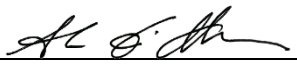
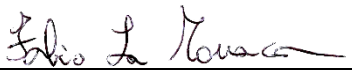
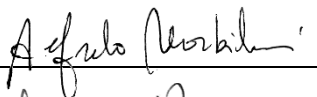
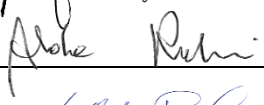
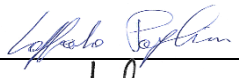
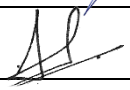
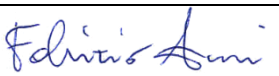
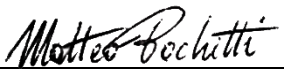
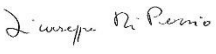
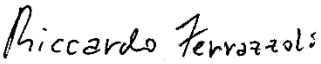
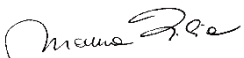
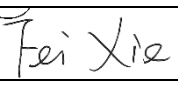
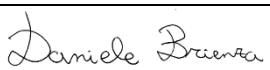
IXPE ITALIAN CONTRIBUTION

DU FM2 E2E Check Report

[AT-003]

Written by	***Responsibility***
Alessio Trois	GSE/AIV-T Manager
Ettore Del Monte	Instrument PO Manager
Antonino Tobia	Electrical Calibration Set-Up
Francesco Santoli	Instrument System Engineer
Guido Parissenti	System AIV/AIT support
Carlo Lefevre	Structural & Thermal Engineer
Daniele Brienza	Instrument PA Manager
Primo Attinà	Italian PM
Fabio Muleri	Project scientist
Yuri Evangelista	Du electronic I/F Eng.
Sergio Fabiani	Calibration scientist

IXPE ITALIAN TEAM

Alessandro Di Marco	Calibration support & data analysis	
Fabio La Monaca	Calibration support scientist	
John Rankin	Data analysis	
Paolo Soffitta	Italian PI	
Raffaele Piazzolla	Mechanical Engineer	
Alfredo Morbidini	Mechanical support	
Alda Rubini	Electronic & test supervisor	
Pasqualino Loffredo	Document manager	
Ajay Ratheesh	Data analysis	
Enrico Costa	Senior Italian Co-PI	
Fabrizio Amici	PA /QA Manager	
Matteo Bachetti	Calibration pipeline	
Mauro Centrone	Calibration support set-up	
Sergio Di Cosimo	Procurement and contract administrator	
Giuseppe Di Persio	Software support	
Riccardo Ferrazzoli	Scientific simulation	
Maura Pilia	Calibration and science analysis	
Fei Xie	Scientific simulation	
Verified by		
Daniele Brienza	Instrument PA Manager	

IXPE ITALIAN TEAM

Francesco Santoli	Instrument System Engineer	
Fabio Muleri	Italian Project Scientist	
Approved by		
Ettore Del Monte	Instrument PO Manager	
Paolo Soffitta	Italian PI	
Luca Baldini	Italian Co-PI	
Primo Attinà	Italian PM	
Pasqualino Loffredo	Italian Documentation Manager	

CHANGE RECORDS

ISSUE	DATE	§ CHANGE RECORDS	AUTHOR
i01p00	11-Nov-2019	First issue	A. Trois, A. Tobia, E. Del Monte, C. Lefevre, G. Parissenti, F. Santoli
i02p00	09-Dec-2019	Second issue: performance test and instrument time test	A. Trois, A. Tobia, E. Del Monte, C. Lefevre, G. Parissenti, F. Santoli

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1. INTRODUCTION

1.1 Scope

This document describes the results of the DU FM2 End to End (E2E) Check test. The main aim of this test has been to verify the functionalities of the DU FM2 in a representative instrument environment composed of the DSU EM and other 2 DU flight models (DU FM1 and DU FM4).

Dry run tests has been performed to validate items, facilities and procedures before to connect DU FM2 into his representative instrument environment.

The test has been executed at INAF Facilities located in IAPS-Rome from 23/10/2019 to 11/11/2019.

This document will describe:

- Test setup
- requirements to be verified in correlation with the VCD
- criteria of success
- Results
- Anomalies
- Synthesis of the test result

1.2 Applicability

This document forms, with its applicable documents, the binding document for the Italian Team in charge of the development and implementation of Instrument models needed for the realization of the IXPE mission.

This document is applicable in the framework of phase C/D activities.

1.3 Document Roadmap

Chapter	Content
1	Introduction to the document & explanation of its contents and scope.
2	List of the documentation linked to the procedure
3	Description of the experimental set-up
4	Participants to the acceptance tests

5	Constraints to the acceptance tests
6	Description of the requirements to be verified during the tests
7	Test results
8	Anomalies
9	Conclusions
10	List of acronyms

2. LINKED DOCUMENTS

2.1 Applicable Documents

[AD 1]	I2C-INFN-ISE-TEC-004	DU User Manual, issue 2, 06 Sep 2019
[AD 2]	I2C-OHBI-IOP-TEC-002	EM DSU User Manual, issue 2, 16 Sep 2019
[AD 3]	I2C-OHBI-ISE-TEC-007	IXPE EGSE USER MANUAL, issue 2, Date: 10 May 2019
[AD 4]	I2C-IAPS-ISE-SPC-004	Instrument Test Specifications, issue 4 rev 1, 2 May 2019
[AD 5]	I2C-IAPS-ISE-REP-002	Instrument Design Report, issue 3, 30 Apr 2019
[AD 6]	I2C-OHBI-ISE-REP-008	DSU Design Report, issue 3, 11 Jun 2018
[AD 7]	I2C-OHBI-ISE-REP-009	IXPE DSU/DU EGSE Design Report, issue 4, 01 mar 2019
[AD 8]	I2C-OHBI-ISE-TEC-009	DSU FPGA DESIGN DESCRIPTION, issue 1, 09 Sep 2019
[AD 9]	I2C-OHBI-ISE-PRC-006	IXPE EM DSU FUNCTIONAL TEST PROCEDURE, issue 1
[AD 10]	I2C-OHBI-ISE-ICD-002	Electrical Interface Control Document (EICD)
[AD 11]	I2C-IAPS-IPA-PLN-003	Instrument PA Plan, issue 4 rev 1, 30 Mar 2018
[AD 12]	I2C-IAPS-ISE-SPC-001	Instrument Technical Specification, issue 7, 30 Apr 2019
[AD 13]	I2C-OHBI-ISE-ICD-003	IXPE DSU-DU EGSE Interface Control Document (ICD), issue 4, 11 mar 2019
[AD 14]	I2C-OHBI-ISW-ICD-002	IXPE Software Telemetry-Telecommand Definitions, issue 3, 20 Sep 2019
[AD 15]	I2C-IAPS-ISE-PRC-017	DU2 E2E Check Procedures, issue 1, 14 Oct 2019
[AD 16]	I2C-OHBI-IOP-TEC-003	DSU User Manual, issue 2, Date: 20 sep 2019

2.2 Reference Documents

[RD 1]	I2C-IAPS-ISE-REP-012	Instrument Calibration Equipment ICE, issue 1,
[RD 2]	I2C-IAPS-ISE-VCD-001 2019	Instrument Verification Control Document, issue 1, 04 Nov

2.3 Standards/Handbooks

[SD 1]	ECSS-E-ST-10-03C	Space Engineering - Testing

3. DESCRIPTION OF THE EXPERIMENTAL SET-UP

The activities are conducted at IAPS/INAF facility inside a ISO 7 cleanroom, the setup is composed by:

- Electrical Ground Support Equipment
- Assembly and calibration equipment (ACE)
- Test Harness
- X-Ray tubes
- Metrological tools

3.1 The Test Scenario and the Electrical Ground Support Equipment (EGSE)

In this scenario the IXPE Instrument EGSE is used to test the Engineering Model (EM) of the Detectors Service Unit (DSU EM). EGSE provides the missing interfaces normally provided by the Spacecraft (Figure 4-1). For the dry run activities DSU EM is connected with DU FM 2 (the Element under test) and other 2 DU flight models (DU FM1 and DU FM4).

As such the EGSE for DU FM2 testing performs the simulation of the missing I/F normally provided by the S/C toward the DSU EM:

- TM/TC packet management
- Scientific data acquisition and verification with a dedicated tool that can validate the received science data
- Pulse-per-second generation
- Power supply

The main EGSE elements involved in this test context are identified in the following image:

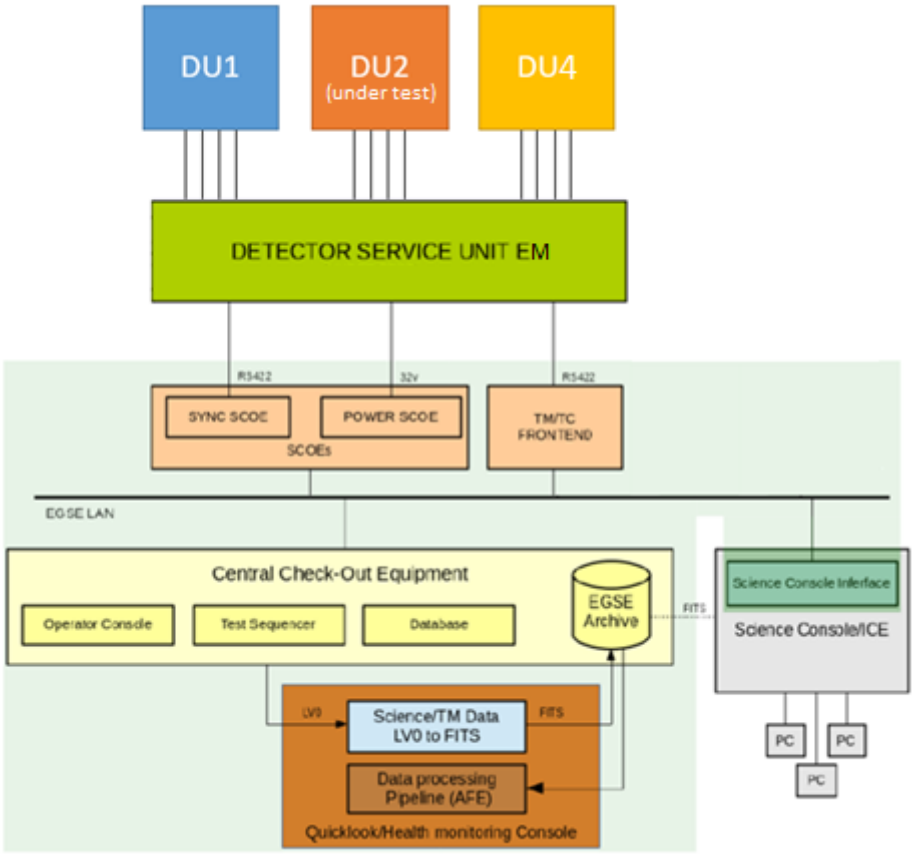


Figure 4-1: DSU EGSE logical breakdown

- The Central Check-Out Equipment (CCOE) is the core of the DSU EGSE, from which all testing is prepared, controlled (Test Sequencer) and results archived (EGSE Archive). It presents the main man machine interface (Operator console), and single point of control, for the supporting of all aspects of the test of the DSU.
- The TM/TC Data Frontend Equipment (TM/TC FE): handles the Telemetry and Telecommand communication between the DSU under test and the missing UUT TM/TC interfaces.
- The Specific Check-Out Equipment (SCOEs): provide the DSU under test with the missing interfaces with UUT, such as synchronization signal and power for the unit itself.
- The Quicklook/Health monitoring console contains a Data Processing and Science/TM data converter that produces LV0a FITS file from the acquired data of the UUT.
- The Science Console I/F allows the basic control of the DU testing. The EGSE archived data are also available to the Science Console, not part of this contract, for further analysis.

3.2 The AIV/T Calibration Equipment (ACE)

The Assembly and Calibration Equipment is the facility assembled for the ground activity of AIV-T at instrument level, moreover the facility is equipped with X-Ray sources needed during end to end tests activities for the evaluation of scientific performance of entire instrument. The facility is located at IAPS/INAF in a ISO 7 cleanroom.

3.3 Detector Unit

The equipment under test is the Detector Unit Flight Model 2 (DU FM2). The Detector Unit is the unit containing the polarization sensitive sensor (GPD) and all the electric boards, thermal and mechanical items required by the GPD. The DU FM2 is connected to the Detectors Service Unit Engineering Model (DSU EM) between the three interfaces: Power, Data and FCW. In Figure 4-3 is reported the rendering of the rear view of DU with the 4 interfaces in evidence.

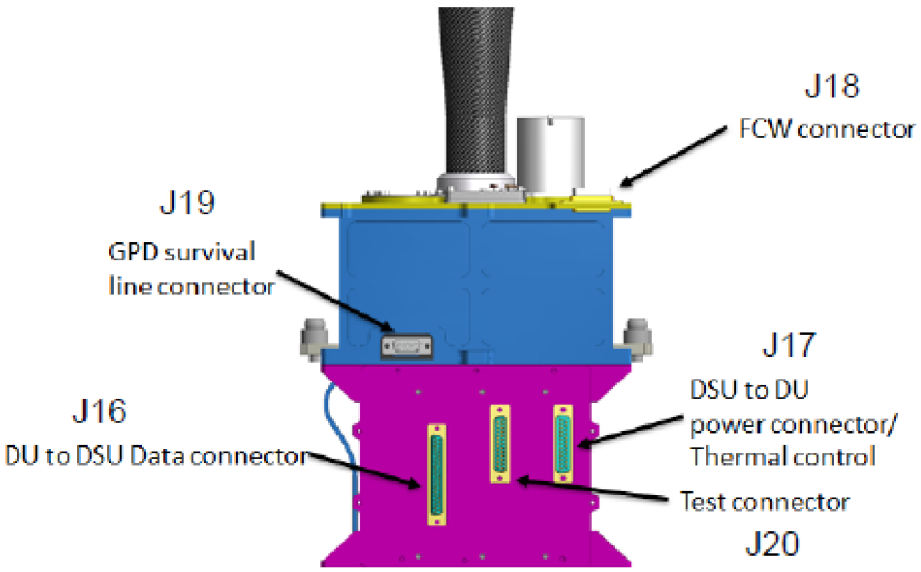


Figure 4-3: DU FM2 mechanical box: rear view

3.4 Detectors Service Unit (DSU)

We performed the End to End Check of the DU FM2 using the DSU EM. The Figure 4-2 shows the external DSU EM connectors configuration positioned on front (S/C side) and back (DUs side) panels; the position of the unit bonding stud is also shown.

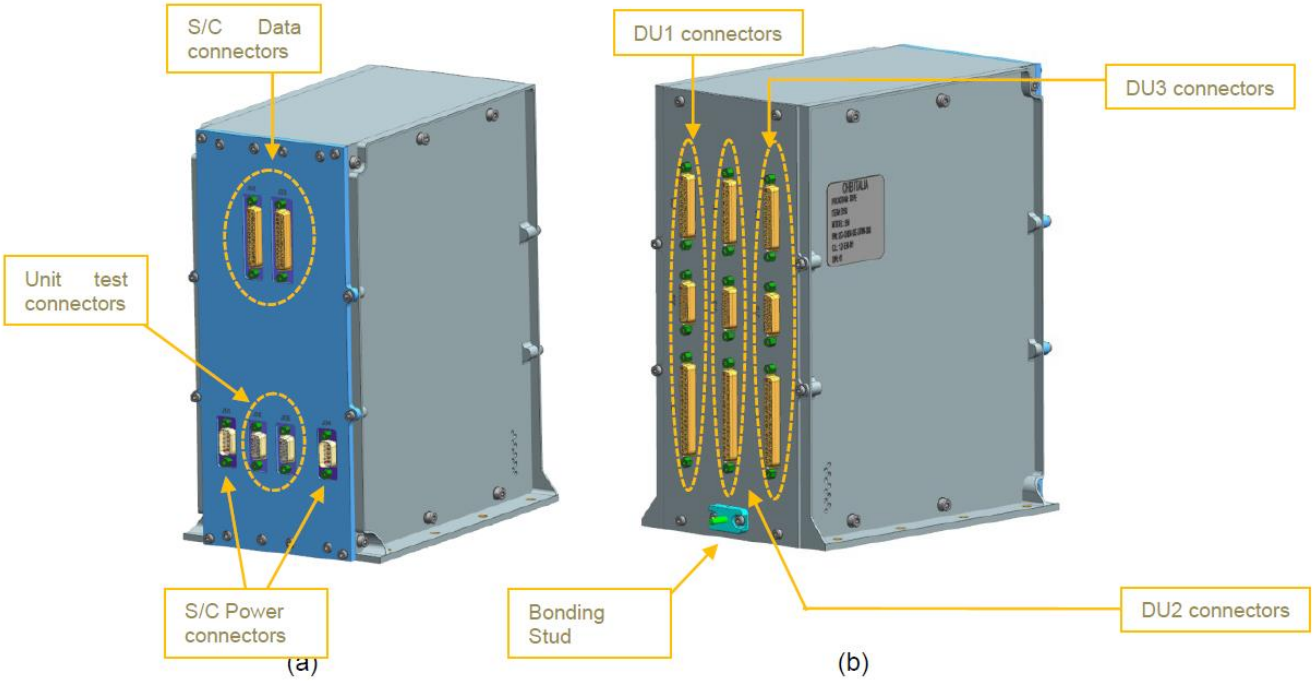


Figure 4-2: DSU EM mechanical box: front (a) and rear (b) view

3.5 Heritage

INAF personnel started training with the EGSE since the beginning of 2019, when the first EGSE was delivered to INFN-Pisa for the integration of the DUs. The training followed during the dry run of ICE before starting the calibration of the DU FMs.

On June 2019 the DSU EM was tested with the DU EM at the OHBI premises using the same EGSE and software mentioned in this document. The procedures defined by OHBI and validated during that activity are included in this document.

3.6 Electrical Interfaces

The electrical interfaces are described in User Manual ([AD 2]and [AD 3]) and ICD ([AD 10]).

