# On-board Control Unit for ICE Cube Experiments

## Executive Summary Report

ICE-OBC-ESR rev. 1.0

N7 SPACE SP. Z O.O.

| Prepared by | Date and Signature |
|---|---|
| Seweryn Ścibior | |
| Verified and approved by | |
| Michał Mosdorf | |

# Table of Contents

# Change Record

| Issue | Date | Change |
|---|---|---|
| 1.0 | 2023-06-21 | Initial release |

# 1 Applicable and reference documents

## 1.1 Applicable documents

| ID | Title | Reference | Rev. |
|---|---|---|---|
| AD1 | ECSS – Space engineering Software | ECSS-E-ST-40C | 6 March 2009 |

## 1.2 Reference documents

| ID | Title | Reference | Rev. |
|---|---|---|---|
| RD1 | On-board Control Unit For Ice Cubes Experiments BSW Software Requirements Specification | ICE-OBC-BSWSRS | 1.7 |
| RD2 | On-board Control Unit For Ice Cubes Experiments ASW Software Requirements Specification | ICE-OBC-ASWSRS | 1.3 |
| RD3 | On-board Control Unit For Ice Cubes Experiments Software Development Plan | ICE-OBC-PL1 | 1.0 |
| RD4 | On-board Control Unit For Ice Cubes Experiments BSW Software Design Document | ICE-OBC-BSWSDD | 1.0 |
| RD5 | On-board Control Unit For Ice Cubes Experiments ASW Software Design Document | ICE-OBC-ASWSDD | 1.0 |
| RD6 | On-board Control Unit For Ice Cubes Experiments Verification Control Document | ICE-OBC-VCD | 4.0 |
| RD7 | On-board Control Unit For Ice Cubes Experiments Application Software Verification Report | ICE-OBC-ASWSVerR | 1.2 |
| RD8 | On-board Control Unit For Ice Cubes Experiments Application Software Validation Report | ICE-OBC-ASWSValR | 1.2 |
| RD9 | On-board Control Unit For Ice Cubes Experiments Application Software Validation Specification w.r.t. TS | ICE-OBC-ASWSValS-TS | 1.3 |
| RD10 | On-board Control Unit For Ice Cubes Experiments Mechanical Specification | ICE-OBC-MECH-1 | |
| RD11 | On-board Control Unit For Ice Cubes Experiments Test Procedure and Test Plan | ICE-OBC-PR | 2.1 |
| RD12 | On-board Control Unit For Ice Cubes Experiments Test Report | ICE-OBC-RP | 2.2 |

# 2 Terms, definitions and abbreviated terms

This document acronyms and abbreviations are listed here under.

| | |
|---|---|
| TS | Technical Specification |
| RB | Requirements Baseline |
| OBCU | On-board Control Unit |
| ICE | International Commercial Experiment |
| ISS | International Space Station |
| ICF | ICE Cubes Facility |
| ASW | Application software |
| BSW | Bootloader software |
| BSP | Board Support Package |
| HAL | Hardware Abstraction Layer |
| OSAL | Operating System Abstraction Layer |
| N7S | N7 Space |

# 3 Introduction

## 3.1 Project background

The International Commercial Experiment (ICE) Cubes Service, operated by a Belgian company Space Applications Services, is meant to facilitate running scientific experiments in the environment of the low Earth orbit while drastically reducing the scope of such a mission. It does so by providing access to a hardware platform hosted on the International Space Station, with a standardized set of interfaces and connectors, allowing for a straightforward process of designing and procuring new experiment cubes. This process could be further streamlined by providing a common electronics platform and a main computer to maintain several more specialized payloads in the same package.

## 3.2 Project objectives

The objective of the activity was to provide such a main computer for use by ESA in other in-orbit demonstration activities, or, directly quoting the statement of work, "to develop [an] On-Board Control Unit (OBCU) that can interface a number of ESA/ESTEC internal experiments and, as a full package, will be flown on board of Ice Cube Facility."

The main technical objectives were related to managing the downstream payload devices in various ways. The OBCU was to provide communication channels to each device and ways for the system operator to inspect and manipulate the state of the devices, including their power status, voltage and current readouts and thresholds. One of its major tasks was also to collect telemetry data from them and store it in a persistent memory for later retrieval by the operator. This in conjunction with implementation of several standard PUS services as the system's telecommand/telemetry user interface, including PUS11, enables autonomous carrying out of dynamically pre-defined mission objectives as well. The activity was expected to result in procurement of two experiment cubes, complete with the OBCU hardware and software installed in chassis appropriate for installation on board of the ICE Cube Facility on the ISS.

