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EUROPEAN SPACE TECHNOLOGY HARMONISATION

PROPOSED WORKPLAN FOR 2020

AND LIST OF TECHNOLOGIES EARMARKED FOR 2021 AND 2022

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1 INTRODUCTION

This document aims to present the proposed technologies which will be covered by the European Space Technology Harmonisation in 2020 and to provide a preliminary list of technologies which are to be considered for Harmonisation for the period 2021 – 2022.

The process of defining the list of subjects for 2020 involved the Technology Harmonisation Advisory Group (THAG), ESA Technology, Engineering and Quality Directorate, ESA Programme Directorates and Industry, and consists of the following steps:

a. Feedback from Industry, through Eurospace and SME4Space, on 2020 Harmonisation topic selection (based upon topics earmarked for 2020 in the 2019 Workplan).

b. Determination of the list of Harmonisation subjects for the year 2020, discussed with THAG at a dedicated session held on the 5th of February 2019 in conjunction with the 1st cycle 2019 Mapping Meetings.

c. Finalisation of 2020 Workplan with THAG and agreement at a dedicated session held on the 9th of April 2019 in conjunction with the 2nd cycle 2019 Mapping Meetings.

Submission of the Harmonisation Workplan 2020 to the June 2019 IPC meeting for approval.

2 CRITERIA FOR IDENTIFICATION AND SELECTION OF TECHNOLOGIES

The technologies for this Workplan are identified from the following input:

a. Actions from previous Harmonisation Meetings

b. Review of the previous Harmonisation subjects and coverage of the ESA Technology Tree

c. Proposals received from THAG Delegations, Industry via Eurospace and SME4Space, ESA Directorates

d. Results of the analysis of the implementation of past harmonised Roadmaps (tracking) and the need to revisit some Technologies.

In order to define the level of priority and identify the subjects to be proposed for next year, the following criteria are taken into account.

<u>1. Technology maturity level</u>
Harmonisation Roadmaps aim at bringing the addressed technologies and products to the necessary maturity, performance and competitiveness levels for the benefit of European institutional and commercial programmes. Harmonisation should not and is not compromising advanced basic research or innovation.

<u>2. Strategic relevance for Europe</u>
Leading edge technologies enabling new missions and technology areas strategic for ensuring European non-dependence have high priority.

<u>3. Mission needs and market potential</u>
Technologies answering to mission requirements or to a market demand.

<u>4. Technology gap or unnecessary duplication</u>
Experts’ inputs to assess gaps and overlaps

<u>5. Need to revisit a technology roadmap</u>
As a general rule, it is intended to revisit previously harmonised subjects every 3-5 years, to check technology or industrial landscape evolution. If not possible within this time frame, the objective is to at least revisit the subject before most of the activities in the previously approved Roadmap are planned to end, in order to ensure Roadmap continuity and avoid gaps. The revisit however depends on the specific subject and a decision on this must be supported by the results of an analysis of past roadmap implementation using the Harmonisation tracking system.

3 LIST OF TECHNOLOGIES FOR 2020

Table 3-1 lists the ten technologies proposed for Harmonisation in 2020. For each of the topic the relevant Competence Domains[1] are indicated.

Table 3-1 List of Technologies for Harmonisation in 2020

1st cycle 2020			
Competence Domain(s)	**Title**	**Revisit**	**New**
CD03, CD01, CD02, CD05	AOCS Sensors and Actuators	2013	
CD03	On-Board Software	2014	
CD08, CD09	Functional Verification and Missions Operations Systems	2014	
CD01	Micro-Nano Technologies - MEMS	2014	
CD08	System Engineering Digital Infrastructure (former System Data Repository)	2014	
2nd cycle 2020			
Competence Domain(s)	**Title**	**Revisit**	**New**
CD05	Critical Active RF Technologies	2014	
CD02	Pyrotechnic Devices	2013	
CD02	Solar Array Drive Mechanism	2014	
CD04	Electromagnetic Compatibility		X
CD03, CD05, CD08	TT&C Transponder and Payload Data Transmission	2012	

The 2020 IPC-THAG Meeting dates are proposed as follows:

14-16	January	2020	1st	cycle	Mapping Meeting
18-20	May	2020	1st	cycle	Roadmap Meeting
9-11	June	2020	2nd	cycle	Mapping Meeting
1-3	December	2020	2nd	cycle	Roadmap Meeting

Note that these dates may be subject to change to minimise conflict with other ESA events and calendars.

[1] Details description of Competence Domains are shown in section 7, Table 7-1.

4 DESCRIPTION OF TECHNOLOGIES FOR 2020

The following descriptions of the technologies proposed for the Harmonisation Workplan for 2020 may be refined at the start of the cycles.

4.1 AOCS SENSORS AND ACTUATORS

The previous Harmonisation of the topic "AOCS Sensors and Actuators" was split in two parts and took place in 2013 and 2015. In the next revisit, it is proposed to address all aspects of AOCS Sensors and Actuators as one combined Harmonisation topic. It would be the fifth Harmonisation of this topic.

4.1.1 Technology Overview

The guidance, navigation, and control (GNC) or attitude and orbit control subsystem (AOCS) of a space vehicle relies on estimating the state of the spacecraft from measurements made by sensors, deriving the required control actions by comparing with the guidance profile to change that state to the desired one using control laws and then realising those control actions using actuators. It is the hardware elements of this system, notably the GNC/AOCS Sensors and Actuators, that are considered in this document.

Within the scope of this document, the sensors and actuators required by a GNC/AOCS system are considered for the following types of application:

- Telecommunications (GEO, MEO, LEO)
- Earth Observation (LEO, GEO)
- Meteorology (GEO, LEO)
- Scientific (observatories, planetary, formation flying)
- Exploration (manned, robotics)
- Navigation (MEO)
- Micro, nano and pico satellites (MNP)
- Launchers

Micro, nano and pico satellites were added as an additional, separate application in the 2009 version of this roadmap due to the expansion of interest in the area. Their specific constraints have indeed fostered disruptive innovations (e.g. sensors on a chip) supporting miniaturisation and low cost, which will also benefit the conventional satellites. The emergence of "new space" has notable impact on the needs for AOCS and GNC sensors and will therefore be taken into consideration in the next update of the roadmap.

4.1.2 Areas Covered by this Technology Topic

This Harmonisation topic addresses especially Technology Domain TD5 – Space Systems Control, and more specifically subdomain / technology group B-II addressing the AOCS/GNC technology covering the implementation technologies (here hardware) for all mission classes.

When this Harmonisation topic was first addressed in 2001, the scope was limited to mainly star sensors, gyros/ IMUs and CMGs. The number of units addressed was expanded during the second Harmonisation round in 2005 to include most of the other mainstream AOCS sensors such as Earth sensors, Sun sensors etc. as well as including reaction wheels.

Following requests, the scope was again increased during the third Harmonisation round in 2009 to cover also the numerous types of navigation sensors as well as the system and general technology studies required to steer the sensor and actuator developments.
Due to the high amount of effort required to revisit such a large roadmap, it was proposed – for its fourth iteration – to have a 2-step approach:

- in 2013 the mainstream core AOCS/GNC equipment was covered (CMOS/APS {as building blocks}, STR, IMU and reaction wheels);
- all other AOCS/GNC equipment was addressed in a second step conducted in 2015.

Despite the effort to manage a large topic, it is considered more favorable, and as such proposed for Harmonisation in 2020, to come back to one single topic covering all AOCS/GNC Sensors and Actuators in order to guarantee a consistency in the analysis of the situation and the recommendation of roadmaps.

The main Sensors and Actuators used in AOCS/GNC are listed in the table below. Those in Italics are not considered in any detail in this topic since they are covered by other Harmonisation Dossiers and Roadmaps.

AOCS/GNC Sensors and Actuators	**Previously addressed**
3-D Cameras	2015
Accelerometers	2013
Active Pixel Sensors (APS)	2013
Control Moment Gyroscopes (CMG)	2015
Earth Sensors (ES)	2015
GNSS	2015
Gyroscopes and Inertial Measurement Units	2013
Hybrid Navigation Sensors	2015
Lidars	2015
Magnetometers (MTM)	2015
Magnetorquers (MTQ)	2015
Optical Navigation Sensors	2015
Propulsion (Electrical & Chemical)	2015
Reaction/Momentum Wheels (RWS)	2013
Star Trackers (STR)	2013
Sun Sensors (SS)	2015

Note that Active Pixel Sensors and Accelerometers are treated within this topic at the same level as units although they do not represent equipment in their own right and are generally incorporated into other units such as IMUs or STRs. It is proposed to present them in dedicated sections in the Dossier due to their importance and the large effort required for their development.

The relevant Competence Domain are CD03, CD01, CD02 and CD05 (see Table 7-1 in Annex).