The DSU interfaces can be divided into two subgroups:

- External interfaces
- Internal interfaces

The DSU external interfaces with S/C are the following:

- A. Nominal Power Supply
  - Power line: 32V + RTN (From IXPE S/C to DSU)
- B. Redundant Power Supply
  - Power line: 32V + RTN (From IXPE S/C to DSU)
- C. Nominal I/O digital data interface
  - CMDs & TOD (From IXPE S/C to DSU)
  - PPS (From IXPE S/C to DSU)
  - H&S (From DSU to IXPE S/C)
  - Science Data (From DSU to IXPE S/C)
- D. Redundant I/O digital data interface
  - CMDs & TOD (From IXPE S/C to DSU)
  - PPS (From IXPE S/C to DSU)
  - H&S (From DSU to IXPE S/C)
  - Science Data, Clock and Enable (From DSU to IXPE S/C)

For each of the above interfaces (A, B, C, D) the DSU provides a dedicated connector

The DSU internal interfaces are the ones between the DSU and the DU, namely:

- DU Data link
  - CCI Command Control Interface
  - SDI Serial Data Interface
  - RESET and auxiliary
  - PPS Pulse per Second
  - 1MHz clock
- DU Power
  - Power supply rails (+5V and +25V)
  - Heater supply rails
  - Peltier supply rails
  - Temperature sensors (PT1000)
- DU Filter & Calibration Wheel
  - Motor phases (Nom / Red)

- Motor Temperature sensors (PT100) (Nom / Red)
- Hall sensors
- Potentiometer

Details about connectors, cables and pin allocation of electrical and power interfaces are reported in [AD 7] about interfaces between EGSE and DSU and [AD 10] about interfaces between DSU and DU.

3.7 Grounding

The Figure 4-4 shows the system grounding diagram, with the internal redundancy and the board division; cables and relevant shielding are also shown. The S/C will be simulated by EGSE during functional tests.

The DSU grounding has the following characteristics:

- A star point inside DSU
- DSU secondary returns connected together near the DC/DC transformer
- In the digital lines, cable shields are connected to the driver (TX) ground; on receiver side, shield is floating
- Cables between DSU and DU have over shields connected to chassis (360° conn.)
- 3 cables between DSU and each DU (Data, Power, FCW)
- DSU secondary ground (nominal & redundant) are connected together on backplane ground plane.

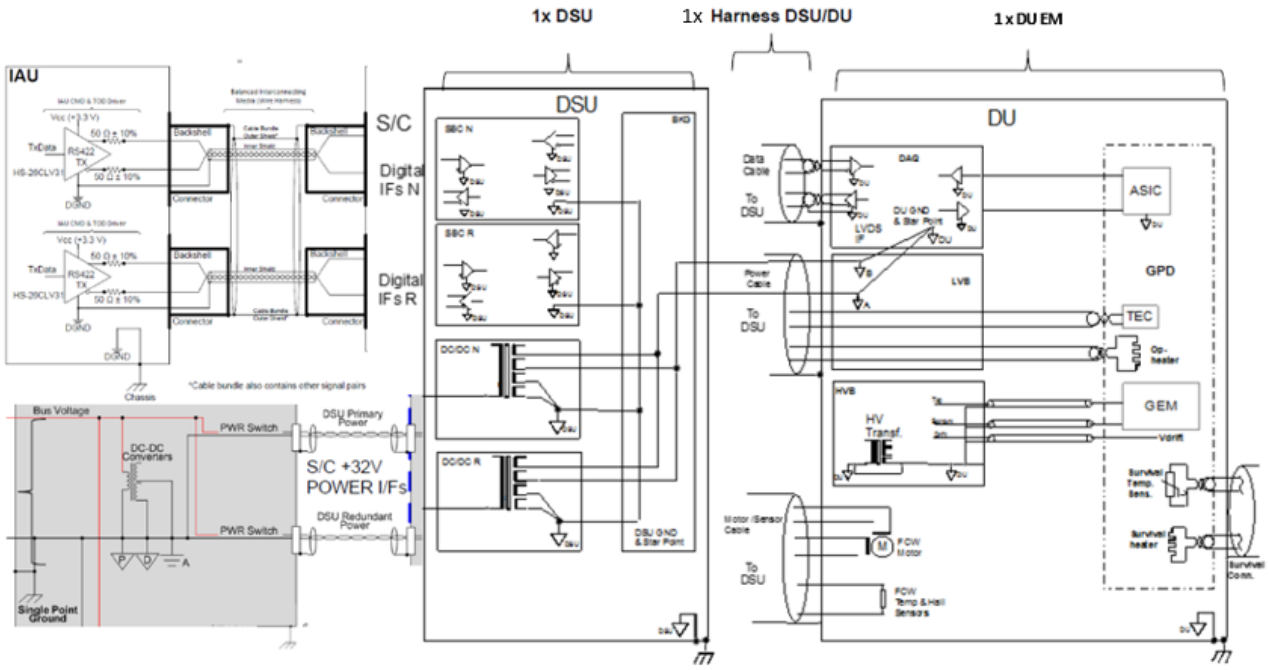


Figure 4-4: Instrument grounding scheme.

The ACE setup reproduce in part the grounding scheme required by the instrument, in particular DSU and DU are bonded to the Optical Bench (conductive surface) and in continuity to the Grounding Box of facility. Following in Figure 4-5 is reported the block scheme of grounding circuit.

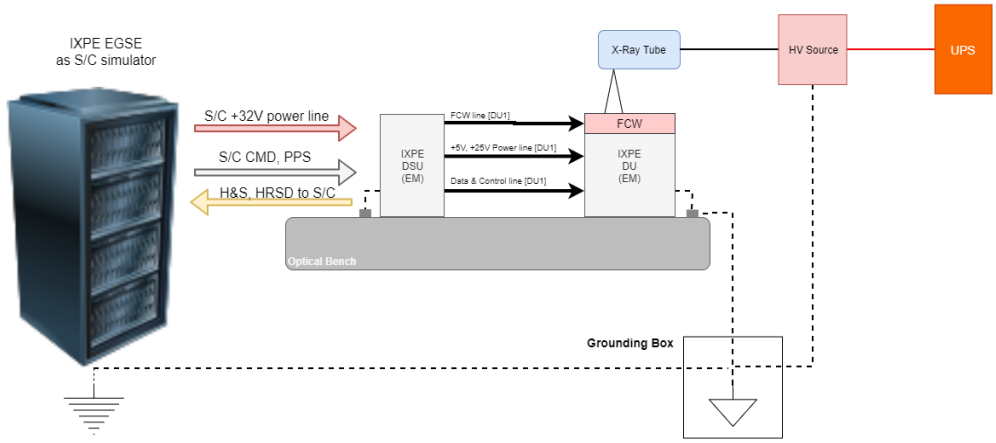


Figure 4-5: Grounding of the ACE

3.8 Mechanical Ground Support Equipment

A description of the mechanical interfaces in the ICE is reported in [RD 1].

During the tests 3 DUs and the DSU are accommodated on the same optical bench. Such bench is provided of an aluminum structure on top where are fixed three X-ray tube sources (Figure 4-6). Any tube is collimated by a cylinder tube with a pinhole at the end. Each cylinder tube has the capability, by X and Y motorised stages, to center the axes tube respect to the X-Ray flow. During the alignment procedure the X-Ray flux to the normal of the ASIC plane is co-aligned.

Each DU is installed on a XY movimentation stage, able to align the center of X-Ray spot respect to the center of the ASIC. Moreover, any XY movimentation stage is mounted on a manual rotative movimentation stage. This allows to simulate a nominal case of single source acquired with 120° of angle difference each other. The correct interfacing between the DUs and the movimentation is guaranteed by three adapter plates.

The DSU will be operated on the same optical bench. It will be located at almost 1m respect to the EGSE (Figure 4-7)

To reduce the air absorbing of X-Ray, a helium fluxed tube will be installed for each DU (Figure 4-8).

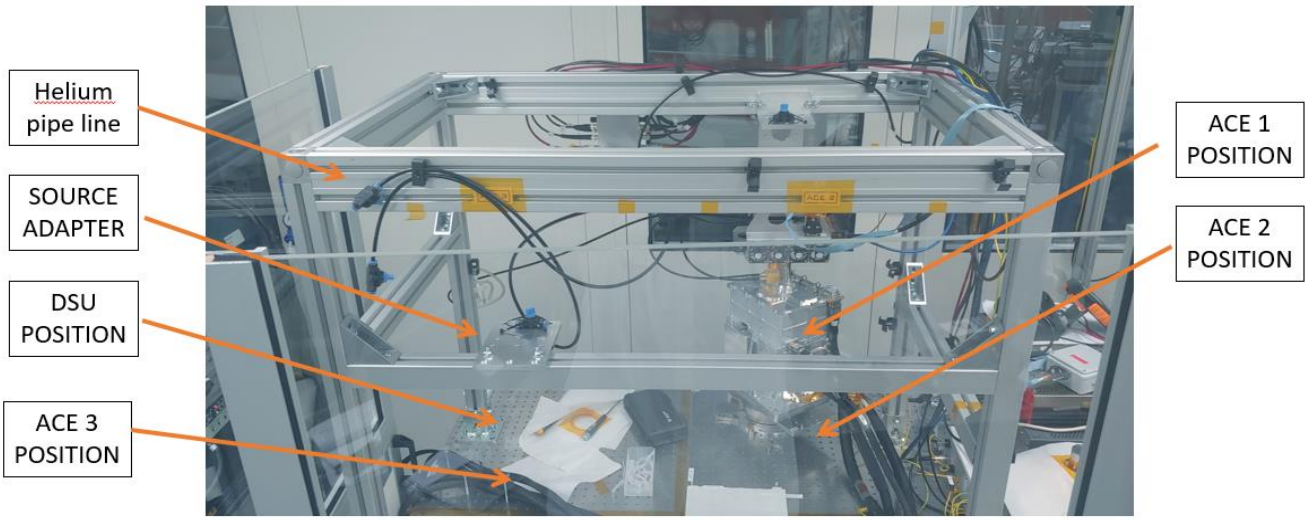


Figure 4-6 ACE E2E description

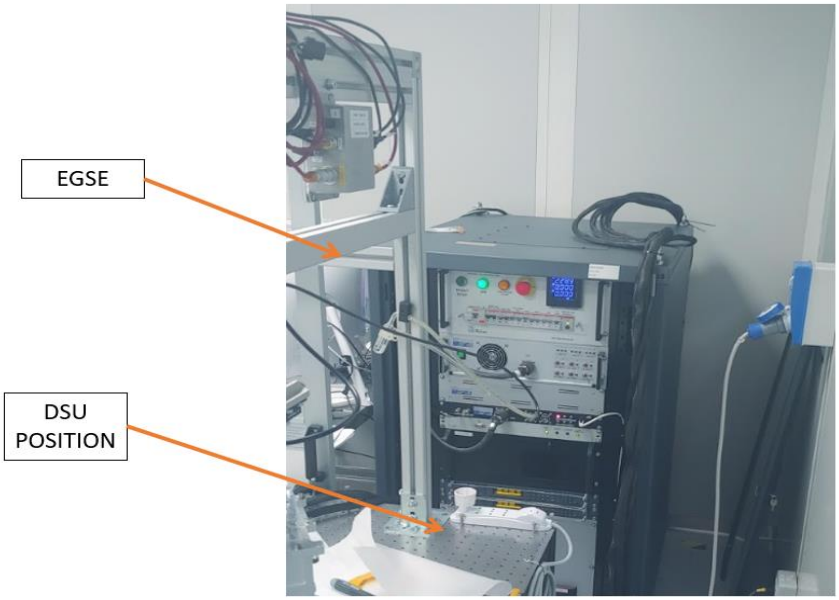


Figure 4-7 DSU and EGSE position

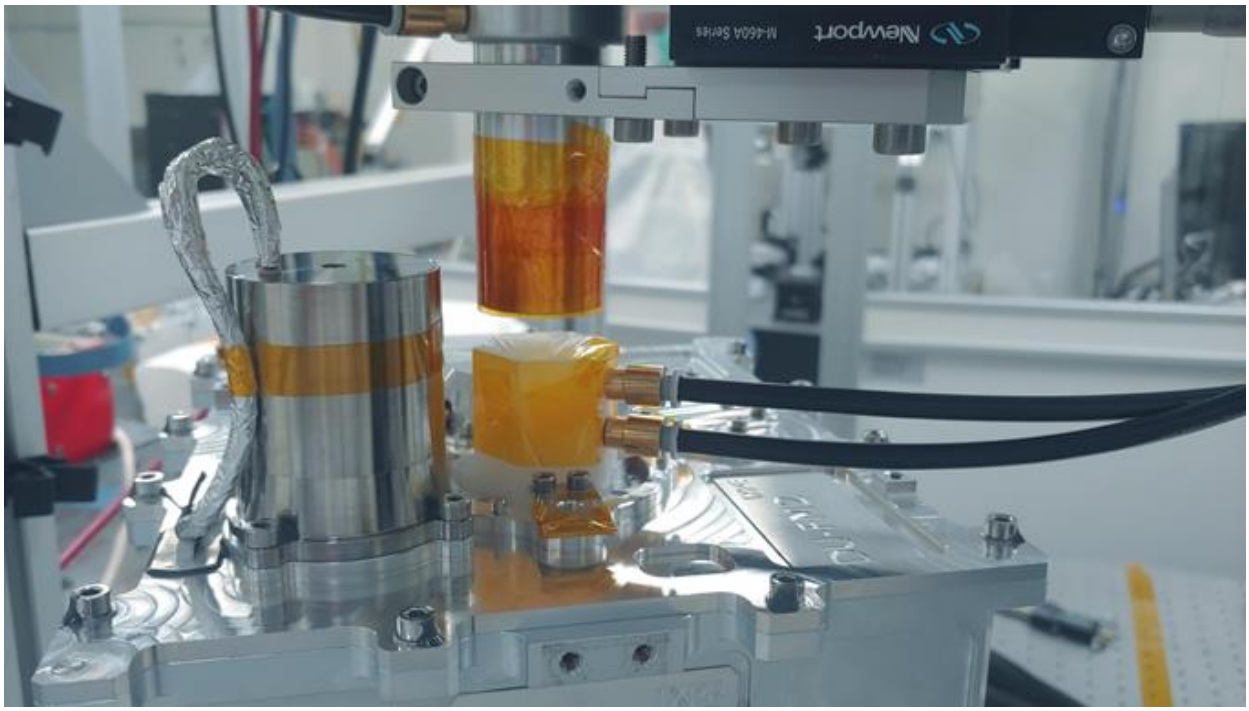


Figure 4-8 DU mounted in ACE with Helium Fluxed tube

3.9 List of instrumentation for the Dry Run E2E Test

N°	EQUIPMENT	MANUFACTURER	P/N	MODEL	REMARKS
	Multimeter			T760-2	

3.10 List of SW for the E2E Dry Run test

Software	Version
build_ixpe_tmparser	
build_ixpe_correction	
gpdsw	
dqmpipeline	
ixpehealth	

3.11 List of IP addresses of ICE devices

Device	IP address
EGSE sn02	150.146.136.141
Science Console 2	192.168.20.50
NAS EGSE 2	192.168.20.115

NAS EGSE 3	192.168.30.115

4. PARTICIPANTS

The E2E Test and the data analysis will be under INAF responsibility.

INAF will be in charge of conduct the test and set up the facility as described in this procedure. Tests has been performed under QA surveillance, in compliance with the PA Plan [AD 11]. INAF QA will witness the test in order to ensure that the procedure is strictly followed and the step-by step sheets are comprehensively filled and signed by relevant personnel, test facility and required tools are conform to the requirements. Problems or malfunction occurring during the test will be managed according to the Non Conformance Control system described in the applicable PA Plans [AD 11].

5. CONSTRAINTS

The data has been analyzed using the software listed in section 3.10.

6. REQUIREMENTS TO BE VERIFIED AND SUCCESS CRITERIA

We list in the table below the requirements to be verified as specified in the Instrument Technical Specification [AD 4].

