

SENTINEL-1B IN-FLIGHT ANOMALY SUMMARY REPORT

This summary report provides:

- an overview of the Sentinel-1B in-flight CAPS anomaly
- a summary of the related root cause investigations and associated results
- an overview of the various recovery attempts performed since the occurrence of the anomaly
- a summary of the parallel Sentinel-1 mission level actions
- some conclusions, recommendations and way forward.

Chronology of events, CAPS anomaly, investigations and recovery attempts

This major Sentinel-1B anomaly occurred on 23/12/2021. The first effect was a failure of the SAR instrument to respond to the main avionics 1553 data bus, which had some impacts on other sub-systems including some thermal and propulsion subsystems elements. During the following days, a number of Anomaly Review Board (ARB) meetings took place, and a modification of the onboard system Failure Detection Isolation and Recovery (FDIR) was prepared, validated by ground simulation and then successfully implemented on board on 30/12/2021 for Sentinel-1B and on 04/01/2022 for Sentinel-1A, so that such anomalous behaviour related to the main avionics 1553 data bus could not occur again.

Detailed investigations, in particular through the satellite telemetry, were performed in parallel to the preparation of the FDIR modifications, focusing on the root cause of the failure of the SAR to respond on the bus that resulted in the 1553 bus disruption of 23/12/2021. On 29/12/2021 it was discovered that the main problem could be related to the 28V regulated bus of the CAPS (C-SAR Antenna Power Supply), as it was observed that the main & redundant 28V power regulators were both unexpectedly OFF when the SAR failed to respond on the bus on 23/12/2021. The CAPS is the unit – part of the electrical power sub-system of the platform – that provides power to SAR elements, including the SAR electronics.

On 03/01/2022 and during the following days until 11/01/2022, the various attempts consisting in commanding the switch ON of the main and redundant 28V power regulators failed. At this stage a failure linked to the CAPS 28V power regulated bus was suspected.

These two 28V power regulators operate in a parallel configuration, in hot redundancy, and the functioning of one of the two is required to supply power to the SAR instrument electronics, which is connected to the 28V power bus.

Up to the end of May 2022, 20 ARB meetings took place, involving experts from ESA (from three directorates: EOP, OPS, TEC; and three establishments: ESTEC, ESOC, ESRIN) and experts from industry, namely from Thales Alenia Space Italy (the satellite prime contractor), Airbus Defence & Space Germany (the SAR instrument prime contractor) and Leonardo (the CAPS supplier).



Detailed investigations were performed to understand the root cause of the CAPS anomaly, in particular by Leonardo and ESA experts, with the identification of 18 potential failure modes using a top-down approach of the various functions of the CAPS unit.

Out of these 18 potential common cause failure modes, one mode was highlighted, and is related to a potential leakage of a ceramic capacitor which is part of the main and redundant regulators of the 28V power regulated bus. This capacitor had to be replaced as a result of a non-compliance detected during the manufacturing and testing phase. For the repair, the capacitor was soldered using a process that may have damaged the component although it was fulfilling product assurance requirements applicable at the time it was applied. This repair process is no longer authorized following revision of applicable ECSS standard in 2017. This process was also used on the Sentinel-1A CAPS but not on the Sentinel-1C and Sentinel-1D CAPS units. The soldering process used on this capacitor is considered the most probable root cause for the failure of the main regulator and a possible root cause for the failure of the main regulator and a possible root cause such as double failure due to independent causes cannot, however, be excluded.

Satellite system level analyses were conducted in parallel, with the aim to perform new recovery attempts of the unit.

The following main types of attempts were performed:

- commanding both regulators with the main and redundant TM-TC interfaces
- commanding a nominal startup of the instrument
- commanding the downstream loads off before starting the regulators
- varying the voltage of the main satellite power bus (within the range 62-67 V) to prompt a different input to the regulators
- execution of new commanding approaches, putting some load on the 28V power bus at the time of switch ON of the regulator(s)
- commanding both regulators while varying the temperature
- commanding both regulators and downstream loads by bursts, with just a few milliseconds separation between commands.
- commanding with similar bursts but for extended periods of several minutes.

Unfortunately, all attempts to bring back the CAPS 28V regulated bus to nominal operations have failed.

Some of the new commanding strategies required substantial work and the preparation of new operational procedures, for instance to execute repetitive switch ON command of the main and redundant regulators by bursts, with separation between commands in the order of 10 milliseconds.

On 04/04/2022, in one of the first attempt to switch ON the main regulator using rapid bursts of commands, the status of the regulator remained ON for 4.4 seconds and was then reverted autonomously to OFF, as observed through the related telemetry. This was the first time this change of status was observed since the start of the recovery attempts in early January 2022.



Whereas this type of recovery did not bring the CAPS 28V back to nominal operation, it did provide valuable observations to identify possible failure modes.

As far as Sentinel-1A is concerned, the satellite was placed in orbit 2 years earlier than Sentinel-1B, it has exceeded its in-orbit design lifetime, and the status of the S1A CAPS have remained nominal since launch. Since the S1B anomaly, the behaviour of the S1A CAPS 28V regulated bus is closely monitored. At the time this report is finalised, the performances of the S1A CAPS main regulator remain nominal. The performances status of the S1A CAPS redundant regulator cannot, however, be monitored from ground when the main regulator is active.