AOCS Sensors and Actuators covers the ESA Technology Tree as per **Error! Reference source not found.**:

Table 4-1: Technology Tree Coverage – AOCS Sensors and Actuators

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	Space System Software	B	Space Segment Software	III	Software Architectures
5	Space System Control	A	Control Systems Engineering	I	AOCS/GNC Architecture
				II	Autonomy and FDIR
				IV	Control Requirements Engineering
				V	Control Design and Verification
		B	Control Systems Innovative Technologies	I	GNC Technologies for Entry, Descent and Landing
				II	GNC Technologies for Cruise, Rendezvous and Docking or Capture
				III	High accuracy Pointing Technologies
				IV	Competitive AOCS technologies
		D	AOCS GNC Sensors and Actuators	I	AOCS/GNC Optical Sensors
				II	AOCS/GNC Inertial and Magnetic Sensors
				III	AOCS/GNC Inertial and Magnetic Actuators
15	Mechanisms	A	Mechanism Core Technologies	I	Actuator Technologies
				IV	Motion & Force Sensor Technologies

16	Optics	C	Optical Equipment and Instrument Technology	II	Cameras, Illumination Devices, Displays
17	Optoelectronics	B	Detector Technologies	I	Visible Detectors (mostly Si based)
23	EEE Components and Quality	B	EEE Component Technologies	VIII	Micro Electro Mechanical Systems (MEMS)

4.2 ON-BOARD SOFTWARE

The previous Harmonisation of the topic "On-Board Software" took place in 2014. The next would be the fifth Harmonisation of this topic.

4.2.1 Technology Overview

The space system on-board software technical domain consists of software applications embedded in space systems. It interfaces with the ground-based software, which is developed to support daily operations after launch.
Indeed, software for on-board space systems usually requires stringent constraints, in terms of real-time execution, dependability, availability, reliability, in order to ensure the success of the space mission, and to optimise the availability, capability, flexibility, and reliability of the system while minimizing cost and risk.
Since space systems rely more and more on software to achieve a large amount of complex functions, cost and risk are consequently closely dependent on software. The uses of new technologies, adequate software engineering methods and tools, standards, and fault-tolerance techniques are domains to study in order to produce better quality software at lower costs.

The 2020 Harmonisation will confirm the Software Factory concept (introduced in 2014) with a focus on the Model Based System Software Engineering and explore the impact of the introduction of new processor technologies, e.g. System-On-Chip (chip grouping multiple processing cores, a reprogrammable FPGA and interfaces). Moreover, the 2020 Harmonisation will cover the introduction of Artificial Intelligence on-board spacecraft. In addition, it will address the supporting technologies and reference implementations related to these main topics. This Harmonisation will use inputs provided by the Space AVionics Open Interface aRchitecture Advisory Group (SAVOIR AG) and its sub-groups.

4.2.2 Areas Covered by this Technology Topic

The On-Board Software is organised according to the Technology Tree in the following manner:
- 2AI - Methods and tools for the software development that are innovative in the commercial world and require analyses for the adoption in the space domain.
- 2-A-II - New functions of the software systems that are anticipated to be needed but that need pre-development or prototyping before actual space developments (autonomy, FDIR).
- 2B - Space Segment Software therefore includes, in a way similar to the previous Dossier:
    - Methods and tools for the On-Board software engineering (all aspects of On Board software engineering, requirement engineering, automation of the life cycle, testing, model based development, etc. In particular, it includes software emulators of on-board processors)
    - Innovative management process (Adaptive engineering, Agile life cycle, new planning approaches, cost estimation methods, distributed development. The focus is put on the system aspects of software, the system software co-engineering. It covers also software hardware co-engineering.)

- Architectures (Software architectures for space segment software, including TSP approach, communication protocols, Plug and Play technologies).

Some of these topics involve not only software, but also control or data handling. They are addressed mainly in the Avionics Embedded Systems topic: hardware software co-design, communication protocols, autonomy and FDIR (except software engineering for dependability addressed here).

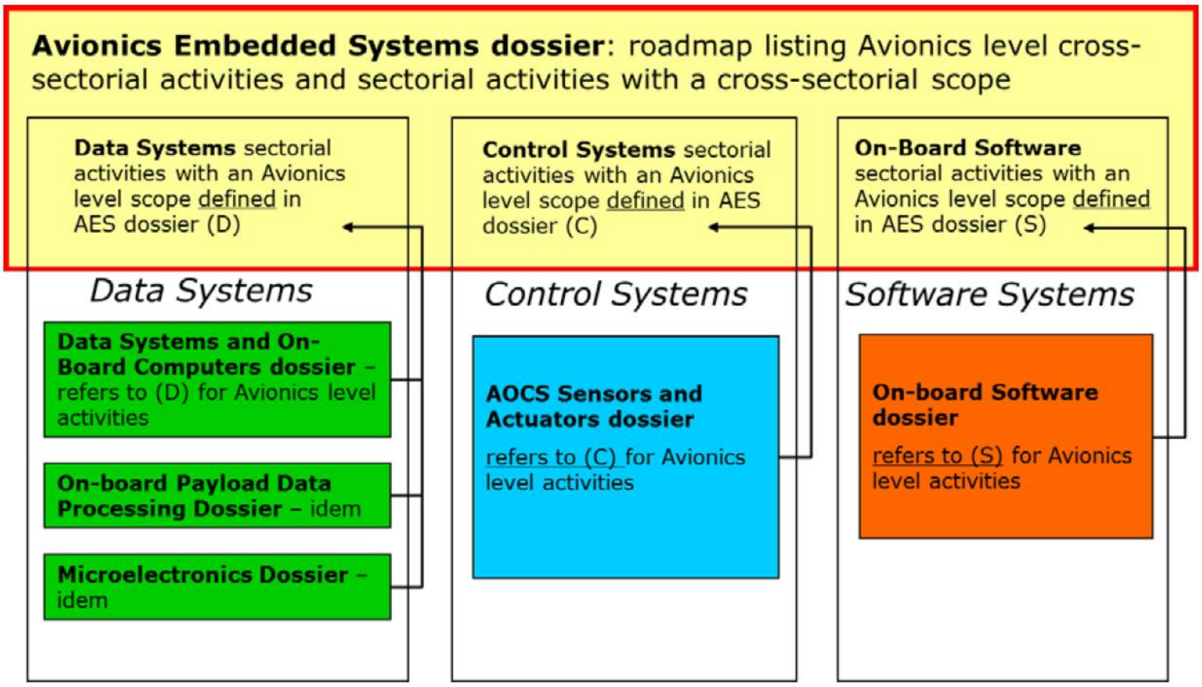


Figure 4.2-1

Integrated Modular Avionics is relevant to avionics, but it is addressed in both topics, i.e. in avionics for the system aspects and in this topic for the pure software aspects related to Time & Space & Security Partitioning.
In addition, for the 2020 edition, it is proposed to associate the on-board software engineering Harmonisation with the software product assurance Harmonisation, represented by the Technical Domain 25 B.
This includes the following generic goals:

- Enabling Technologies: Development of leading-edge technologies in the PA&S disciplines to support the future success of ESA projects;
- Methods, Tools & Standardization: Provide methods, tools, standards and specifications for the enhancement of effectiveness and efficiency of ESA projects;

Upgrade effective software PA methods and tools to deal with the evolution of software development methodologies.

The relevant Competence Domains is CD03 (see Table 7-1 in Annex) with the aspects related to Artificial Intelligence covered by Competence Domain CD09.

With reference to the ESA Technology Tree, this topic covers the following Technology Domains:

Table 4-2: Technology Tree Coverage – On-Board Software

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	Space System Software	A	Advanced Software Technologies	I	Advanced Software Development Methods and Tools
				II	Advanced software functions
		B	Space Segment Software	I	Methods and Tools for On-board Software Engineering Processes
				II	Innovative Software Management Process
				III	Software Architectures
25	Quality Dependability and Safety	B	Software Quality	I	SW Process Quality Techniques
				II	SW Product Quality Techniques
26	Others				Avionics Embedded Systems

4.3 FUNCTIONAL VERIFICATION AND MISSION OPERATIONS SYSTEMS

The previous Harmonisation of the topic “Functional Verification and Mission Operations Systems” took place in 2014. The next would be the third Harmonisation of this topic.

4.3.1 Technology Overview

Functional Verification i.e. Functional Verification and AIT covers methods, standards and tools as well as infrastructures (hardware, software and data) necessary to develop, assembly, integrate and verify space systems in the pre-launch phase. Functional Verification encompasses Functional Engineering Simulators (FES), Software Verification Facilities (SVF), Spacecraft AIV Simulator and Electrical Ground Support Equipment (EGSE).

Mission Operations Systems encompasses Mission Control, Flight Dynamics, Training, Operations and Maintenance Simulators and Mission Planning Software and the associated networks, stations and archiving systems.

The areas of Functional Verification and Mission Operations Systems are closely related, since both are linked to the operational design of a space system. They need to have access to design and development data, operational data, covering different phases over the entire project life cycle. In fact, the continuity between Functional Verification & AIT phase and the Operations phase is foreseen to be a cost effective approach, namely considering Monitoring & Control solutions and Validation (e.g. procedures, synoptics). Therefore, an integrated system from Phase A until Phase F is required to reduce cost and complexity and enforce compatibility for data production, archiving and distribution across different Science Centres.
The main technology push to improve the system design and verification process is in the area of model-based system engineering, covering the entire lifecycle of a space project. It addresses the overall process of system engineering, focussing on the use of (virtual) models to support the design, analysis and verification process up to operations, allowing advancing some critical tasks (such as system verification) to earlier phases in comparison to the conventional practice (“nested” verification Vs).

This approach will improve the output of the formulation phases, establishing a more solid foundation for the development phases and reducing the technical risks. With the present focus on functional verification, significant links to the operational phase (in terms of operations and related infrastructure / models) can be established early on. However, even with this focus on Functional Verification other needs of AIT and OPS will be addressed as well.