Procedure Section	Requirement ID	Description	Remarks
7.1 7.3 7.7 7.9 7.13 7.14 7.16	ISW-14	**DSU Operating modes –** IXPE Instrument **shall** implement at least the following operative modes: ● "BOOT" is the start-up mode at power on; ● "MAINTENANCE" is reserved by DSU to support the in-orbit maintenance program; ● "STAND-BY" is the mode devoted to perform the instrument monitoring, configuration and control; ● "OBSERVATION" is reserved to the DUs scientific, calibration and diagnostic data acquisition; ● "SAA" is reserved for the south atlantics anomaly crossing. ● "SAFE" is an operational mode introduced to guarantee the safety of the instrument.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.1	ISW-16	**Bootstrap Software Program functionalities** – The Bootstrap software program **shall**, as a minimum, provide the following capabilities: ● Initializes the hardware (Trap table, CPU registers, memory controller configuration, watchdog, link to the spacecraft); ● tests available memories (PROM, MRAM, SRAM); ● At the end of the bootstrap a Boot Report telemetry packet is generated and sent to ground containing: Software parameters, Memory tests results; Parameters copy from non-volatile memory (MRAM) to volatile memory (SRAM).	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)

7.1 7.3 7.4 7.5 7.6 7.8 7.9	ISW-12	*Req. ID:* ISW-12 **DSU SW tasks** – The DSU SW **shall** be in charge of performing at least the following tasks: ● Manage of the operational modes of the Instrument; ● Acquire and process the scientific data ● Manage retransmission of scientific data according CRC or dead-time evaluation; ● Prepare packets for transmission to S/C; ● Collect HK data and prepare packets for transmission to S/C; ● Generate all the telemetries provided for the Instrument; ● Deliver packets to S/C; ● Accept, process and execute the TCs coming from the S/C; ● FDIR management; ● Control and configure the DSU and the DUs; ● Maintenance the DSU SW; ● Report SW activities.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.2	ISW-22	**TM Packets –** The TLM packets provided by the IXPE Instrument **shall** be compliant to CCSDS protocols as defined in [RD 3].	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.2 7.5	ISW-213	**Instrument HK –**The DSU **shall** collect the HKs in order to monitor onboard and on ground the health of the Instrument	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.2 7.5	ISW-214	**Instrument HKs categories** - The Housekeeping **shall** be cataloged in the following groups:	TO BE VERIFIED DURING Instrument E2E

7.13		Sensor housekeeping: ● From temperature sensors, ● From voltage sensor, ● From current sensor, ● From on/off sensors, ● From FCW position sensors Science housekeeping: ● GPD scientific ratemeters, ● DSU scientific processing ratemeters	Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.2 7.5	ISW-215	**Instrument maximum HKs rate –** The rate of HKs produced by the Instrument **shall** be <=10 kbit/s.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.2 7.5	ISW-216	**HKs Sampling period –** The sampling period of the HKs **shall** be configured by telecommand.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.8 7.9 7.13	IINT-522	**Science Data Compression enable/disable capability** – The compression of scientific data (ref. IINT-512) shall be enabled/disabled by dedicated TC.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.8 7.9 7.13	ISW-226	**Scientific data identification -** The DSU **shall** associate a unique identification to the scientific data packets retrieved by each different DU.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.8	ISW-227	**Run ID -** The DSU shall associate a unique, sequential identification to the TM packets, according to the operative phase changes.	TO BE VERIFIED DURING

			Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.9 7.11	ISW-85	**DSU telecommands management –** The DSU TCs **shall** be able to manage at least the functions defined in following table (**TBC**) [AD 4].	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.10 7.11	ISW-23	**Telemetry packet generation –** The DSU **shall** be able to produce at least the telemetry report shown in following table (**TBC**) [RD 4]	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.12	IINT-519	**HV ramp-up/down** - The switch on/off of the HVB output lines **shall** be performed with ramp-up/down speeds not greater than 200 V/s (+/-10%) for the drift channel and 50 V/s (+/-10%) for the two GEM channels.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.13	IINT-159 (Partially) ISW-10	**Telemetry and Telecommand rate** – The TLC/TLM data rate expected from the S/C, and delivered to the S/C, **shall** be as specified in Instrument to S/C ICD	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.13	ISW-10	**DSU Scientific Data format –** The DSU **shall** format scientific data for transmission to S/C in the format provided by the team with a dedicated technical note.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.15	IINT-14	**Maximum counting rate** – The Instrument **shall** be able to acquire and process a steady maximum counting rate of 900 cts/s (corresponding to ~2 times the Crab Nebula in 1 – 12 keV).	
7.15	IINT-499	**Expected over-flux** - In case the source flux is expected to be such that the counting rate would exceed 900 cts/s, a gray filter (in the	TO BE VERIFIED DURING

		filter and calibration wheel) **shall** be used to reduce the incoming flux.	Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.15	IINT-500	**Unexpected over-flux** - The instrument **shall** be able to withstand, without changes in the GPD operations, any unexpected increase of the source flux such that the counting rate would exceed 900 cts/s.	
7.15	IINT-426	**Science data rate** – The science data rate produced by the Instrument after the filtering **shall** not exceed 2 Mbit/s.	
7.15	IINT-512	**Science Data Compression** – The DSU **shall** be able to compress scientific data, transmitted contemporaneously from the 3 DUs, with the lossy algorithm ('orphans suppression') proposed by the scientific team in 2C-IAPS-ISE-TEC-005 'FPGA based orphan removal algorithm'.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.15	IINT-522	**Science Data Compression enable/disable capability** – The compression of scientific data (ref. IINT-512) shall be enabled/disabled by dedicated TC.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.15	IINT-514	**DU-DSU maximum data rate –** The data interface between each DU and the DSU **shall** be able to transmit with zero loss, simultaneously for all DUs, up to 0.75 Mbit/s of data, corresponding to the "DU maximum counting rate" requirement IINT-14	
7.15	ISW-7	**DSU SW saturation** – The DSU SW **shall** be able to manage the saturation of data Buffers.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.15	ISW-8	**DSU SW buffers management**– The DSU SW **shall** be able to trace with a dedicated TM Report the saturation of data Buffers.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)

7.15	ISW-9	**DSU SW de-saturation report** – The SW **shall** be able to trace with a dedicated TM report the desaturation of the data buffers.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.16	IINT-163 (partially)	**Instrument fault monitoring and protection** – The IXPE Instrument **shall** provide fault monitoring and protection.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.16	IINT-134	**Switch-off** – IXPE Instrument **shall** survive an intentional or unintentional switch-off in any configuration without degradation of nominal performance.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.17	IINT-16	**Instrument time accuracy** – The Instrument **shall** time stamp detected X-ray photons during observation with an accuracy of +/- 94 µs (at 99%) with respect to a time-base defined by leading edges of the 1-PPS pulses from the Spacecraft, at the DSU input.	
7.17	IINT-524	**Instrument Timing Synchronization –** When the GPS is un-locked, the DSU **shall** manage the timing synchronization of the Instrument, according to I2C-IAPS-ISE-TEC-004i01p00 'Instrument Timing Management'.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.17	IINT-523	**Instrument clock performance** – DSU **shall** provide the Instrument with a 1-Mhz clock signal with an accuracy <=4 ppm in all temperature range.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM + DU FM1 +DU FM3 +DU MF4)
7.17	IINT-430	**Pulse-Per-Second management** – The Instrument **shall** be capable of receiving from the spacecraft a PPS signal and an indication if the GPS is locked or not.	TO BE VERIFIED DURING Instrument E2E Test (DSU PFM +

			DU FM1 +DU FM3 +DU MF4)
7.17	IINT-520	**Alarm_in auxiliary lines -** The DSU **shall** manage the auxiliary Alarm_in_1 lines in order to perform, as a minimum, the following actions: ● (Internal mode) generate and send to DUs a programmable time tagged signal (pulses sequence). ● (External mode) feed to DUs the signal provided by the EGSE through the test connector.	
7.18	IINT-424	DU data and HK identification – The instrument shall associate a unique identification to the data and HK packages retrieved by each different DU.	

6.1 TEST SUCCESS CRITERIA

We list in the table below the tests and their success criteria.

Section	Test	Success Criteria	Remarks
7.1	DSU POWER ON/OFF	– Boot OK – Boot Report Telemetry generation OK – Stand-By operative mode OK – HK apid 1200 generation	DUs off
7.2	DSU - HKs checks and rates management	– HK apid 1200 generation – HKs rates change OK – main parameters within the limits	DUs off
7.3	DSU - memory checks and management	– Maintenance operative mode OK – read/write MRAM with dedicated TC OK	DUs off
7.4	DU 5V Power ON/OFF	– BEE 5V ON success – HK apid 1321 generation – HK apid 1324 generation – main parameters within the limits	HV off
7.5	DU - HKs check and rates management	– HK apid 1321 generation – HK apid 1324 generation – HKs rates change OK – main parameters within the limits	HV off
7.6	DU - Configuration	– TC BEE setup success – HK apid 1324 checks OK	HV off

		– main parameters within the limits	
7.7	Instrument Observation - DU pixel scan	– TC PIxel Mask – Events acquisition – Packets 1119 generation – Packets 1203 generation (scientific Ratemeters) – no CRC – Scientific Data quality success – Ratemeters coherent with the configuration	HV off
7.8	Instrument Observation - DU pixel scan (Charge Injection)	– TC PIxel Mask – Events acquisition – Packets 1119 generation – Packets 1203 generation (scientific Ratemeters) – no CRC – Scientific Data quality success – Ratemeters coherent with the configuration	HV off
7.9	Instrument Observation - DU pedestal calibration	– Events acquisition – Packets 1120 generation – Packets 1203 generation (scientific Ratemeters) – no CRC – Scientific Data quality success – Ratemeters coherent with the configuration	HV off
7.10	FCW rotation	– Position OK – power consumption OK	HV off
7.11	DU Thermal Control	– Peltier OK	ISW-85

		– Heater OK	
7.12	HV Management	– HV Power ON OK – power consumption OK – HV ramp up procedure OK – HV ramp down procedure OK – main parameters on the limits – ramp up / ramp off rates within the limits	HV on
7.13	Instrument Observation - Nominal acquisition	– Events acquisition – Packets 1118 generation – Packets 1203 generation (scientific Ratemeters) – Scientific Data quality success – Orphan Removal ON/OFF – Ratemeters coherent with the configuration	HV on
7.14	Instrument SAA Mode	– Events inhibition – HV ramp down – OBS to SAA – SAA to OBS – HV ramp up after SAA – check telemetries produced – DU and DSU HKs coherent – no CRC – No scientific Ratemeters	HV ramp down and ramp up
7.15	Instrument Scientific Rate Management	– Events acquisition – maximum rate respected – Saturation/Desaturation buffer OK – Saturation/Desaturation Telemetries generated	HV on

		– DU and DSU HKs coherent – no CRC – Scientific Data quality success – Orphan Removal ON/OFF – Ratemeters coherent with the configuration	
7.16	Instrument DU Alarm - Configuration and Management	– TC DU alarm configuration write the registers – Alarm trigger generation – Alarm trigger DSU reaction with DU OFF	HV on
7.17	Instrument Timing Management	– TOD receiving ok – PPS management ok – Timing test internal trigger ok (DSU on board management) – Timing test external trigger ok (egse management) – Packets 1118 generation – checks time-tag events ok	HV on

7. E2E TEST RESULTS

7.1 DSU Power ON/OFF Procedure

Date 20191022 h09	**RUN 020089-20097**	
Criteria Success	**Results**	**Remarks**
Boot OK	The DSU has been booted. At the end of the process the DSU SW entered in standby mode. The power absorption was nominal: VOLTAGE = 32.006V DSU PSU CURRENT = 0.580 A	PASSED
Boot Report Telemetry generation	The TM reports has been produced as expected: 1220 (boot SW report): 020095/1220/ixpe20191022T124729.298_0202_020095_05_001.lv0.bin 1221 (ASW start report): 1221/ixpe20191022T124729.356_0202_020095_05_001.lv0.bin	PASSED
Stand-By operative mode	At the end of the process the DSU SW entered in standby mode.	
HK apid 1200 generation	After the boot the DSU started to produced the DSU HK Telemetry (apid 1200): ixpe20191022T124651.590_0202_020095_1200.lv0.bin ixpe20191022T124736.343_0202_020096_1200.lv0.bin ixpe20191022T124741.344_0202_020096_1200.lv0.bin	PASSED

7.2 DSU - HKs checks and rates management

Date 20191022 h09	**RUN 20107**	
Criteria Success	**Results**	**Remarks**
HK apid 1200 generation	The DSU HK telemetry (apid 1200) is produced with a period of 5 seconds	PASSED
HKs rates change OK	The rate of the DSH HK telemetry has been modified with success. The DSH HK telemetry generation has been disabled/enalbled with success.	PASSED
main parameters within the limits	The main parameters are within the limits SBC voltage (4.5 < V < 5.3) 5.1 V SBC current (0.2 < A < 1.2) 0.6 V Test Point 15V (14 < V < 16) 15.2 V PSB Temperature (18<degC<75) 40.5 C SBC Temperature (18<degC<55) 33.0 C	PASSED

7.3 DSU – Memory checks and management

Date 20191022 h09	**RUN 20108- 20111**	
Criteria Success	**Results**	**Remarks**
Maintenance operative mode OK	The DSU SW has been moved in maintenance mode with success	PASSED
read/write MRAM with dedicated TC OK	During the test the MRAM register DDD1212X has been changed with success	PASSED

7.4 DU Power ON/OFF Procedure

Date 20191022 h13	**RUN 20111**	
Criteria Success	**Results**	**Remarks**
BEE 5V ON success	DU2 5V STATUS = On DU1 5V STATUS = Off DU3 5V STATUS = Off	PASSED
HK apid 1322 generation HK apid 1325 generation	After the the DU started producing the fast and slow HKs telemetries. ixpe20191022T124651.590_0202_020095_1200.lv0.binixpe20191022T124736.343_0202_020096_1200.lv0.binixpe20191022T124741.344_0202_020096_1200.lv0.bin	PASSED
main parameters within the limits	Vref XOP: 787.2 mV I 3V3: 640 mA I 1V8: 407 mA I 1V5: 154 mA GPD Temperature: 21.7 °C DSU EGSE HK: • DSU PSU VOLTAGE = 32.006 V • DSU PSU CURRENT = 0.78 • Power consumption (DSU EM +DU FM2) 25.06 W	PASSED

Instrument Status:

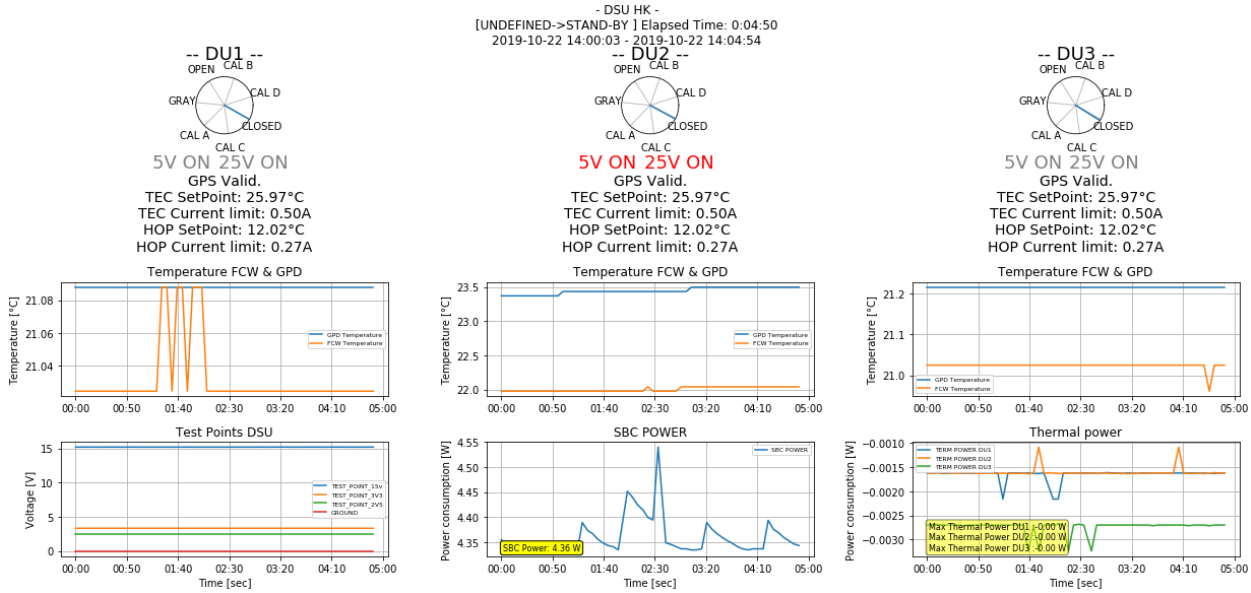


Fig 7-1: Instrument status at the completion of the DU Power ON/OFF Procedure (sec. 7.4). The DSU EM is powered on, the DU FM2 is powered on with both 5 V and 25 V. DU FM1 and DU FM4 are powered off.

Instrument Power State:

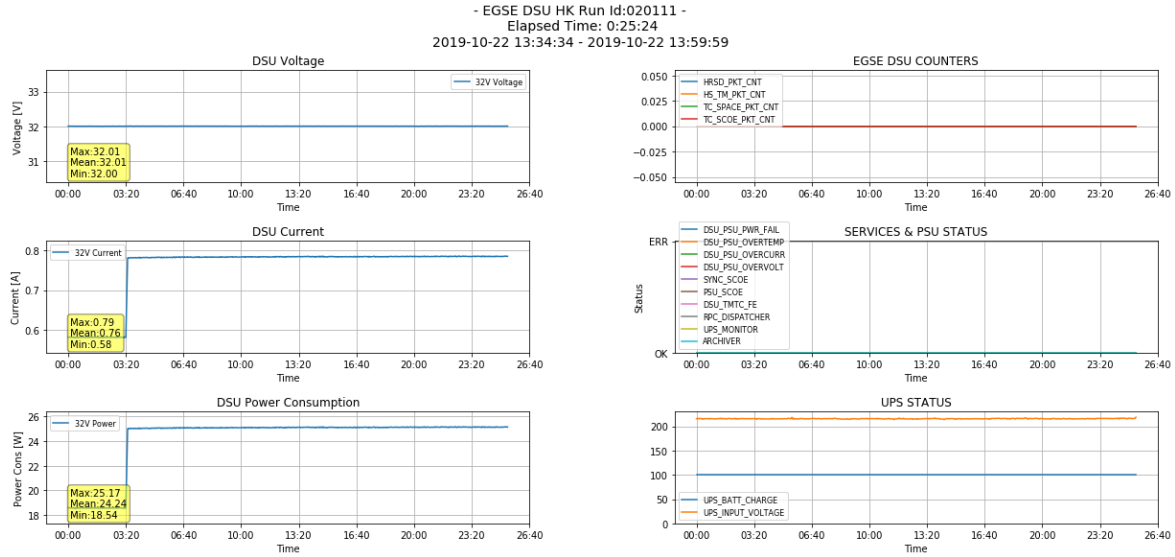


Fig. 7-2: Instrument power state at the completion of the DU Power ON/OFF Procedure (sec. 7.4). The DSU EM is powered on, the DU FM2 is powered on with both 5 V and 25 V. DU FM1 and DU FM4 are powered off.