Those objectives, as well as ones described in the SoW, were ultimately captured in the Software Requirement Specifications for the BSW [RD1] and the ASW [RD2]; in the Requirements of the Mechanical Box [RD10]; and the Verification Control Document [RD6].

# 4 Work logic

Work Breakdown Structure is illustrated in [RD3].

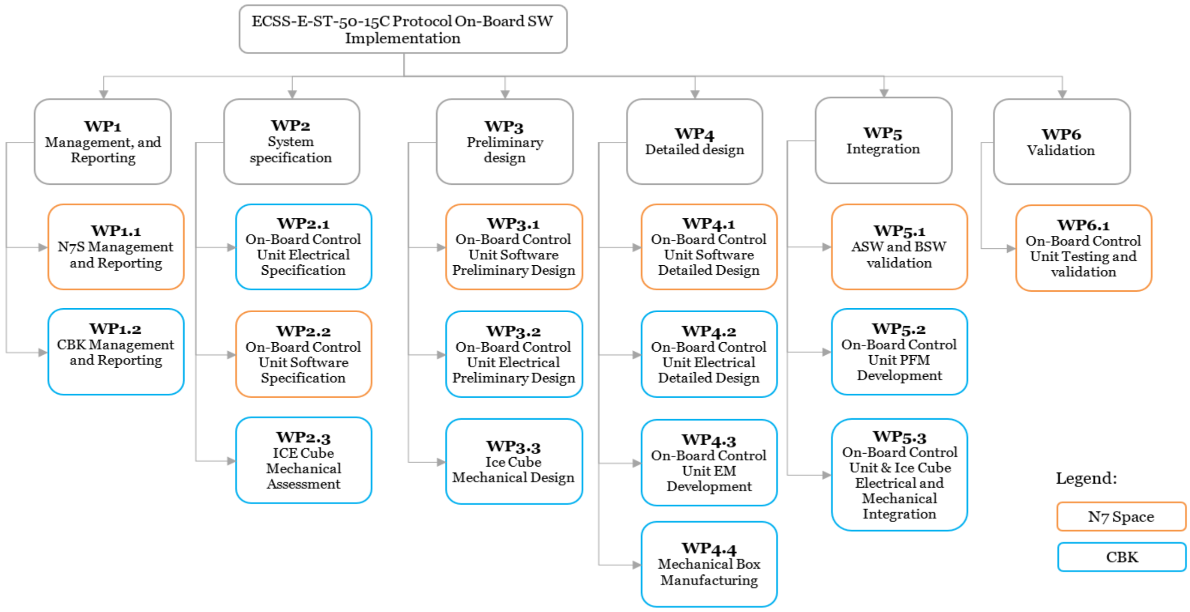


Figure 1 – Project Work Breakdown Structure (WBS)

The project was divided into the following work-packages and tasks:

- **WP 1.x – Management and Reporting**
  - General management of the project.
  - Communication with the customer.
  - Cost and schedule control.
  - Risk Management.
  - Contract and possible change requests management.
  - Review meetings organization.
  - Review and acceptance of the project documentation.
  - PA/QA support (supported by the PA/QA personnel).
  - Process monitoring.
- **WP 2.x – Specifications and Assessments of OBCU**
  - Preparation of the development plans.
  - Consolidation of requirements and elaboration of technical specification.
  - Definition of the interface between the OBCU and upstream.
  - Preparation of a preliminary CAD model.
- **WP 3.x – Preliminary Design**
  - Preparation of preliminary software design based on the software requirements specification.
  - Update of the source code and documentation of the reused bootloader to incorporate changes in user interface.
  - Preparation of preliminary hardware design of the OBCU, including selection of EE components.
  - Definition of the Verification Control Document and test plans.
  - Preparation of mechanical drawings.

- **WP 4.1 and 4.2 – Detailed Design**
    - Finalization of software design.
    - Preparation and implementation of software testing scenarios.
    - Update of documentation.
- **WP 4.3 – Development of Engineering Model**
    - Preparation of manufacturing files.
    - Procurement of parts.
    - In-house assembly.
    - Preparation of the EGSE platform.
    - Electrical and functional testing of the engineering model.
- **WP 4.4 – Manufacturing of Mechanical Box**
    - Procurement of parts.
    - In-house production using CNC machining.
    - Measurements and installation of connectors.
    - Conduction of fit-check and preliminary integration of the engineering model and the mechanical box.
- **WP 5.x – Validation, integration and development of Proto-flight Model**
    - Execution of the software validation campaign.
    - Preparation of manufacturing files and procurement of PCBs.
    - External assembly and inspection.
- **WP 6.x – Testing and validation of the OBCU**
    - Mechanical and electrical integration of the OBCU and the Mechanical Box
    - Quality inspections
    - Final updates to test procedures, collecting test reports