4.3.2 Areas Covered by this Technology Topic

The technology areas covered by this topic come mainly from three domains of the Technology Tree: Technical Domain TD2-C Ground Segment Software, TD2-D Data Archiving Systems for M&C related data; Technical Domain TD-8D System Design and Verification - Verification and AIT; and Technical Domain TD-9-B Mission Operations and Ground Data Systems - Mission

Operations as well as TD-9-C Mission Operations and Ground Data Systems - Ground Data Systems.
The Technical Domain TD2-C Ground Segment Software covers mission control system software design, verification, validation and maintenance methods/tools. Application of modern IT technologies to spacecraft operations, including Service-oriented Technologies.
The Technology Domain TD-8D System Design and Verification – Verification and AIT covers technology, methods and tools to support the System Engineering processes (specification, design, and verification) of space systems during the complete lifecycle of space missions (phases 0 to F). It focuses on the problematic of reducing the schedule and/or cost of the development process of the space system (i.e. space and ground segment) whilst controlling quality and risk (mission success) to the required level. It covers new paradigms (e.g. model-based systems engineering), approaches and techniques for the development of space systems, which are mostly common to several service domains.
The Technology Domain TD-9 Mission Operations and Ground Data Systems addresses aspects related to the control and operations of space systems (space segment and ground segment), and the technologies associated to the supporting systems and tools. The domain is centred on Mission Control Systems (MCSs), which are used to monitor and control both space and ground segments.
This Harmonisation topic provides an overview of the various subsystems within the Functional Verification and Mission Operations Systems with the aim of providing a picture of the present status of technology and an overview of the expected future trends.
The Harmonisation addresses in general the following facilities and subsystems:

- Functional Engineering Simulators (FES)
- Software Verification Facility (SVF)
- Spacecraft AIV Simulator
- Ground System Test Simulator
- Training, Operations and Maintenance Simulator (TOMS)
- Electrical Ground Support Equipment (EGSE) systems
- Mission Control Systems (MCS)
- Flight Dynamics Systems (FDS)
- Mission Planning Systems (MPS)

Note: the FES is not considered for roadmap Harmonisation.

As well as subsystems and components used inside or across these major facilities:

- Mission DataBase (MDB)
- Automated Procedure Preparation, Execution and Post-processing Tools
- Data archiving and distribution, including long term archive

Related to these facilities, this Harmonisation topic covers also process definitions, standards and reference architectures as well as supporting methodologies.

This topic has some overlap with other Harmonisation topics:
Harmonisation topic on Space System Software covers software for both space and ground segment as well as all basic techniques and technologies in the field of software and information technology with respect to their application to space missions. It has an overlap with the ground segment software for functional verification such as SVF and EGSE facility software.

The Harmonisation topic on System Modelling and Simulation Tools covers tools used at system level for space system development. There is an overlap related to Functional Verification facilities such as SVF and EGSE. However, the focus is different. The topic on System Modelling and Simulation Tools covers the Technology Domain TD8-C System Analysis and Design while this Harmonisation topic covers, among others, the Technology Domain TD8-D Verification and AIT.
The Harmonisation topic on System Data Repository (to be titled System Engineering Digital Infrastructure from 2020) covers methods and tools for information exchange as part of the system engineering process ensuring semantic interoperability during the complete lifecycle of a space system. It has an overlap related to databases, e.g. Mission Database, used in the various subsystems related to Functional Verification and AIT and Mission Operations Systems.
For this round of Harmonisation, the early engineering phases related to the Functional Engineering Simulators domain are not considered. For the Software Verification Facility (SVF) the Spacecraft AIV Simulator and Ground System Test Simulator as well as Training, Operations and Maintenance Simulator (see ECSS-E TM-21A), the monitoring and control, procedure execution as well as configuration database are targeted for Harmonisation in this Dossier and Roadmap.

The relevant Competence Domains are CD08 and CD09 (see Table 7-1 in Annex).

The Functional Verification and Mission Operations Systems topic covers the ESA Technology as per Table 4-3

Table 4-3: Technology Tree Coverage – Functional Verification and Mission Operations Systems

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	Space System Software	D	Ground Data Processing	I	Data Archiving Systems
8	System Design and Verification	D	System Verification and AIT	I	Advanced AIT Methods
				II	Ground Support Equipment
9	Mission Operation and Ground Data Systems	C	Ground Data Systems	I	Mission Control System, Automation, Mission Planning, Simulators and Station M&C and Data Centre Architecture and Technologies
				II	Preparation and Procedure Tools
				III	Human–Computer Interfaces and Technologies

4.4 MICRO-NANO TECHNOLOGIES

The previous Harmonisation of the topic “Micro-Nano Technologies” took place in 2014. The next would be the second Harmonisation of this topic.

4.4.1 Technology Overview

MEMS technology starts to play a key role in the on-going miniaturisation of electronic modules and systems in ESA: AOCS modules, payload for earth observation (S3 MEMS rate sensor and AEOLUS O2 Laser cleaning system MEMS Pressure Sensors), also scientific payload (JWST and GAIA micro-propulsion). Of the MEMS technologies available and in development for space applications three main are part of this topic: MEMS Pressure Sensors, MOEMS and RF MEMS.

MEMS Pressure Sensors covered by this topic are in particular capacitive, piezoresistive and micromachined Pirani Gauges. Mainly suitable for applications where size, accuracy and environmental conditions are key requirements. MEMS Pressure Sensors are an enabling technology that will benefit space domain of application such as propulsion systems, propellant gauging systems or simply integrated in a specific instrument for scientific purposes.

Micro Opto Electro Mechanical Systems (MOEMS) components are MEMS with the ability to alter or modulate a light beam by reflection, diffraction or refraction. Therefore, they combine optical, mechanical and electrical functions. MOEMS is an enabling technology for some terrestrial applications, such as optical communications and projection displays. They will benefit to space domains of application such as space telecommunication, earth observation and scientific instruments.

RF MEMS technology could play a key role in the on-going miniaturisation of electronic modules and systems in the future telecommunications, observation and space exploration satellites and probes. While MEMS operating in the low-frequency region are currently being employed, e.g. acceleration sensors in automotive applications, the field of RF MEMS is still in a state of research and early development in Europe. RF MEMS switches exhibit excellent RF properties as low insertion loss, low power consumption and high isolation. In addition, MEMS can very straightforwardly be integrated into RF sub-modules to achieve a higher degree of functionality, for example in phase shifters, power routing networks or reconfigurable antennas. Space environment is a harsh environment as such, so wafer level packaging is needed to protect the RF MEMS components as soon as it is produced. These constraints can challenge the overall performance and lifetime of the device. Compliance with a large temperature range, mechanical vibrations, shock, etc. has to be achieved not only by a single MEMS device but also by MEMS based packaged subsystems. Adapted packaging technology with high reliability is one of the key issues for the application of RF MEMS technology in the aforementioned fields.

4.4.2 Areas Covered by this Technology Topic

MEMS Pressure Sensors will find applications in scientific instrumentation, propulsion and propellant gauging systems. The most relevant TSDs (Technology Sub-Domains) of the ESA technology tree are TD 23-B-VII 19-D-II and they appear under I-C-1-i and II-B-1-i in ESA generic product tree.

Within the scope of 2020 Harmonisation, the following categories of MEMS Pressure Sensors are to be addressed:

- Piezoresistive Pressure Sensors
- Capacitive Pressure Sensors
- Micromachined Pirani Sensors

MOEMS will find applications in telecommunications systems, Earth Observation and scientific instrumentation.
MOEMS devices are promising for the implementation of on-board optical communication systems with high bandwidth (several GBit/s), thanks to their low consumption, low volume and low mass. Optical payload elements concerned with telecommunications, on-board data-handling or data communications, might be incorporating MOEMS devices. Considered in this topic are the components falling under the following categories:

- Optical switches and switching matrices
- Variable optical attenuators
- Tilting micro-mirrors for fine optical beam steering

MOEMS-based Spatial Light Modulator (SLM) components will permit the development of small, low-cost, light, and scientifically efficient instruments, and allow breakthroughs in observational astronomy and related fields:

- Programmable micromirror arrays
- Programmable microshutter arrays
- Programmable Micro Diffraction Gratings
- Deformable mirrors for adaptive optics
- Hermetic solutions for MOEMS

In this topic, it is not intended to consider the components falling under the categories Bolometers for imagers, Terahertz reflectors and imagers, Tunable and movable micro-lenses and Micro-interferometers.

RF MEMS will find applications primarily in telecommunications, but additional usage in scientific instrumentation and earth observation payloads are also predicted.
Within the scope of 2020 Harmonisation, the following RF MEMS components are to be considered:

- RF MEMS switches and associated matrices
- Micromachined RF filters (MEMS fabrication processes but no moving part)
- RF MEMS varactor
- Associated RF MEMS Hermetic packaging

The relevant Competence Domain is CD04 (see Table 7-1 in Annex).

The Micro-Nano Technologies topic covers the ESA Technology Tree as per Table 4-4

Table 4-4: Technology Tree Coverage – Micro-Nano Technologies

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	RF Systems Payloads and Technologies	E	RF Technologies and Equipment	III	RF Devices
15	Mechanisms	E	MEMS Technologies		
16	Optics	B	Optical Component Technology and Materials	II	Micro-Optics Components, MOEMS, Optical Fibres and Passive Integrated Optics
23	EEE Components and Quality	B	EEE Component Technologies	VIII	Micro Electro Mechanical Systems (MEMS)

4.5 SYSTEM ENGINEERING DIGITAL INFRASTRUCTURE (FORMER SYSTEM DATA REPOSITORY)

The previous Harmonisation of the topic “System Data Repository” took place in 2014. The next would be the second Harmonisation of this topic.