DU FM2 HKs after boot:

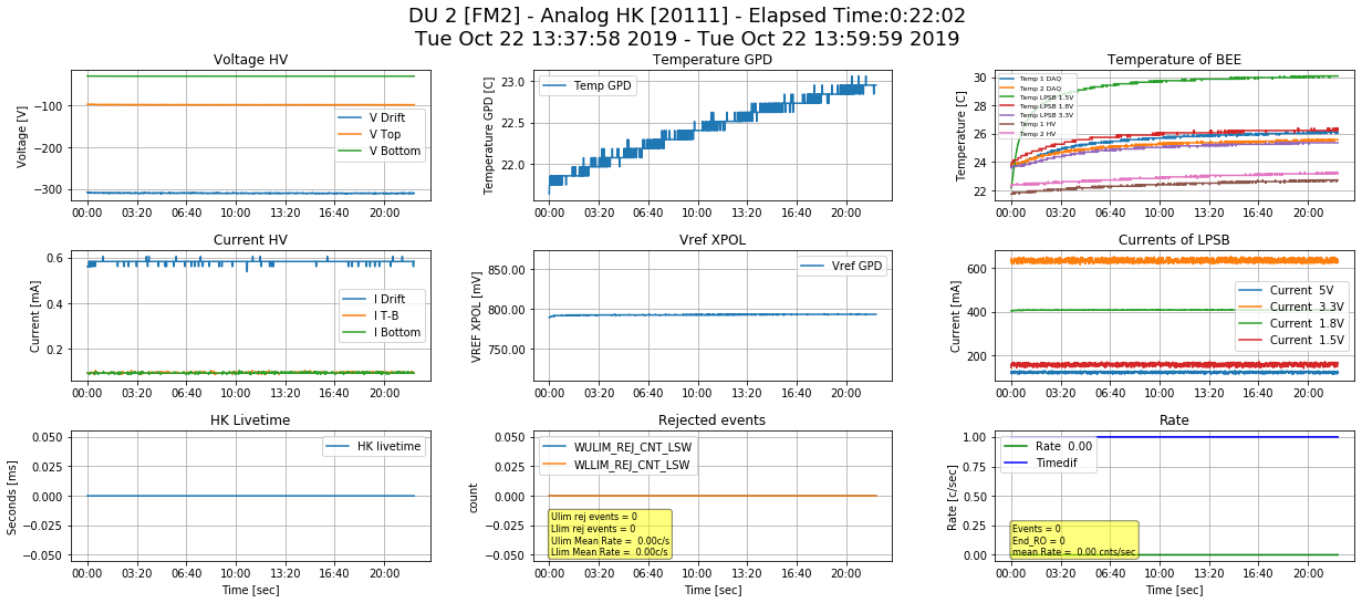


Fig 7-3: DU FM2 HKs at the completion of the DU Power ON/OFF Procedure (sec. 7.4). The DSU EM is powered on, the DU FM2 is powered on with both 5 V and 25 V. DU FM1 and DU FM4 are powered off.

7.5 DU - HKs check and rates management

Date 20191022 h13	**RUN 020111**	
Criteria Success	**Results**	**Remarks**
HK apid 1322 generation HK apid 1325 generation main parameters within the limits	see Test 7.4 (it has been performed during the same run)	PASSED
HKs rates change OK	The sampling time of the Fast HK (1322) was changed with success from 1 to 5 seconds.	PASSED

	The sampling time of the Slow HK (1325) was changed with success from 10 to 1 second.	Initial sample time of the 1322 (Fast HKs) was 1 second Initial sample time of the 1352 (Slow HKs) was 5 second
Disable HK Telemetry	Thee Fast HK (1322) and the Slow HK (1325) generation was disabled with success..	PASSED

7.6 DU - Configuration

Date 20191022 14	**RUN 20120 20121**	
Criteria Success	**Results**	**Remarks**
TC BEE setup (UUU11156) HK apid 1325 checks	The TC has been successful accepted and the DU has been configured. The crosscheck has been made with the 1325 telemetry in which the DU configuration is reported. see picture below	PASSED The TC BEE SEtup is the main DU configuration telecommand. It configures the logic of the BEE.
TC Pixel Mask (UUU11153)	The TC has been successful accepted and the DSU has performed the procedure to inhibits the noisy pixels on the DU.	PASSED The TC Pixel Mask needs to inhibit the noisy pixels in order to avoid spurious trigger.
Patch and Dump BEE TC	The TC has been successful accepted and the read/write value has been checked with the telemetry.	PASSED The TC is used to patch a single bank register of the BEE

main parameters within the limits	see picture below	PASSED

DU FM2 Configuration:

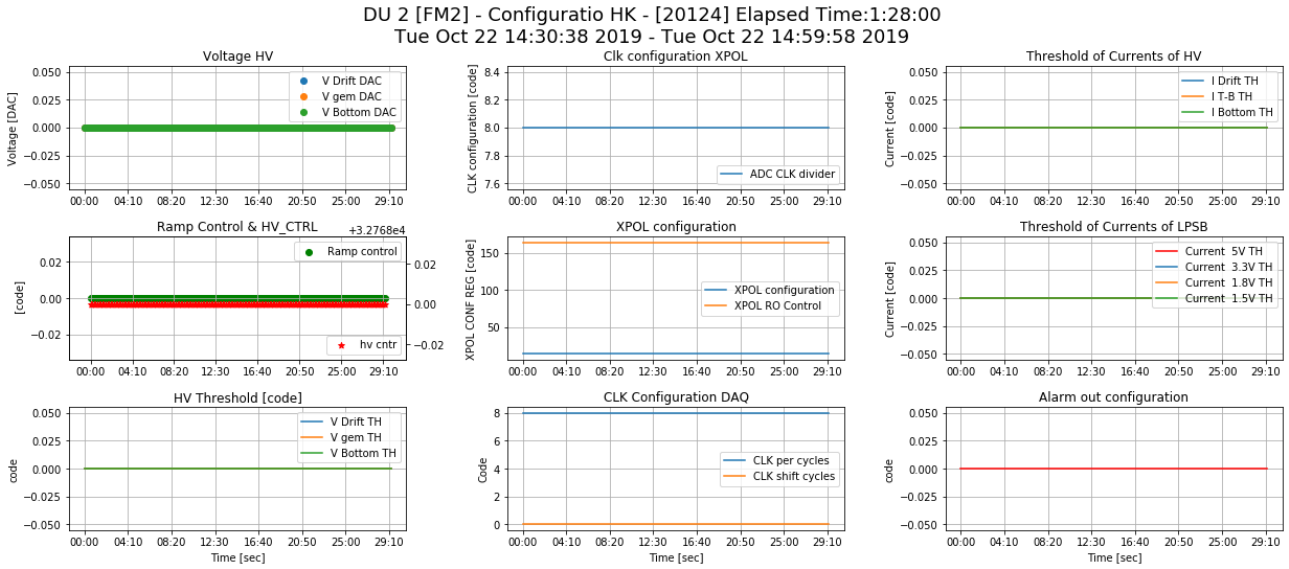


Fig 7-4: Configuration of the DU FM2 at the completion of the DU - Configuration Procedure (sec. 7.6).

DU FM2 HKs:

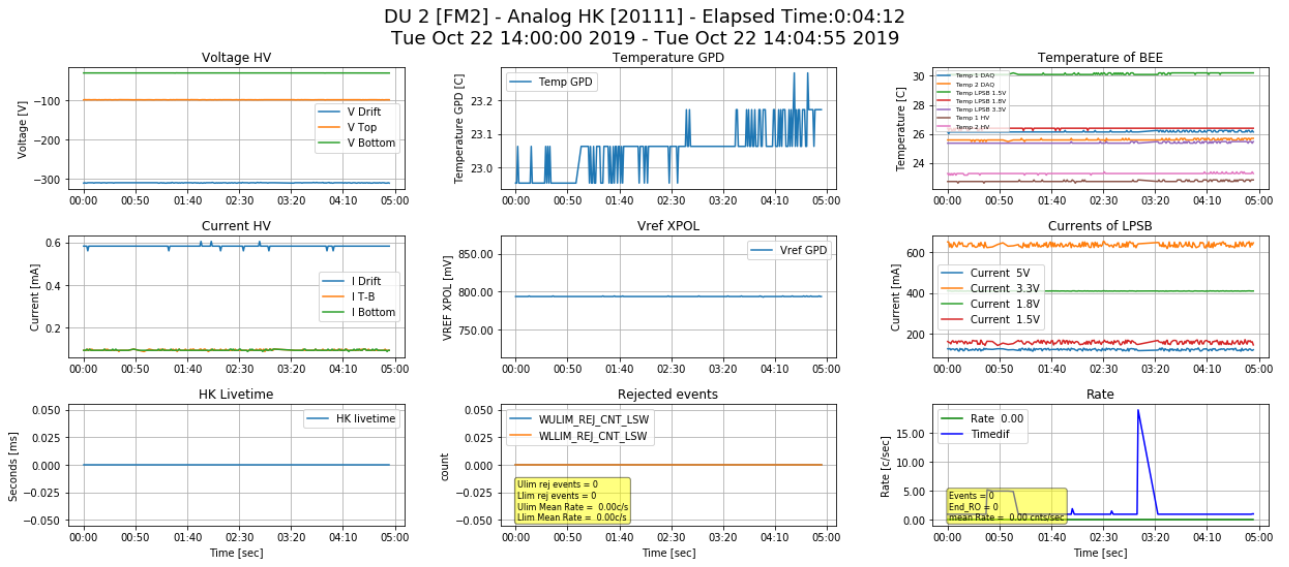


Fig 7-5: Analog HKs of the DU FM2 at the completion of the DU - Configuration Procedure (sec. 7.6).

7.7 Instrument Observation - DU Charge Injection

Date 20191022 h14	**RUN 20122**	
Criteria Success	**Results**	**Remarks**
TC PIxel Mask	This procedure has been performed during the test described in 7.6	PASSED
Events acquisition Packets 1119 generation Packets 1203 generation (scientific Ratemeters)	The DU has produced the telemetry 1119 (scientific - pixel scan operative mode). Also the DSU started producing the scientific ratemeters telemetry see plot below	PASSED
CRC Error	no CRC errors see plot below	PASSED
Scientific Data quality success	see plot below	PASSED
Ratemeters coherent with the configuration	The ratemeters were coherents with the configuration of the charge injection: pixel stimulated: 150, 130	PASSED

Instrument Configuration and Power consumption:

DSU EM	ON
DU FM2 5V	ON
DU FM2 25V	ON

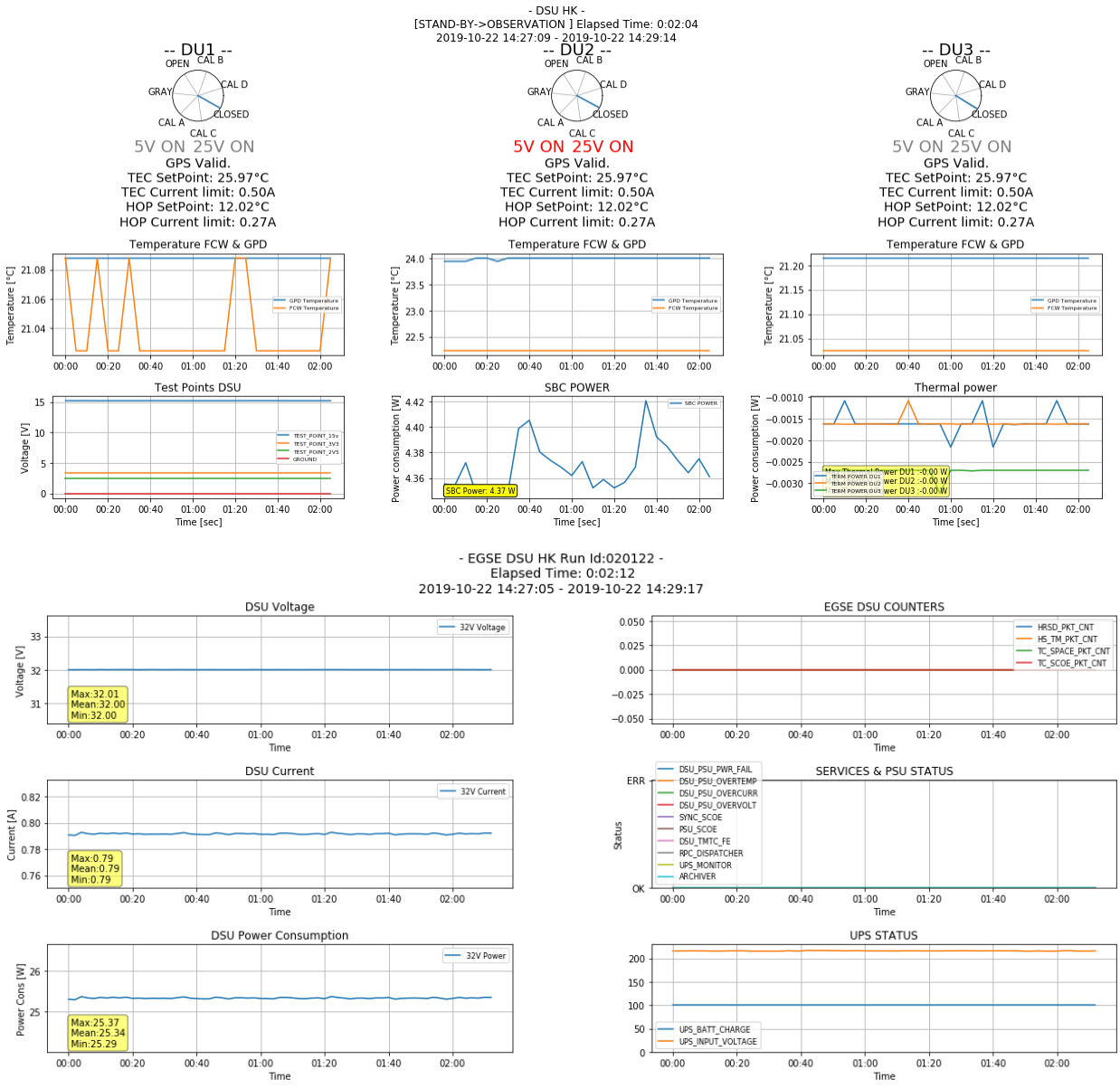


Fig 7-6: Instrument status during the DU Charge Injection Procedure (sec. 7.7). The DSU EM is powered on, the DU FM2 is powered on with both 5 V and 25 V. DU FM1 and DU FM4 are powered off.

Scientific Ratemeters:

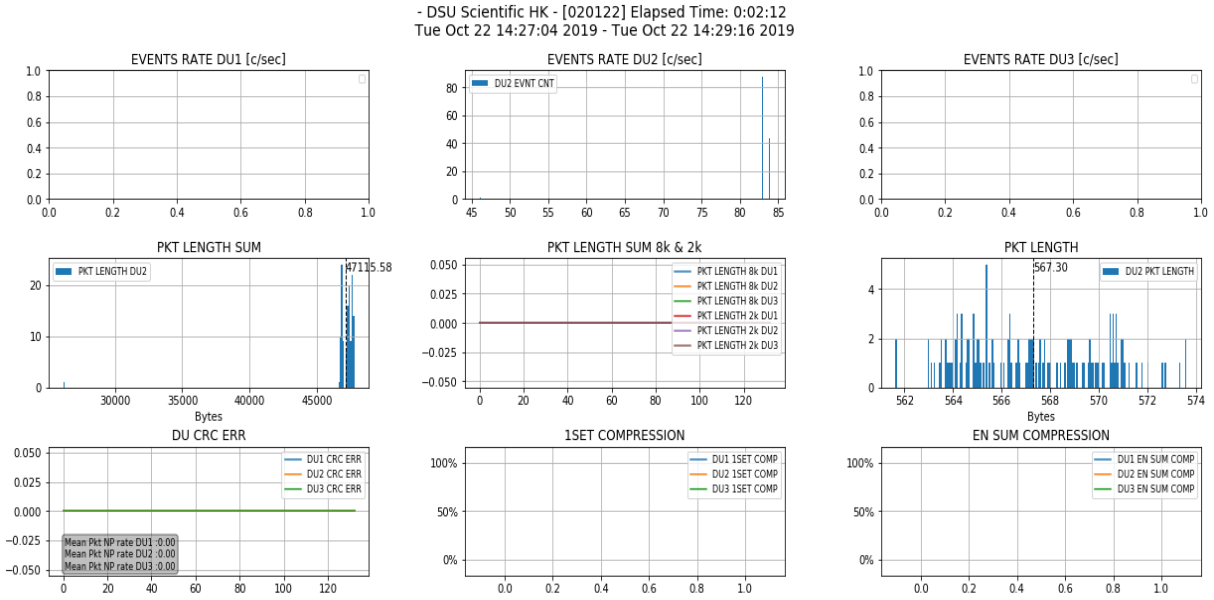


Fig 7-7: DSU Scientific Ratemeters (APID 1203) during the DU Charge Injection Procedure (sec. 7.7). The DU FM2 is powered on and is acquiring charge injection. DU FM1 and DU FM4 are powered off.

