Nastran, Adams, ESATAN TMS or ThermXL, STK, VTS (CNES), and more if possible. As part of continuous evaluation of the operation use of OCDT in the ESA CDF a number of potential improvements to E-TM-10-25 have been collected as recommendations. A subset of improvements for implementation is to be selected.

This activity encompasses the following tasks:

- Elaborate an eco-system architecture for the Digital Engineering Hub based on the existing E-TM-10-25 and OCDT. The architectural design must support future extensibility such that the resulting eco-system can later be transformed to use a different open MBSE/data exchange standard. In particular the Common Information Platform that is being developed in the ESA MARVL activity shall be taken into account.
- Define a number of representative use cases.
- Implement and demonstrate a data exchange interface with the Capella tool, at least of a subset of the modelling concepts used in Phases 0 and A.
- Implement and demonstrate a data exchange interface with the Matlab tool, at least of a subset of the modelling concepts used in Phases 0 and A.
- Implement and demonstrate a data exchange interface with the ESOC Paperless E2E Ground Station Engineering Environment.

- Implement and demonstrate a data exchange interface with the EcosimPro tool, at least of a subset of the modelling concepts used in Phases 0 and A. Target in particular the EcosimPro tools for Propulsion and Electric Power.
- Implement and demonstrate a data exchange interface with thermal analysis tools via the ECSS-E-ST-31-04C (STEP-TAS) standard and possible ThermXL, at least of a subset of the modelling concepts used in Phases 0 and A.
- Implement and demonstrate various viewpoint/view as well as report generator applications that support suitable views and reports from the perspective of different engineering disciplines.
- Collect, analyse and implement improvements to the E-TM-10-25 Annexes A, B and C.
- Produce end user documentation and training materials in order to make the results available for the widest possible set of end users in the European space industry.

The activity can use the OCDT portal (ocdt.esa.int) for collaboration, documentation, software configuration and version control (Gitlab), issue tracking and agile software engineering, continuous integration, continuous delivery and code quality analysis. The activity aims at implementing a first version of a working digital engineering hub that can over time be transformed into a full-fledged operational eco-system, when improved, richer data exchange standards have matured. It allows to realise an initial version of Digital Twin representation of a progressing architectural design of a space mission as well as the realisation of the idea of a 'single source of truth' data.

**Deliverables:** Study report, Guidelines for the applicability of the proposed methodology, any developed tool, and the results of simulations and/or tests performed.

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

**Target Application/ Timeframe:** AIT operations. TRL 6 by 2019.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

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| *Domain* | *Design to Produce* |
| *Tech. Domain* | *26 - Others* |

**Ref. Number:** **GT1P-007MX** **Budget (k€):** 700

**Title:** **D2P - Multidisciplinary 3D Digital Models for AIT environment**

**Objectives:** The objective is to increase the integration of 3D digital models in order to improve the efficiency and effectivity of the assembly, integration and test procedures and documentation, fully integrated into the overall space system lifecycle.

**Description:** Currently a wide variety of digital models are used during the AIT phases, in particular when dealing with multi-disciplinary aspects / multi-physics phenomena, e.g. thermoelastic behaviour. The models often contain different kinds of information at different levels of detail. Establishing and maintaining the true baseline of the 'as tested' configuration of the item under test and the test facility, sensor locations and another properties and parameters, as well as the combination of diverse physical parameters is a cumbersome, time-consuming and therefore error-prone procedure. Defining a format capable to maintain the as tested configuration is therefore a crucial step.

Since 1994 when the first ISO 10303 STEP standard was released, 'STEP' has become the global reference for neutral open standard representation of 3D geometry and topology. Since then, several editions were released, allowing a larger amount of information to be captured. The exploitation of the enhanced standard could be beneficial for the representation of the space system during its lifetime.

The adoption of the STEP AP 242 data format to capture the state of an item under test (e.g. the typical spacecraft physical models STM, EM, QM, FM) including its instrumentation, material properties, links to associated engineering analysis / simulation models, digital images (pictures and videos), test meta-data, test results, etc. would allow to establish unambiguously what exactly has been tested and where all sensors were located in an open neutral format. This format is also suitable for long term archiving, so it could also be used in case of later on-orbit anomalies to provide detailed information on what past AIT configurations looked like, in tools of the day that are probably a number of versions ahead of the versions of the tools that were used during the actual AIT activities.

Data-fusion of multi-disciplinary/multi-physics digital models (structural, thermal, electrical, optical), and their integration into AIT environment (e.g. facilities, MGSE - Mechanical Ground Support equipment - and EGSE - Electrical Ground Support Equipment) would improve the efficiency, with considerable savings in time, and reduction of anomalies and mistakes.

The data exchange among different digital models of the space system used throughout the design phase and the AIT processes, in one word the data-fusion, would allow to emulate its behavior, therefore helping the verification and testing processes by supporting virtual testing, the combination of test sequences, the integration of subsystem and system level testing.