4.5.1 Technology Overview

Developing space systems implies complex activities involving many parties who are widely distributed in location and time. Such development requires efficient and effective information exchange during the complete lifecycle of the space system. This is integral part of the system engineering process and can only be achieved by realizing semantic interoperability between all involved parties, i.e. ensuring that the suppliers and the customers of the data that is exchanged have the same semantic understanding of the information represented/carried by that data.

Semantic interoperability requires that the information models used by the suppliers and those used by the customers are formally expressed and compatible.

The last years have seen several developments addressing this problem area. The system engineering process has a long heritage of being structured (e.g. in the ECSS standard ECSS-E-ST-10C, the ISO/IEC 15288, or the System Engineering Handbook of INCOSE). These initiatives being focused on stakeholders and processes, they do not provide proper references on the level of the information model specification required to guarantee a safe data exchange protocol. In particular, there is the need for an evolution of the current process description to clearly identify the data exchange and tie this into the (semantic) data description. This becomes more and more relevant in the general trend of model-based system engineering (MBSE), which is “the formalized application of modelling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development, verification and operations life cycle phases” (source: “INCOSE Systems Engineering Vision 2020” TP- 2004-004-02, v2.03, Sep 2007). The rigorous definition of models and their relations to the stakeholders and the related views can serve as guidance to limit the problem of interoperability. The standard ISO/IEC/ IEEE 42010 “Systems and software engineering — Architecture description” can also provide elements to be considered in a methodology for specifying system models.

For the purpose of this topic, using the term “formal” will indicate "logic based". This definition is selected due to one of the objectives of "modelling" that is to enable automated treatment / reasoning on the information modelled and possibly to automate the production of solutions, e.g. the automatic code generation to produce solutions in the functional domain. In that case, the productive nature of the model requires the strictest formalism.

Contrary to “formal”, the term "standardised" refers to a "per consensus" agreement, and does not need to be "logic based". Standards give a direction for everyone willing to develop products or to re-design existing products for the purpose of enabling interoperability between these different products in a supplier / customer relationship. Harmonisation will consider the current solutions and provide a view to adapt these solutions for the purpose of solving interoperability issues. This can provide important elements for a standardisation process.

The term “modelling” will be used when addressing this topic to describe the translation into machine-readable and processable form of (engineering) information. This is supported by tools, which are usually storing the model in a tool- or implementation dependent representation (see figure below: Model, tool and meta-model relations below). These models are therefore discipline-specific and depend on specific meta-models and related methodologies. The related representations rely on specific languages (graphical or others).

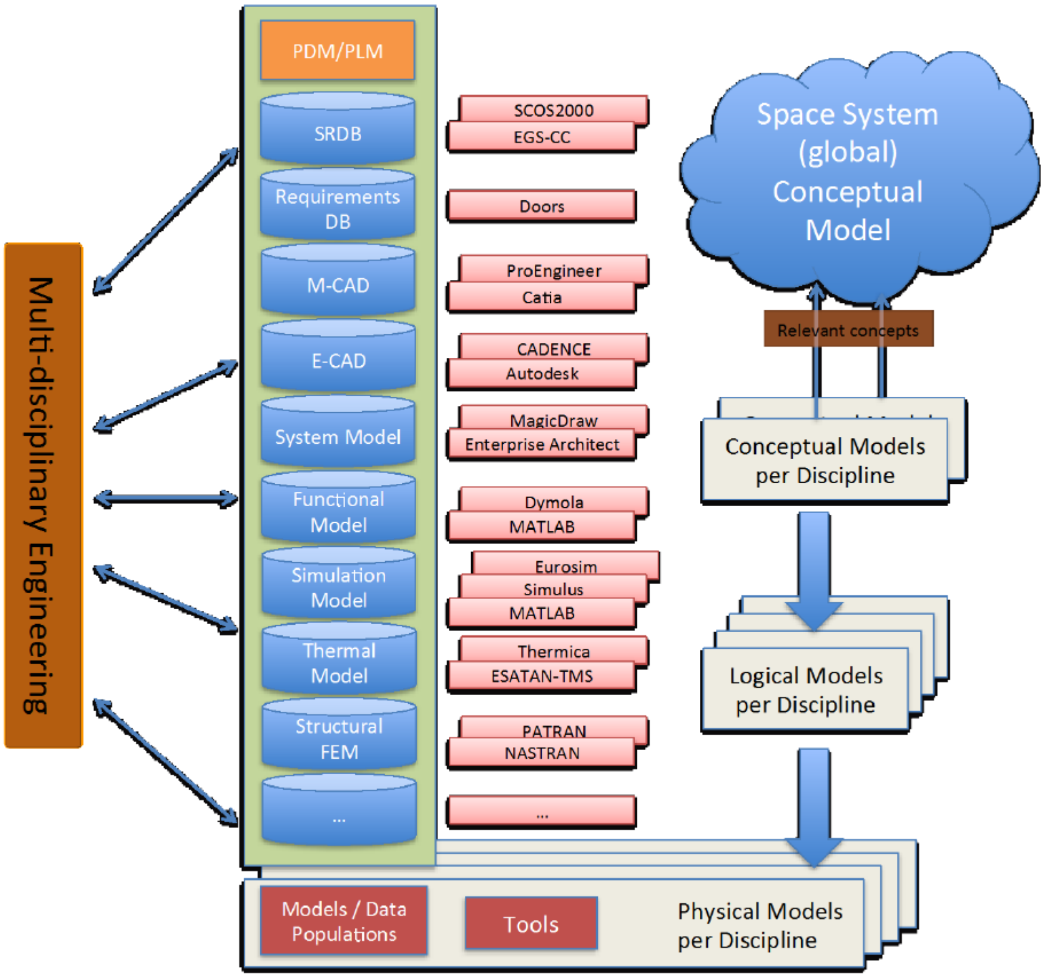


Figure 4.5-1

The role of the different stakeholders and processes is not represented above. The relation of the tools / model types identified is only meant to illustrate the general situation, and the relation of PLM / PDM systems and the individual models is not meant to represent the correct situation in an industrial context today. Programmatic data is presently omitted on purpose, according to the initial scoping outlined above.

4.5.2 Areas Covered by this Technology Topic

The broad technology areas covered are in the scope of the ESA Technical Domain (TD) 8, System Design and Verification. The main areas are:

- TD8-B-II: Collaborative and Concurrent Engineering, covering aspects related to the process of concurrent engineering as well as the data underlying multi-disciplinary collaboration, in

particular Data Exchange, covering methods and standards to support the exchange of multi-disciplinary data, focusing on the data aspects of collaborative engineering and,
- TD8-A-I: Mission and System Specification, covering the early phases of a project development life-cycle, focussing on requirements engineering, specification and architecture formulation, including methods and tools to support the capture, modelling and validation of requirements, including definition and formalisation of system architectures.
Specific issues of databases are also closely linked to TD9, in particular the aspect of operational databases (SRDB). It is therefore important to include any requirements from operational use of the modelled data in any specifications of supporting infrastructure.
The focus of the Harmonisation will be in the following subjects:

- Methodology used to specify system models (top-down approach). The difference between conceptual data modelling and "instance" modelling needs to be respected.
- Scope of the system model and guidelines for modelling / tracing engineering data relevant at system level along the complete life-cycle, from requirements to the as-built configuration
- Tools and technologies supporting modelling, taking into account heritage where necessary and addressing development and maintenance issues

All information requiring an exchange between two or more disciplines are relevant at system level. In addition, more data can be defined to be system relevant and needs to be available at system level (e.g. data to generate budgets might come from a single domain). However, the purpose is not to reproduce all necessary data and information at system level, but rather to establish semantically correct links between the owner of this data and the system level, together with the relevant data transformations to ensure an automatic propagation of this data if needed.
A distinction needs also to be made between the exchange between disciplines on one side, and between stakeholders on the other side. Related governance and lifecycle issues need to be addressed. Underlying structure is already captured to a large extent in ECSS standards, starting from the key elements of the overall ECSS System, that are used between branches and between domains (e.g. the functional/physical views of a space system such as functional tree, product tree, topology), but also the concepts related to the overall development lifecycle (requirements, architecture, integration, … verification/validation).

It is also acknowledged that the information amount and density increases during the lifecycle. If at the beginning of a project, the relevant information is more focusing on the requirements specification and analysis, it moves from design description into manufacturing (assembly and integration) and verification data (including analysis and test) at system level. The corresponding information needs to be formally defined in order to make it machine-readable and "processable".
Considering the system design process, it will be necessary to address the related data as well as the functional and process models. The links between existing design structures (such as a product tree, a configuration, a functional architecture or an operational scenario) need to be captured and represented. Their relation to the system requirements needs to be addressed and linked to the corresponding verification process and activities.
It needs to be highlighted that a smooth transition towards a model-based approach needs to be supported by tools and interfaces providing an easy access to the underlying required infrastructure.

The relevant Competence Domain are CD09 and CD08 (see Table 7-1 in Annex).