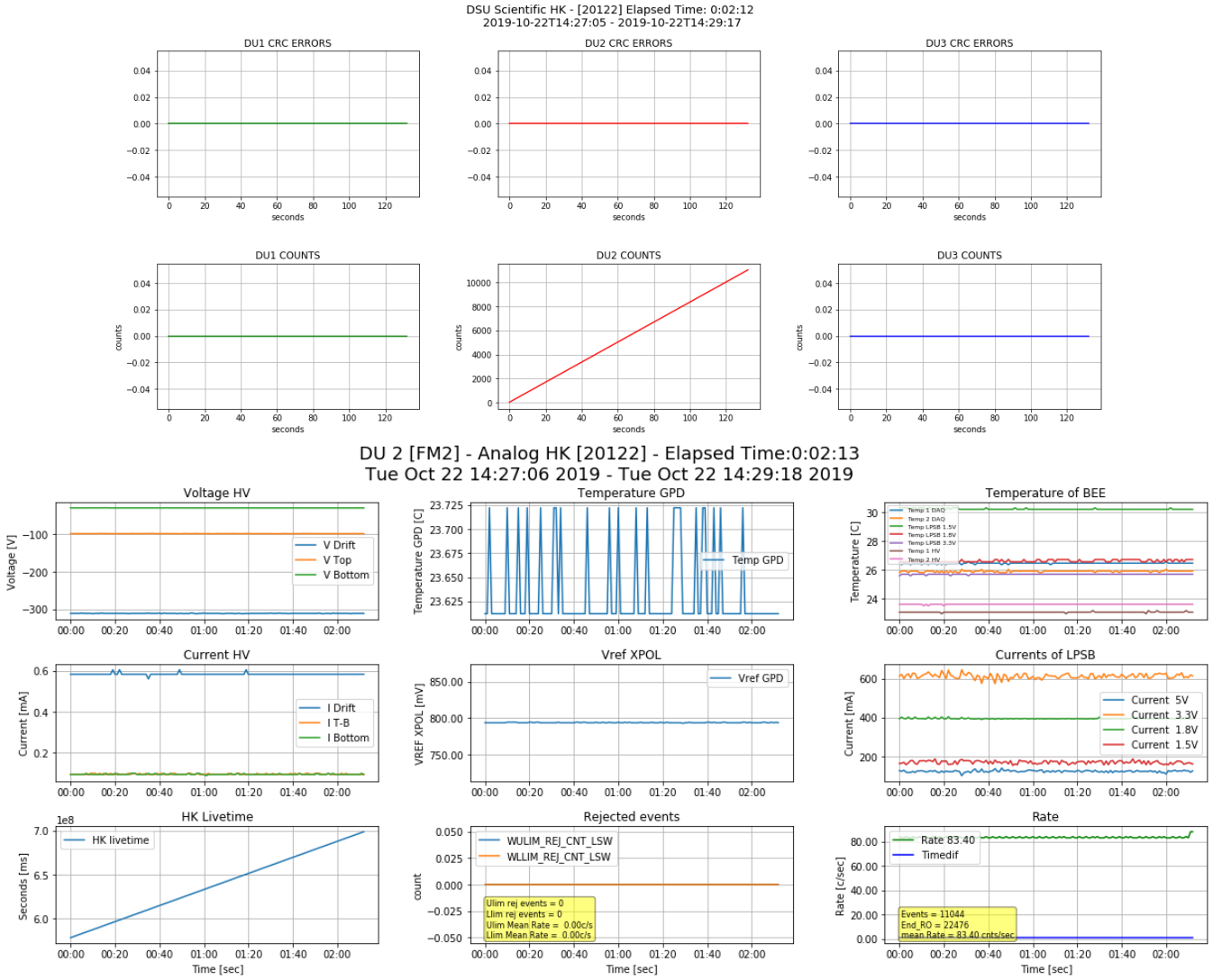


Fig 7-8: DSU Scientific Ratemeters (APID 1203) and DU FM2 HKs (APID 1322) during the DU Charge Injection Procedure (sec. 7.7).

From telemetry 1119 has been extract the charge map of charge injection on pixel (130,150), following the picture:

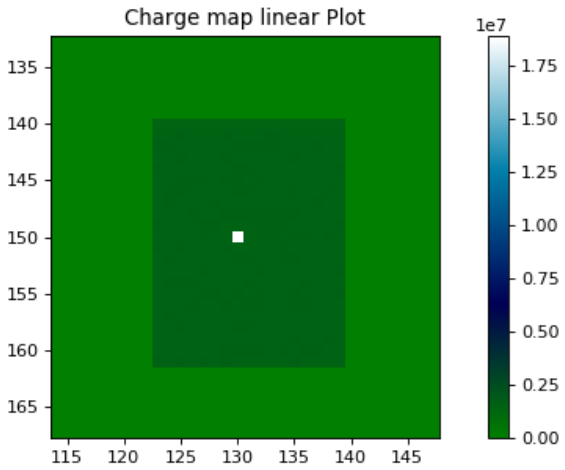


Fig. 7-9: Zoomed view of the charge map during the charge injection (sec. 7.7). The only pixel providing charge in output is (150, 130) as configured

7.8 Instrument Observation - DU pixel scan

Date 20191022 h15	**RUN 20124**	
Criteria Success	**Results**	**Remarks**
TC PIxel Mask	This procedure has been performed during the test described in 7.6	PASSED
Events acquisition Packets 1119 generation Packets 1203 generation (scientific Ratemeters)	The DU has produced the telemetry 1119 (scientific - pixel scan operative mode). Also the DSU started producing the scientific ratemeters telemetry see plot below	PASSED

CRC Error	no CRC errors	PASSED
Scientific Data quality success	see plot below	PASSED
Ratemeters coherent with the configuration	The ratemeters were coherents with the configuration of the charge injection	PASSED

Extracting from 1119 telemetry the charge map of the pixel scan test can be appreciate the uniformity ASIC behavior for all the clusters:

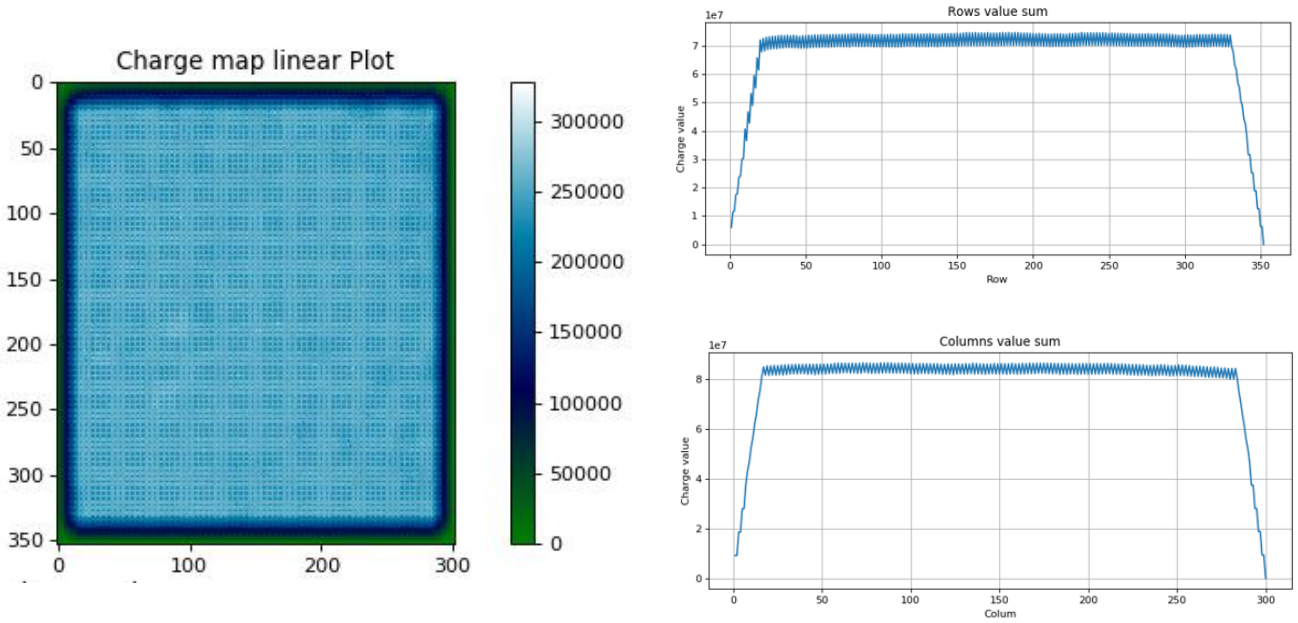


Figure 7-10: Charge map of pixel scan (left) and Rows and Columns charge sum (right)

Scientific ratemeters and HKs:

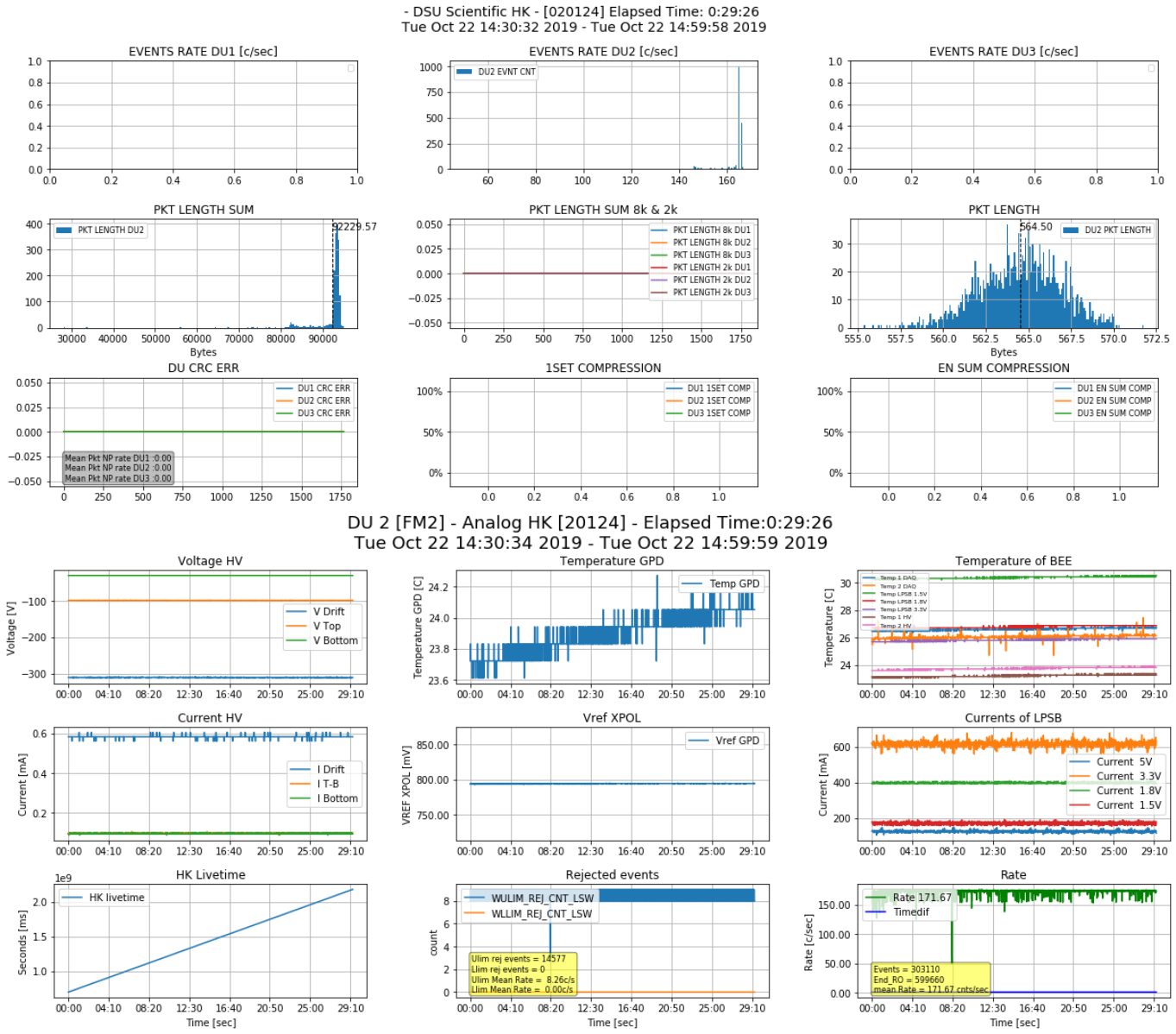


Fig 7-11: DSU Scientific Ratemeters(APID 1203) and DU FM2 HKs (APID 1322) during the DU Pixel Scan Procedure (sec. 7.8). The DU FM2 is powered on and is acquiring pedestal calibration. DU FM1 and DU FM4 are powered off.

7.9 Instrument Observation - DU pedestal calibration

Date 20191023 h16	**RUN 20131**	
Criteria Success	**Results**	**Remarks**
TC PIxel Mask	This procedure has been performed during the test described in 7.6	PASSED
Events acquisition Packets 1120 generation Packets 1203 generation (scientific Ratemeters)	The DU has produced the telemetry 1120 (pedestal scan operative mode). Also the DSU started producing the scientific ratemeters telemetry see plot below	PASSED
CRC Error	no CRC errors see plot below	PASSED
Scientific Data quality success	see plot below	PASSED
Ratemeters coherent with the configuration	The ratemeters were coherents with the configuration of the pedestal calibration.	PASSED

Scientific ratemeters and HKs:

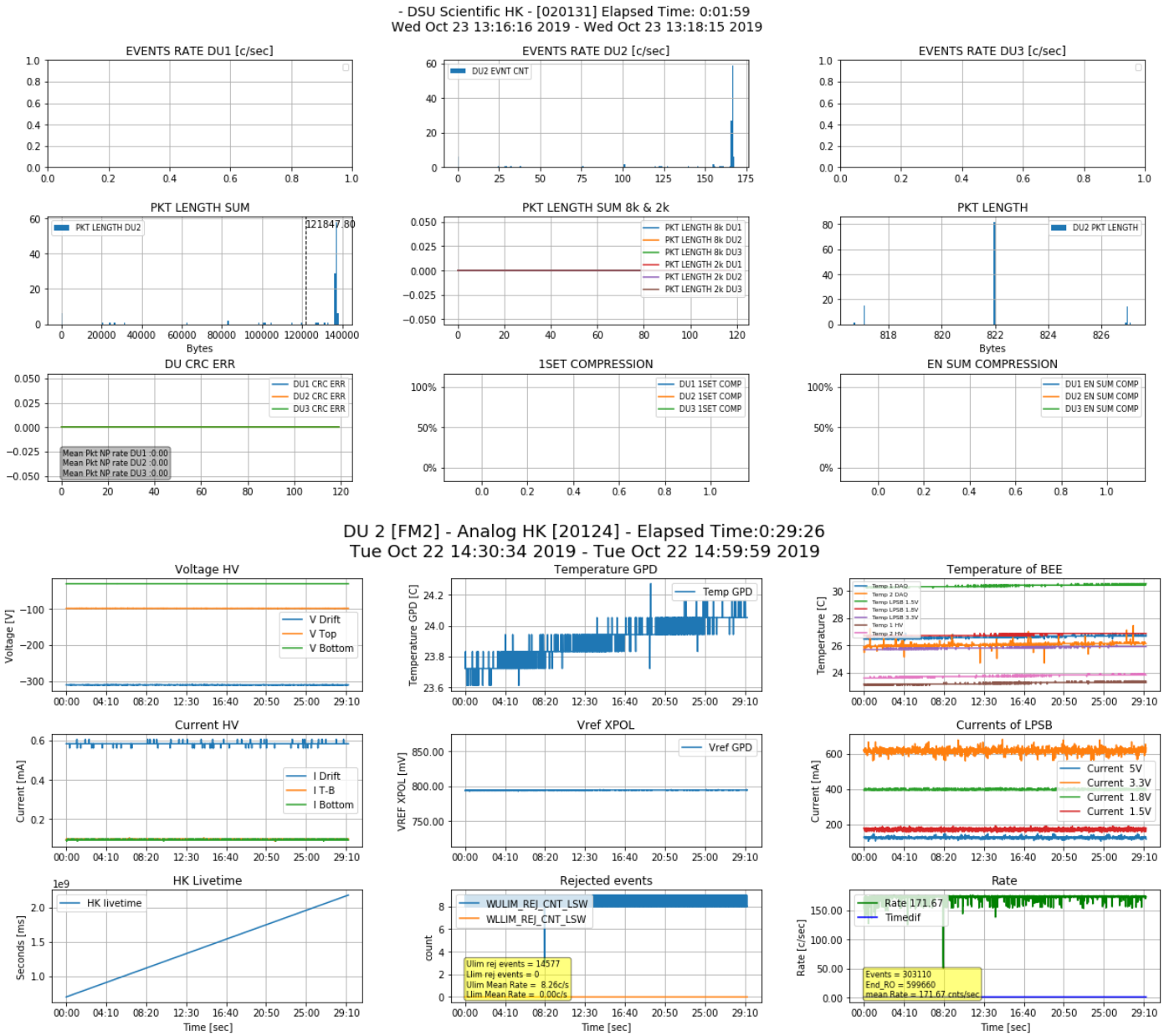


Fig 7-12: DSU HKs (APID 1200) and DU FM2 HKs (APID 1322) during the DU Pedestal Calibration Procedure (sec. 7.9). The DU FM2 is powered on and is acquiring pedestal calibration. DU FM1 and DU FM4 are powered off.