In the mechanical domain, an attempt to increase the test effectiveness is already on going and it is referred as Virtual Testing. Ad-hoc virtual testing workbenches have been developed and used in the preparation of specific vibration test campaigns, by linking the models of mechanical facilities (e.g. shakers) to the model of the item under test and by simulating their interaction, till the extent to correlate the results of the simulation (virtual test) to the real test case. This approach could then be extended to other domains by defining a common

approach to the multi-physics modelling, starting from a common data format (e.g. STEP file) for capturing the state of the item under test.
The activity aims to develop the process and identify models required to demonstrate feasibility and benefits of integrating data from multi-physic models into AIT environment.
The activity shall consider a use case requiring diverse (2 or more) models (such as thermal, structural or optical) to be cross-linked (e.g. data fusion) to perform a representative analysis for AIT operations.
This activity encompasses the following tasks:

- Review of the new release of STEP AP 242.
- Define the level of information to be encompassed in the file format.
- Draft guidelines for the use of the common file format (STEP) and for the subsequent integration and/or mapping of the domain specific physical models (e.g. Thermal model, mechanical model).
- Propose and agree with the Agency a representative use case, covering different domains relevant to AIT activities and requiring different models (e.g. structural, thermal) to interact (data exchange).
  - Analyse the state of the art in terms of available tools and models solution for the selected use cases.
  - Define the process required to perform the tasks associated to the use case.
  - Identify available models and/or tools supporting the process, exploiting at the maximum extent their capabilities and their customization.
  - Define potential gaps and identify solutions to bridge them.
- Select the baseline of the representative models to be used, analysis and generalization.
  - Determine and implement the data exchange/data fusion among the selected models, and where possible, use of multi-physics models and simulation tools.
  - Demonstrate the feasibility and the benefits of the approach to the use case.
- Update the guidelines, including the workflow supporting the implementation of the data fusion and a set of guidelines and information to be used in similar cases in future development.

The activity aims at implementing one of the first steps towards the creation of the end-to-end Digital Model (or Digital Twin) 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 cloud of repositories) which would act as 'single truth source', reducing inconsistencies and increasing efficiency.

**Deliverables:** Study report, Guidelines for the applicability of the proposed methodology, any developed tool, and the results of simulations and/or tests performed.

| **Current TRL:** | 3 | **Target TRL:** | 6 | **Duration (months):** | 24 |
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**Target Application/ Timeframe:** AIT operations.

**Applicable THAG Roadmap:** Not related to a Harmonisation subject.

# 3.8. Deep-space Optical Communication System

## 3.8.1. Deep-space Optical Communication System

### 3.8.1.1. TD12 - Ground Station Systems and Networks

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|---|---|
| *Domain* | *Deep-space Optical Communication System* |
| *Tech. Domain* | *12 - Ground Station Systems and Networks* |

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|---|---|---|---|
| **Ref. Number:** | **GT1D-001GS** | **Budget (k€):** | 6,500 |

**Title:** **Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD) Ground Terminal Technology Developments**

**Objectives:** This frame proposal combines the technology developments needed for the ground terminal of the Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD). This proposal is for the first 3 priority 1 activities in the timeframe 2017-2019, see below: DOCS-Ground-1, DOCS-Ground-3 and DOCS-Ground-7.

**Description:** Future deep space communication ground terminals will need to have a diameter of 12m.. The aim for DOCS will be for a 4-6m diameter optical antenna. In addition a photon-counting optical communications detector breadboard funded under TRP has started. An adaptive optics feasibility study funded under CTE is under preparation, that should be followed by a TRP funded highly selective optical receiver filter system breadboard, and a photon-counting short wave infrared (SWIR) 2D tracking detector array breadboard. Based on the above funded low TRL technology development activities and the missing elements for a complete optical terminal the following additional activities are proposed.

The priority 1 activities proposed are: DOCS-Ground-1, DOCS-Ground-3, DOCS-Ground-7.

- DOCS-Ground-1: Deep Space High Rate Optical Ground Receiver (SCPPM). Development of a deep space optical communication modem according to CCSDS High Photon Efficiency (HPE) standard (Serially Concatenadated Pulse Position Modulation, SCPPM). 1,500 kEUR.
- DOCS-Ground-3: Deep Space 4-6m Optical Antenna Detailed Design. Deep Space Low Cost 4-6m class Optical Antenna for Day/Night Operations, Detailed Design and breadboarding of critical elements. 2,000 kEUR.
- DOCS-Ground-7: Deep Space High Power (5 kW) Uplink Beacon System Development of a High Power (5 kW) Uplink Beacon System including optical terminal, laser transmitter, and safety system. 3,000 kEUR.