With reference to the ESA Technology Tree, this topic covers the following Technology Domains as per Table 4-5:

Table 4-5: Technology Tree Coverage – System Data Repository

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	Space System Software	D	Ground Data Processing	I	Data Archiving Systems
8	System Design and Verification	A	Mission and System Specification	I	Specification Methods and Tools
		B	Collaborative and Concurrent Engineering	II	Data Exchange

4.6 CRITICAL ACTIVE RF TECHNOLOGIES

The previous Harmonisation of the topic "Critical Active RF Technologies" took place in 2014. The next would be the third Harmonisation of this topic.

4.6.1 Technology Overview

The scope of this topic is to cover gallium nitride (GaN), silicon (Si) based technologies at RF frequencies.

Gallium Nitride Technology
Wide bandgap semiconductors are semiconductors which have an intrinsic energy gap of 2 eV or greater. There are a number of these materials, but the two most common are SiC and GaN. Wide bandgap semiconductors have fundamental material properties which make them highly promising for a variety of RF and microwave applications. These electrical properties include a bandgap that is much higher than silicon or gallium arsenide (GaAs) - e.g. 3.4 eV for GaN compared with 1.4 eV for GaAs and 1.1eV for Si -, a large breakdown electrical field and a high-saturated electron velocity. However, GaN is far more versatile than SiC and is the only wide bandgap to be addressed in this topic. Indeed the high electron mobility of GaN, compared to SiC, means that it is the preferred choice for RF applications, with operating capability up to 150 GHz already reported in the literature. When grown on SiC, GaN exhibits a very high thermal conductance (thermal conductivity of 4H SiC is ten times as high as that of GaAs). As a result, GaN on SiC offers significant potential for realising microwave components with an order of magnitude improvement in output power capability compared to GaAs or Si. Another key advantage of wide band gap semiconductors is that they are radiation hard and have the ability to be operated at high junction temperatures. The potential benefits to space systems are simplified shielding requirements and reduction in the size, mass and complexity of cooling systems. These performance benefits are of significant interest for realising next generation space based payloads. As a direct consequence, the development and availability of this technology is considered strategic.

Research on Wide Band Gap materials started in the mid 1990's in Europe and major investment were made by the US Department of Defence (DoD) starting from the early 2000. Europe decided to support and develop European GaN technology with dedicated activities sponsored by the European Commission, Space and Defence Agencies with few years of deferral. The initial activities undertaken for technology development have been to make available high quality materials in order to be able to supply the processing R&D entities. Several activities are ongoing in Europe, but specific actions need to be continued to ensure that at least one or two industrial sources are made available for (i) SiC substrates and (ii) GaN epitaxy to allow a fully European non-dependent supply chain to be established.

Since the first Harmonisation of this topic, significant progress have been made and earlier limiting factors in terms of reliability and quality such as crystalline defects, impurities, traps and surface states have been mostly overcome leading to the release of GaN Technology in the US and Japan, and more recently in Europe. However, further work is necessary in order to mature the GaN technology, show fully all the advantages and potentially replace GaAs technology.

Silicon Technologies
For long, GaAs has been almost the only semiconductor technology addressing applications beyond a few hundred megahertz: a good example of this is the RF front-end of the early GSM mobile phones. However, the demand for higher computing power and higher integration level, which means more integrated circuits (ICs) per wafer or more functions per IC, has led to the development sub-micronic CMOS processes (the fastest first generation Pentium® were running at less than 100 MHz while today the clock frequency reaches several gigahertz, early DRAM chip had a capacity in the range of few kilobits while the latest generation offers several gigabits).

Compared to compound semiconductors, silicon has greater ease of manufacturing, levels of integration and economy of scale, and constitutes over 95% of semiconductor devices. However, it has poorer operating speed, noise and efficiency. CMOS silicon’s speed can be boosted by shrinking transistor dimension from 130 nm to firstly 90nm then 65 nm, 45 nm and 28nm, but only at great expense and difficulty, especially as the limits of CMOS scaling are approached.
Alternatively, performance can be extended by adjusting the energy bandgap using higher-carrier mobility material such as strained silicon/silicon-germanium (SiGe), particularly if fabricated on silicon-on-insulator (SOI) substrates.

Silicon germanium technology is increasingly influencing next generation consumer devices and applications. It is also destined for playing a significant role in future equipment for space applications. SiGe HBT enables integration of RF/analogue and CMOS digital logic functions into fully monolithic BiCMOS structures resulting in reduced cost and increased functionality. Such “hybrid” approaches are particularly interesting for realising highly integrated multi-function chips (i.e. variable attenuator + variable phase shifter + gain blocks), frequency generation (PLLs, VCOs, prescalers) or High-speed A/D and D/A converters. The latest development of this technology has allowed Ft values of approximately 250 GHz (0.13um process from IHP) to be achieved and is allowing applications to be realised that have been traditionally the realm of GaAs.

The silicon-on-insulator (SOI) technology is a continuation of the bulk MOSFET technology with improved performance. The key is to fabricate the transistors on top of an insulating layer (SiO2, sapphire) which results in reduced parasitic, higher operating frequency and inherently radiation-hardened devices. Furthermore, the passive elements can be implemented on high resistivity silicon facilitating low-loss RF matching circuitry on the chip. The use of SOI processes helps in obtaining RF circuits with performances similar to GaAs except for applications requiring very low noise or high output power.

Despite these great advantages, gaining access to Si-based technologies remains a significant hurdle due to the low volume requirements of the space market. To overcome this problem, a possible approach is to focus the development efforts on a few generic functions and to carry out product qualification using available European processes. Another possibility would be to go to a multi-project wafer approach.

4.6.2 Areas Covered by this Technology Topic

Semiconductor applications can be classified in three categories. The first two, namely power

generation and low noise amplification, are today mostly covered by III-V technologies, essentially gallium arsenide (GaAs) and marginally indium phosphide (InP) or metamorphic material.
However, new technologies - silicon carbide (SiC) and gallium nitride (GaN) - so called "wide bandgap (WBG) semiconductors", are emerging for power amplification applications with breakthrough performances. The third and last application at microwave frequencies, which can be labelled as "general purpose" (gain block, switch, mixed functions, etc.), was until recently, also covered only by GaAs. However, this category is now more open to "new-comers", originating from the silicon semiconductor technology world, e.g. radio-frequency (RF) CMOS, silicon germanium (SiGe), silicon on insulator (SOI).

The relevant Competence Domain is CD05 (see Table 7-1 in Annex).

The Critical Active RF Technologies topic covers the ESA Technology Tree as per Table 4-6.

Table 4-6: Technology Tree Coverage – Critical Active RF Technologies

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	RF Systems Payloads and Technologies	E	RF Technologies and Equipment	II	RF Equipment
				III	RF Devices
				V	Time and Frequency
23	EEE Components and Quality	B	EEE Component Technologies	II	Silicon-Based Components
				III	RF Microwave and Millimetre Wave Components
				VI	Power Components
				VII	Wide Band Gap Technologies

4.7 PYROTECHNIC DEVICES

The previous Harmonisation of the topic “Pyrotechnic Devices” took place in 2013. The next would be the fourth Harmonisation of this topic.