7.10 FCW rotation

Date 20191023 h17	**RUN 020134**	
Criteria Success	**Results**	**Remarks**
GRAY FILTER Position power consumption	Potentiometer value: 2.433V (1993)	PASSED
SOURCE_A Position power consumption	Potentiometer value: 3.150V (2580)	PASSED
SOURCE_C Position power consumption	Potentiometer value: 3.874V (3173)	PASSED
SOURCE_D Position power consumption	Potentiometer value: 0.261 V (214)	PASSED
SOURCE_B Position power consumption	Potentiometer value: 0.985 V (807)	PASSED
OPEN Position power consumption	Potentiometer value: 1.709 V (1400)	PASSED
250 steps forward Position power consumption	Visual verification Potentiometer value: 4.606 V	PASSED

250 Steps Backward Position power consumption	Visual verification Potentiometer value: 1.709 V (1400)	PASSED
CLOSED Position power consumption	Potentiometer value: 4.607 V (3773)	PASSED

Below the plot of power consumption of the instrument with only DSU Powered ON and FCW of FM2 under test of functionalities

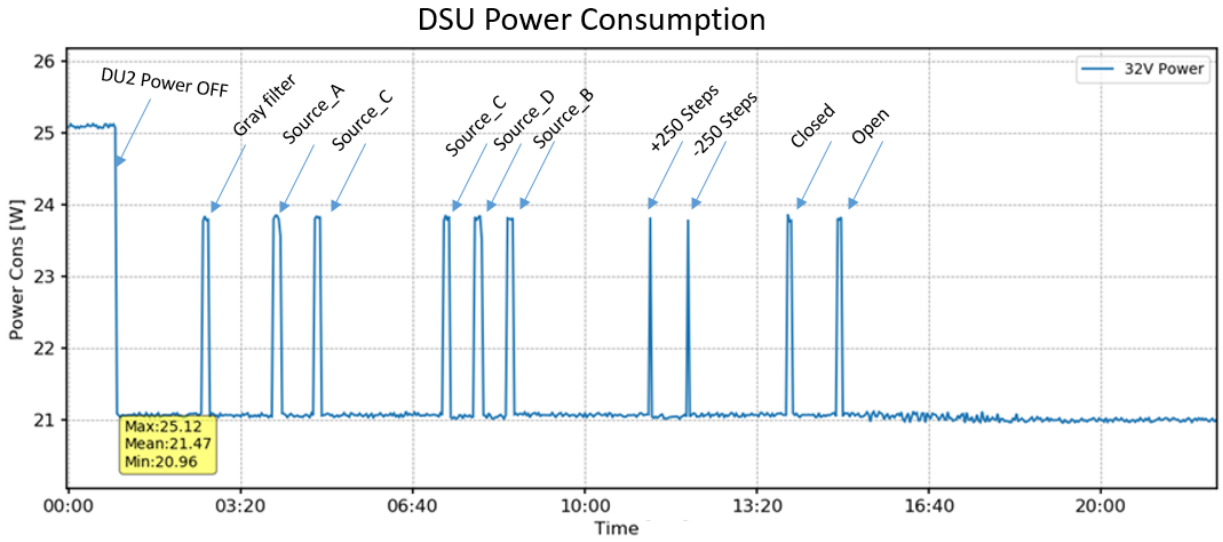


Figure 7-13: Power Consumption trend during FCW FM2 tests

7.11 DU Thermal Control

Date 20191023 h17	**RUN 020135 - 020136**	

Criteria Success	Results	Remarks
Changing parameters in DSU MRAM:	In RUNId 020135 TEC SetPoin:24.98°C in RunId 020136 TEC SetPoin:20.01°C	PASSED See Figure XY
Peltier	Activation of Peltier	PASSED
Heater	Activation of Heater	PASSED

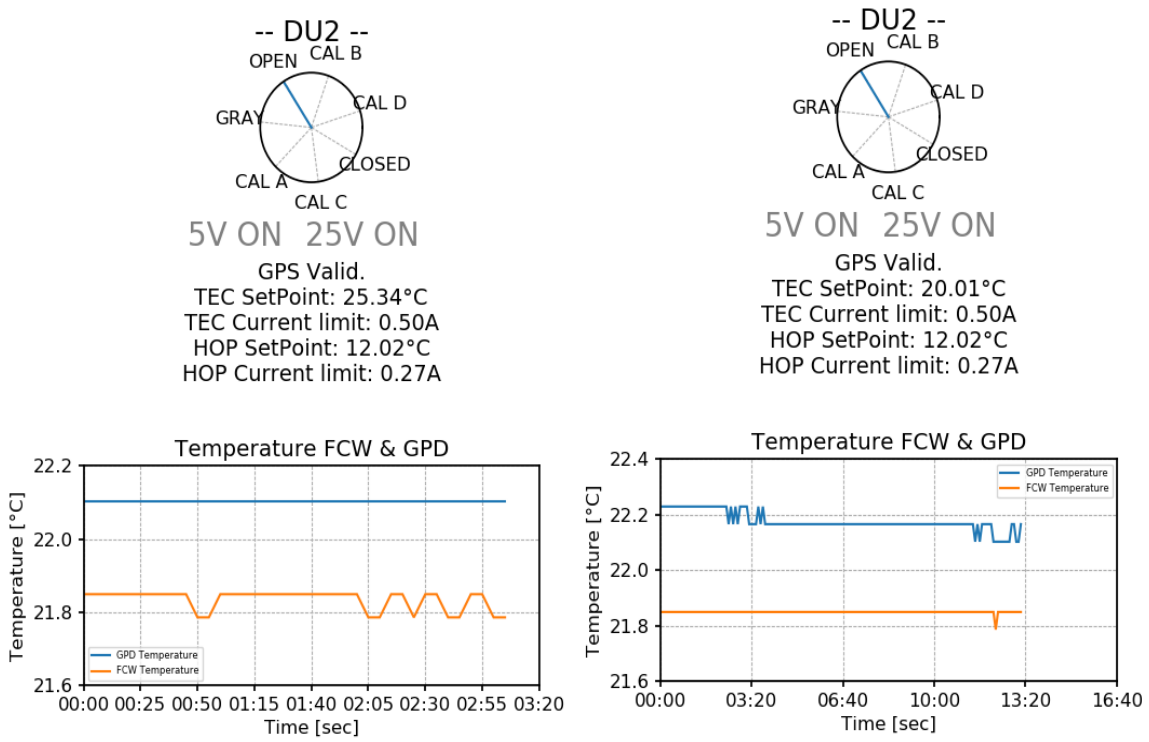


Figure 7-14: GPD temperature (blue line) before (left panel) and after (right panel) the activation of the Peltier Thermoelectric Cooler (TEC). In the right panel the TEC set point is at 20.01°

In air the thermal control needs a lot of time to produce a appreciable temperature variation, after 15 minutes has been appreciate a slow GPD temperature decrease due the Peltier activation (see figure 7-14

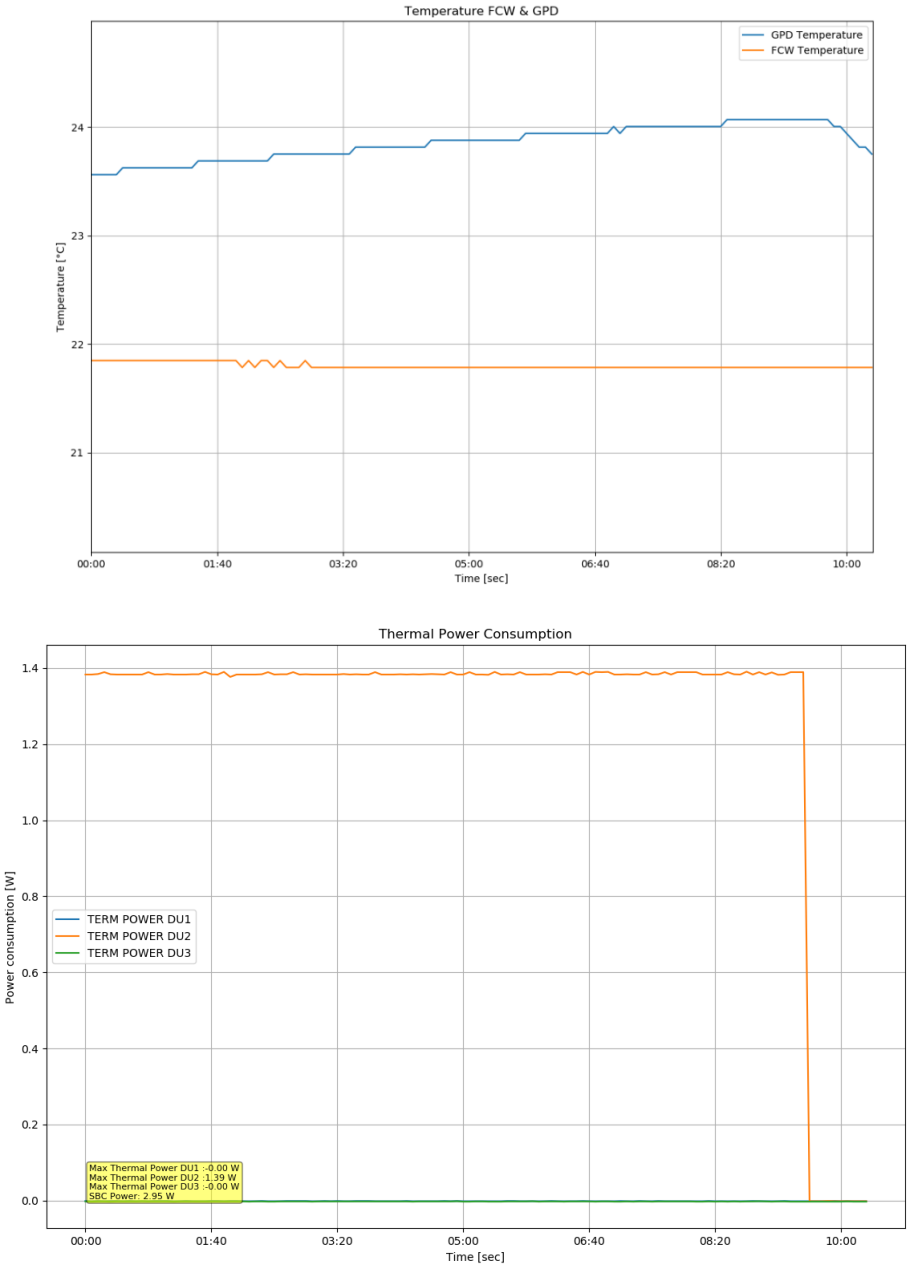


Figure 7-15: above GPD temperature after the activation of the Heater. Below the thermal power consumption.

7.12 HV Management

Date 2019-10-23	**RUN 020138 - 020140**	
Criteria Success	**Results**	**Remarks**
High Voltage Ramp Up	From HIGH and LOW rate telemetry can be verified the right behavior	PASSED See Figure XZ
High Voltage Ramp Down	From HIGH and LOW rate telemetry can be verified the right behavior	PASSED See Figure YZ

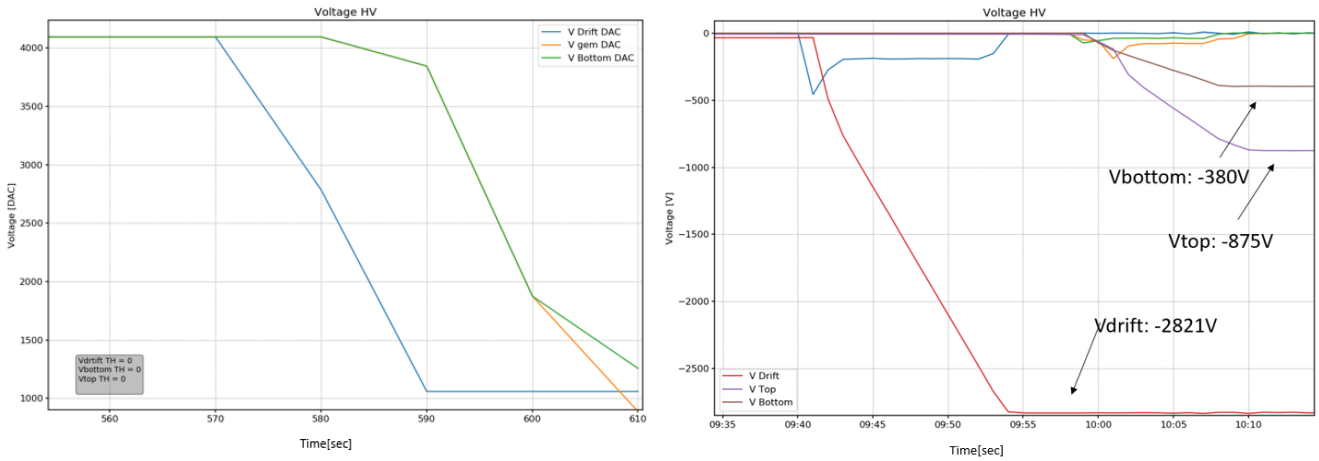


Figure 7-16: Ramp UP, DAC HV configuration from LOW RATE (APID 1325) telemetry (left), Output High Voltages housekeeping from HIGH RATE (APID 1322) telemetry (right)

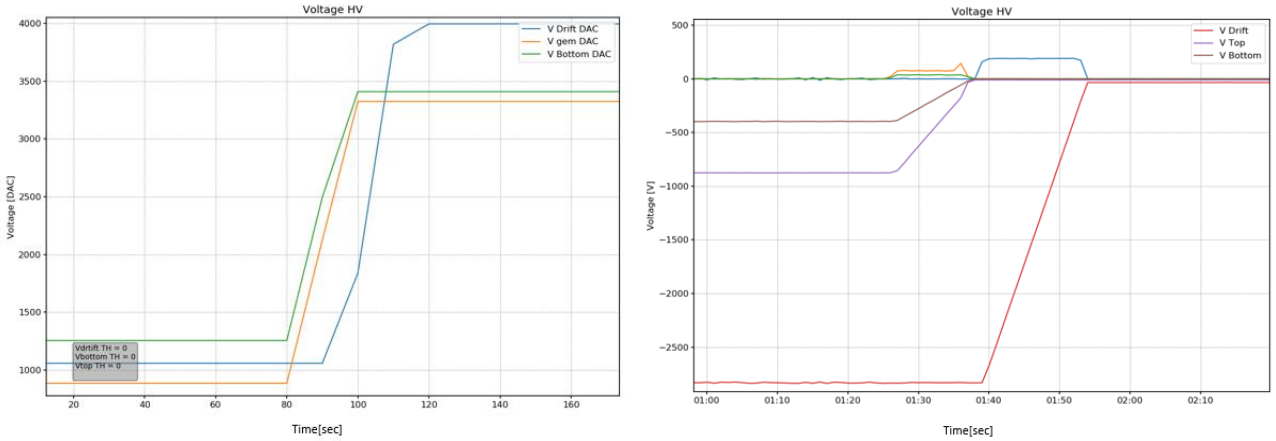
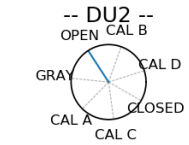


Figure 7-17: Ramp DOWN, DAC HV configuration from LOW RATE (APID 1325) telemetry (left), Output High Voltages housekeeping from HIGH RATE (APID 1322) telemetry (right)

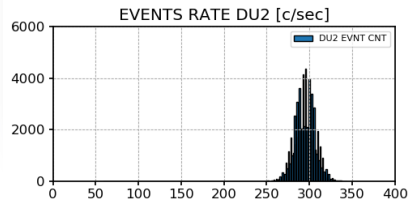
7.13 Instrument Observation – Nominal Acquisition

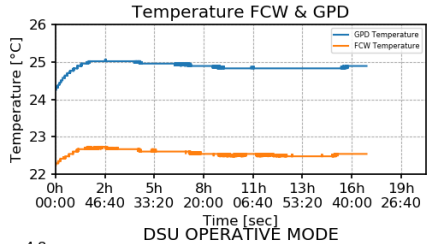
Date 2019-10-23	**RUN 020141**	
Criteria Success	**Results**	**Remarks**
Events acquisition Packets 1118 generation Packets 1203 generation (scientific Ratemeters)	The DU has produced the telemetry 1118 (scientific - acquisition operative mode). Also the DSU started producing the scientific ratemeters telemetry see plot below	PASSED
Orphan Removal	The acquisition has been performed with the processing operated by the DSU	PASSED
Scientific Data quality success	see performance test	PASSED
Ratemeters coherent with the configuration	The ratemeters were coherents with the configuration of the observatio injection	PASSED

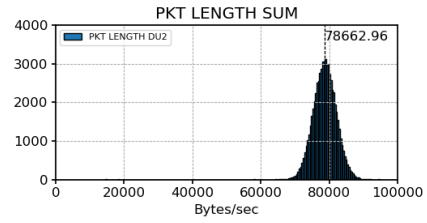


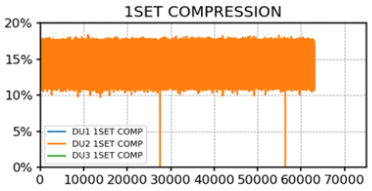
5V ON 25V ON

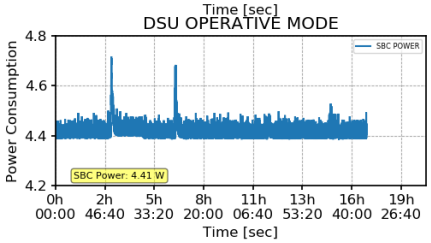
GPS Valid.
TEC SetPoint: 25.97°C
TEC Current limit: 0.50A
HOP SetPoint: 12.02°C
HOP Current limit: 0.27A

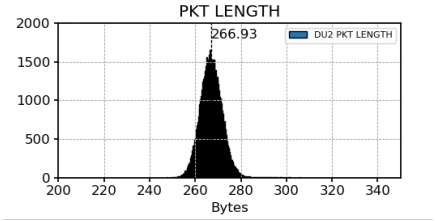


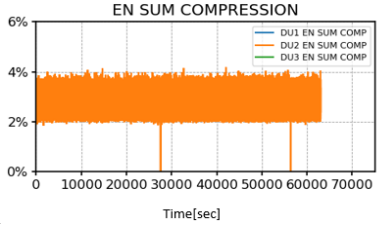




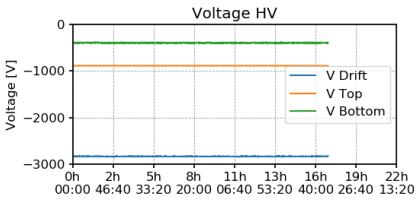


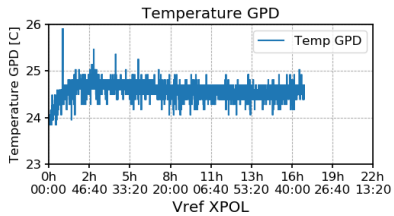


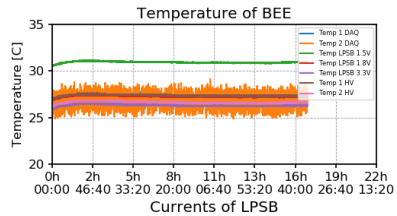


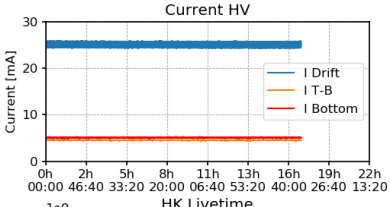


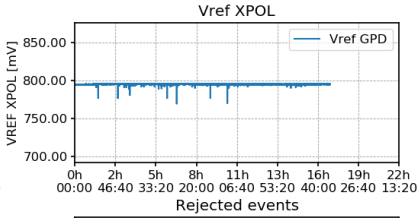
DU 2[FM2] - Analog HK - 20143
2019-10-23 15:16:39 - 2019-10-24 08:47:04

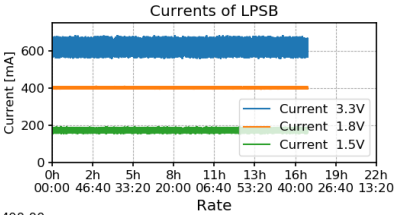


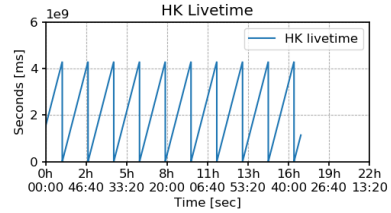


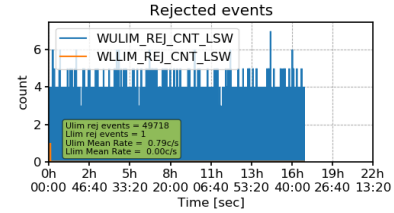












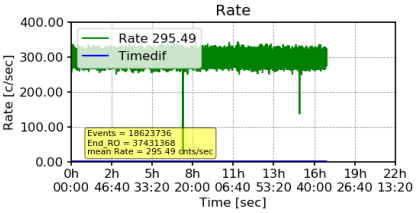


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Fig 7-18: DSU Scientific Ratemeters (APID 1203) and DU FM2 HKs (APID 1322) during the DU Nominal Acquisition Procedure (sec. 7.13). The DU FM2 is powered on and is acquiring photons in nominal configuration from an ^{55}Fe source.