# 5 Project achievements

## 5.1 Control unit application software

The application software was built primarily with the original project objective in mind: at its core, the ASW was meant to provide two-way communication channels with arbitrary devices connected to the OBCU, to persistently store their output data and to enable autonomous carrying out of custom mission objectives pertaining to controlling the payloads. In this objective, it succeed: implementation of both standard and custom PUS2, PUS11 and PUS15 services provides all necessary functionality and interfaces to perform the expected tasks both by the software and by its operator.

The scope of new technologies researched and applied in the project proved to be a risk severely impacting the final delivery date. Development of the ASW saw application of MBSE practices with Papyrus, introduction of C++ and its associated tooling and wide adoption of reused and off-the-shelf open-source components in the form of the bootloader, the TCP/IP stack library and the underlying operating system. Design and development processes for the application software also strictly followed conventional guidelines for creating reusable, extendable software. As a result, the ASW employs several techniques facilitating adaptation to new hardware platforms and software supporting components with use of a hardware and operating system abstraction layers. While the additional tangible advantages for the operator may be of limited consequence, the experience gathered during the activity will nonetheless greatly improve management, decision-making and shorten development times in future projects.

## 5.2 Deployment-ready control units

The ultimate goal of the activity was to deliver two proto-flight models of the OBCU ready for deployment on the ICE Cube Facility on the ISS. Two such models were successfully developed, following an extensive process of iterative design and thorough validation. The units are based around the SAMV71Q21RT microprocessor and can thus be programmed with commercial off-the-shelf debuggers. The validation campaign included a successful data processing bandwidth test, verifying that the OBCU is capable of maintaining stability and responsiveness even under saturating load from the maximum number of supported payloads. Along with dedicated chassis, the resulting cube can be fitted with mission-specific payloads, connected to the OBCU with UART and dedicated power connectors and sent onto the ISS.

OBCU hardware consists of two stacked PCBs: the Mainboard and Mezzanine board, both in PC104 standard. The design successfully divided functions of the OBCU between two boards, according to project requirements. The Mainboard hosts the microcontroller and external memory ICs and can be also used as a generic On-Board Computer for a CubeSat. It was designed to utilise as many data interfaces of SAMV71Q21RT as possible, while providing external volatile and non-volitile memory. All ICE Cube specific features not used on a standard CubeSat are implemented on the Mezzanine board. This PCB hosts components for Ethernet interface, data buffers for IoDs and power section for Experiment boards. The power section provides overcurrent and overvoltage protection and measures power consumption of the IoDs. The Control Unit can support up to four Experiments store their data in non-volatile memory. The Cube draws power from the facility and can be interfaced via Ethernet.

# 6 Software validation and hardware testing

The detailed findings of the testing activities are reported in the Software Verification Report [RD7] and in the Software Validation Report [RD8]. The achieved software requirement coverage is 84/85, 98.8%. The non-covered requirement pertains to branch coverage of the ASW, the required level of which was not possible to be reached using the available tools. The software validation campaign was executed in stages, with some requirements being verified automatically only in a mocked environment, but manually, through larger validation test scenarios, on the target PFM hardware as well.

The final delivered data pack contains all of the artefacts of the validation campaign, including automatically generated logs and statistical and coverage data. Given an equivalent testing environment described in the Software Validation Specification [RD9], the delivered build system will enable reproduction of those results through construction of a software image and execution of the validation campaign on the delivered control unit.

All hardware tests were conducted according to Test Procedure document [RD11] to meet specification from Verification Control Document [RD6]. Both EM and PFMs were extensively tested and the results are presented in Test Report [RD12]. To conduct the tests, additional boards needed to be designed. First one is a mock of ICF and can provide power and Ethernet communication with the same DSUB connector as the Facility. The second board is an IoD mock used for fit-checking fully assembled stack of the OBCU and 4 IoDs inside the mechanical enclosure. The tests proved successful operation of the OBCU hardware.

# 7 Conclusions

Substantial challenges arising from the combination of extensive technical scope and limited temporal and financial budget of the activity created a unique environment of growth for all involved parties. While the activity was targeting a relatively low qualification level C, the risks posed by involving a number of new and not thoroughly verified technologies in the design and development process should still be avoided in the future to prevent major delays. Ultimately, the stated objectives of the activity have been achieved and the OBCUs will likely be launched onto the ISS for purposes of in-orbit demonstration.