4.7.1 Technology Overview

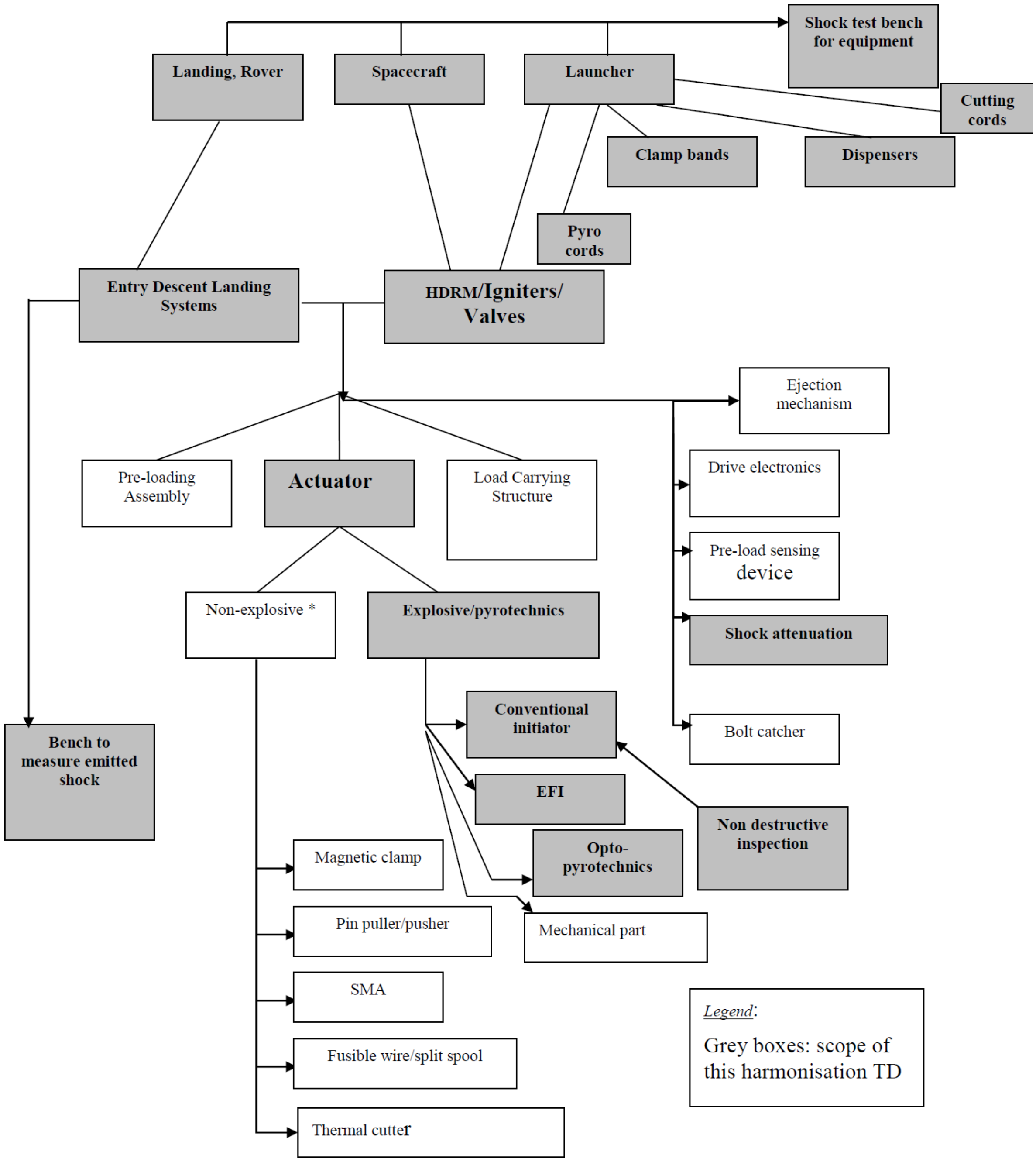
Space Pyrotechnic Devices, in the context of release devices, refer to the category of devices that utilise the energy released from a controlled explosion to perform useful work.
Many crucial operations are needed only once in a space mission. These operations include rocket ignition, safety and recovery, launcher stage and fairing separations, launcher-payload separations, releases of solar arrays, antennas, booms, covers, inflation of systems for shielding, protection and landing, propulsion system valve operations, momentum wheel releases, mechanism off-load releases, experiment and sensor cover releases.
Recently, new applications have appeared like the need for passivation at satellites end of life related to the French law on reduction of space debris and the ESA Clean Space programme. These applications generate new missions profiles which have to be considered.
In addition, the Clean Space programme requires the need to be REACH compliant. This has consequences on the usage of some substances or materials (Lead Azide explosive or Lead used in the pyrotechnics cutting cords).
The trend today is to use non-explosive devices on satellites. It should be noted here that non-explosive devices are mainly interesting when they are re-settable and this is not qualified yet at least in Europe for a wide operational temperature range (even if ESA and CNES are presently working on it).

In addition, the pyrotechnics devices are still necessary for launchers. It should be considered that the main advantages of pyrotechnics devices are that they usually allow a much faster release than the non-explosive devices and allow therefore synchronisation and quick response for launchers systems, which is not the case for state-of-the-art non-explosive devices. This is due to the high energy stored. For these reasons, they do not have competitors on launchers. Moreover, the pyrotechnics devices occupy a much lower volume and have a lower mass compared to non-explosive devices.
Finally, the heritage with pyrotechnics devices is much larger than with non-explosive devices.
The energy is used as heat or shock to ignite motors, as shock wave in transmission lines and high velocity effects in cutting charges or as pressure in piston or tube actuators performing useful mechanical work. Careful design assures high triggering energies to prevent unwanted function.

The most critical aspects are those related to reliability and safety of ignition. Due to their simplicity, pyrotechnic devices have higher reliability than most other devices. The most common means of triggering is by power pulses from spacecraft electrical systems.
For all singular functions, reliability and prevention of unwanted operation are critical. Pyrotechnics offer high performance with demonstrated reliability. Fast response with small dispersion allows simultaneous operation of several points, such as used in payload separations, large solar arrays, synthetic aperture radar arrays and antenna dishes. Their minimal needs for power translate into minimal power demand and thermal burden in the system thus reducing mass and launch cost. The rapid releases of strain energy result in undesirable shock, but this can be reduced and attenuated by design.

Component batch qualification and lot acceptance philosophies are needed. Product Assurance is thus an essential part of success in ensuring that new flight items are identical to those used for all tests upon which confidence is based.

4.7.2 Areas Covered by this Technology Topic



The relevant Competence Domains is CD02 (see Table 7-1 in Annex).

With reference to the ESA Technology Tree, this topic covers the following Technology Domains:

Table 4-7: Technology Tree Coverage – Pyrotechnic Devices

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	Mechanisms	H	Pyrotechnic Technologies	I	Explosive Composition Technologies
				II	Thermite Technologies
				IV	Optical Ignition Technologies
				V	Advanced Electropyrotechnics
				VI	Development of New Devices for Future Exploration and Exploitation Missions
		B	Non Explosive Release Technologies		

4.8 SOLAR ARRAY DRIVE MECHANISMS

The previous Harmonisation of the topic “Solar Array Driving Mechanisms” took place in 2014. The next would be the fourth Harmonisation of this topic.

4.8.1 Technology Overview

Most of the three-axis stabilized satellites use solar panels to generate the necessary electrical power for their equipment. For better performances, these solar panels have to be aligned continuously such as to get normal incident sun light onto the solar cells. In most of the cases, when the satellite’s body is pointing towards a defined target and its orientation is not sufficiently fixed with respect to the sun, a relative motion between the satellite’s body and the solar panels must be provided. The rotating mechanism performing this task is usually called the Solar Array Drive Mechanism (SADM). A SADM acts as the solar array motor and electrical power (and data) transfer between the considered “mobile” solar arrays and the “fixed” spacecraft body. The minimal design consists of a motor that is used to rotate the solar array at the required speed and in the required direction, and a specific electrical device (slip-ring, cable-wrap, twisted capsule, etc.) is used to transfer the power (and data) between the solar array and the satellite.

The SADM design is usually optimised with respect to the specific satellite platform design and its power needs. Several types of SADM exist on the market and cover a wide range of power transfer capability per Solar Array wing (from ~500W to ~20kW). More recently, the power capability has further extended toward the even lower power range (CubeSat and small-sat applications) and toward the higher power range (electric propulsion needs).

4.8.2 Areas Covered by this Technology Topic

The relevant Competence Domain is CD02 (see Table 7-1 in Annex).

With reference to the ESA Technology Tree, this topic covers the following Technology Domains:

Table 4-8: Technology Tree Coverage – Solar Array Drive Mechanisms

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	Mechanisms	A	Mechanism Core Technologies	I	Actuator Technologies
				III	Motion Transformer Technologies
				V	Guiding Technologies
				VI	Sealing Technologies
				VII	Electrical Transfer Technologies

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
		D	Control Electronics Technologies		
		F	Tribology Technologies	I	Lubrication Technologies
				II	Material Surface Technologies
		G	Mechanism Engineering	I	Engineering Disciplines
				II	Engineering Tools

4.9 ELECTROMAGENTIC COMPATIBILITY

The topic “Electromagnetic Compatibility” is new for Harmonisation. This would be the first Harmonisation of this topic.

4.9.1 Technology Overview

Electromagnetic Compatibility (EMC) is known as the ability of electrical equipment to work as intended in their given environment without disturbing each other and introducing inacceptable levels of noise into their environment, which is very important for every spacecraft and mission. A lack of EMC can lead to reduced performance of a spacecraft, functional failures and in the worst case to a loss of mission. Thus, basically all applications have to deal with EMC:

- Telecommunications
- Earth Observation
- Science
- Human Spaceflight, Robotics and Exploration
- Navigation
- CubeSats (also Micro, Nano and Pico Satellites)
- Launchers

EMC is a very wide discipline covering electromagnetic emissions, electromagnetic immunity, auto compatibility, radio frequency compatibility and electrostatic discharge. It also includes magnetic cleanliness, which is of high importance to achieve the scientific target for missions with sensitive magnetic instruments.

The increased use of higher integration levels, digital technology, and higher frequencies is a challenge for EMC engineers and calls for new approaches and methods to achieve compatibility.

Achieving EMC starts with the electrical design, taking into account EMC aspects and making an increased use of simulation tools to predict the behaviour of electrical circuits, equipment and systems. Simulation models are required to represent complex circuits in a simplified form for the purpose of EMC simulations as an important tool for supporting EMC analysis and verification.

Testing and measurement still have a very important role in the EMC verification. Standard testing techniques need to be adapted and refined as well as new testing and measurement techniques need to be developed to adapt and fulfil future needs.

The topic of magnetic cleanliness was for long time in a dormant status, but is coming back into focus today due to the requirements from scientific missions like BepiColombo, Solar Orbiter and Juice. To achieve magnetic cleanliness on satellites, magnetic characterisation, magnetisation / demagnetisation as well as magnetic modelling and simulation are required. Also for magnetic cleanliness existing measurement methods need to be adapted and refined and the tools for prediction of the magnetic field on the spacecraft at the position of the sensitive instruments need to be further developed in order to cope with highly demanding requirements and future needs.

4.9.2 Areas Covered by this Technology Topic

The subdomain C of Technology Domain 7 covers the following areas for EMC:

- Development of specific EMC models and simulation tools. Since testing and measurement are cost and time intensive and required not only for qualification, but also during the development phase, simulation can be a powerful tool to accompany or even replace measurements and tests.