7.14 Instrument SAA (postponed to performance test)

Date 20191028 h15 - 20191111	**RUN 20426-21806**	
Criteria Success	**Results**	**Remarks**
Events inhibition	As expected the scientific telemetry (1118,1119,1120) has been inhibited after mode transition	PASSED see performance test section
HV ramp down/up during SAA	as expected the HV ramp down/up entering/exiting in/from SAA has been performed succesfully	PASSED see performance test section
SW mode changes OBS to SAA SW mode changes SAA to OBS	mode transition ok	PASSED see performance test section
check telemetries produced DU and DSU HKs coherent no CRC No scientific Ratemeters		PASSED see performance test section
no CRC	not crc was detected during SAA crossing in the telemetries	PASSED see performance test section
No scientific Ratemeters	due to the actual DSU SW version the DSU doesn't inhibit the scientific ratemeter telemetry. This behaviour will be fixed in the next version of the DSU SW and checked during the Instrument E2E Test	NOT PASSED

7.15 Instrument Scientific Rate Management (postponed to performance test)

Date	**RUN**	
Criteria Success	**Results**	**Remarks**
Events acquisition	The DU has produced the telemetry 1118 (scientific - acquisition operative mode).	PASSED see performance test section
maximum rate respected		PASSED see performance test section
Saturation/Desaturation buffer OK Saturation/Desaturation Telemetries generated		PASSED see performance test section
no CRC (<1%)		PASSED see performance test section
no CRC Scientific Data quality success Orphan Removal ON/OFF Ratemeters coherent with the configuration		PASSED see performance test section

7.16 Instrument DU Alarm Configuration and Management

Date 20191024	**RUN - 020148**	
Criteria Success	**Results**	**Remarks**
TC DU alarm configuration	The DU alarm thresholds has been configured in order to trigger an alarm during the ramp up of the V Drift	PASSED
Alarm trigger generation	The alarm has been generated correctly by the DU	PASSED
Alarm trigger DSU reaction with DU OFF	The DSU reacted to the alarm switching off the DU	PASSED

Below in Fig. 7-19 is reported the collection of the housekeeping that show the reaction of DSU to a signal on the DU ALARM OUT line. The DU can be configured to monitor different analog housekeeping and generate ALARMs when one or more comes above the configured threshold. In this test we verify the ability of DSU to react so we stimulate the ALARM . In particular, we test the on Vdrift monitor.

Starting with the DU fully powered ON (+5V and +25V) we changed the Vdrift threshold value (black-line) and we started the ramp UP (blue-line monitor of Vdrift). When the Vdrift monitor cross the DAC Vdrift threshold (the detail is not present in the image because the reaction occurs in less that housekeeping sampling time) the DSU power OFF the involved DU (Red-Line).

Between 860 and 890 seconds the DU is powered OFF, it has been powered ON by operator after 890 seconds to continue the test activities.

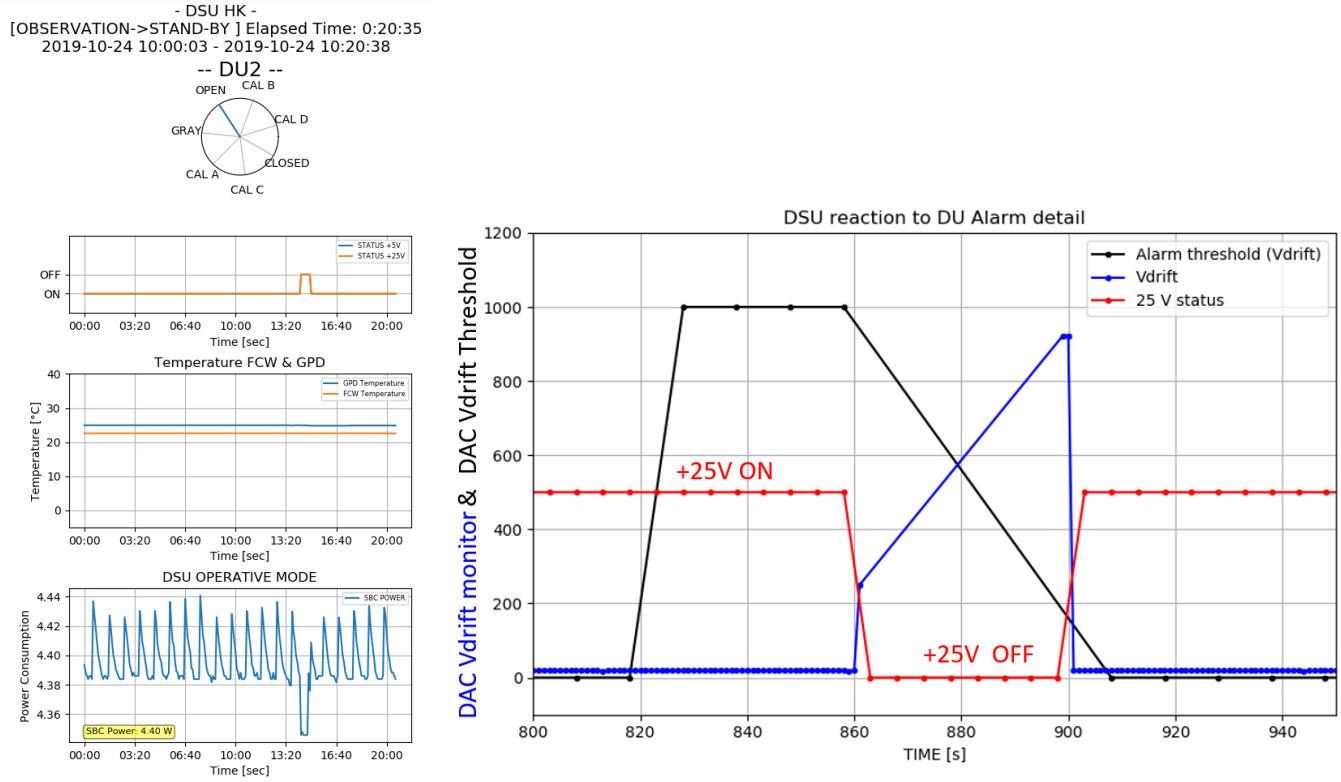


Fig. 7-19: Power off of the 25 V after the detection of an over threshold on the Vdrift HV.

7.17 Instrument Timing Management

Date 20191024 and 20191115	**RUN 20163 and 21895-21889**	
Criteria Success	**Results**	**Remarks**
TOD receiving ok PPS management ok	The TOD has been processed as expected by the instrument. The PPS has been managed as expected by the instrument.	PASSED Due to the clock frequency of the DSU (1Mhz) the MOBT is incremented with a

		delay of 3 us with respect to the PPS. Due to the clock frequency of the Dus (50MHz) the LOBTs are incremented with a delay << 1us respect to the PPS.
Timing test external trigger ok (egse management)	See description below	PASSED
Timing test internal trigger ok (DSU on board management)	See description below	PASSED
Packets 1118 generation checks time-tag events ok	OK	PASSED

The Instrument timing performance [AD nota timing] has been measured using the capability of the EGSE to send a trigger signal to the DUs phased with the same PPS provided by the EGSE to the DSU.

These signals are sent through the test connector to the DSU and to the the DUs using the Alarm_in_1 line between the units.

The EGSE local oscillator has the following characteristics:

TCXO Characteristics Frequency 10 MHz

Initial accuracy ..... ±1.5 ppm

Aging per year ..... ±1 ppm

Temperature stability (0 to 55 °C)2 ..... ±2 ppm

Based on these characteristics we assume that the contribute of the time accuracy of the triggers generated by the EGSE is negligible.

In the first test (RUN 21895) we have generated triggers with a frequency of 1Hz .
The aim of this measure has been to avoid the drift due to the local oscillator located in the DSU. This local oscillator provides the 1MHz to the DUs and his accuracy, in the case of the DSU EM, is +-10ppm.

The result of the test has been:
mean 0.96 us
standard deviation 0.20

In the second test (RUN 21889) we have generated triggers with a frequency of 100Hz.
In order to reconstruct the time tag we used the obt error information in order to subtract the accuracy of the DSU local oscillator

The result of the test has been:
mean 0.97 us
standard deviation 0.53

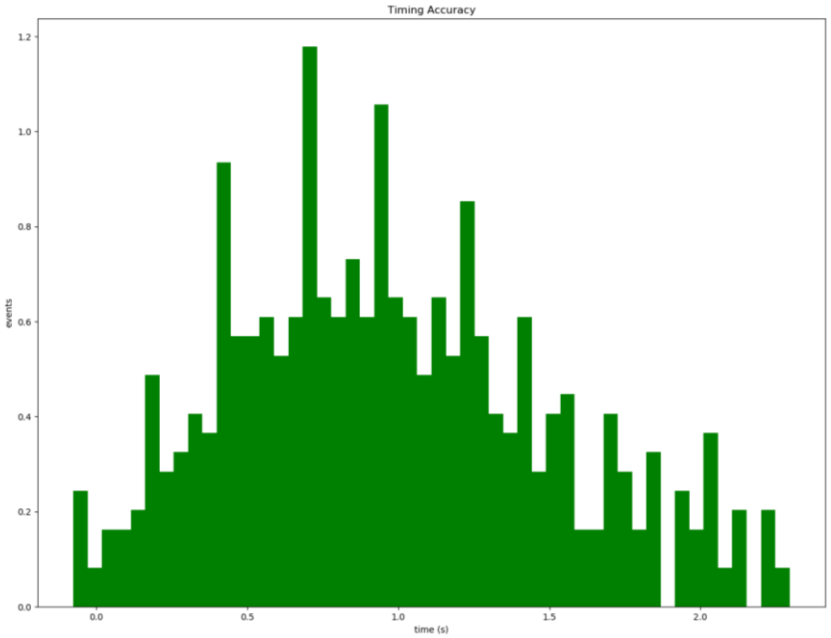


Fig. 7-20: Instrument Time Accuracy.

The test demonstrate that the Instrument Time accuracy is around 1 microsecond.

Also the DSU can generate and send to DUs a programmable time tagged signal.

Also in this case the start of the train signals is phased with the PPS and we expected that the Master OBT located on the DSU and the Local OBTs located in the DUs remain aligned along the test.

The test was performed during the RUNID 20163 generating triggers with a frequency of 100Hz.

Considering the natural drift of the local oscillator located in the DSU, the MOBT and the LOBT remained aligned along all the test.

These tests verify the following requirements:

IINT-16	Instrument time accuracy – The Instrument shall time stamp detected X-ray photons during observation with an accuracy of +/- 94 µs (at 99%) with respect to a time-base defined by leading edges of the 1-PPS pulses from the Spacecraft, at the DSU input.
IINT-537	The delay between the trigger in the detector and the time tag associated to the event shall be calibrated to an accuracy of 20 microseconds.
IINT-520	Alarm_in auxiliary lines - The DSU shall manage the auxiliary Alarm_in_1 lines in order to perform, as a minimum, the following actions: ·(internal mode) generate and send to DUs a programmable time tagged signal (pulses sequence). ·(external mode) feed to DUs the signal provided by the EGSE through the test connector.

7.18 Performance Test

The purpose of this test was to simulate the operational phase of the instrument during orbit.

The test has been performed from 2019-10-28 to 2019-11-12 (runid from 20453 to 21848).

The instrument is turned on and completely configured to carry out its activity.

We use two sources of Fe55 and an X-ray tube with Rh anode (fluorescence line at 2.7 keV) in order to stimulate the Nominal Acquisition (FCW open position).

The logical sequence of operations is represented in the following table and has been executed in loop for 14 consecutive days.

During the performance test we simulated 190 orbital cycle.

The Instrument acquired the total 628 × 10^6 events subdivided in the following mode:

DU FM1: 183 × 10^6 events

DU FM2: 255 × 10^6 events

DU FM3: 190 × 10^6 events

The total amount of scientific packets sent from the DUs to the DSU with CRC error has been 14 subdivided in the following mode:

DU FM1: 4

DU FM2: 4

DU FM3: 6

The instrument performed 190 passages from OBS to SAA to OBS without evidencing any failure.

Instrument Orbit cycle Configuration				
DU FM#	**DU FM2**	**DU FM#**	**Duration**	**Remarks**
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	50’	
Calibration with source	Nominal Acquisition	Nominal Acquisition	10’	Enter Standby Mode HV ramp down FCW rotation HV ramp up

				Enter Observation Mode HV ramp down FCW rotation HV ramp up (Ref. 7.13)
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	20’	Enter Observation Mode (Ref. 7.13)
Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	10’	Enter SAA Mode (ref. 7.14)
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	60’	Enter Observation Mode
Nominal Acquisition	Calibration with source	Nominal Acquisition	10’	Enter Standby Mode HV ramp down FCW rotation HV ramp up Enter Observation Mode HV ramp down FCW rotation HV ramp up (Ref. 7.13)
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	20’	Enter Observation Mode (Ref. 7.13)
Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	10’	Enter SAA Mode (Ref. 7.14)
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	60’	Enter Observation Mode
Nominal Acquisition	Nominal Acquisition	Calibration with source	10’	Enter Standby Mode

				HV ramp down FCW rotation HV ramp up Enter Observation Mode HV ramp down FCW rotation HV ramp up
Nominal Acquisition	Nominal Acquisition	Nominal Acquisition	20’	Enter Observation Mode
Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	Standby and HV low (SAA crossing)	10’	Enter SAA Mode

Power consumption of Instrument:

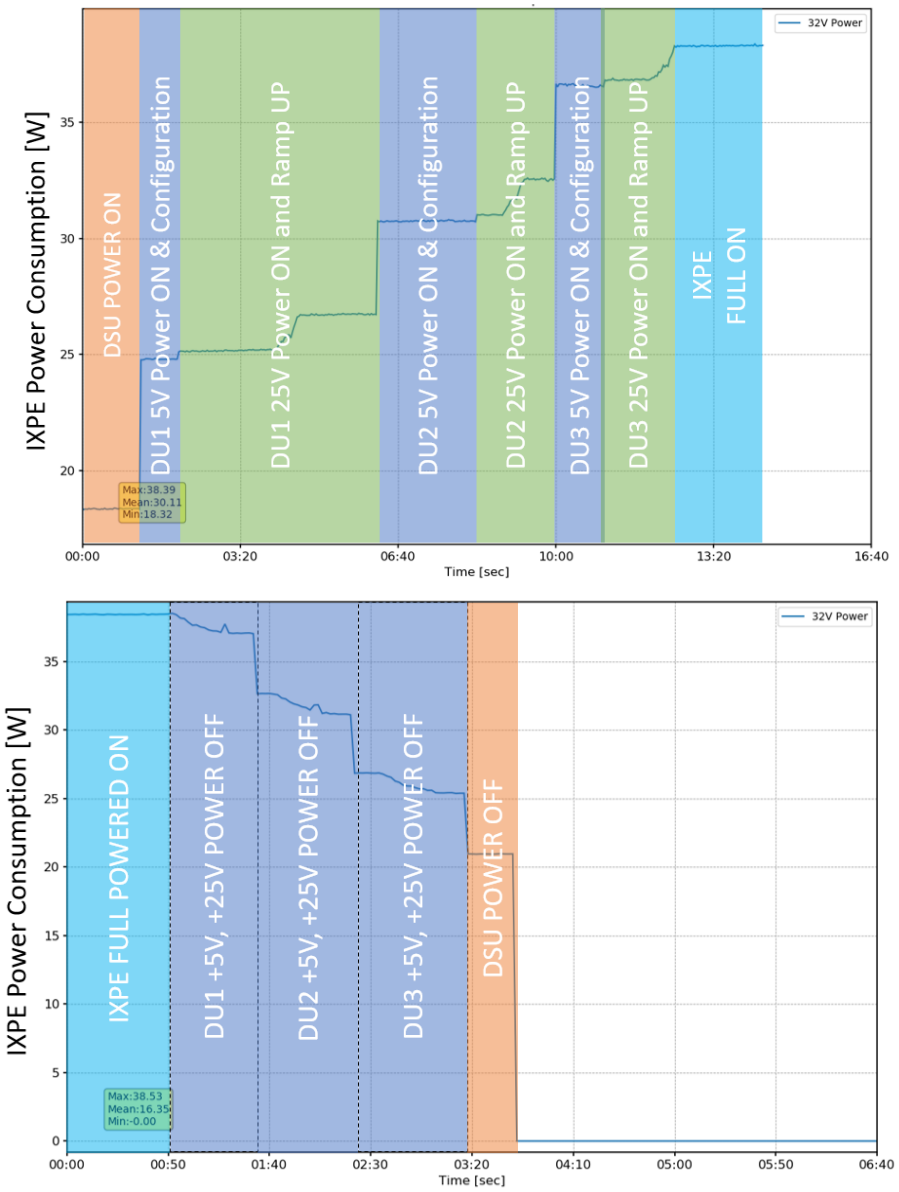


Fig. 7-21: Trend of the Instrument power consumption in air during power on (top panel) and power off (bottom panel) procedures.