For reference, the other (priority 2) DOCS-Ground activities are the following

- DOCS-Ground-2: Deep Space Photon-Counting Optical Communications Detector. Development of a deep space photon-counting optical communication detector (follow-on from TRP). 700 kEUR
- DOCS-Ground-4: Deep Space Photon-Counting Acquisition Detector. Deep Space Photon-counting Short Wave Infrared (SWIR) 2D (Acquisition and Tracking) Detector Array Development (follow-on from TRP).
- DOCS-Ground-5: Deep Space Optical Background Rejection System. Development of a combined adaptive optics and filter system for background rejection during day-time operation, and small Sun-Earth-Probe angles (follow-on from TRP).

- DOCS-Ground-6: Deep Space 4-6m Optical Antenna Prototype. Deep Space Low Cost 4-6m class Optical Antenna for Day/Night Operations, Prototype development for deployment of the DOCS in-orbit demonstration on the SWE L5 mission.
- DOCS-Ground-8: Integration SWE L5 4-6m Optical Ground Station. Integration and Validation of the 4-6m optical antenna and all subsystems at a suitable site, e.g. Tenerife, as part of the DOCS SWE L5 in-orbit demonstration.

**Deliverables:** Prototype

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|---|---|---|---|---|---|
| **Current TRL:** | 3 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** DOCS IOD for launch in SSA SWE L5 mission in 2023. TRL 6 by 2019 for PDR. (The priority 1 activities in the timeframe 2020-2023 will lead to the prototype terminal for the SWE L5 mission in-orbit demonstration).

**Applicable THAG Roadmap:** Ground Station Technology (2015).

### 3.8.1.2. TD17 - Optoelectronics

| | |
|---|---|
| *Domain* | *Deep-space Optical Communication System* |
| *Tech. Domain* | *17 - Optoelectronics* |

**Ref. Number:** **GT1D-002MM** **Budget (k€):** 5,900

**Title:** **Deep-space Optical Communication System (DOCS) In-Orbit Demonstration (IOD) Space Terminal Technology Developments**

**Objectives:** This frame proposal combines the technology developments needed for the space terminal of the DOCS IOD. This proposal is for 5 priority 1 activities in the timeframe 2017-2019, see below: DOCS-Space-1, DOCS-Space-3, DOCS-Space-5, DOCS-Space-6 and DOCS-Space-7.

**Description:** Future deep space optical communication terminals on spacecraft at distanced up to 3 AU (Mars) will require a telescope assembly with a diameter of 200 mm, a laser and data modulator, a highly efficient amplifier, a communication and ranging receiver, an acquisition and tracking sensor, an optical bench with fine pointing assembly and terminal control system and finally a data coding and modulation system. The above mentioned technologies have been developed to low TRL level and the following activities are proposed to develop an engineering model of a complete optical space terminal:

The priority 1 activities proposed are: DOCS-Space-1, DOCS-Space-3, DOCS-Space-5, DOCS-Space-6 and DOCS-Space-7.

- DOCS-Space-1: Telescope Assembly. Development of an a-thermal optical communication telescope with 200 mm aperture diameter, without central obscuration and large corrected field of view. 1,500 kEUR.
- DOCS-Space-3: Laser amplification system. Development of a deep-space laser amplification system with high peak to average power ratio and single-mode (TEM00) operation in a wavelength range between 1530 and 1577 nm. 1,200 KEUR.
- DOCS-Space-5: Acquisition and tracking sensor. To increase the technology readiness level of an IR enhanced CMOS sensor for earth beacon acquisition, tracking and tele-command reception. 1,000 kEUR.
- DOCS-Space-6: Optical bench inclusive fine pointing assembly and terminal control system to design and environmentally test an a-thermal optical bench and to add a tip/tilt mechanism and a terminal control system. 1,500 kEUR.
- DOCS-Space-7: Digital Modulator for Deep Space Optical Missions Study, design and develop (up to EM) the digital functionalities of a deep space pulsed position modulator (PPM) based on the relevant CCSDS draft standard with a target data rate of about 10 Mbit/s and the potential to scale to 100 Mbit/s. 700 kEUR.

For reference, the other (priority 2) activities will depend on the achievements of the preceding TRP activities. The activities will lead to the engineering model of a deep-space optical communication terminal for the SWE L5 mission in-orbit demonstration. These activities are: DOCS-Space-2 and DOCS-Space-4.

- DOCS-Space-2: Laser and Modulator. Development of a laser source and modulator system for data rates between 100 kbps and 10 Mbps. 800 KEUR.
- DOCS-Ground-4: Communication and ranging data receiver. Development of a communication and ranging receiver for encoded deep-space optical beacons. 1,000 KEUR.

**Deliverables:** Engineering Model

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|---|---|---|---|---|---|
| **Current TRL:** | 4 | **Target TRL:** | 6 | **Duration (months):** | 18 |

**Target Application/ Timeframe:** DOCS IOD for launch in SSA SWE L5 mission in 2013. TRL6 by 2019 for PDR.

**Applicable THAG Roadmap:** Optical Communication for Space (2012).