- EMC test techniques (e.g measurement of low frequency AC electric and magnetic fields). Standard test and measurement techniques are not suitable to cover high demanding and non-standard requirements from science and earth observation missions, thus new techniques need to be developed (and standardised) in order to enable the verification of those requirements by test and measurement. Also for Nano-, Micro- and Picosatellites the standard techniques cannot be applied and new measurement techniques need to be developed and validated.

- Magnetic test methods, magnetic modelling and simulation, measurement of magnetic fields, magnetisation/demagnetisation, magnetic characterisation. The currently existing measurement methods need to be adapted and refined and the tools for prediction of the magnetic field on the spacecraft at the position of the sensitive instruments need to be further developed in order to cope with highly demanding requirements and future needs.

The relevant Competence Domain is CD04 (see Table 7-1 in Annex).

The Electromagnetic Compatibility topic covers the ESA Technology Tree as per Table 4-9

Table 4-9: Technology Tree Coverage – Electromagnetic Compatibility

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUPS
7	Electromagnetic Technologies and Techniques Covers antennas and related technologies, wave interaction and propagation, and electromagnetic compatibility.	C	EMC/RFC/ESD Covering design, models, simulation, testing techniques and technologies in the fields of electromagnetic compatibility (EMC), radio frequency compatibility (RFC), electrostatic discharge (ESD), and magnetic cleanliness.	I	EMC Modelling and Simulation Covering development of specific EMC models and simulation tools for application to spacecraft.
				II	EMC Test Techniques Covering validation of new EMC designs and novel EMC and magnetostatic test methods for application to spacecraft.

4.10 TT&C TRANSPONDER AND PAYLOAD DATA TRASMISSION

The previous Harmonisation of the topic “TT&C Transponder and Payload Data Transmission” took place in 2012. The next would be the fourth Harmonisation of this topic.

4.10.1 Technology Overview

This topic addresses TT&C transponders, transceivers (e.g., proximity links) and Payload Data Transmitters (PDT) for missions in the categories of space science, space operations, Earth Exploration Satellites (EES) and specific telecom missions, such as relay satellites using PDT’s. The purpose of this topic is to describe the status of TT&C transponders and PDT’s available in Europe; assess how successfully the TT&C developments outlined in the previous Harmonisation have been implemented and to identify the needs for new developments.

The topic does not address the technologies of any external power amplification units such as solid state power amplifiers or travelling wave tubes, Radio Frequency Distribution Units (RFDU), Waveguide Interface Units (WIU) or TT&C antennas, which when considered together can be classed as the complete communication subsystem of a typical spacecraft. The electrical interfaces to the communications subsystem are usually provided by the platform data handling subsystem, which is the subject of another technical topic.

The TT&C transponder and the dedicated PDT represent core elements of the on-board communication subsystem and are those elements which were addressed primarily within this technology topic in the past. It is, however, important to include also subsystem issues, such as architectural design and functional partitioning in order to fully enable the performances given at unit level. Therefore, the scope of this Harmonisation topic is focused more towards (sub)system engineering issues in order to ensure corresponding integrity that is crucial if the enormous potential of TT&C and PDT capabilities shall be further exploited. This might require interdisciplinary approaches, interactions and cooperation in some areas and between technology domains with their individual harmonisation efforts.

Optical communications technology is receiving a large amount of attention for use in future payload data transmission applications, especially for deep space communications, inter-satellite links and near Earth science missions positioned at the Lagrange points. While the technology development for optical communications equipment is addressed in another Harmonisation topic, it is clear that optical PDT’s are an evolution from RF based PDT’s and thus are subject of this topic in the context of PDT system engineering.

TT&C Transponders and PDT’s are the core elements of this Harmonisation. After setting the technical framework and defining the subjects of this Harmonisation, it is a main purpose of this Harmonisation topic to establish technical context, applicability and traceability to programmatic and strategic policies. In order to establish immediate goals, technology needs will be identified and aligned with European missions as projected at this time. For long-term goals, opportunities will be addressed to further expand capabilities in future. These objectives will flow down into a blueprint of proposed activities reflected later in the Dossier and Roadmap.
TT&C is a mission-critical function for all space missions. It is the means of transferring commands, spacecraft telemetry, mission data for robotic exploration and added voice and video

for human exploration missions, maintaining accurate timing and providing navigation support. The spacecraft TT&C transponder is the radio communication element which ensures radio contact with the corresponding Earth station, or other associated communications unit such as in the case of proximity links. It provides the umbilical connection for the up-link of telecommands, the transmission of the telemetry data and normally the tracking of the spacecraft through range and range rate measurements. When on-board turn around functions (i.e., ranging and coherent frequency scheme) are not required, the unit is commonly referred to as a transceiver.
The TT&C transponder belongs to the mission-critical elements. Robustness and high reliability are amongst the main design drivers for such a unit. With the increased demand in performances (in terms of demodulation, modulation, flexibility, etc.), the transponder has experienced an evolution away from mainly analogue to predominantly digital technology. Digital technologies allow for re-configurability, higher modularity and enhanced performances but usually at a cost of increased power consumption.
The design, testing and production philosophies have drastically changed and interdisciplinary expertise (radio frequency, digital H/W and software) is now mandatory to build and integrate state of the art transponders. Over the years, many improvements in VLSI techniques, higher levels of component integration, advanced simulation tools and the advent of space qualified FPGA's/ASIC's have led the way in developing a new generation of transponder equipment using:

- Digital Signal Processor (DSP) for signal acquisition/tracking/demodulation,
- Flexible Frequency Synthesisers based on Numerically Controlled Oscillators (NCO) and/or Fractional PLL techniques,
- Digital interfaces for greater housekeeping and commanding functionality.

Most of the recent TT&C transponder developments are based on these advanced design concepts. Command receivers have been developed that are capable to receive command signals across 750 MHz bandwidth, with the actual receiver frequency selectable on-board.
In addition to the TT&C transponder, also the PDT belongs to the communications subsystem. It takes the telemetry data from (payload) instrumentation or a spacecraft mass memory, properly encodes the data stream and ensures its transmission to Earth without errors, via an appropriate ground station.
Also, Relay Satellites, such as EDRS, deploy PDT technology. Strong PDT synergies exist between different mission applications and irrespective of the PDT's belonging to payload or spacecraft bus.
In some missions, the TT&C subsystem covers radio communication links referred to as proximity links, for the following typical scenarios:

- A communications link between two spacecraft in close proximity (e.g. ATV to the ISS)
- A transceiver on-board a probe, lander or rover which is required to provide the communications to and from a spacecraft orbiting a planet. In some scenarios, a direct line of sight communications link to and from the Earth is required.

For reasons of strong similarity, the radio communication unit on-board the orbiter required to communicate with the probe, lander or rover is also named a transponder or sometimes a data relay unit or transceiver. In other missions, the TT&C links are established via relay satellites (e.g., TDRSS, ARTEMIS, and EDRS).

4.10.2 Areas Covered by this Technology Topic

This Harmonisation topic covers all the aspects of TT&C transponders and PDT's, which provide the essential communication link with the ground (uplink telecommand, downlink telemetry and ranging) and therefore comprise part of the essential communications subsystem on all spacecrafts. Currently, four categories of TT&C transponders have been or are being developed in Europe:

- TT&C transponders for near Earth applications operate in S (2 GHz) or X (8 GHz) bands and using either standard phase modulation or spread spectrum technology. Near Earth missions requiring higher data rates will have to move to the K-band (26 GHz) frequency band in the near future.
- TT&C transponders for deep space missions operating in the X (8 GHz) and Ka (32 GHz) frequency bands (although obsolete for new ESA deep space missions, Rosetta still uses also S-Band).
- TT&C transmitters, receivers and flexible (un-/modulated) beacons (with in-orbit frequency selection) for telecommunication satellites operating in C, Ku- or Ka-band, and PCC transceivers for payload control and configuration. This covers both conventional (FM/PM) and spread-spectrum approaches.
- TT&C transmitters, receivers and beacons for telecommunication satellites (commercial/military) operating in X, Ka and EHF, using direct sequence spread spectrum technology.

Furthermore, the Harmonisation covers PDT's that are dedicated to the transmission of science payload data. At present, most PDT's operate in the X-, K- and Ka-band frequency allocation using a relatively simple communications infrastructure. Higher order modulation and more powerful coding scheme and the use of directive antennas are expected in the future, in order to avoid frequency band congestion and interference issues.

The relevant Competence Domains are CD05 and CD02 (see Table 7-1 in Annex).

The Technology Domains interested by this subject are reported in Table 4-10:

Table 4-10: Technology Tree Coverage – TT&C Transponder and Payload Data Transmission

TD	TECHNOLOGY DOMAIN	TSD	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	RF Systems, Payloads and Technologies	C	TT&C and Payload data modulator (PDM) systems/subsystems	II III	Deep-Space Transponders Near-Earth Transponders
				IV	Proximity Link
				V	High-speed Downlink PDM
				I	TT&C System Tools
16	Optics	C	Optical Equipment and Instrument Technology	VI	Optical Communications

5 LIST OF EARMARKED TECHNOLOGIES FOR 2021 – 2022

Error! Reference source not found. and **Error! Reference source not found.** list the technologies earmarked for Harmonisation in 2021 and 2022, based upon end of current Roadmaps and requests received. The actual topics for the relevant years will be selected taking into consideration previous commitments and the proposals received from ESA Technical and Programme Directorates, Industry (via Eurospace and SME4Space) and THAG Delegations during the preparation of the Harmonisation Workplan.