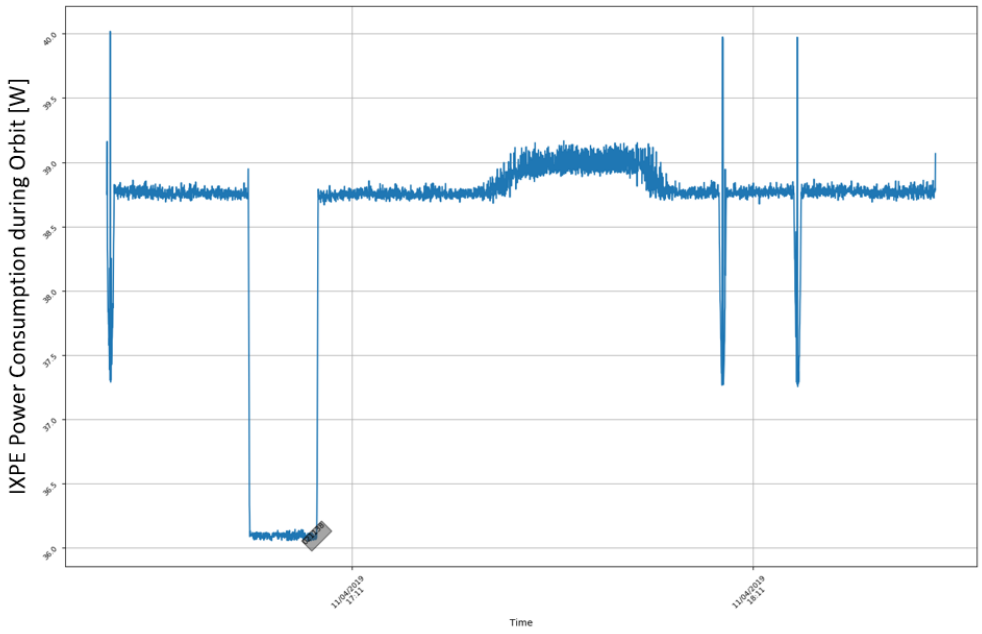


Fig. 7-22: Instrument power consumption during an orbit cycle, defined in the table above. The dip represent the ramp off of HVs during SAA, the spikes represent the rotation of the FCW.

DSU orphan removal

Below the comparison between two acquisitions of 20 minutes of the same source with and without Orphan removal, in particular:

RUN 020635 : Without Orphan Removal (blue histogram)

RUN 020642 : With Orphan Removal (orange histogram)

We show in fig. 7-23 the superposition of the histograms of the relevant parameters from the track reconstruction (ixperecon) software: ratio between axis of track's charge distribution (top panel), track size (middle panel) and track skewness (bottom panel). In the figure, the histogram in blue is from data acquired with the orphan removal algorithm, and the histogram in orange is from data without the orphan removal algorithm. The histograms with and without orphan removal are compatible, consequently the algorithm is not significantly affecting the shape of the tracks.

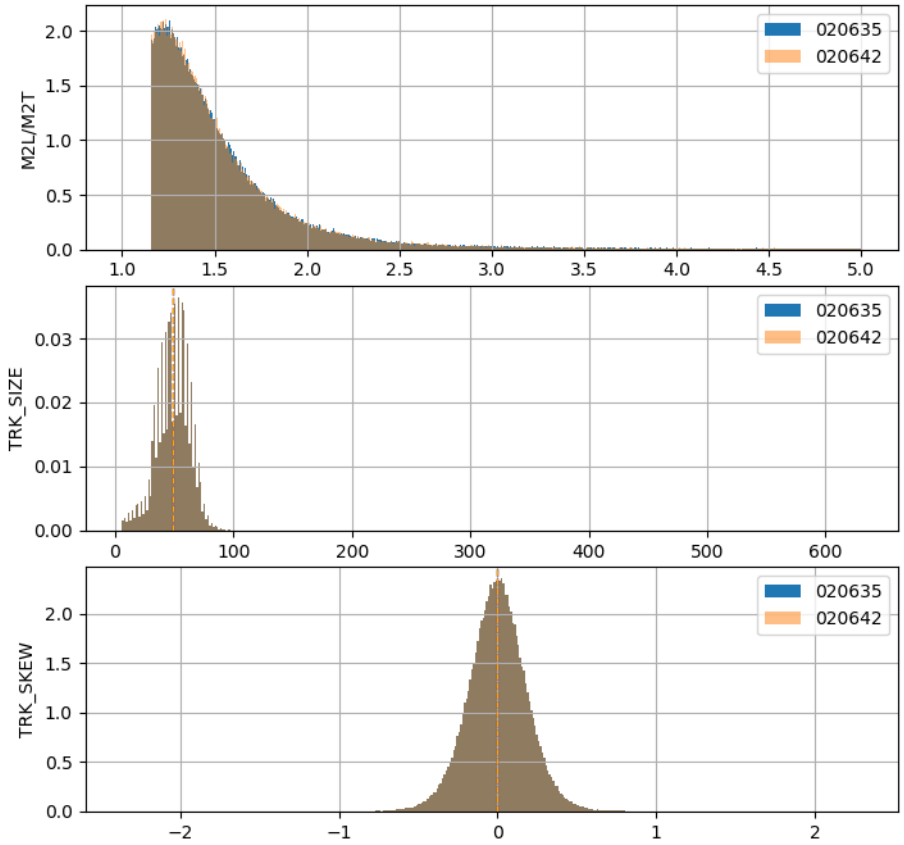
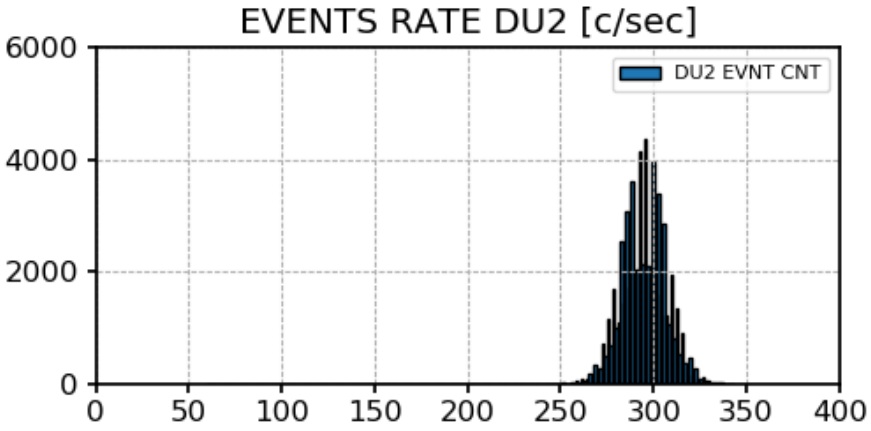


Fig. 7-23: Superposition of the histograms of the parameters ratio between axis of track's charge distribution (top panel), track size (middle panel) and track skewness (bottom panel) with (blue) and without (orange) orphan removal.

Instrument Rate Management



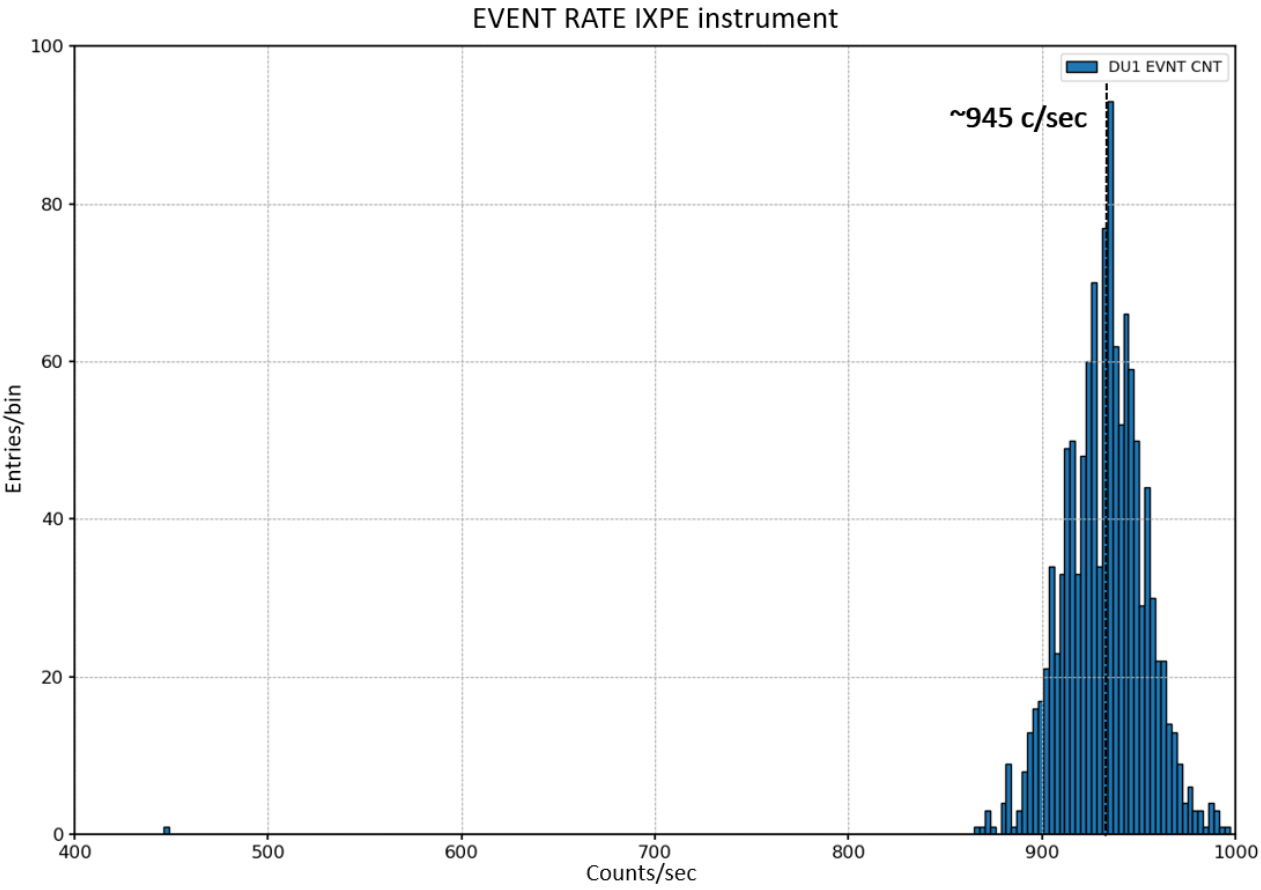


Fig. 7-24: Counting rate measured on the DU FM2 (top panel) and on the whole Instrument (bottom panel).

The instrument acquired during 9 days at the average maximum rate as shown in the fig. 7-24 (bottom panel).

The DUs were configured in order to have an average scientific packet size of 300 bytes(from DUs to DSU) as shown in the fig. 7-24 (top panel).

We use two sources of Fe55 and an X-ray tube with Rh anode (fluorescence line at 2.7 keV) in order to stimulate the Nominal Acquisition.

We use two sources of 55Fe and an X-ray tube with Rh anode and PVC filter (fluorescence line at 2.7 keV) in order to stimulate the Nominal Acquisition. In particular we assumed that the X-ray tube with Rh anode, used for stimulate the DU FM2, is representative of the average spectrum of the Crab Nebula.

During the performance test the instrument demonstrated to be able to acquire around 945 cts/s with overflux until 1000 cts/s without any change in the instrument operation/configuration and without any buffer saturations.

This verify the following requirements:

IINT-14	Maximum counting rate – The Instrument shall be able to acquire and process a steady maximum counting rate of 900 cts/s (corresponding to ~2 times the Crab Nebula in 1 – 12 keV).
IINT-500	Unexpected over-flux - The instrument shall be able to withstand, without changes in the GPD operations, any unexpected increase of the source flux such that the counting rate would exceed 900 cts/s.

During the performance test the instrument produced an average rate of 1.15Mbps between DUs and DSU and an average rate of 1.01Mbps between DSU and Spacecraft Simulator (EGSE).

This demonstrated that the instrument respects the following two:

IINT-514	DU-DSU maximum data rate – The data interface between each DU and the DSU shall be able to transmit with zero loss, simultaneously for all DUs, up to 0.75 Mbit/s of data, corresponding to the "DU maximum counting rate" requirement IINT-14
IINT-426	Science data rate – The science data rate produced by the Instrument after the filtering shall not exceed 2 Mbit/s.

We verified that DSU associate a unique identification to the scientific data writing a specific field in the data header.

The DU HKs telemetries are identified by the APID.

This verify the following requirement:

IINT-424	DU data and HK identification – The instrument shall associate a unique identification to the data and HK packages retrieved by each different DU.

8. Anomalies

No NCRs for the DU FM2 have been issued at the end of the E2E Check.

During the E2E Check we found bugs in the DSU software, that we provided to OHBI:

- During the SAA operative mode, TM packets of scientific ratemeters (APID 1200) are produced by the DSU although the HVs of the GEM in the GPD are powered OFF
- A small number of configuration parameters (e.g. activation of the data compression in the DSU) are not maintained during the transition from the operative mode SAA to the operative mode OBSERVATION;
- The first TM packet of scientific ratemeters (APID 1200) in the OBSERVATION mode is not updated but contains the Run ID of the previous STANDBY or SAA mode

During the E2E Check an anomalous behavior of the DSU EM main section has been traced with the NCR IAPS-NCR-009.

9. Conclusions

During the E2E Check we tested the DU FM2 in a representative instrument configuration, including the DSU EM, the DU FM1 and the DU FM4. With this test we verified that the DU FM2 can be successfully connected to the DSU EM for electrical, telecommand and telemetry interfaces. In addition, we verified that the operative modes designed for the DU FM2 in orbit can be successfully employed and the orbital cycles, composed of OBSERVATION, passage in the SAA and calibration using the FCW, can be successfully reproduced.

During the E2E Check we verified that the DU FM2 is compliant to the requirements listed in the table below (from [RD 2]):

Req. ID	Requirement text	Verification method	Verification references	Requirement Source	Compliance status	O/C	RFD/RFW	Remarks
IINT-14	Maximum counting rate – The Instrument shall be able to acquire and process a steady maximum counting rate of 900 cts/s (corresponding to ~2 times the Crab Nebula in 1 – 12 keV).	T or AoUT	I2C-IAPS-ISE-PLN-002 Verification & Test Plan I2C-IAPS-ISE-SPC-004 Instrument Tests Specifications I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	INT-14	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2
IINT-16	Instrument time accuracy – The Instrument shall time stamp detected X-ray photons during observation with an accuracy of +/- 94 μs (at 99%)	T	I2C-IAPS-ISE-PLN-002 Verification & Test Plan I2C-IAPS-ISE-SPC-004 Instrument Tests Specifications	INT-16	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2

	with respect to a time-base defined by leading edges of the 1-PPS pulses from the Spacecraft, at the DSU input.		I2C-IAPS-ISE-REP-034 DU2 E2E Check Report					
IINT-424	DU data and HK identification – The instrument shall associate a unique identification to the data and HK packages retrieved by each different DU.	I and T	I2C-IAPS-ISE-REP-002 Instrument Design Report I2C-IAPS-ISE-PLN-002 Verification & Test Plan I2C-IAPS-ISE-SPC-004 Instrument Tests Specifications I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	INT-424	C	O		Complete for DU FM2
IINT-426	Science data rate – The science data rate produced by the Instrument after the filtering shall not exceed 2 Mbit/s.	A	I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	INT-426	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2
IINT-500	Unexpected over-flux - The instrument shall be able to withstand, without changes in the GPD operations, any unexpected increase of the source flux such that the counting rate would exceed 900 cts/s.	T	I2C-IAPS-ISE-PLN-002 Verification & Test Plan I2C-IAPS-ISE-SPC-004 Instrument Tests Specifications I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	INT-497	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2

IINT-514	DU-DSU maximum data rate – The data interface between each DU and the DSU shall be able to transmit with zero loss, simultaneously for all DUs, up to 0.75 Mbit/s of data, corresponding to the "DU maximum counting rate" requirement IINT-14	T and AoUT	I2C-INFN-AIT-REP-012 DU-FM2 Full Functional Test Report I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	Instrument conceptual design	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2
IINT-520	Alarm_in auxiliary lines - The DSU shall manage the auxiliary Alarm_in_1 lines in order to perform, as a minimum, the following actions: ·(internal mode) generate and send to DUs a programmable time tagged signal (pulses sequence). ·(external mode) feed to DUs the signal provided by the EGSE through the test connector.	T	I2C-IAPS-ISE-PLN-002 Verification & Test Plan I2C-IAPS-ISE-SPC-004 Instrument Tests Specifications I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	Instrument conceptual design	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2

IINT-537	The delay between the trigger in the detector and the time tag associated to the event shall be calibrated to an accuracy of 20 microseconds.	T	I2C-IAPS-ISE-REP-034 DU2 E2E Check Report	INT-519	C	O		Preliminary test performed on E2E check configuration. Complete for DU FM2

At the completion of the E2E Check we declare that the DU FM2 is compliant to the requirements reported in the [RD 2]. No open issues nor NCRs have been found for the DU FM2 related to the E2E Check.

Annex 1: As Run Procedure

As run procedure refer to:

I2C-IAPS-ISE-PRC-017 , FM2 E2E Check Procedure AS-RUN, i03p00, 24 Oct 2019

10 LIST OF ACRONYMS

ADC	Analog to Digital Converter
AFE	Agency Furnished Element
AIT	Assembly, Integration and Test
BB	Breadboard
BEE	Back End Electronics
CPU	Central Processing Unit
DAQ	Digital Acquisition
E2E	End to End
ECSS	European Cooperation for Space Standardization
EGSE	Electrical Ground Support Equipment
EM	Engineering Model
FM	Flight Model
FFT	Full Functional Test
GPD	Gas Pixel Detector
GSE	Ground Support Equipment
H&S	Health and Status
HVPS	High Voltage Power Supply
H/W	Hardware
HK	Housekeeping

ICE	Instrument Calibration Equipment
IF	Interface
ITE	Instrument Test Equipment
LVPS	Low Voltage Power Supply
MGSE	Mechanical Ground Support Equipment
N/A	Not Applicable
PA	Product Assurance
PFM	Proto Flight Model
RD-n	Reference Document n
S/C	Spacecraft
SFT	Short Functional Test
S/W	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBR	To Be Reviewed
TBW	To Be Written
TC	Tele Command
TEC	Thermoelectric Cooler
TM	Telemetry
TOD	Time of Day
UUT	Unit Under Test

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