Parallel Sentinel-1 mission level actions

- Adjustments of the Sentinel-1A observation scenario

Following the Sentinel-1B anomaly (unavailability of several months) a number of adjustments have been performed on the Sentinel-1A observation scenario in order to reduce the impact of missing Sentinel-1B data. This was based on various needs expressed by key users / communities. Sentinel-1A was already operated close to its maximum capacity, preventing the addition of substantial observations. These adjustments were performed outside Europe and European waters, as in Europe all potential Sentinel-1A passes are already part of the standard plan.

- Derived modifications of Sentinel-1C and Sentinel-1D spacecraft

Following the Sentinel-1B anomaly investigations, a number of modifications, both at system and CAPS unit levels, have been identified as design improvement opportunities in the frame of the design detailed review performed after the anomaly.

They have already been implemented in the Sentinel-1C spacecraft, and will be later implemented in Sentinel-1D.

They are based on:

- Increasing the CAPS unit reliability operating the unit in cold redundancy
- Implementing electrical design modification in order to increase the robustness of the electrical design of the regulator.

- <u>Prepare for a launch of Sentinel-1C at the earliest possible opportunity</u>

The Sentinel-1C Launch Services Contract was signed between ESA, in delegation from the European Commission, and Arianespace on 22 March 2022, for launching onboard a VEGA-C in 2023. This Sentinel-1C launcher procurement has been placed as agreed with the European Commission to issue an ad-hoc Invitation To Tender for Arianespace in anticipation to the Framework Contract for Copernicus and Galileo, being negotiated between the Commission and Arianespace.

The Launcher Services activities were kicked-off on 30 March 2022, and the Preliminary Mission Analysis Review (PMAR) took place on 24 May 2022.



A Launch Term is fixed by the contract between 1 May 2023 and 31 October 2023. However, it is noted that the contract foresees priority for a forward launch in case the spacecraft scheduled for launch in the first quarter of 2023 is delayed. The Launch Period of 15 April – 14 July 2023 has actually been recently agreed between ESA and Arianespace. This possibility shall be confirmed, at the latest, in July 2022.

- <u>Substitute a fraction of Sentinel-1B data with Copernicus Contributing Mission (CCM)</u> <u>data</u>:

As soon as the unavailability of Sentinel-1B was understood as potentially spanning over several weeks, actions were implemented to substitute, to some extent, a fraction of Sentinel-1B data with Copernicus Contributing Mission (CCM) data.

This mainly concerned an increased use of Radarsat-2 C-band data to support the sea-ice monitoring activities of the Copernicus Marine Environment Monitoring Service (CMEMS), as well as, to a lesser extent, an increased quota for X-band mission data (Cosmo-Skymed, Terrasar-X, PAZ) involved in this CCM activity.

In agreement with the Canadian Space Agency and in coordination with the European Commission in the frame of the Canada-EU agreement on Copernicus, the observation frequency of Radarsat Constellation Mission (RCM) data over CMEMS sea-ice monitoring areas was increased. In addition, the European Commission asked for RCM data coverage over specific land areas of EU Member States to evaluate the suitability of the mission to support the monitoring of agricultural activities in the context of the EU Common Agricultural Policy (CAP). Related assessments are on-going at the time of finalizing this report.

Conclusions, recommendations and way forward

The Sentinel-1B Payload cannot be operated since 23/12/2021 because of a failure located in the Platform CAPS 28V regulated bus.

A detailed root cause analysis was performed. The most probable common cause is the soldering process used to repair a ceramic capacitor on both the main and the redundant CAPS 28V regulator boards. Additional failure modes, such as double failure due to independent causes cannot, however, be excluded.

The CAPS 28V regulated bus is considered unrecoverable and the capability of Sentinel-1B to support the mission, at the time of finalising this report, is considered lost.

Additional monitoring and FDIR modifications were put in place on Sentinel-1A. The performances of the CAPS and, in particular, its 28V regulated bus, remain nominal.

Outside the ARB, ESA has planned the following three medium-term actions, to be completed indicatively by end 2022:

- Modification of Sentinel-1C and Sentinel-1D CAPS and operation of the unit in cold redundancy to increase the robustness and reliability
- Further support the lack of S1B data with Copernicus Contributing Mission (CCM) data
- Technological tests to be carried out by two main means:



- Manufacturing of a breadboard model including relevant functionalities of the CAPS 28V bus regulator boards, and execution of a series of tests to better understand the identified in-flight failure scenario, better isolate the failure cause and potentially help safeguard the Sentinel-1A operations
- Relevant tests to be performed on Sentinel-1B, if considered appropriate.

The current plans, devised by the ESA Sentinel-1 Steering Group, are the following:

- Before the launch of Sentinel-1C, Sentinel-1B will be located in a "parking" orbit preventing any risk related to the Sentinel-1C launch and LEOP, with the two main following envisaged options:
 - Locate Sentinel-1B at a specific location in the constellation orbital plane
 - Lower the Sentinel-1B orbit so that it remains outside the launcher dispersion envelope.
- The preparation of the Sentinel-1B disposal phase has started. It requires detailed analyses in the domains of satellite engineering, mission analysis and flight operations. This preparatory phase is planned to last until end Q1 2023.
- Due to manpower operational constraints, the execution of the Sentinel-1B disposal cannot take place in parallel to the Sentinel-1A operations and to the Sentinel-1C related activities (launch preparation, launch execution and Commissioning). It is therefore planned to start the Sentinel-1B disposal after the In-Orbit Commissioning Review (IOCR), indicatively during Q3 2023. The de-orbiting activities will last several months (current estimate in the order of 9 months).