Table 5-1: List of Potential Technologies for the 2021 Harmonisation Workplan

	2021	Revisit
1	Multibody Dynamic Simulations (*)	2014
2	Electrical Motors	2015
3	Ground Station Technology	2015
4	Optical Detectors – Visible Range	2015
5	Power RF Measurements & Modelling	2015
6	Radiation Environments & Effects	2015
7	Avionics Technologies (**)	2016
8	Solar Generators and Solar Cells	2015
9	Technologies for Hold Down, Release, Separation and Deployment Systems	2015
10	Miniaturised Propulsion Components (TBC)	New

(*) in 2014 only the Mapping took place
(**) Topic combining together Avioncs Embedded Systems, On-Board Payload Data Processing, Data Systems and On-Board Computers

Table 5-2: List of Potential Technologies for the 2022 Harmonisation Workplan

	2022	Revisit
1	Electric Propulsion Pointing Mechanisms	2016
2	RF Metamaterials and Metasurfaces	2016
3	Microelectronics – ASIC and FPGA	2016
4	Technologies for Passive Millimetre and Sub-Millimetre Wave Instruments	2016
5	Reflector Antennas	2016
6	Electric Propulsion – Large	2018
7	Artificial Intelligence (TBC)	New
8	TBD topic	
9	TBD topic	
10	TBD topic	See Table 6-1

6 OVERVIEW OF TECHNOLOGIES 2000-2022

The Table 6-1 provides an overview of the technologies that have been harmonised since 2000, organised per Competence Domains:

Table 6-1: Harmonised Technologies organised per Competence Domain

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmonisation
1	EEE / Components / Photonics / MEMs	Optical Detectors, Visible Range	(2006.1	2021
			2011.1)	
			2015.1	
		Optical Detectors, IR Range	(2006.1	
			2011.1)	
			2017.2	
		Micro-Nano Technologies - MEMS	2008 (MP)	2020
			2014.2	
		Photonics	2018	
2	Structural / Mechanisms / Materials / Thermal	Electrical Motors	2002.2	2021
			2007.2	
			2015.2	
		Deployable Booms & Inflatable Structures	2003.2	
			2010.2	
			2018	
		Solar Array Drive Mechanisms	2003.2	2020
			2008.2	
			2014.1	
		Electric Propulsion Pointing Mechanisms (EPPMs)	2004.2	2022
			2009.2	
			2016.2	
		Position Sensors	2009.1	
			2018	
		Technologies for Hold Down, Release, Separation and Deployment Systems	2004.1	2021
			2008.2	
			2015.2	
		Pyrotechnic Devices	2003.1	2020
			2006.1	
			2013.1	
		Two-Phase Heat Transport Systems	2003.1	
			2009.1	
			2017.1	
		Cryogenics and Focal Plane Cooling	2001	2019.1
			2007.1	
			2013.2	
		Composite Materials	2005	2019.1
			2010.2 (MP)	
			2014.2	
		Additive Manufacturing	2015.1	

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmonisation
			2017.1	
		Coatings	2018	
3	Avionic Architecture / DHS / OnBoard S/W / FDIR / GNC / AOCS / TT&C (E2E)	Avionics Embedded Systems	2006.2	
			2010.1	
			2016.1	
		On-Board Payload Data Processing	2003.1	
			2006.2	
			2011.2	
			2016.1	
		Data Systems and On Board Computers	2003.1	
			2006.2	
			2011.2	
			2016.1	
		Microelectronics - ASIC & FPGA	2002.2	2022
			2007.1	
			2011.2	
			2016.1	
		On-Board Software	2003.1	2020
			2006.2	
			2010.1	
			2014.2	
		AOCS Sensors and Actuators (Part I & Part II)	(2001	2020
			2005.1	
			2009.1)	
			2013.1 (Part I) & 2015.2 (Part II)	
		On-Board Radio Navigation Receivers	2002.1	2019.2
			2007.2	
			2013.2	
		RF & Optical Metrology	2008.1	
			2018	
		TT&C Transponders and Payload Data Transmitters	2003.1	2020
			2007.2	
			2012.2	
4	Electric Architecture / Power & Energy / EMC	Solar Generators and Solar Cells	2004.2	2021
			2009.1	
			2015.1	
		Electrochemical Energy Storage	2002.1	2019.1
			2006.1	
			2010.2	
			2014.1	
		Power Management and Distribution	2003.2	2019.1
			2008.2	
			2013.2	
		Electromagnetic Compatibility		2020

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmonisation
5	E2E RF & Optical Systems and Products for Nav, Comms & Remote Sensing	Power RF Measurements & Modelling	2004.1 2007.2 2015.1	2021
		Critical Active RF Technologies	2004.2 2014.1	2020
		Frequency and Time Generation and Distribution (Space & Ground)	2005.2 2011.1 (G) 2013 (S) 2018	
		Technologies for Passive Millimetre & Submillimetre Wave Instruments	2006.2 2010.2 2016.2	2022
		Array Antennas	2005.2 2011.2 2017.1	
		Reflector Antennas	2004.2 2009.2 2016.2	2022
		RF Metamaterials and Metasurfaces	2016.2	2022
		Microwave Passive Hardware	2017.2	
		Technologies for Optical Passive Instruments (Stable & Lightweight Structures)	2008.2 2013.1	2019.2
		Technologies for Optical Passive Instruments (Mirrors)	2008.2 2013.1	2019.2
		Optical Communication for Space	2004.1 2008.2 2012.2 2017.2	
		Lidar Critical Subsystems	2005.2 2010.1 2017.2	
		Ground Station Technology	2015.1	2021
6	Life / Physical Science Payloads / Life Support / Robotics and Automation	Automation and Robotics	2001 2007.1 2012.1 2017.2	
		Life Support Technologies	2018	
7	Propulsion, Space Transportation and Re-entry Vehicles	Fluid Mechanic and Aerothermodynamics Tools	2002.1 2007.1 2012.2	2019.2
		Chemical Propulsion - Micropropulsion	2002.2 2007.2 2011.2	2019.1

<table>
<tr><th>CD ID</th><th>Competence Domain</th><th>Related Harmo Roadmap</th><th>Past Revisit</th><th>Planned/Ongoing Harmonisation</th></tr>
<tr><td rowspan="11"></td><td rowspan="11"></td><td rowspan="4">Chemical Propulsion - Components (including Tanks)</td><td>(2002.2</td><td rowspan="4"></td></tr>
<tr><td>2008.1)</td></tr>
<tr><td>2012.2</td></tr>
<tr><td>2018</td></tr>
<tr><td rowspan="3">Chemical Propulsion - Green Propulsion</td><td>2002.2</td><td rowspan="3"></td></tr>
<tr><td>2008.1</td></tr>
<tr><td>2012.1</td></tr>
<tr><td rowspan="4">Electric Propulsion Technologies</td><td>2004.2</td><td rowspan="4"></td></tr>
<tr><td>2005.1</td></tr>
<tr><td>2009.2</td></tr>
<tr><td>2013-2017*</td></tr>
<tr><td rowspan="6">8</td><td rowspan="6">Ground Data Systems / Mission Operations</td><td rowspan="3">Functional Verification and Missions Operations Systems</td><td>(2002.2)</td><td rowspan="3">2020</td></tr>
<tr><td>(2008.1)</td></tr>
<tr><td>2014.2</td></tr>
<tr><td rowspan="3">System Modelling and Simulation Tools</td><td>2006.2</td><td rowspan="3"></td></tr>
<tr><td>2012.1</td></tr>
<tr><td>2018</td></tr>
<tr><td rowspan="4">9</td><td rowspan="4">Digital Engineering for Space Missions</td><td>System Data Repository</td><td>2014.1</td><td>2020</td></tr>
<tr><td>Multibody Dynamic Simulation</td><td>2014.1(MP)</td><td>2021</td></tr>
<tr><td>Thermal & Space Environment S/W Tools and Interfaces</td><td>2002.1</td><td></td></tr>
<tr><td>Big Data from Space</td><td>2017.1</td><td>2019.2</td></tr>
<tr><td rowspan="4">10</td><td rowspan="4">Astrodynamics / Space Debris / Space Environment</td><td rowspan="3">Radiation Environments & Effects</td><td>(2005.2)</td><td rowspan="3">2021</td></tr>
<tr><td>(2009.2)</td></tr>
<tr><td>2015.2</td></tr>
<tr><td>De-orbiting Technologies</td><td>2018</td><td></td></tr>
</table>

** The last revisit of the EP Harmonisation Roadmap started in 2013 and continued to 2015 when was put on-hold. It has been finalised in 2017.*

Legend:
MP: Mapping only
RM: Roadmap only

7 ANNEX – COMPETENCE DOMAINS

Table 7-1: Competence Domains' Titles

CD	Competence Domain Title
01	EEE / Components / Photonics / MEMs
02	Structures / Mechanisms / Materials / Thermal
03	Avionic Architecture / DHS / On-Board SW / FDIR / GNC-AOCS / TT&C (E2E)
04	Electric Architecture / Power and Energy / EMC
05	E2E RF&Optical Systems & Products for Navigation, Communication and Remote Sensing
06	Life / Physical Science Payloads / Life Support / Robotics and Automation
07	Propulsion / Space Transportation and Re-entry Vehicles
08	Ground Systems / Mission Operations
09	Digital Engineering for Space Missions
10	Astrodynamics / Space Debris / Space Environment